

Demographic diversity of the municipalities in Bosnia and Herzegovina: A clustering approach

Boris Avdić^{1, CDMR}, Aida Avdić Marić^{2, CFMR}, Amina Sivac^{3, DFMR}

^{1,3}University of Sarajevo, Department of Geography – Faculty of Science; Zmaja od Bosne, Sarajevo, Bosnia and Herzegovina;

¹e-mail: borisavdic@pmf.unsa.ba; ³e-mail: amina.sivac@pmf.unsa.ba; Independent Researcher, Sarajevo, Bosnia and Herzegovina, ²e-mail: avdicmaric@gmail.com (corresponding author)

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Abstract. The demographic development of Bosnia and Herzegovina is a highly relevant topic in academic, political and public discourse, particularly amid ongoing depopulation trends that align with broader demographic challenges in Central, Eastern and South-eastern Europe. Negative natural population change and pronounced demographic ageing stem from post-war transitions and socio-economic conditions. While geographical, economic and social factors shape regional demographic disparities, spatial heterogeneity remains insufficiently researched. This paper analyzes local demographic trends through selected indicators and applies clustering methods to identify distinct demographic groups among municipalities and cities. The findings contribute to a better understanding of regional demographic patterns and provide a framework for comparative studies in broader European contexts.

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1. Introduction

Over the next three decades, the majority of countries in Central, Eastern and South-eastern Europe are projected to experience substantial population declines due to persistently low fertility rates and sustained emigration trends (Ilyina et al., 2019). These demographic shifts pose significant challenges to economic development, social stability and long-term demographic sustainability (Ilyina et al., 2019). Current demographic trends in Bosnia and Herzegovina align with broader patterns observed across the regions mentioned above, particularly concerning issues of population ageing, depopulation and reduced natural population growth (Sobotka & Fürnkranz-Prskawetz, 2020; Gukalova, 2023). Bosnia and Herzegovina exemplifies some of the most pronounced demographic challenges in the region of South-eastern Europe, due to its post-war socio-political context (Gavrić et al., 2013), fragmented governance structures (European Commission, 2023) and economic instability (Kromják, 2021). The demographic situation in Bosnia and Herzegovina is widely recognized as a pressing social issue and is often reported on in the media. However, a significant number of these reports tend to focus on surface-level narratives, often shaped by unverified statistics or misinterpretations that obscure the real, objective causes of negative demographic trends and pronounced demographic disparities. While media discourse underscores the urgency of demographic challenges, there is a noticeable gap in comprehensive research that systematically examines the factors driving population decline and regional disparities. There is a noticeable lack of studies addressing demographic problems at the level of all local administrative units in Bosnia and Herzegovina (143 municipalities/cities) (Mujakić, 2016) and considering a broader range of demographic and spatial indicators. This limitation partially stems from the statistical base being limited, especially with regard to the long periods between official censuses. The last official census in Bosnia and Herzegovina was conducted in 2013, while the previous one was conducted in 1991; consequently, only one official census has been carried out since Bosnia and Herzegovina became an independent state. Additional challenges arise from the asynchronous publication of individual demographic indicators by entity-level statistical institutions (Delegation of the European Union to Bosnia and Herzegovina & European Union Special Representative in Bosnia and Herzegovina, 2024). In Bosnia and Herzegovina, the entity level refers

to the Federation of Bosnia and Herzegovina and to Republika Srpska. Demographic research at the municipal level in Bosnia and Herzegovina represents a crucial aspect of studying all spatial-social dimensions, including economic, political and cultural. Such analyses are vital for planning and creating regional policies, particularly in light of current demographic challenges.

Throughout its history, Bosnia and Herzegovina has experienced various developmental and cultural periods that have significantly impacted its demographic profile. Factors such as political circumstances, migrations and economic changes have left a deep mark on the overall demographic development (Dugandžić, 2018). The consequences of these factors have been especially visible since the war and the war-induced demographic and economic transition, leading to deepening depopulation and intense population ageing across the country (Pobrić & Avdić, 2020; Avdić et al., 2022). According to the latest census in 2013, Bosnia and Herzegovina has ~3.5 million inhabitants, which is a significant decrease compared to the pre-war population of 4.4 million (Agency for Statistics of Bosnia and Herzegovina, 2023). More recent estimates confirm the continuation of these unfavorable trends. Population estimates for Bosnia and Herzegovina vary across methodological sources. According to World Population Prospects 2024 (UN Department of Economic and Social Affairs, 2024), Bosnia and Herzegovina's mid-year population was estimated at ~3.185 million in 2023, whereas the Agency for Statistics of Bosnia and Herzegovina (2025a) reported a mid-year estimate of 3.422 million for the same year. The gap between these estimates stems from fundamentally different estimation approaches. The domestic post-censal projection draws on the 2013 Census and operates largely within a closed-population framework, which constrains its capacity to account for international migration flows, a component that has grown increasingly consequential in shaping Bosnia and Herzegovina's demographic development in recent decades. Official vital statistics for the same year further confirm persistent negative natural population change, as reflected in a vital index (the ratio of births to deaths) of 74.57 live births per 100 deaths, equivalent to a birth-to-death ratio of 0.746 (Agency for Statistics of Bosnia and Herzegovina, 2025b).

Unfavorable demographic trends had already characterized Bosnia and Herzegovina at the end of the 20th century, but the post-war and post-transition social context further intensified depopulation, population ageing and pronounced emigration, particularly among young and educated population

groups (Emirhafizović & Zolić, 2017). Under the medium scenario of World Population Prospects 2024, the population of Bosnia and Herzegovina is projected to decline from ~3.176 million on 1 January 2024 to 1.374 million on 1 January 2100, representing a decrease of ~56.7% (UN Department of Economic and Social Affairs, Population Division, 2024). The same projection indicates continued demographic ageing, with the median age expected to increase from 45.3 years in 2024 to 53.9 years by the end of the century (UN Department of Economic and Social Affairs, Population Division, 2024). Low fertility rates further complicate the demographic situation (Emirhafizović, 2018), highlighting the urgent need for effective population policies. The analysis of recent publications on the topic of demographic development in Bosnia and Herzegovina reveals a very small number of papers that cover the entire territory of Bosnia and Herzegovina. Studies with an explicitly geographical perspective are also scarce, despite the importance of spatial, socio-economic and political factors in shaping demographic patterns (Kugler & Rhamey, 2023). Previous analyses of certain demographic and socio-economic indicators in Bosnia and Herzegovina show that there are pronounced regional disparities, which can also be recognized along the center–periphery line (Avdić & Avdić, 2023; Kadušić et al., 2025b), indicating that there are demographically weakened peripheral parts of the state and a pronounced concentration of demographic resources characterizing the national center (both geographically and functionally). Pronounced disparities are also recognized in analyses of depopulation, where areas/municipalities with particularly sensitive depopulation trends have been detected (Pobrić & Robinson, 2015; Kadušić et al., 2023a), as have areas of highly pronounced demographic ageing (Kadušić et al., 2023b).

