

SPATIAL DISPARITIES IN POPULATION AGEING IN BOSNIA AND HERZEGOVINA: K-MEANS CLUSTERING APPROACH

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ABSTRACT – Population ageing is one of the main demographic issues in Bosnia and Herzegovina. This country has been facing significant ageing, with spatial differences in the pace and level of ageing. To determine spatial disparities in population ageing in Bosnia and Herzegovina, data on ageing coefficient, ageing index, dependency ratio, old-age dependency ratio, and the average age in the period from 2013 to 2023 were used. Cluster analysis is applied to determine groups of municipalities with similar levels of ageing. To group municipalities into clusters, a non-hierarchical clustering method, k-means clustering, is used. Analysis was performed by experimenting with various clustering alternatives between 2 and 5 clusters, while the Elbow method, Calinski-Harabasz pseudo F-statistic, and Tukey's Honestly Significant Difference test were used to validate the appropriate number of clusters. Results confirmed clusters with different levels of population ageing in Bosnia and Herzegovina. The most adverse trends in population ageing are confirmed in the rural municipalities of Western Herzegovina and Eastern Bosnia. The results of this study can serve as a basis for further research on the population ageing process and the planning of future demographic development in Bosnia and Herzegovina.

Keywords: Bosnia and Herzegovina; population ageing; spatial disparities; cluster analysis; k-means clustering.

RESUMO – DISPARIDADES ESPACIAIS NO ENVELHECIMENTO POPULACIONAL NA BÓSNIA E HERZEGOVINA: ABORDAGEM DE CLUSTERING K-MEANS. O envelhecimento da população é um dos principais problemas demográficos na Bósnia e Herzegovina. Este país tem enfrentado um envelhecimento significativo, com diferenças espaciais no ritmo e no nível de envelhecimento. Para determinar as disparidades espaciais no envelhecimento da população na Bósnia e Herzegovina, foram utilizados dados sobre o percentual da população com 65 anos ou mais na população total, o índice de envelhecimento, o rácio de dependência, o rácio de dependência dos idosos e a idade média no período de 2013 a 2023. A análise de clusters foi aplicada para identificar grupos de municípios com níveis de envelhecimento semelhantes. Para agrupar os municípios em clusters, foi utilizado o método de agrupamento não hierárquico k-means. A análise foi realizada experimentando várias alternativas de agrupamento entre 2 e 5 clusters, enquanto o método Elbow, a estatística pseudo-F de Calinski-Harabasz e o teste de diferença significativa de honestidade de Tukey foram usados para validar o número apropriado de clusters. Os resultados confirmaram a existência de agrupamentos de municípios com diferentes níveis de envelhecimento populacional na Bósnia e Herzegovina. As tendências mais adversas no envelhecimento da população foram observadas nos municípios rurais da Herzegovina Ocidental e da Bósnia Oriental. Os resultados deste estudo podem servir como base para futuras investigações sobre o processo de envelhecimento da população e para o planeamento do desenvolvimento demográfico futuro na Bósnia e Herzegovina.

Palavras-chave: Bósnia e Herzegovina; envelhecimento populacional; disparidades espaciais; análise de agrupamento; agrupamento k-means.

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HIGHLIGHTS

- Determined spatial patterns of population ageing in Bosnia and Herzegovina.
- Applied k-means clustering to identify spatial disparities in the level of population ageing in municipalities of Bosnia and Herzegovina.
- Identified three distinct clusters with different levels of population ageing.
- Determined that Bosnia and Herzegovina is facing adverse population ageing trends.
- Results of the study can be used as a basis for future demographic research and suggest the necessity of creating regional strategies of demographic development in Bosnia and Herzegovina.

1. INTRODUCTION

Population ageing can be considered a global phenomenon characterized by an increasing proportion of the population older than 65 years of age in populations worldwide. In the past decades, the issue of population ageing has received attention from numerous authors. Studies of importance highlight that global population ageing is a consequence of declining fertility rates and increasing life expectancy (Kong, 2018), while Lo (2023) and Zlotnik (2016) highlight the influence of globalisation, or economic, political, and social changes caused by globalisation, on population ageing. Europe is among areas with high levels of ageing (Cristea *et al.*, 2021; Kočanová *et al.*, 2023), and recent studies of demographic ageing in Europe suggest a significant increase in population ageing indicators in the countries of Southeastern and Eastern Europe (Jakovljevic *et al.*, 2021; Jakovljevic & Laaser, 2015). Therefore, a considerable number of studies explored the trends of population ageing in countries of the region. Gabor *et al.* (2022) and Jemna and David (2021) have researched the demographic ageing trends in Romania, Lillova (2021) in Bulgaria, Roszkowska (2018) in Poland, Gnjatovic and Devedzic (2016) in Serbia, etc. Several studies have been conducted on population ageing in Bosnia and Herzegovina that highlight the challenges caused by this demographic process. Gekić *et al.* (2020) and Gekić *et al.* (2019) reported a rapid increase in elderly population, which poses challenges to the economic and social system and causes serious issues for the demographic development of Bosnia and Herzegovina. Kadušić *et al.* (2016) researched the causes and consequences of population ageing in Bosnia and Herzegovina and noticed a rapid decline in population bio-dynamics and an increase in ageing coefficients and the average age of the population.

