River flows as drivers of population distribution and settlement patterns in Bosnia and Herzegovina: a GIS-based analysis

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Abstract
This paper analyzes the distribution and size structure of settlements along the primary river courses of Bosnia and Herzegovina, considering both hypsometry and socioeconomic dimensions of space, which contribute to demographic transformations. Using GIS tools, an analysis was conducted on the number of settlements according to hypsometric levels in the river basins of the Black and Adriatic Seas, alongside demographic changes during the latest intercensal period. Spatial analysis methods in GIS enabled the identification of population changes, settlement sizes, and spatial distribution patterns. Analysis of buffer zones within 5 km of river streams reveals a predominant spatial clustering of settlements along these waterways, while a fragmentation of settlement networks is observed farther away from the main streams.

Keywords
river basins, hypsometric zones, population, settlements, Bosnia and Herzegovina

Izvleček
Rečni tokovi kot vodilo za porazdelitev prebivalstva in naselbinski vzorec v Bosni in Hercegovini: GIS analiza
Članek analizira porazdelitev in velikostno strukturo naselij vzdolž glavnih rečnih tokov Bosne in Hercegovine, pri čemer upošteva tako hipsometrijo kot socioekonomske dimenzije prostora, ki prispevajo k demografskim spremembam. Z uporabo GIS orodij je bila izvedena analiza števila naselij glede na hipsometrične nivoje v porečjih Črnega in Jadranskega morja ter demografskih sprememb v zadnjem medpopisnem obdobju. Metode prostorske analize v GIS so omogočile identifikacijo sprememb prebivalstva, velikosti naselij in vzorcev prostorske razporeditve. Analiza varovalnih pasov v razdalji 5 km od rečnih tokov razkriva prevladujoče prostorsko združevanje naselij vzdolž teh vodotokov, medtem ko je fragmentacija naselbinskih omrežij opazna dlje od glavnih tokov.

Ključne besede
porečja, hipsometrične cone, prebivalstvo, naselja, Bosna in Hercegovina

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1 Introduction

The population, being the fundamental factor in space, is the subject of research in various social and natural sciences (Wertheimer-Baletić, 1999). The dynamics of its development changes under the direct or indirect influence of various factors, which depend on what the spatial distribution of the population will be. These factors can be categorized into natural (climate, relief, soil, resources, spatial relations) and social, encompassing a broad spectrum of demographic, economic, political societal and other spatial dimensions (including the level of economic development, population structures, cultural elements, fertility and mortality rates, migration patterns) (Nejašmić & Toskić, 2000). The first settlements in the development of human civilization were formed in river valleys, and in those areas, they developed into today's large urban agglomerations, which are usually the densest and most populated. The relationship between human settlement locations and water resources has changed over time. In the past, people lived close to rivers and utilized water for both domestic consumption and agriculture, as well as for navigation, which led to people following rivers during migration (Rodriguez-Iturbe et al., 2009) and settling there (Kummu et al., 2011). Over time, they were able to reduce their dependence on direct proximity to rivers by developing advanced measures to transport from other sources through canals, groundwater pumping, and desalination (MacDonald, 2010). With the advancement of land (rail and road) and air transport, water transport is losing its importance (Grübler, 1990). Mousazadeh (2022) undertook research examining how attitudes and emotions towards a location impact the quality of life within an urban community situated adjacent to a river. The study underscores the significant relationship between natural elements, the sense of place, and the well-being of residents. One of the problems that arose in the settlements along the river was the risk of flooding. The development of flood protection measures and measures to reduce flood risks is increasing (Di Baldassarre et al. 2013). According to Dongya & Xudong (2020), the research results related to flood risk reduction could serve as a reference for the local government to formulate population and environmental protection policies to achieve harmony between nature and people. Analysing the coevolution of people and water resources between 1790 and 2010 in the United States of America, Fang & Jawitz (2019) point out that people moved closer to large rivers in the preindustrial period but began to move away from them after 1870. During this period, people used rivers for trade and transportation, which was the leading factor for settlement and population concentration. The 20th century saw a change in attitudes towards water resources, and people began to be more inclined to areas above large aquifers because of the greater availability of groundwater. According to Fang & Jawitz (2019), regional heterogeneity resulted in different trajectories of settlement proximity to major rivers, with the attractiveness of rivers increasing in arid regions and decreasing in humid areas. The formation of today's structure and distribution of settlements was greatly influenced by the inherited structure of settlements, the way cities were created, the existence and proximity of state borders, as well as the degree of utilization of natural and human resources. According to Nejašmić & Toskić (2000), recognizing when certain influences prevailed is difficult due to the complex influence of all these factors on population distribution.

The relationship between settlement and physical elements of the area, such as relief and climate in Bosnia and Herzegovina, has often been the subject of geographical considerations, where the main patterns of population concentration in lower hypsometric levels and areas with a more favourable and moderate climate have been confirmed (Ahmetbegović, 2014; Ahmetbegović et al., 2015). The analysis of the

distribution of the population in relation to the hydrographic network has practical significance, especially for the purpose of assessing the risk of floods and the vulnerability of the area, which is very important for Bosnia and Herzegovina, considering the fact that it often faces floods, of which the ones from 2014 stand out. Therefore, previous research has been based on the creation of flood hazard and risk maps for specific watersheds (Blagojević et al., 2018; Šeperović & Kupusović, 2015) analyzes of infrastructure vulnerability to floods (Živanović et al., 2014; Kobold et al., 2015) and the ecological consequences of the aforementioned natural disasters (Medunić & Šmit, 2016). According to Kummu et al. (2011), the direct dependence of the population and water bodies changed due to physical, socioeconomic and, of course, demographic changes, which have recently affected Bosnia and Herzegovina. The surrounding area, including water resources, has been significantly impacted by the accelerated urbanization and increasingly dynamic human activities (Liyanage & Yamada, 2017). The problems of sustainable development, preservation of watercourses, and water quality are being increasingly emphasized in studies concerning the issue of interdependence between population and water resources in terms of the convenience of settlement and increasing economic utilization of space. The analysis of the population from the aspect of its concentration in relation to river flows has not been elaborated in detail so far. It is known that the proximity of larger rivers, the fertile soil of river terraces and alluvial plains for the development of agriculture, but also the concentration of industrial zones is taken as a leading factor in the distribution of settlements and the concentration of the population in Bosnia and Herzegovina. This type of geographical research has great practical significance and relevance especially in the domain of GIS use. Over the past few decades, the swift advancement of GIS techniques has offered numerous opportunities to uncover spatial features of the constructed environment (Hegedűs et al., 2023; Hrelja et al., 2021; Smajić et al., 2020). GIS provides a powerful tool for analysing population density and distribution by combining spatial population data with different layers of information, such as topography, hydrology, infrastructure, and other spatial features. Through hydrological analyses, GIS enables the identification of key water resources, such as rivers, lakes and areas of high risk of flooding, which can affect housing and the quality of life of the population. On the other hand, demographic analysis through GIS enables the study of population distribution in relation to various geographic characteristics, such as urban/rural area, access to infrastructure or socioeconomic status. The integration of these analytical methods in GIS enables a deeper understanding of spatial patterns of the population and the identification of trends and potential problems in urban planning, resource management and social policy.