In contemporary geographical scientific discourse, the creation of complex synthetic indicators based on demographic and socio-economic indicators is an increasingly common practice (Nejašmić & Mišetić, 2010; Marić et al., 2020; Marić & Avdić, 2023; Kadušić et al., 2025a). These indicators not only enable identification, evaluation and comparison, but also provide a basis for various typologies of spatial units. A similar typology was carried out in a socio-demographic study of border municipalities and cities (Avdić et al., 2022). The composite marginalization index derived from numerous demographic indicators using multi-criterion geographic information system (GIS) analysis allowed for the detection of demographically endangered/marginal areas, where center–periphery relations again showed very clear spatial patterns (Marić & Avdić, 2023). More

recently, Kadušić et al. (2025a) applied a k-means clustering approach to analyze spatial disparities in population ageing in Bosnia and Herzegovina, focusing specifically on ageing indicators such as the ageing coefficient, ageing index, dependency ratio, old-age dependency ratio and average age. The classification of municipalities and cities based on selected demographic indicators, using statistical quantiles, is one of the authors' attempts at creating a typology of local government units in Bosnia and Herzegovina (Avdić et al., 2024). In previous research, the authors classified municipalities and cities into quartiles (i.e., categories containing equal numbers of units) on the basis of selected demographic indicators. The present study extends this approach by applying multivariate clustering to identify groups of municipalities with similar profiles across several demographic dimensions. Specifically, to comprehensively address the adverse demographic situation in Bosnia and Herzegovina, it is crucial to employ a multifaceted methodological approach to effectively identify potential causative factors. More sophisticated methods have rarely been used to classify local administrative units, largely because of limitations in the available statistical data. The scenario in which it is possible to classify all local government units into similar clusters/groups implies the availability and methodological consistency of input parameters for classification, which in the case of Bosnia and Herzegovina requires careful selection. Therefore, this study applies k-means clustering to 143 local administrative units in Bosnia and Herzegovina, based on selected indicators of population change, population density, natural population dynamics, age structure and educational attainment. The aim is to develop a demographic typology of municipalities and cities and to identify the main spatial patterns of demographic differentiation across the country.

2. Methodology

2.1. Statistical context, data availability and data collection

The methodological design of this study was strongly influenced by the specific structure of the statistical system in Bosnia and Herzegovina. Due to the country's complex administrative and political organization, demographic, social and economic data are produced and published by several statistical institutions. The Agency for Statistics of Bosnia and Herzegovina is the central statistical institution

responsible for publishing data at the state level, while the Federal Bureau of Statistics publishes data for the Federation of Bosnia and Herzegovina and the Republika Srpska Institute of Statistics publishes data for Republika Srpska. Statistical data for Brčko District are collected and processed through a branch office within the Agency for Statistics of Bosnia and Herzegovina.

This institutional structure has important implications for demographic research at the municipal level. While the Agency for Statistics of Bosnia and Herzegovina generally publishes aggregated data for the state and entity levels, more detailed data for municipalities and cities are usually available in entity-level statistical publications. Consequently, research covering all local administrative units in Bosnia and Herzegovina requires the harmonization of data from several statistical sources. In addition, some indicators are not published according to a fully compatible methodological framework across entities, which limits the possibility of applying a single analytical approach to the entire country. For this reason, the first phase of the research consisted of collecting, checking and harmonizing data from official census publications and entity-level statistical yearbooks.

A further limitation is the long interval between population censuses. During the last several decades, only two population censuses have provided a complete demographic basis for Bosnia and Herzegovina: the 1991 Census, conducted in the former Yugoslav statistical system, and the 2013 Census, which remains the most recent official census. The absence of a more recent census is especially important because Bosnia and Herzegovina has undergone substantial demographic changes since 2013, including continued population ageing and intensive emigration. Post-censal population estimates should therefore be interpreted with caution, particularly at lower territorial levels, because they cannot fully capture the scale and spatial selectivity of external migration.

The comparability of census data is additionally complicated by post-war administrative-territorial changes. Following the *Dayton Peace Agreement* and the establishment of the Inter-Entity Boundary Line, the number and boundaries of municipalities changed significantly (Mirić, 2011). At the time of the 1991 Census, Bosnia and Herzegovina consisted of 109 municipalities. The 2013 Census covered 142 local administrative units: 79 in the Federation of Bosnia and Herzegovina, 62 in Republika Srpska and Brčko District. Following the Census, the municipality of Stanari was established in 2014 from settlements previously belonging to the City of Doboï, increasing the number of local administrative units

in Republika Srpska to 63 and the countrywide total to 143.

The empirical analysis is based on official demographic data for all 143 municipalities and cities in Bosnia and Herzegovina. Data from the 1991 and 2013 population censuses were used to calculate the inter-census population change index, while the 2013 Census was used for population density, the share of the population aged 65 years and over, and the share of the highly educated population. Vital statistics were collected for the five-year pre-pandemic period from 2015 to 2019. For the present analysis, the municipal vital index was calculated as the total number of live births divided by the total number of deaths during 2015–2019; values above 1.00 indicate more births than deaths. This period was selected in order to reduce the influence of short-term annual fluctuations and to avoid the COVID-19 pandemic years, during which mortality patterns were affected by exceptional circumstances.

A specific adjustment was required for Stanari. As the municipality was established in 2014 from settlements previously belonging to the City of Doboï, its 2013 population count was reconstructed by aggregating the census populations of the constituent settlements. For indicators that could not be reconstructed separately, the corresponding values for Doboï were used as proxies. The classification of Stanari should therefore be interpreted with caution.

2.2. Indicator selection

In this paper, demographic development is understood as a multidimensional process reflected in changes in population size and spatial distribution, natural population dynamics, age structure and the human-capital profile of the population. The selection of indicators was guided by three main criteria: availability for all 143 municipalities and cities in Bosnia and Herzegovina, methodological comparability across the Federation of Bosnia and Herzegovina, Republika Srpska and Brčko District, and relevance for capturing the main dimensions of demographic differentiation. Accordingly, five indicators were selected: inter-census population change index, population density, vital index, share of population aged 65 years and over, and share of highly educated population.