Taking into account the significant demographic changes that have affected Bosnia and Herzegovina in the recent period, it is important to detect the effects and factors of such changes, especially for the purposes of population policy planning. The war during the period 1992-1995, as well as the slow economic progress of the country due to numerous social problems (Nurković, 2006), resulted in the pronounced depopulation, demographic aging (Kadušić et al., 2023), and a large emigration wave (Pobrić, 2002). The demographic situation of the country is characterized by the mentioned trends, but there are also significant demographic disparities that can be observed on the center-periphery line (Avdić & Avdić, 2023). Negative demographic trends are particularly evident in rural settlements of karst areas due to the limited conditions for agriculture development and the implementation of various infrastructure projects (Avdić, Avdić & Sivac, 2019). The authors highlight that during the last intercensal period, over 100 rural settlements in the karst region of Bosnia

and Herzegovina were left uninhabited, while at the state level there are about 500 such settlements.

Considering the above, the main research goal is to analyse the distribution and size structure of settlements along the main river courses of Bosnia and Herzegovina, taking into account both hypsometry and socioeconomic dimensions of space, which are increasingly factors of demographic transformations. Using GIS tools, an analysis was made of the number of settlements according to hypsometric levels in the river basins of the Black and Adriatic Seas, as well as demographic changes in the last intercensal period. The outcomes of this study could lay the groundwork for crafting strategies aimed at regional development, while also pinpointing essential intervention zones in the event of natural disasters.

2 Methodology

Considering the main goal of the study, the phases of the database preparation are shown schematically (Figure 1). The study is based on hydrological and demographic analysis conducted in GIS.

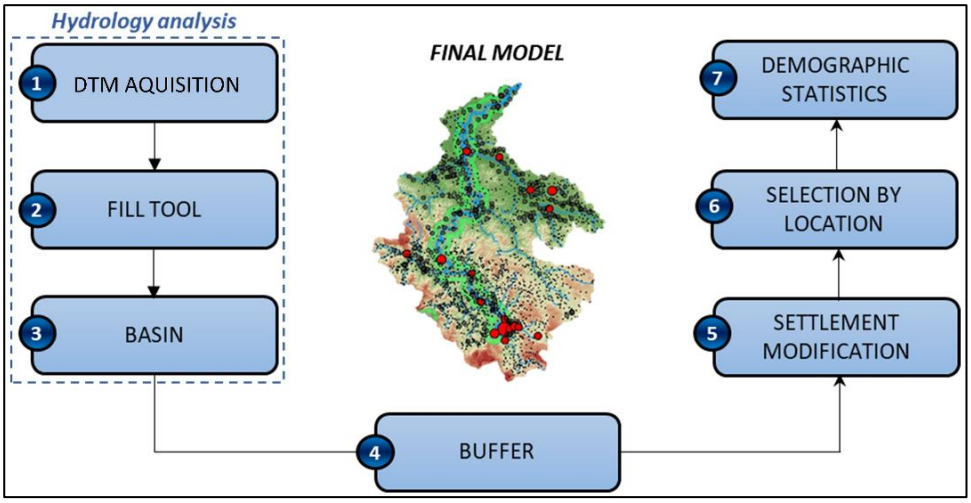

Figure 1: Database preparation stages.
Source: Authors.

In the case of hydrological analysis, whose main goal was to identify river basins, the basis was represented by a digital relief model (DTM), which serves as a template for generating flow direction. When the direction of water runoff from each element of the grid is known, it is possible to define the boundary of the topographic basin and watershed and the drainage network of the runoff using adequate GIS tools. However, before that process, it is necessary to prepare a DTM, that is, to remove certain errors that occur in the form of illogical lower points in relation to the surrounding area, which is a consequence of certain technical errors during the collection of height data. The fill tool was employed to eliminate the most extreme points of depression. The key part of determining the hydrological characteristics is the already mentioned determination of the runoff direction based on the steepest slope. The determination of topographic basins is established through the detection of drainage basins, that is, the space within which all surface water converges to a certain point. The model of

the drainage basin is obtained automatically, using the basin tool. This study shows that this procedure is mostly used to distinguish larger basin areas, while also effectively identifying smaller sub-basins within them.

The preparation of the layer with settlements implied the adaptation of the available network and settlement system of Bosnia and Herzegovina to the latest administrative-territorial arrangement, so that the results of Census data from 2013 would be comparable for settlement units. Taking into account the changes that took place in Bosnia and Herzegovina in the last intercensal period (1991-2013), which refers to numerous divisions of local self-government units along the Inter-Entity Boundary Line, it was necessary to clearly differentiate newly created settlements as well as abandoned settlements, of which around 500 were detected. At the same time, the demographic database consists of basic demographic indicators, such as the total number of inhabitants, population density and indicators of inter-census changes in the number of inhabitants (index of changes in the intercensal period – 1991-2013). By separating the buffer zones from the main river flow, the categories of settlements were separated - those that are in the immediate influence zone of the water (distance up to 1km), settlements at a distance of 2km and settlements that are significantly further away from the river flow (5km distance). Comparing the demographic parameters of the settlements with the distance from the river course was done using the separated zones as a basis (descriptive statistics). Extracting buffer zones around rivers is a valuable tool for spatial analysis of population distribution in relation to water resources. This information is valuable for urban planning, resource allocation, and decision-making processes aimed at sustainable development and disaster risk reduction.

As significant factors in the legal distribution of the number of inhabitants, relief was considered, as well as the socioeconomic basis, which in recent times represents the most significant modifier of the demographic state of a certain area. This particularly applies to the migration component of the population, which, along with other demographic indicators (negative natural change and demographic aging), increasingly influences the creation of highly pronounced demographic disparities in the country. A significant output for further analysis, stemming from the methodology described above, are the maps of river basins with highlighted settlement buffer zones, created based on the distance from the river course.

3 Results

3.1 Territorial scope of research

This study focuses on the river basins of Bosnia and Herzegovina, serving as the principal territorial units for demographic analysis. On the territory of Bosnia and Herzegovina, there are two main basin areas that belong to the basins of the Black and Adriatic Seas (Figure 2). The spatial coverage of the Black Sea basin in Bosnia and Herzegovina is 38,223.5 km^2, and the Adriatic Sea basin is 2,955.5 km^2 (Drešković & Mirić, 2017).

The Black Sea basin also known as the Sava River Basin and it drains water towards the Danube and eventually the Black Sea. Nine sub-basins divide the main basin areas. The hydrographic system of Bosnia and Herzegovina is formed depending on the interaction of physical-geographical factors, firstly, the geological structure, geomorphological, and climatic characteristics of this area. In addition to the marine

water area in the extreme south of the country, the freshwater hydrographic system appears in the form of surface and underground type of runoff, which is directly related to the hydrogeological characteristics of the area. Bosnia and Herzegovina's permanent surface river network has a total length of 20,918.68 km, with a river network density of approximately 0.41 km/km^2 (Table 1).