These indicators do not represent the full theoretical scope of demographic development, but rather the most reliable and comparable municipal-level approximation possible within the existing statistical system of Bosnia and Herzegovina. The inter-census population change index captures

long-term demographic transformation between 1991 and 2013; population density reflects the spatial concentration of population and the demographic weight of local units; the vital index represents recent natural population dynamics; the share of the elderly population captures demographic ageing; and the share of highly educated population is used as an indicator of human capital and broader socio-demographic development. Several theoretically relevant demographic indicators were not included due to data limitations. Although the total fertility rate (TFR) is one of the most important fertility indicators, reliable and comparable municipal-level TFR values are not officially available for all local administrative units in Bosnia and Herzegovina. Its calculation would require age-specific fertility rates and reliable female population denominators by age group for each municipality and year, which is particularly problematic in the post-censal period and in small municipalities with a very low number of births. Similarly, life expectancy at birth – $e(0)$ – was not included because it requires stable age-specific mortality rates and life-table construction, which are not available as a consistent official municipal-level dataset for the whole country. Migration was also not used as a separate clustering indicator because official statistics capture registered internal migration more reliably than external emigration, while international migration is difficult to measure at the

municipal level. The effects of migration are therefore indirectly reflected through inter-census population change, population density and the educational structure of the population.

2.3. Analytical framework and clustering procedure

The analytical framework of this study is based on the application of k-means clustering to identify and analyze demographic disparities among municipalities and cities in Bosnia and Herzegovina. Clustering is widely recognized as an effective technique for regional demographic analysis (Khavari et al., 2021; Yang et al., 2023; Masías et al., 2024; Kadišić et al., 2025a), as it allows for the identification of spatial patterns and demographic typologies that may extend beyond administrative boundaries. The method was selected because it is appropriate for numerical, standardized datasets and enables the classification of a large number of territorial units into interpretable groups based on similarities across several demographic dimensions. However, it is applied here as an exploratory method, since the resulting clusters depend on the selected indicators, standardization procedure and predefined number of clusters.

Prior to clustering, a descriptive spatial analysis was conducted for each selected indicator. The values of the indicators were standardized in relation to the national average, where the national average was

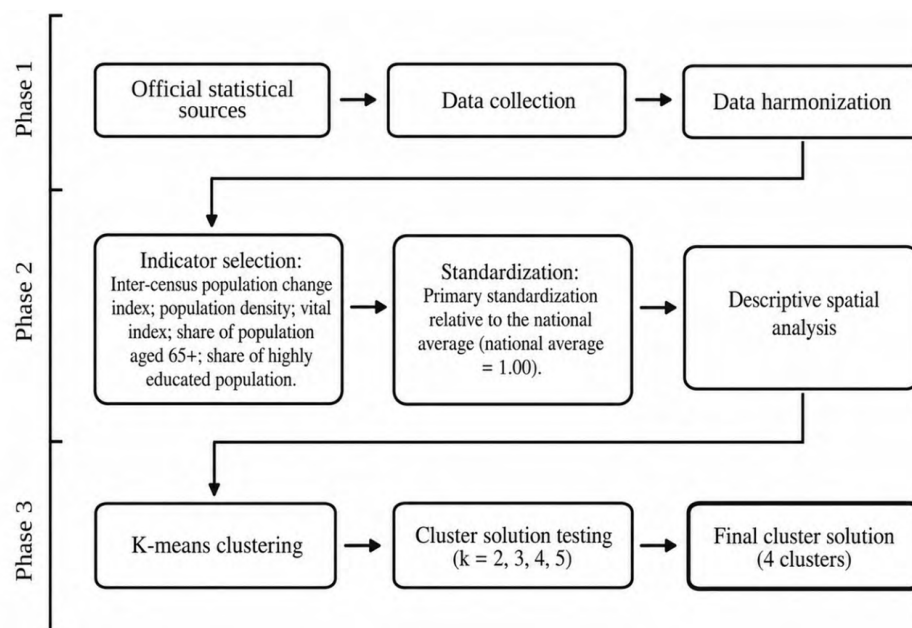


Fig. 1. Methodological workflow of the study; authors' elaboration
Source: Authors' own elaboration

assigned a standardized value of 1.00. This transformation was used only for the descriptive maps (Figs. 2–6), for which each municipal value was divided by the corresponding country-level value. For the k-means analysis, the five municipal indicators were standardized as z scores (mean = 0, standard deviation = 1) to place them on a common scale. The relative values shown on the maps were not used as inputs to the clustering procedure. For cartographic visualization, the Jenks natural breaks method (a method that groups similar values while keeping the groups as distinct as possible) was used to classify municipalities and cities into groups according to the relative favorability of each demographic indicator.

Finally, the standardized values of all five indicators were integrated in order to obtain statistical clusters, i.e. groups of municipalities and cities with similar demographic profiles. K-means is one of the most commonly used clustering methods in data analysis, and its basic aim is to group observations by minimizing variation within clusters, namely the sum of squared distances between points within the same cluster (Morales et al., 2020; Guiné et al., 2022; Ikotun et al., 2023). The procedure is usually performed iteratively (Ismkhan, 2018; Liu et al., 2021), and the number of iterations was considered as one of the criteria for selecting the final number

of clusters. In this study, solutions with two, three, four and five clusters were tested. The final selection was based on the analysis of variance (ANOVA) p-value for each indicator, the number of iterations, and the distribution of municipalities across clusters (Dikmen et al., 2009; Coelho et al., 2022).

Given the limitations of the available data and the sensitivity of clustering results to indicator selection, the obtained clusters should be interpreted as relative demographic profiles rather than as fully homogeneous or fixed demographic regions.

3. Results

Spatial analysis of the population change index for the most recent inter-census period (1991–2013) in Bosnia and Herzegovina reveals significant disparities in demographic trends (Fig. 2). Given that the country as a whole underwent a decrease in population during the indicated period, the national index stands at 0.81 (a 19% decrease compared to 1991), indicating general depopulation.

Most municipalities and cities exhibit an index value of less than 1, indicating a population decline, with the most severely affected municipalities including Kupres

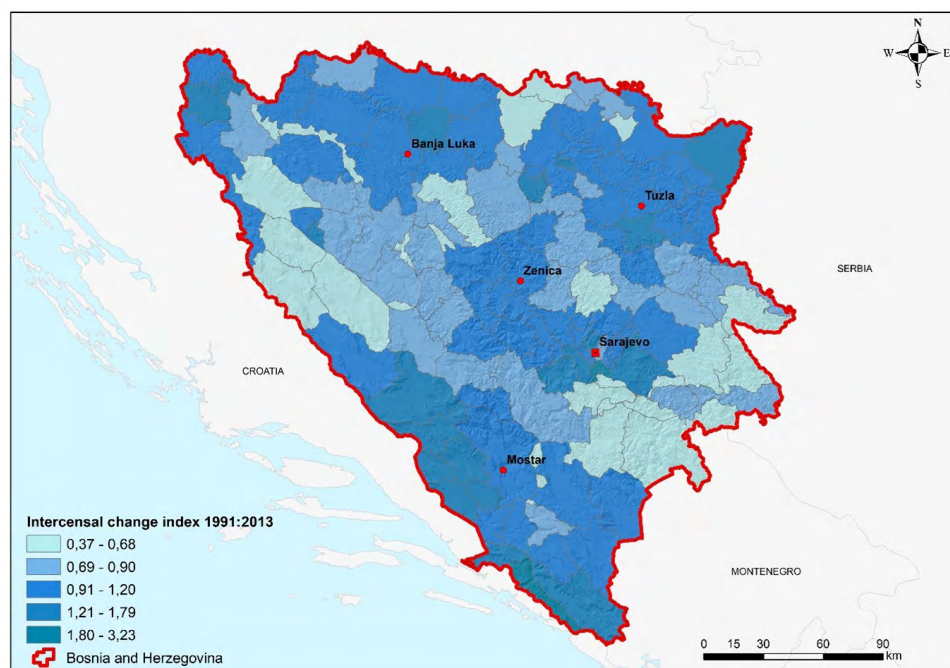


Fig. 2. Spatial disparities in standardized values of the population change index (1991–2013) in Bosnia and Herzegovina, expressed relative to the corresponding country-level value (1.00 = national reference); classes defined using the Jenks natural breaks method.

Note: The indicator is based on the 1991 and 2013 population censuses, the two most recent complete official census datasets available for Bosnia and Herzegovina. The absence of a more recent census reflects unresolved economic, political and statistical-methodological issues related to the organization of a new population census.

Source: Authors' elaboration based on data from the Agency for Statistics of Bosnia and Herzegovina (2016)

– Republika Srpska (RS), Srebrenica, Dobretići, Glamoč and Bosansko Grahovo, whose index value is less than 0.40. This value indicates a reduction in total population of more than 60% in 2013 compared to the 1991 census. Only 22 local administrative units exhibited population growth, with the most prominent municipalities being Istočno Novo Sarajevo, Ravno, Istočna Ilidža, Pale – RS, Doboj Jug, Čitluk and Posušje, each with an index higher than 1.20 (a population increase of more than 20% compared to 1991). Interestingly, most of these municipalities belong to suburban zones or zones of influence of larger cities, as is the case with Sarajevo. This analysis highlights the importance of a geographical approach to understanding demographic changes. Various factors such as historical, political and spatial influences play a key role in shaping the demographic landscape of the country. It also emphasizes the need for a differentiated approach in developing policies that support sustainable growth and development in different parts of Bosnia and Herzegovina. Cartographic visualization of these data makes it clear that areas most affected by wartime devastation and migrations (Eastern Bosnia, Western Bosnia and Posavina [the lowland region along the Sava River] in the north) are

also those that demonstrate the largest inter-census population decrease.

Municipalities and cities with a higher population concentration are generally considered to be more socially vital and demographically prosperous. In terms of population density, there are significant spatial variations, and the standard deviation in this regard is notably greater than in the remaining four criteria (Fig. 3). In 2013, the average population density in the country was 69 inhabitants/km², yet there are extreme differences at the municipal and city levels. The analysis reveals a wide range of population density values among municipalities and cities. The highest population density is found in the urban and suburban municipalities of Sarajevo, particularly in Novo Sarajevo, at ~7,000 inhabitants/km², which is nearly 100 times higher than the national average. Other densely populated areas include the Sarajevo-Zenica Basin in the central part of the country, the lowlands of north-eastern Bosnia, the Banja Luka basin in the north-west, and Cazinska Krajina in the far north-west. In contrast, extensive high-mountain and karst areas have very low population densities. This is particularly evident in the High Karst region of western Bosnia and

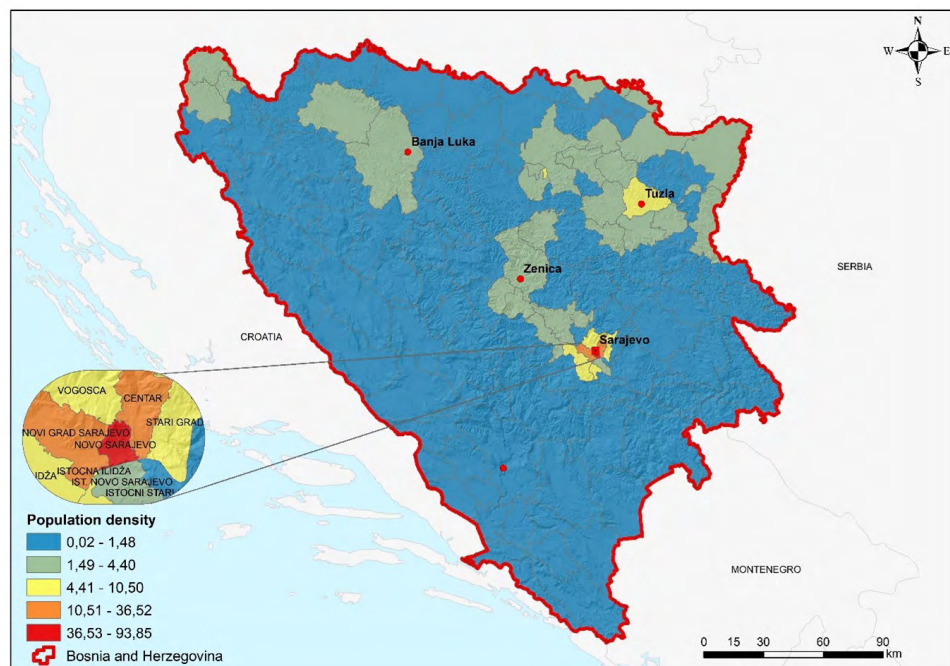


Fig. 3. Spatial disparities in standardized values of population density in Bosnia and Herzegovina (2013), expressed relative to the corresponding country-level value (1.00 = national reference); classes defined using the Jenks natural breaks method

Note: The indicator refers to the 2013 Census year; however, since the final official census results were published in 2016, the 2016 publication is cited as the data source.