Of the nine sub-basins that make up Bosnia and Herzegovina's area, six of them feature a cross-border component. These are the Una and Drina basins, the immediate basin of the Sava, Neretva, Trebišnjica basins and the Cetina and Krka basins. As a whole, only the basins of the rivers Bosna and Vrbas belong to the territory of Bosnia and Herzegovina. Depending on the geological-geotectonic and geomorphological characteristics, in the territory of Bosnia and Herzegovina, the dendroid type of river network prevails with the appearance of tectonically predisposed, radial riverbeds.

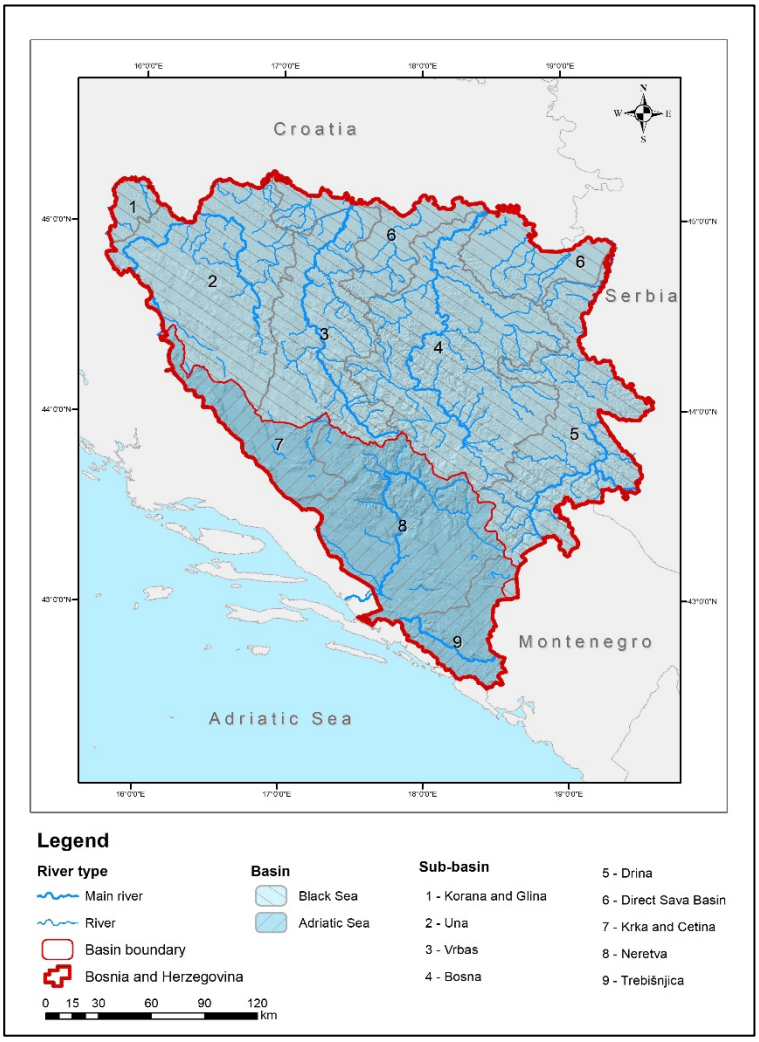

Figure 2: Geographical position and main basin areas of Bosnia and Herzegovina.
Source: Authors.

Table 1: Basic morphometric and hydromorphological indicators of the surface river network in Bosnia and Herzegovina (total length of river courses in the basin – Ltot, total length of river courses whose length is greater than 10 km - LL, area of basin – A, specific outflow – q).
Source: according to Dreško vić & Mirić, 2017.

No	River basins	L_{tot} (km)	$L_{L>10}$ (km)	A (km²)	q (l/s/km²)
1	**Immediate basin of the Sava**	3,197.30	1,693.2	5,323.10	11.4
2	**Glina and Korana**	500.22	128.5	705.57	24.6
3	**Una**	2,747.71	1,480.7	7,962.10	26.1
4	**Vrbas**	2,654.14	1,096.3	6,288.59	19.9
5	**Bosna**	5,910.79	2,321.9	10,758.99	16.1
6	**Drina**	3,167.67	1,355.6	7,185.10	21.2
Black Sea basin		**18,177.83**	**8,076.2**	**38,223.45**	**119.3**
1	**Neretva**	1,961.79	732.2	7,947.51	38.1
2	**Trebišnjica**	298.79	154.6	2,254.94	49.4
3	**Cetina and Krka**	480.27	177.0	2,753.10	34.6
Adriatic Sea basin		**2,740.85**	**1,063.8**	**12,955.54**	**122.1**

3.2 Population and settlement distribution in the Black and Adriatic Sea basins

The basins of Glina, Korana, Una, Vrbas, Ukrina, Bosna and Drina, as well as the immediate basin of the Sava, belong entirely or partially to the Black Sea basin. Within this area, analysis was conducted across 12 hypsometric levels, each 200 meters in height, to examine settlement and population distribution (Figure 3). Notably, the largest settlement in terms of population is located at the hypsometric level of 200 to 400 meters above sea level. It is Cazin, located on the banks of the Čajin stream, which according to data from 2013 had 13,863 inhabitants. Furthermore, within the hypsometric zone up to 200 meters, the largest populated settlement is Velika Kladuša in the Grabarska river valley with more than 4,500 inhabitants (Census 2013). Additionally, several settlements emerged within the river valley: Poljana, Gradina, Grabovac, Dolovi, Crvarevac, Varoška Rijeka, Bužim, Kopići, Čizmići, Mutnik and Čehići.

In the sub-basin area of the Una River on the territory of Bosnia and Herzegovina, the largest number of inhabitants (39,690), according to the results of the population census held in 2013, lives in Bihać, which is located in the hypsometric zone from 200 to 400 meters above sea level, in the Una River valley. The second largest settlement, in terms of the number of inhabitants, in the Una River basin on the territory of Bosnia and Herzegovina is Prijedor, in the Sana River valley, which is located in the lowest hypsometric zone. In 2013, 29,555 inhabitants lived in this city. In addition to Bihać, larger settlements located along the Una River are Bosanska Krupa, Bosanski Novi, Bosanska Dubica and numerous other smaller settlements. Drvar is located on the banks of the Unac, as well as the smaller settlements of Bastasi, Boboljušci, Vrtoče,

and Šipovljani. In the valley of the Sana River, next to Prijedor, two larger settlements Sanski Most and Ključ were created.

The sub-basin area of the Vrbas River is entirely within the territory of Bosnia and Herzegovina, encompassing the territories of 21 municipalities, of which 10 belong entirely to this sub-basin, while the rest belong partially (Ovčina, 2021). The least populated hypsometric zone in the sub-basin area of the Vrbas River is the zone from 1400 to 1600 meters above sea level. In this zone, there are only two inhabited and 3 uninhabited settlements according to the last Census, with less than 100 inhabitants. In the river valley, the highest number of inhabitants is found in the hypsometric zone up to 200 meters, which has increased compared to the previous census. The largest settlement according to the number of inhabitants in 2013 in the sub-basin area of the Vrbas River is Banja Luka with 138,963 inhabitants. The city of Banja Luka is located in the valley extension of the Vrbas River and its tributaries in the zone up to 200 meters above sea level. Bugojno, with 15,555 inhabitants, is the second largest town in the Vrbas sub-basin. It is located in the hypsometric zone between 400 and 600 meters, in the valleys of three rivers: Vrbas, Duboka river and Poričnica. The settlements Jagodići from the municipality of Bugojno (3) and Božikovac from the municipality of Jajce (4) had the fewest inhabitants in 1991. These settlements are located within the hypsometric range of 1000 to 1200 meters above sea level. None of them are located near the river course, and according to the 2013 census, the settlements have ceased to exist.

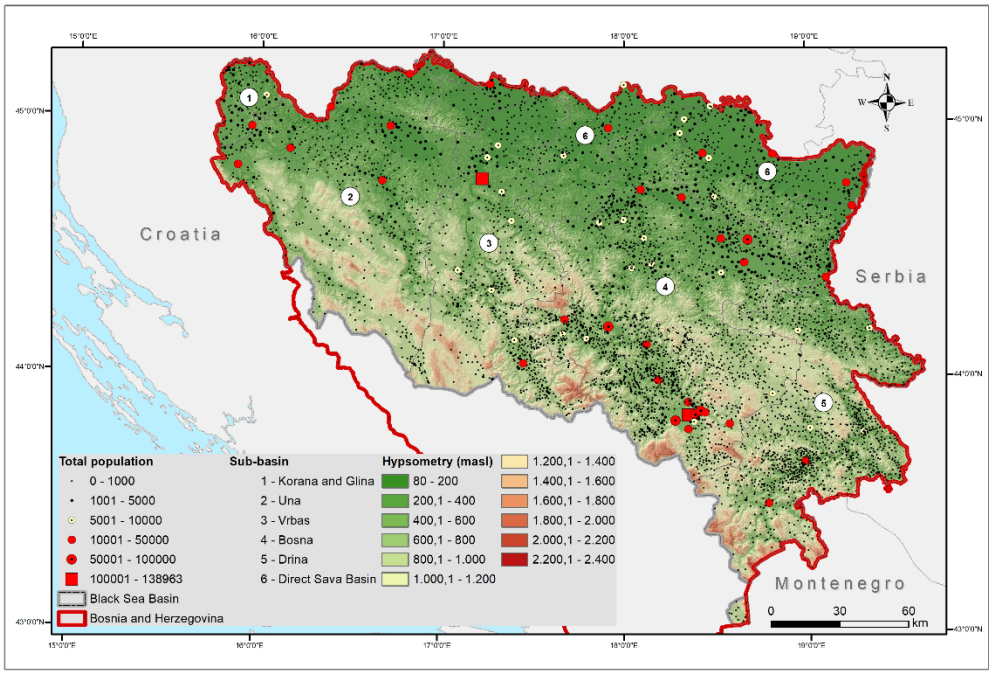

Figure 3: Distribution of settlements and number of inhabitants in the Sava (Black Sea) basin area on the territory of Bosnia and Herzegovina (2013).
Source: Authors according statistika.ba and DEM terrain model 25x25.

Since the Middle Ages, the sub-basin area of the Bosna River has been a significant hub for settlement and the development of larger communities. According to

Ahmetbegović (2014), the Sarajevo-Zenica valley has historically stood out in Bosnia and Herzegovina due to its significant industrial development. This region, along with the Lašva Valley, used to be the focal point for ferrous metallurgy and various other types of processing industries. Apart from the Sarajevo-Zenica valley, which encompasses the cities of Sarajevo and Zenica located in the Bosna valley, other highly populated regions within this sub-basin include the broader Tuzla area. This area is situated in the Jala river valley and is characterized by its tributaries, namely Solina and Grbovački stream. Although the sub-basin of the Bosna River, based on the results of the 2013 census, lost 302,800 inhabitants in 22 years, it is still inhabited by about 48% of the total population of Bosnia and Herzegovina. In 2013, there were 1,470,437 inhabitants in 1,816 settlements in the Bosnia sub-basin (Table 2).

The Drina sub-basin includes the eastern parts of Bosnia and Herzegovina. According to the last census, the smallest population lives in the hypsometric zone from 1400 to 1600 meters and that's a total of 3 inhabitants. The largest number of inhabitants live in Goražde, which is located on the banks of the Drina river. It belongs to the hypsometric zone from 200 to 400 meters above sea level and according to the results of the 2013 Census, it had 11,806 inhabitants. Among the settlements located in the lowest hypsometric zone, specifically up to 200 meters above sea level, Janja in the municipality of Bijeljina is the most populous with 11,710 inhabitants. Another settlement in this area with a significant population is Zvornik, which has 11,497 inhabitants. In this zone, there is an increase in the number of inhabitants compared to the previous census (population change index = 101.4).

There are four hypsometric zones with 556 settlements in the area of the immediate Sava basin in Bosnia and Herzegovina. According to the last Census, 483,829 inhabitants live in this sub-basin area. The largest number of inhabitants live in 362 settlements located in the zone up to 200 meters. In the lowest hypsometric zone, Bijeljina has the largest number of inhabitants according to data from 2013 and it amounts to 42,278 inhabitants, while Brčko with 39,893 inhabitants is the second largest in this area.

Table 2: Number of settlements and inhabitants of Bosnia and Herzegovina according to hypsometric zones in the Black Sea basin area in 1991 and 2013.
Source: Authors' own calculations according to statistika.ba and DEM terrain model 25x25.

Hypsometric level	**Number of settlements**	**Number of inhabitants 1991. (P_1)**	**Number of inhabitants 2013. (P_2)**	**Population change index** P_2/P_1*100
Sub-basin Glina and Korana				
< 200	24	29,185	22,192	76.0
200 – 400	68	82,321	78,728	95.6
400 – 600	6	6,071	5,629	92.7
Total	**98**	**117,577**	**106,549**	**90.6**
Sub-basin Una				
< 200	120	190,016	155,325	81.7
200 – 400	246	194,126	140,651	72.5
400 – 600	97	51,027	30,534	59.8
600 – 800	61	20,096	9,854	49.0
800 – 1000	57	9,997	2,987	29.9
1000 –1200	9	558	398	71.3
1200 – 1400	4	27	41	151.9

Total	**594**	**465,847**	**339,790**	**72.9**
Sub-basin Vrbas				
< 200	71	202,384	202,708	100.2
200 – 400	82	74,954	60,443	80.6
400 – 600	100	103,912	70,227	67.6
600 – 800	163	72,650	48,575	66.9
800 – 1000	126	34,387	16,204	47.1
1000 – 1200	61	16,830	9,491	56.4
1200 – 1400	14	3,044	485	15.9
1400 – 1600	5	265	97	36.6
1600 – 1800	1	0	0	0
Total	**623**	**508,426**	**408,230**	**80.3**
Sub-basin Bosna				
< 200	87	171,334	146,735	85.6
200 – 400	426	636,979	530,570	83.3
400 – 600	485	752,427	637,538	84.7
600 – 800	403	128,960	93,005	72.1
800 – 1000	250	64,356	52,885	82.2
1000 – 1200	139	17,861	8,651	48.4
1200 – 1400	21	1,271	998	78.5
1400 – 1600	3	13	30	230.8
1600 – 1800	0	0	0	0
1800 – 2000	2	36	25	69.4
Total	**1,816**	**1,773,237**	**1,470,437**	**82.9**
Sub-basin Drina				
< 200	41	59,133	59,970	101.4
200 – 400	197	142,546	99,856	70.1
400 – 600	318	104,798	66,798	63.7
600 – 800	345	57,443	26,169	45.6
800 – 1000	235	27,762	10,622	38.3
1000 – 1200	116	10,232	3,547	34.7
1200 – 1400	19	922	271	29.4
1400 – 1600	1	16	3	18.8
1600 – 1800	1	0	0	0
Total	**1,273**	**402,852**	**267,236**	**66.3**
Immediate basin of the Sava				
< 200	362	453,469	382,466	84.3
200 – 400	167	123,281	93,576	75.9
400 – 600	25	14,248	7,787	54.7
600 – 800	2	0	0	0
Total	**556**	**590,998**	**483,829**	**81.9**