Source: Authors' elaboration, based on data from the Agency for Statistics of Bosnia and Herzegovina (2016)

Herzegovina (a mountainous Dinaric limestone zone characterized by elevated plateaus and large enclosed karst depressions), Eastern Herzegovina and Upper Podrinje (the region along the upper course of the Drina River). Municipalities with particularly low population densities (below 10 inhabitants/km²) are: Istočni Drvar, Petrovac, Kalinovik, Istočni Mostar, Bosansko Grahovo, Glamoč, Trnovo – Federation of Bosnia and Herzegovina (FBiH), Kupres – RS, Berkovići, Kupres – FBiH and Ravno.

The vital index represents the ratio of number of births to the number of deaths and is calculated for the period between 2015 and 2019. Similar to natural increase rates, it is based on vital statistics data, but, unlike them, it does not depend on the quality of population estimates, making it a more reliable demographic indicator in this context. During the observed period, only 17 municipalities/cities recorded a higher number of births compared to deaths, resulting in a vital index value greater than 1. Among the ten local administrative units with the highest vital index, most are located in the Sarajevo Canton (one of the ten cantons that constitute the Federation of Bosnia and Herzegovina) (Ilijaš, Vogošća, Ilidža and Hadžići – all suburban municipalities of Sarajevo). The Zenica-Doboj Canton

is also significantly represented (Tešanj, Doboj Jug and Kakanj), while two municipalities from the Una-Sana Canton (Bužim and Velika Kladuša) and Posušje from the West Herzegovina Canton traditionally rank high. Overall, with a few exceptions, the state of vital statistics is much more favorable in the central part of the country compared to its peripheral areas. This trend is also observed when comparing the Federation of Bosnia and Herzegovina to Republika Srpska. The lowest values of the vital index are recorded in rural and depopulated areas, particularly in newly established municipalities along the Inter-Entity Boundary Line, such as Istočni Drvar, Istočni Mostar, Kupres – RS, Ravno, Donji Žabar, Pelagićevo and Krupa na Uni. Viewed geographically, these disparities show that Western Bosnia (excluding the Cazinska and Bihaćka Krajina) is the most demographically endangered part of Bosnia and Herzegovina. More specifically, this refers to the area of Canton 10, the eastern part of the Una-Sana Canton, and the Prijedor region in Republika Srpska (Fig. 4).

The percentage of the population aged 65 years and older represents one of the fundamental indicators of demographic ageing. It is typically highly correlated with vital statistics (particularly death rates), albeit

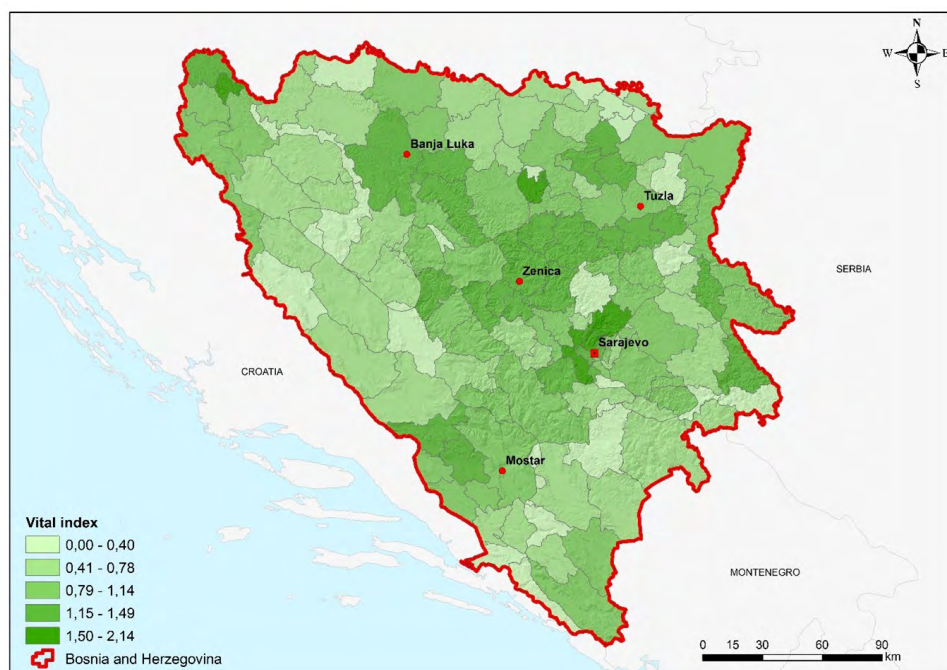


Fig. 4. Spatial disparities in standardized values of the vital index in Bosnia and Herzegovina (2015–2019), expressed relative to the corresponding country-level value (1.00 = national reference); classes defined using the Jenks natural breaks method

Note: The 2015–2019 period was selected as a pre-pandemic reference period to avoid distortions in vital statistics caused by the exceptional mortality conditions during the COVID-19 pandemic

Source: Authors' elaboration, based on data from the Federal Bureau of Statistics (2020) and the Republika Srpska Institute of Statistics (2020)

characterized by a longer inertia period relative to new demographic trends. This is also the only one of the five examined indicators where higher values represent a less favorable condition. According to the 2013 census results, the most favorable age structure was observed in the Tuzla Canton, which includes five of the eleven local administrative units nationwide whose elderly population ratio is below 10% (Fig. 5). However, the lowest proportion of elderly population was recorded in the municipality of Bužim (7.2%), with similar indicators observed in other municipalities in the extreme north-west of Bosnia and Herzegovina (Una-Sana Canton). The situation is also relatively favorable in the central regions of the country, specifically in the Zenica-Doboj, Central Bosnia and Sarajevo cantons. This clearly reflects the spatial concentration of the Bosniak population, the largest of Bosnia and Herzegovina's three constituent ethnic groups (the other two are Serbs and Croats). On the other hand, Republika Srpska is notably further advanced in the ageing process, most evidently in the mountainous areas in the east. However, the least favorable demographic situation is found in municipalities with a majority Serb returnee population in the western part of the Federation of Bosnia and Herzegovina (Bosansko Grahovo, Glamoč, Drvar

and Bosanski Petrovac) along with some small newly established municipalities, such as Kupres – RS.