The basin area of the Adriatic Sea is very specific both in terms of natural and social characteristics. The prevalence of limestone terrain and the significant processes of karstification have contributed to a lower density of surface river networks in the region and they have also impacted the diminished population density in the area, as well as the uneven distribution of settlements and inhabitants. Considering the relief characteristics, this area is also divided into hypsometric zones of 200m each, starting from 0 m above sea level up to >2000m. In the area of the Adriatic Sea basin in Bosnia and Herzegovina, the following sub-basins are distinguished: Neretva,

Trebišnjica, Cetina and Krka (Figure 4). There are a total of 716 inhabited places within the Neretva sub-basin. During the analysed period, the population declined by just under 49,000 individuals. The zone up to 200 meters above sea level, located within the area of the Neretva sub-basin, has the highest concentration of inhabitants, with a recorded population of 163,307 according to the 2013 census. This is the area where the city of Mostar is located as a regional center, followed by Čapljina, Ljubuški and Stolac, in the valley of the Neretva River and its tributaries Trebižat and Bregava. The zone with the fewest inhabitants is 1400 to 1600 meters above sea level, with only 13 inhabitants. Although they have 2 settlements in the higher hypsometric zones, they are uninhabited.

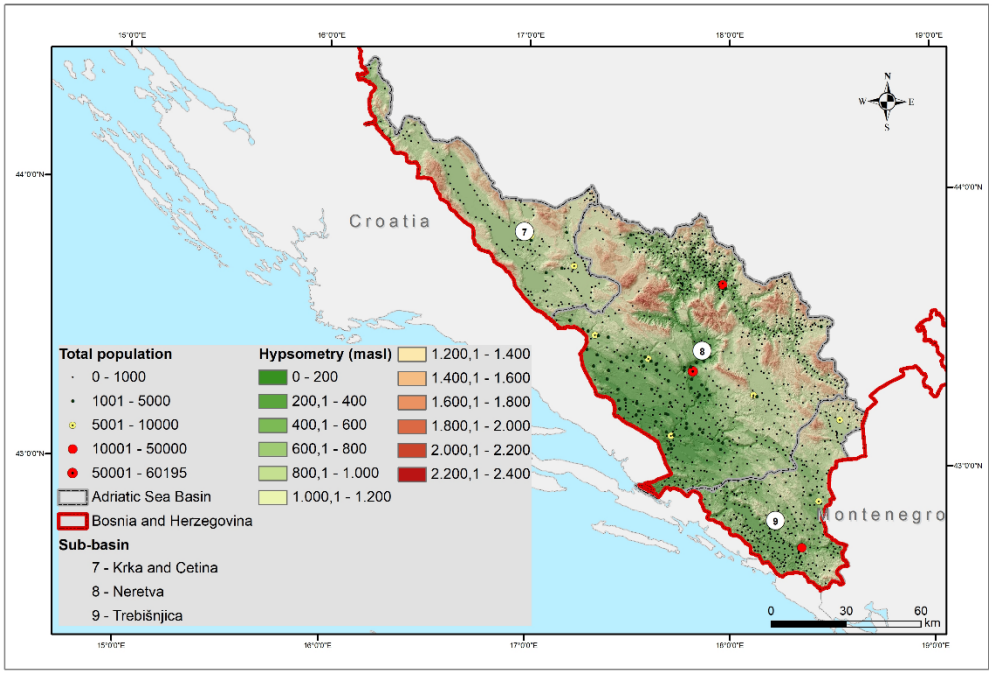

Figure 4: River sub-basins in the Adriatic Sea basin in Bosnia and Herzegovina.
Source: Authors according statistika.ba and DEM terrain model 25x25.

The total area of the Trebišnjica sub-basin is 2,254.9 km² and includes the territory of 6 municipalities, some of which are partially part of this sub-basin. The central component of the river network is formed by the Trebišnjica River, previously recognized as one of the longest underground rivers, stretching approximately 90 km prior to the implementation of hydromelioration operations. In the hypsometric zone from 200 to 400 meters, the largest number of settlements and inhabitants was recorded in the analysed census years. This is the zone where the number of inhabitants increased in 2013 with a change index of 106. This especially applies to the city of Trebinje, located in the valley of Trebišnjica. According to data from 1991, 50% of the total population in the area of the Trebišnjica sub-basin lived in the hypsometric zone from 200 to 400 m above sea level, while in 2013 that percentage increased to 57% (Selimović, 2021).

The Cetina and Krka sub-basins represent the westernmost part of the Adriatic Sea basin in Bosnia and Herzegovina. Regionally, it belongs to the Visoko karst region,

which historically and presently retains a depopulated character (Avdić, Avdić & Sivac, 2019). Within this sub-basin area a total of 170 settlements were recorded, experiencing a decrease in population with a change index of 84.5 during the analysed period (Table 3).

The zone ranging from 600 to 800 meters above sea level hosts the largest number of settlements and inhabitants. In 1991, this zone accommodated 43,573 inhabitants, decreasing to 35,994 inhabitants by 2013. Notably, parts of the municipalities of Livno and Tomislavgrad with a larger population are situated within this zone. The population level in this zone corresponds closely to that of the area between 800 and 1000 meters above sea level. It is noteworthy that, during the analysed period, only Tomislavgrad experienced a population growth, with a population change index of 111.5.

Table 3: Number of settlements and inhabitants according to hypsometric zones in the basin area of the Adriatic Sea in 1991 and 2013.
Source: Authors according statistika.ba and DEM terrain model 25x25.

Hypsometric level	**Number of settlements**	**Number of inhabitants 1991. (P_1)**	**Number of inhabitants 2013. (P_2)**	**Population change index** P_2/P_1*100
Sub-basin Neretva				
0-200	102	178,163	163,307	91.7
200-400	160	105,699	100,034	94.6
400-600	94	21,707	14,674	67.6
600-800	109	37,145	29,363	79.0
800-1000	123	27,004	20,498	75.9
1000-1200	95	9,235	3,952	42.8
1200-1400	28	2,008	603	30.0
1400-1600	3	220	13	5.9
1600-1800	1	0	0	0
1800-2000	1	0	0	0
Total	**716**	**381,181**	**332,444**	**87.2**
Sub-basin Trebišnjica				
0-200	0	0	0	0
200-400	108	28,118	29,811	106.0
400-600	68	14,303	14,420	100.8
600-800	53	2,756	1,257	45.6
800-1000	45	8,527	6,885	80.7
1000-1200	17	1,499	1,256	83.8
1200-1400	4	97	69	71.1
1400-1600	0	0	0	0
1600-1800	0	0	0	0
1800-2000	0	0	0	0
Total	**295**	**55,300**	**53,698**	**97.1**
Sub-basin Cetina and Krka				
0-200	0	0	0	0
200-400	0	0	0	0
400-600	4	723	81	11.2
600-800	80	43,573	35,994	82.6
800-1000	69	34,954	31,783	90.9
1000-1200	13	1,686	691	41.0

1200-1400	4	679	397	58.5
1400-1600	0	0	0	0
1600-1800	0	0	0	0
1800-2000	0	0	0	0
Total	**170**	**81,615**	**68,946**	**84.5**

3.3 Buffer zones and settlements in the sub-basins of the Black and Adriatic Sea basins in Bosnia and Herzegovina

In the Black Sea basin, particularly within the Sava River basin in Bosnia and Herzegovina, the highest concentration of inhabitants is situated in the valleys of major rivers. This population cluster is predominantly located within the hypsometric zone ranging from 200 to 400 meters above sea level (Table 4). In 2013, the population count stood at 1,003,824 inhabitants, representing a decrease of approximately 250,000 compared to 1991. Only 32.6% of the total population of the Black Sea basin resides within this hypsometric zone. The greatest indices of change and population increase was observed in the Bosna sub-basin within the zone 1400-1600 meters (230.8), followed by the Una sub-basin between 1200 and 1400 meters above sea level (151.9), and in zones up to 200 meters within the Drina (101.4) and Vrbas (100.2) sub-basins. It is necessary to further clarify that the values of the population change index at the hypsometric level above 1200 meters above sea level do not provide a clear picture of the real situation and it could be misleading. This concerns mountain settlements, which recorded an increase of only about twenty inhabitants in the last inter-census period (an increase from 13 to 30 inhabitants, resulting in an index value greater than 200). Despite the relatively significant figures, these numbers yield high index values. Therefore, the increase in the population of such settlements cannot be relevantly interpreted in the context of the study's subject matter.

Conversely, the lowest index of change and a significant decrease in population were recorded in the Vrbas sub-basin within the hypsometric zone of 1200-1400 meters (15.9). The overall index of change for the Sava River basin area during the analysed period is 79.7, which closely aligns with the national average of 80.7 and indicates a decline in population numbers.

The significant population decline observed during the inter-census period is primarily attributed to the devastating effects of war, resulting in casualties, as well as the migration of a considerable number of residents across all age groups. In addition, a significant contributing factor is the availability of economic opportunities that encourage an increasing number of people to emigrate. Based on the 2022 World Bank Report, Bosnia and Herzegovina is facing one of the highest emigration rates in the Western Balkans region, due to the consequent reduction in social benefits (www.fipa.gov.ba). Rural-urban migrations are pronounced in this area. Limited or absent investment in infrastructure development in villages, including transportation and communal facilities, among other factors, deters the younger population, as well as potential investors. Investors tend to allocate their resources in well-developed suburban areas. Investments correlate directly with labour demand on one hand, and job availability on the other. The development of cities as administrative, educational, cultural and industrial hubs, along with the presence of diverse service activities, attracts young individuals seeking employment or education opportunities.

Table 4: The number of settlements and the ratio of the number of inhabitants in 1991 and 2013 in the Black Sea basin by hypsometric zones.
Source: Authors according statistika.ba and DEM terrain model 25x25.

Hypsometric level	Number of settlements	Number of inhabitants 1991. (P_1)	Number of inhabitants 2013. (P_2)	Population change index (P_2/P_1*100)
0-200	705	1,105,521	969,396	87.7
200-400	1,186	1,254,207	1,003,824	80.0
400-600	1,031	1,032,483	818,513	79.3
600-800	974	279,149	177,603	63.6
800-1000	668	136,502	82,698	60.6
1000-1200	325	45,481	22,087	48.6
1200-1400	58	5,264	1,795	34.1
1400-1600	9	294	130	44.2
1600-1800	2	0	0	0
1800-2000	2	36	25	69.4
Total	**4,960**	**3,858,937**	**3,076,071**	**79.7**

A concerning trend within the Black Sea basin in Bosnia and Herzegovina is the abandonment or closure of several dozen settlements. Additionally, numerous settlements in the region, as per the 2013 census, had fewer than 10 inhabitants, suggesting the possibility of their disappearance. It's noteworthy that these settlements are predominantly located at higher hypsometric levels and are not situated in the valleys of major rivers. The increase in population in certain settlements in this area is largely driven by economic factors (Avdić, Avdić & Sivac, 2024; Development Programming Institute of FBiH, 2023; Nurković, 2006). The valleys of the Sava tributaries in Bosnia and Herzegovina, where larger cities have emerged, boast fertile land suitable for agriculture and significant industrial production, thus offering employment opportunities that attract residents.

In the basin area of the Adriatic Sea, between 1991 and 2013, the population change index was 87.8 (Table 5), indicating an overall decline in the total number of inhabitants. The largest population resides in the zone up to 200 meters above sea level. According to the 2013 census, zones with the fewest settlements are above 1600 meters, each with one settlement and no inhabitants. The lowest population count was recorded in the zone between 1400 and 1600 meters above sea level, where the population change index of 5.9 indicates a decrease of about 95% compared to the previous census. In this zone, the number of inhabitants was reduced from 220 to only 13 in 3 settlements.

Table 5: The number of settlements and the ratio of the number of inhabitants in 1991 and 2013 in the basin area of the Adriatic Sea by hypsometric zones.
Source: Authors according statistika.ba and DEM terrain model 25x25.

Hypsometric level	Number of settlements	Number of inhabitants 1991. (P_1)	Number of inhabitants 2013. (P_2)	Population change index (P_2/P_1*100)
0-200	102	178,163	163,307	91.7
200-400	268	133,817	129,845	97.0
400-600	166	36,733	29,175	79.4
600-800	242	83,474	66,614	79.8
800-1000	237	70,485	59,166	83.9
1000-1200	125	12,420	5,899	47.5
1200-1400	36	2,784	1,069	38.4
1400-1600	3	220	13	5.9
1600-1800	1	0	0	0
1800-2000	1	0	0	0
Total	**1,181**	**518,096**	**455,088**	**87.8**

The largest increase in population was observed in settlements within the municipalities of Posušje and Čitluk, as well as in the municipalities of Tomislavgrad, Široki Brijeg, Grude, Neum, and Ravno. These settlements are primarily situated in zones up to 600 meters above sea level, with the exception of Tomislavgrad, which lies above this hypsometric zone. Upon comprehensive examination of the sub-basins of the Neretva and Trebišnjica rivers, it becomes apparent that the right sub-basin area of the Neretva is more densely populated. Furthermore, the valley extensions of the Neretva, encompassing cities such as Mostar, Jablanica, Čapljina, and Konjic, exhibit higher population concentrations. Slightly less populated areas are found in the south, around Trebinje. The extreme western and eastern parts of this sub-basin area are sparsely inhabited or uninhabited, largely due to the characteristic mountainous terrain and waterless karst fields (*poljas*).