Spatial disparities in the highly educated population ratio in Bosnia and Herzegovina reflect significant socio-demographic development gaps between different parts of the country (Fig. 6). According to the 2013 census, the proportion of highly educated individuals in Bosnia and Herzegovina was 9.6%, which is relatively low compared to other European countries. The highest share of highly educated individuals was observed in urban and university centers such as Sarajevo, East Sarajevo, Banja Luka and Mostar, as well as in some Herzegovinian towns and municipalities like Trebinje, Neum and Široki Brijeg. There are also notable spatial variations within Republika Srpska, where municipalities like Foča, Gacko, Višegrad and Han Pijesak had relatively high proportions of highly educated individuals compared to the lowland northern areas where agriculture and industry play a more significant socio-economic role. These findings underscore the importance of urban centers and university towns as attractive locations for highly educated individuals, while rural areas and less-developed regions have a lower proportion of this population. This is especially evident in peripheral

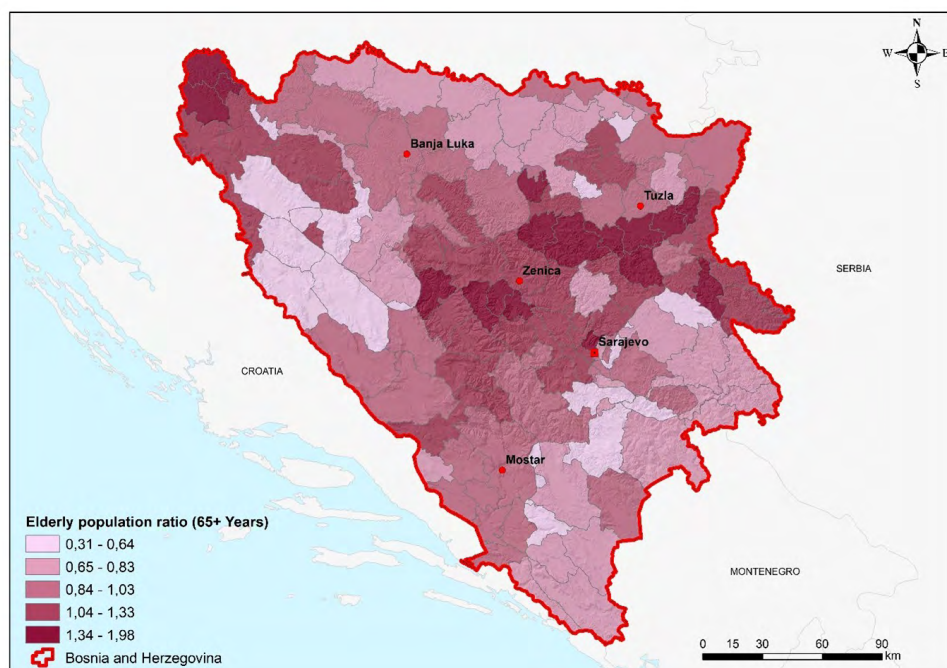


Fig. 5. Spatial disparities in standardized values of the elderly population ratio (65+ years) in Bosnia and Herzegovina (2013), expressed relative to the corresponding country-level value (1.00 = national reference); classes defined using the Jenks natural breaks method

Source: Authors' elaboration, based on data from the Agency for Statistics of Bosnia and Herzegovina (2016)

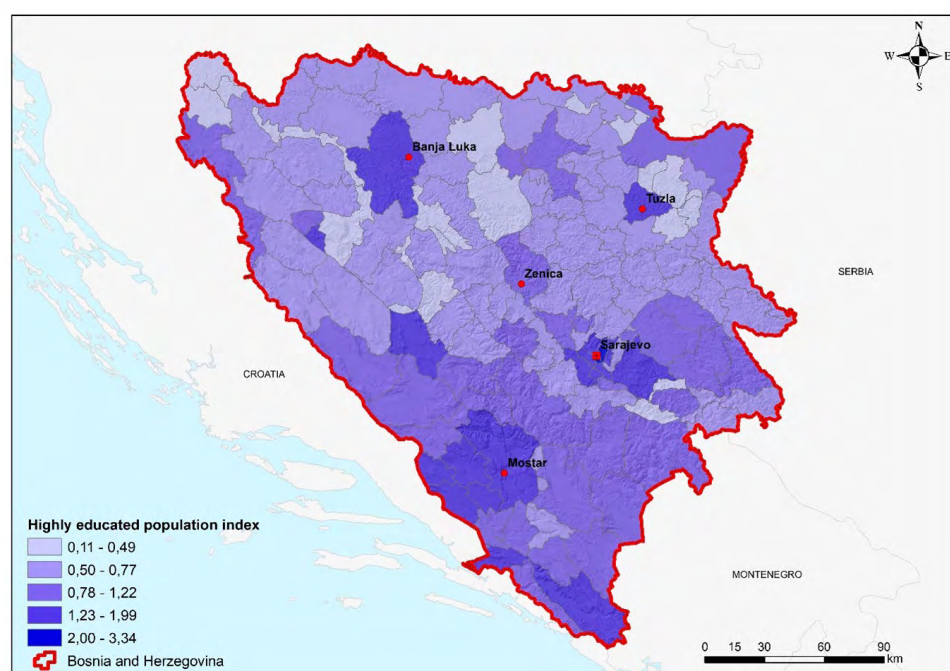


Fig. 6. . Spatial disparities in standardized values of highly educated population in Bosnia and Herzegovina (2013), expressed relative to the corresponding country-level value (1.00 = national reference); classes defined using the Jenks natural breaks method

Source: Authors' elaboration, based on data from the Agency for Statistics of Bosnia and Herzegovina (2016)

hilly-mountainous areas, which are generally characterized by socio-economic marginalization.

Individual analysis of the five indicators offers only a partial view of demographic disparities in Bosnia and Herzegovina. To integrate these insights into a unified model, this study conducted a k-means cluster analysis, as previously explained (Table 1).

Initially, a variant was tested that had only two clusters, which were obtained after three iterations. However, analysis of variance (ANOVA) showed that, with only two out of five criteria, a statistically significant p-value was achieved. The next step was to test a variant with three clusters, where after five iterations a statistically significant p-value ($<.05$)

was achieved for four criteria, but not for the elderly population ratio (65+ years). The minimum number of clusters where statistical significance was achieved for all criteria is four, which required as many as nine iterations. Among the clusters obtained this way, the first cluster comprises only one member, the second 20 members, the third 45 members, and the fourth as many as 77 members. Given the generally uneven distribution of members (local government units), a variant with five clusters was also tested. This required only four iterations, and statistical significance was again achieved in the context of differences within all criteria, but the distribution of members across clusters was now markedly more disproportionate.