The western part of the Adriatic basin is occupied by the sub-basin of Cetina and Krka, which is relatively sparsely populated except for Tomislavgrad and Livno. Tomislavgrad is situated adjacent to Duvanjsko polje in the valley of the river Šujica, while Livno developed alongside Livanjsko polje and Lake Buško (Selimović, 2021).

Alongside the river courses, the main transportation arteries are predominantly formed within the river valleys, representing the most suitable terrain for their construction. Within the Adriatic Sea basin area, several main roads connect the largest regional centers. Notably, the M17 (E73) road stands out as the longest and most significant road in the region, serving as a vital link between Mostar and Sarajevo, as well as connecting Bosnia and Herzegovina with the neighbouring Republic of Croatia. Branching off at Buna, the main road M17.3 leads through Stolac, Hutovo to Neum. Additionally, the main road M6.1 runs northwest-southeast, and M6 road to Croatia. These road routes, situated in river valleys, connect municipal centers and generally exhibit higher population density compared to less accessible areas.

The distribution of population in the Adriatic Sea basin can be attributed to the availability of favorable terrain for settlement, economy, and industry development. This phenomenon is particularly noticeable in the valleys of rivers like the Neretva and its larger tributaries, as well as along the edges of fields. In these areas, the presence of urbanized and developed settlements serves as an attractive factor for

less developed ones, resulting in population migration from higher to lower altitudes. Analysing the distance of settlements and population concentration in relation to the main streams was conducted using GIS tools to extract buffer zones. Three zones were defined in relation to the main river of the sub-basins: up to 1km, 2km, and up to 5km (adapted from Fang and Jawitz, 2019). Overlaying population data onto these zones is crucial for visualizing and identifying human settlement patterns, as well as determining areas of high population density or vulnerability.

In the Black Sea basin, a notable characteristic is the concentration of the highest population numbers in the sub-basins of the Una, Vrbas, Bosna, and Drina rivers within the first buffer zone, compared to other analysed areas (Figure 5 and Figure 6). This zone hosts administrative and industrial centers that attract a larger number of residents due to the services they provide. Only 8.6% of the settlements in the first buffer zone of the Black Sea basin contain around 22% of the total population. Additionally, it's noteworthy that 33.17% of all settlements in the basin are situated within a distance of up to 5km from the main rivers, housing approximately 45% of the total basin population.

Figure 5: Buffer zones and settlements in the Neretva, Bosna, and Drina sub-basins.
Source: Authors according to statistika.ba and DEM terrain model 25x25 from the Geo-database of GIS Center, Department of Geography, University of Sarajevo – Faculty of Science, adapted using ArcGIS Version 10.6.1.

Figure 6: Buffer zones and settlements in the sub-basins of the Una with Glina and Korana, the immediate basin of Sava, Vrbas, and Trebišnjica.
Source: Authors according to statistika.ba and DEM terrain model 25x25 from the Geo-database of GIS Center, Department of Geography, University of Sarajevo – Faculty of Science, adapted using ArcGIS Version 10.6.1.

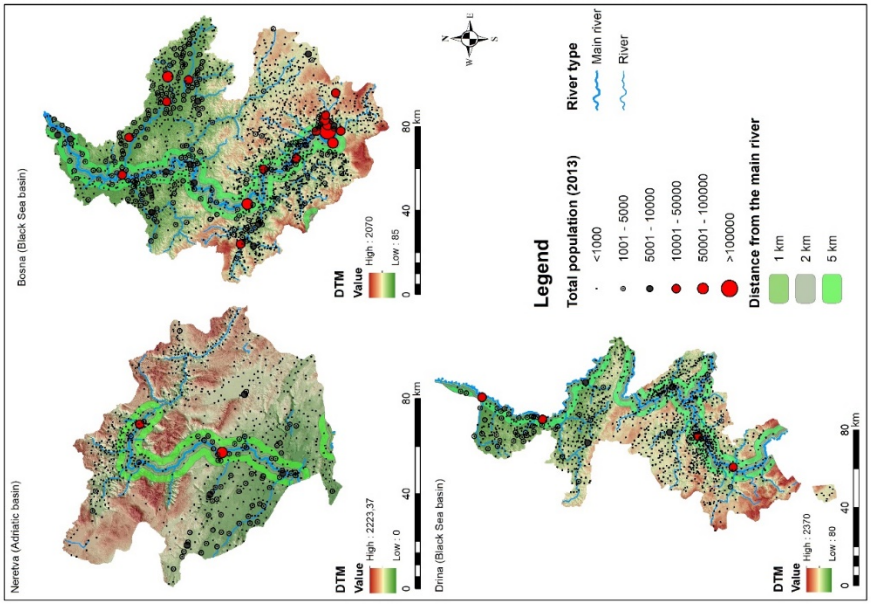

Figure 5

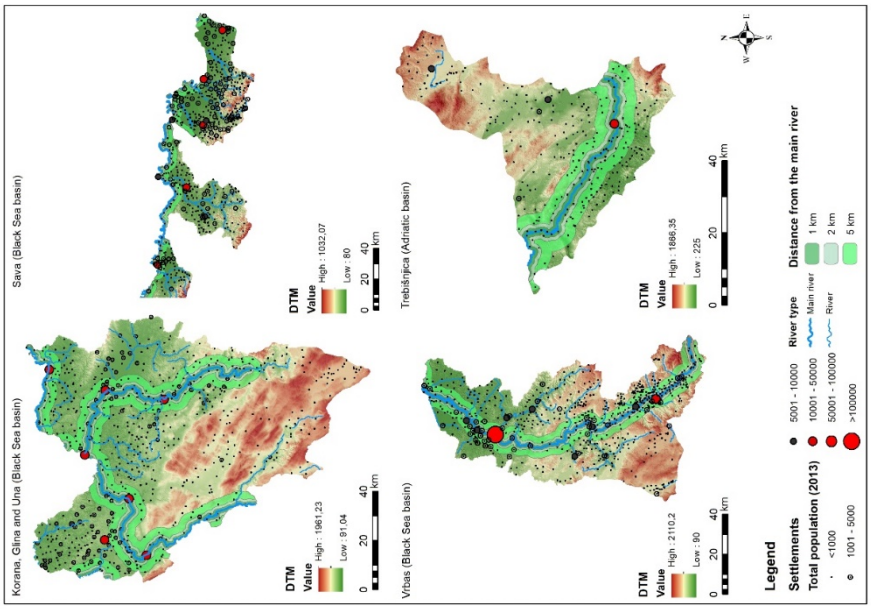

Figure 6

Hypsometric relationships also significantly influence population distribution within river basins. These relationships have shaped the establishment and growth of settlements in alluvial plains and river terraces situated in lower hypsometric zones. These areas offer favourable conditions for various activities and facilitate settlement expansion due to their developmental and utilization suitability.