Table 1. Criteria for selecting the number of clusters within the k-means method

Number of clusters	Number of iterations	Population change index	Population density	Vital index	% 65+ population	% highly educated population	Members per cluster
ANOVA							
2	3	.841	$< .001$	.176	.681	$< .001$	3-140
3	5	$< .001$	$< .001$	.038	.927	$< .001$	1-23-119
4	9	$< .001$	$< .001$	$< .001$	$< .001$	$< .001$	1-20-45-77
5	4	$< .001$	$< .001$	$< .001$	$< .001$	$< .001$	1-5-7-48-82

Source: Authors' calculations based on data from the Agency for Statistics of Bosnia and Herzegovina (2016), the Federal Bureau of Statistics (2020) and the Republika Srpska Institute of Statistics (2020).

Primarily for this reason, the variant with four clusters was chosen as the most appropriate one (Table 2).

The first cluster includes only the municipality of Novo Sarajevo, primarily because of its exceptionally high population density compared with all other local administrative units in Bosnia and Herzegovina. Consequently, this cluster is more appropriately interpreted as representing an “outlier” than as a substantively distinct group of municipalities. Although Novo Sarajevo may be considered alongside the second cluster for interpretive purposes, it remains formally assigned to the first cluster and is not included among the 20 units in the second cluster. The second cluster comprises 20 local government units. These include the remaining urban municipalities of Sarajevo (Stari Grad, Centar and Novi Grad), three urban municipalities of East Sarajevo (Istočna Ilidža, Istočno Novo Sarajevo and Pale), other major cities (Banja Luka, Tuzla, Mostar and Bijeljina), as well as a larger regional sub-cluster in the southern part of the country (Trebinje, Neum, Stolac, Ljubuški, Čitluk, Široki Brijeg, Grude and Tomislavgrad). Additionally, two small rural municipalities – Istočni Drvar and Ravno – are statistical members of the second cluster primarily due to small-number effects in official demographic data. In municipalities with very small population bases, even minor annual changes, such as a single birth or death, may produce disproportionately high or low standardized values. Therefore, their cluster membership should be interpreted with caution, as it may partly reflect statistical sensitivity rather than the actual demographic vitality of these municipalities. Overall, the main characteristic of the cities/municipalities in this cluster is a significantly more favorable educational structure of the population compared to other parts of Bosnia and Herzegovina, and most are also characterized by high values of the inter-census population change index. These facts also indicate migrations that have occurred in the recent past or are still ongoing.

The third cluster includes 45 municipalities/cities (Fig. 7), which primarily stand out for their favorable values of vital statistics and age structure of the population. This cluster includes the majority of municipalities/cities from Central Bosnia, Zenica-Doboj, Tuzla and Una-Sana cantons, as well as the suburban municipalities of Sarajevo Canton. From other areas, this cluster includes two Herzegovinian municipalities in the Federation of Bosnia and Herzegovina (Jablanica and Posušje), a total of six local administrative units from the Republika Srpska (Laktaši, Čelinac, Kotor Varoš, Zvornik, Bratunac and Milići), and Brčko District. The entity composition of the third cluster is markedly uneven: 38 of its 45 units (84%) are located in the Federation of Bosnia and Herzegovina, while six are located in Republika Srpska and one is Brčko District. This pattern is reversed in the fourth cluster, where 50 of the 77 units (~65%, or nearly two thirds) are located in Republika Srpska.

The fourth cluster is the largest, comprising 77 municipalities and cities. It includes most local administrative units in Republika Srpska, but also a significant share of municipalities and cities in the Federation of Bosnia and Herzegovina, including all municipalities from the Posavina and Bosnian-Podrinje cantons, most municipalities from Canton 10 and at least one municipality from all other cantons in the Federation of Bosnia and Herzegovina (Fig. 7). The main characteristics of this cluster are below-average values for all analyzed indicators, particularly unfavorable values of the vital index, and a high share of elderly population. Municipalities and cities in this cluster especially need pro-natalist measures within population policies, as well as other forms of strategic regional planning aimed at mitigating the negative effects of existing demographic trends and preventing further socio-economic marginalization and depopulation of these areas.

Table 2. k-means cluster analysis for four clusters (Df = degrees of freedom; Sig. = significance level)

	Mean Square	Df	Mean Square	Df	F	Sig.
ANOVA						
Z Score (population change index)	18.397	3	.625	139	29.458	< .001
Z Score (population density)	39.446	3	.170	139	231.709	< .001
Z Score (vital index)	26.204	3	.456	139	57.460	< .001
Z Score (% 65+ population)	28.467	3	.407	139	69.912	< .001
Z Score (highly educated population)	28.466	3	.407	139	69.904	< .001

Note: The first pair of Mean Square and Df columns refers to between-cluster variation (Cluster), whereas the second pair refers to within-cluster variation (Error)

Source: Authors' calculations based on data from the Agency for Statistics of Bosnia and Herzegovina (2016), the Federal Bureau of Statistics (2020) and the Republika Srpska Institute of Statistics (2020).

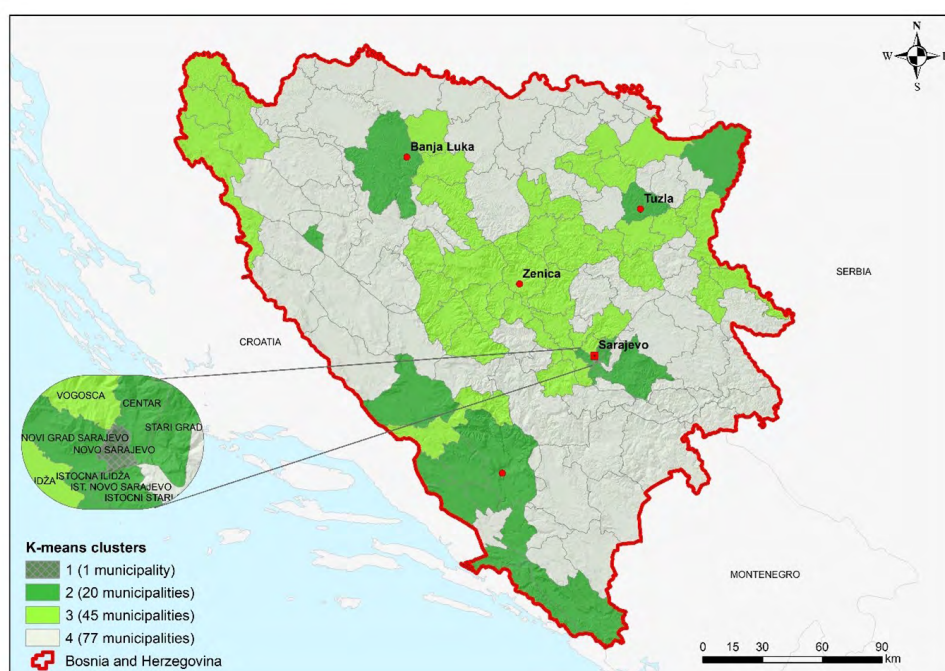


Fig. 7. Spatial distribution of the k-means clusters

Source: Authors' elaboration based on data from the Agency for Statistics of Bosnia and Herzegovina (2016), the Federal Bureau of Statistics (2020) and the Republika Srpska Institute of Statistics (2020)

4. Discussion and conclusion

The obtained clusters of municipalities in Bosnia and Herzegovina derived using cluster analysis (k-means approach) represent a significant contribution to the demographic typology of local government units from the perspective of selected demographic indicators. The input parameters used in the analysis provide an objective insight into the demographic profile of municipalities and cities as statistical units, thereby covering inter-census population change, population density as a significant geographical indicator (Zeng & Zong, 2023), vital statistics, elderly population ratio and highly educated population as indicators of socio-demographic development (OECD, 2019). However, the interpretation of the obtained clusters should be considered in relation to the limitations of the available demographic database. Although recent population estimates and population projections confirm the continuation of unfavorable demographic trends in Bosnia and Herzegovina, their direct incorporation into the clustering model is limited by the quality and comparability of municipal-level data. Post-censal population estimates at lower territorial levels are largely based on a closed-population framework and therefore do not sufficiently capture external migration, especially its scale and spatial selectivity. This is particularly important in Bosnia and Herzegovina, where external migration represents

one of the main components of recent demographic change. Moreover, some other indicators used in this study, including educational attainment and detailed age structure, are available in a complete and comparable form only from census data. Therefore, the obtained clusters should be interpreted as relative demographic profiles based on the most recent complete official data available for all local administrative units, not as a full representation of all current demographic processes.

The resulting demographic clusters clearly reveal specific socio-demographic patterns identified in the analysis and mutual comparison of the obtained groups, highlighting highly urbanized areas of Bosnia and Herzegovina, or the largest regional centers as focal points with relatively favorable socio-demographic indicators, such as a significantly higher proportion of the highly educated population (Kreso Pašalić, 2017; Avdić et al., 2022). The cluster of cities and municipalities with these dominant characteristics primarily includes the university centers of Bosnia and Herzegovina, whose educational function influences the gravitational pull of the city (Pejanović, 2008). Population growth in municipalities surrounding macro-regional centers has been influenced by the centers' gravitational pull and by suburbanization processes associated with later stages of urban development (Milojević, 2013; Žuljić et al., 2015). The group of municipalities and cities that constitute

the more demographically vital units is the result of various spatial characteristics, such as historical, economic, ethnocultural, environmental and social features that reflect natural and migratory population trends (Pobrić, 2002). The demographically weakened local administrative units, according to most of the parameters used in the analysis, have been previously recognized as emigration areas and socio-economically marginalized and peripheral regions compared to the developmental centers (UNICEF, 2020; Avdić & Avdić, 2023).

However, the obtained cluster groups of municipalities and cities cannot be validated by comparing them with an official classification of municipalities based on demographic indicators, as such classifications have not been conducted. The available classification of municipalities at the level of the Federation of Bosnia and Herzegovina is based on the development index, which aggregates some demographic indicators such as population trends and the elderly population ratio. According to this source, the majority of municipalities in the cluster of demographically endangered areas fall into the category of severely underdeveloped local government units (Government of the Republika Srpska, 2019; Federal Institute for Development Programming, 2023). The most relevant link between this study and other socio-economic indicators is the educational composition of the population, specifically the proportion of the highly educated population within the total population. In the case of the Republika Srpska entity, the clustering model produced a less differentiated internal structure, since most of its local administrative units were grouped into the demographically weaker cluster. This indicates a relatively homogeneous demographic profile of many municipalities in this entity according to the selected indicators.

It is also important to emphasize that the obtained clusters represent an exploratory demographic typology rather than clearly bounded and fully homogeneous demographic regions. The structure of clusters is inevitably influenced by the selected indicators, the standardization procedure and the predefined number of clusters. A different set of indicators could produce a somewhat different classification of municipalities and cities, especially if reliable municipal-level data on total fertility rate, life expectancy at birth or migration were available. Consequently, the policy relevance of the clusters should be understood primarily as a diagnostic and comparative framework for identifying dominant demographic patterns, not as a definitive basis for direct regional policy intervention.

In future research and attempts to classify municipalities and cities in Bosnia and Herzegovina according to demographic criteria, it will be necessary to

consider additional parameters for analysis. Selected with methodological complexity and relevance in mind, such parameters would allow a more detailed representation of demographic processes. In addition to redefining criteria, it is necessary to test other classification methods. The k-means approach is a widely used data clustering algorithm, but it has its limitations. One of these limitations is the degree of arbitrariness in determining the number of clusters and its sensitivity to outliers in the data, as demonstrated by the case of Novo Sarajevo, whose exceptionally high population density contributed to its separation as a single-member cluster. Future research should therefore compare the k-means solution with results obtained using alternative clustering methods. It could also combine factor analysis, used to summarize the original indicators into a smaller number of dimensions, with cluster analysis, as demonstrated by Rašić Bakarić (2005).

In forthcoming research projects of a similar nature, particular attention should be paid to small municipalities located along the Inter-Entity Boundary Line (Raos, 2010), as their demographic indicators may be highly sensitive to small-number effects and registration-related discrepancies. This problem became evident in the classification of some municipalities whose cluster membership does not fully correspond to the actual demographic situation on the ground (Bljesak.info, 2014). Similar methodological challenges have also been identified in the ranking of municipalities and cities based on the development index (Federal Institute for Development Programming, 2023).

Ultimately, the question arises as to what practical value municipal classifications based on selected demographic criteria can offer. The primary objective is to detect the most significant patterns and factors leading to demographic disparities, and subsequently to target the problems arising from such conditions. A crucial strategic step in developing planning documentation to propose measures for mitigating negative demographic processes and potentially revitalizing regions is recognizing spatial regularities, as differentiated spatial patterns require a differentiated approach in creating strategic measures. This is particularly important in the context of Bosnia and Herzegovina, given its internal social complexity. On the other hand, optimizing methodologies in this regard can also be useful in examining demographic disparities in other countries. Thus, a nuanced and continuously refined approach is essential for developing effective and equitable demographic policies, which can ultimately foster sustainable development and social cohesion.

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