The analysis of sub-basins in the Adriatic Sea basin focuses on the Neretva and Trebišnjica sub-basins. The Krka and Cetina sub-basins lack surface flow constituting the main river of the area (Figure 2). The geological terrain structure, dominated by Jurassic and Cretaceous limestones with intense karstification processes, has influenced the formation of a river network comprising smaller surface streams and underground rivers.

In the first buffer zone of the Adriatic Sea basin, a total of 386,142 inhabitants were recorded in 8.2% of all settlements, accounting for approximately 34.5% of the total population in the Neretva and Trebišnjica sub-basins. The Adriatic Sea basin contains 28.4% of settlements up to 5km from the main rivers, where 48% of its population resides.

In the sub-basin of the Trebišnjica River, 47.7% of the population inhabits the first buffer zone, while 32.4% resides in the Neretva sub-basin. Except for the Korana and Glina sub-basins, the average number of inhabitants per buffer zone in all sub-basins consistently decreases (Table 6).

This deviation can be attributed to the presence of tributaries of the Korana and Glina rivers within the territory of Bosnia and Herzegovina. Settlements have developed along these rivers, complicating the separation of buffer zones according to established methodology. The most significant reduction in the average number of inhabitants per settlement is observed in the vicinity of the Una and Vrbas rivers in the Black Sea basin and the Neretva River in the Adriatic basin. A slightly smaller reduction in this indicator is evident in the Bosna sub-basin, reflecting the historical core of settlement development along the Bosna River, with settlements gradually expanding further from the river over time.

When considering the number of settlements in buffer zones within the Black and Adriatic basins, the research did not establish a consistent trend of decline with distance from the main river courses. However, the analysis revealed a concentration of settlements with more than 10,000 inhabitants along the rivers, while the demographic size of settlements decreases as they move away from the main river courses. Regional variability observed in this regard is influenced by climatic conditions and socio-economic development. Consequently, it can be inferred that proximity to the river affects the size of the settlement.

Table 6: The average number of inhabitants per buffer zone of the hydrographic backbone of the sub-basins and the percentage share of settlements and population in relation to the total number of inhabitants of the sub-basins according to the 2013 census.
Source: Authors' own calculations.

Main river of the sub-basin	**Area (km²)**	**Average number of inhabitants per settlement** *(distance from the main river)*			**Percentage of settlements and population within 5 km distance from the main river**	
		Up to 1 km	**1-2 km**	**2-5 km**	**Settlements in total number of settlements (%)**	**Population in total population (%)**
Korana and Glina	705.57	295.50	407.00	802.60	14.29	8.85
Una	7,962.14	2,430.44	459.73	413.50	40.24	67.74
Vrbas	6,288.59	2,617.46	594.52	372.07	44.62	72.83
Bosna	10,758.99	1,924.79	1,090.37	1,089.71	25.11	40.95
Drina	7,185.1	415.76	289.15	131.06	42.89	51.53
Direct Sava basin	5,890.47	1,589.74	964.40	611.39	20.14	20.26
Black Sea Basin	**38,790.9**	**1,657.67**	**627.67**	**524.17**	**33.17**	**44.69**
Neretva	7,947.53	2,070.71	433.45	378.66	23.92	46.64
Trebišnjica	2,254.94	827.10	74.05	50.85	40.14	56.89
Adriatic Basin	**10,202.5**	**1,606.23**	**313.65**	**227.36**	**28.64**	**48.06**

4 Conclusion

This research offers valuable insights into the relationship between settlement distribution and river flows in Bosnia and Herzegovina. By analysing hydrological and demographic characteristics using GIS technologies, the study identifies key factors influencing population distribution in relation to the physical features of the area. The process of database preparation enables precise delineation of river sub-basins and watersheds, essential for subsequent analyses. Significant changes in the administrative-territorial organization of Bosnia and Herzegovina during the last intercensal period (1991-2013) necessitated adjustments to demographic data at the level of inhabited places to ensure comparability across different time periods.

Analysis of demographic data from population censuses reveals trends in population settlement and migration concerning river flows. Key findings indicate a correlation between proximity to a river and population density, with a decrease in settlement

size observed as distance from the river increases. These insights are crucial for urban planning, resource allocation, and decision-making processes aimed at promoting sustainable development and reducing risks associated with natural disasters.

Research findings indicate that approximately one-fifth of the total population of the Black Sea basin resides within the first buffer zone of 1 km. In the case of the Adriatic basin, this percentage exceeds one-third of the total population in the basin. Analysis of sub-basins reveals significant differences emphasizing the role of hypsometric regularities in shaping the settlement network along rivers. In the Adriatic Sea basin area, 64% of the total population resides at altitudes up to 400 m above sea level, where municipal and cantonal centers are located, and approximately 68% of settlements are distributed above this altitude. A similar situation is observed in the Black Sea basin area, where 64% of the total population resides in 38% of settlements located up to 400 m above sea level.

Furthermore, a noticeable decrease in the number of inhabitants is observed across the analysed categories. In the Black Sea basin, population decline is partly attributed to war events and economic challenges that encourage emigration from rural areas. Conversely, certain zones with larger urban centers experience population growth driven by economic potential and infrastructural development. Conversely, in the Adriatic Sea basin, similar trends of population decline are observed, especially inland, while larger cities along the rivers remain attractive for living.

This research underscores the importance of balanced development and resource management to ensure settlement sustainability and reduce vulnerability to natural and social changes. The obtained results, derived from descriptive statistics and GIS analysis of spatial data, serve as the foundation for further research and analysis based on inferential statistics, providing more detailed insights into the statistical significance and dependence of population size, settlements, and their distance from main river courses.

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Povzetek

Dinamična in kompleksna interakcija med prebivalstvom in vodo odpira ključna vprašanja glede geografske razporeditve naselij v povezavi z vodnimi viri. Voda, kot bistveni element, vpliva na oblikovanje naselij, prostorsko konfiguracijo in izbiro industrijskih lokacij, kar potrjujejo številne geografske študije. Rezultati analiz v prispevku kažejo na večjo gostoto prebivalstva ob rekah in na regionalne razlike pod vplivom podnebja, reliefa in socialno-ekonomskih dejavnikov. Analiza vplivnih pasov, ki obsegajo 5 km od rečnih tokov, razkriva izrazito koncentracijo naselij vzdolž vodotokov. Ugotovitve se razlikujejo od razpršenega vzorca poselitve, opaženega na območjih bolj oddaljenih od glavnih tokov, kjer se kaže razdrobljena poseljenost. V kontekstu urbanističnega in prostorskega načrtovanja je takšna analiza uporabna za zagotavljanje dragocenega vpogleda v kompleksne interakcije med populacijsko dinamiko in vodnimi telesi v kontekstu Bosne in Hercegovine. Zemljevidi porečij z vplivnimi pasovi poselitve služijo kot dragoceno orodje za nadaljnje analize in načrtovanje, medtem ko so statistični podatki iz popisov prebivalstva ključni vir informacij za razumevanje demografske dinamike v Bosni in Hercegovini. Ti rezultati prestavljajo osnovo za načrtovanje zaščite pred poplavami, določanje indeksov poplavne nevarnosti in oblikovanje ukrepov regionalne prostorske razvojne politike.