Recent studies have shown that population ageing is accelerating with spatial and temporal disparities in different world regions (Li *et al.*, 2019; Wan *et al.*, 2022;). Therefore, researchers have shown an increased interest in spatial disparities or regional differences in population ageing. Wan *et al.* (2022) investigated population ageing on a global scale, noticing significant regional disparities in ageing patterns, with developed countries ageing faster, while Li *et al.* (2019) have reported that differences in ageing rates in world countries have been increasing, suggesting that global population ageing is becoming more spatially differentiated. In Turkey, Yakar and Özgür (2024) analysed ageing patterns and identified regions with different levels of ageing. Basile *et al.* (2023) addressed the spatial-temporal aspect of population ageing in Italy and identified how ageing varies across different regions of the country. Zhang *et al.* (2022) reported that the spatial distribution of the population in Jiangsu Province in China is also showing significant spatial discrepancy, etc. In Bosnia and Herzegovina, Avdic and Avdic (2023) analysed spatial disparities in regional development and noted significant demographic challenges in peripheral regions of this country, while Avdić *et al.* (2022) noticed that population ageing has more adverse characteristics in border regions of Bosnia and Herzegovina. Kadušić *et al.* (2023a) analysed the spatial distribution of ageing coefficient and ageing index, and research results confirmed the concentration of these indicators, suggesting unequal ageing in different areas of Bosnia and Herzegovina. Pronounced polarization of demographic development and population ageing, at the national, regional, and local levels in Bosnia and Herzegovina, is also mentioned in the research study by Gekić *et al.* (2019) highlighting the necessity for adopting adequate population policy for future demographic development.

Therefore, population ageing is a demographic process with pronounced spatial differences, and peripheral areas are very often exposed to more adverse ageing trends (Krisjane *et al.*, 2023). In recent years numerous conducted studies applied cluster analysis to identify spatial patterns of demographic

processes and phenomena, including population ageing (Ahmadov, 2023; Jurun *et al.*, 2017; Yakar & Özgür, 2024). According to Kastreva and Patarchanova (2021), clustering is a process of classifying data into clusters, while the clustering method can be defined as a technique used for grouping statistical data based on similarities in variables.

Various techniques were used to research or determine spatial disparities in population ageing, and in recent studies, k-means clustering is often recognized as a very useful technique for determining spatial differences in ageing (Abbas *et al.*, 2020; Jurun *et al.*, 2017; Yakar & Özgür, 2024). According to Rašić-Bakarić (2007) in social sciences cluster analysis is recognized as the most suitable method of classifying units of similar characteristics, while Ismail *et al.* (2016) indicate that k-means clustering can effectively identify spatial patterns in demographic ageing. In recent years, k-means clustering has been often applied in demographic analysis and in researching spatial disparities of population ageing. For example, Inoue and Inoue (2024) applied the k-means algorithm to analyse prospects of population ageing in Japan, Yakar and Özgür (2024) used this technique to identify distinct ageing regions in Turkey, while Ismail *et al.* (2016) utilized k-means to investigate the demographic change in Malaysia, etc. Together these studies provide important insights into the utilization of k-means clustering in identifying spatial patterns of ageing.

Previous research on population ageing in Bosnia and Herzegovina has primarily focused on descriptive analysis at the national level (Gekić *et al.*, 2020; Kadušić *et al.*, 2016). Only a few studies addressed spatial differences in this demographic process (Avdic & Avdic, 2023; Avdić *et al.*, 2022; Gekić *et al.*, 2019). While Kadušić *et al.* (2023a) used spatial autocorrelation to analyse the clustering of population ageing indicators, there is a lack of studies that used advanced spatial statistical techniques to identify spatial differences in demographic ageing in Bosnia and Herzegovina.

This study aims to address this research gap by applying k-means clustering to identify population ageing patterns on municipal level in Bosnia and Herzegovina. The Elbow method, Calinski-Harabasz pseudo F-statistic, and Tukey's Honestly Significant Difference test will be used to validate the number of clusters and determine differences between ageing clusters. This approach offers a new perspective in demographic research in Bosnia and Herzegovina by applying a non-hierarchical multivariate statistical method to determine spatial disparities in ageing and the effect of spatial factors on the ageing process. Accordingly, the study addresses the following questions: Are there areas in Bosnia and Herzegovina particularly vulnerable to adverse population ageing? Which regions and municipalities are experiencing the highest levels and rates of ageing? Is there an evident clustering of the ageing process? What are the potential causes of the current spatial distribution of ageing? What are the next steps in spatial demographic development of the country? What implications do spatial disparities have for regional development in Bosnia and Herzegovina?

By addressing these questions, this study contributes to the understanding of a spatial aspect of population ageing in Bosnia and Herzegovina. The findings of the study can be useful for spatial and strategic planning of regional development in Bosnia and Herzegovina, supporting the development of measures to address economic and social issues caused by the ageing process, particularly in regions affected by adverse population ageing.

2. THEORETICAL BACKGROUND: SPATIAL DEMOGRAPHY AND CLUSTERING APPROACHES TO POPULATION AGEING ANALYSIS

Population ageing research has experienced a theoretical expansion, moving beyond analyses at the national level. As a result, numerous studies explore spatial and regional differences in this demographic phenomenon (Yakar & Özgür, 2024; Zhang *et al.*, 2022). Indicators of the ageing process, such as the ageing coefficient, ageing index, dependency ratio, average age, etc., provide insight into the intensity of population ageing (Harasty & Ostermeier, 2020; Nejašmić, 2005; Wu *et al.*, 2021). Spatial-demographic research indicates that the geographic distribution of these ageing indicators is not uniform, and that the ageing process is a complex demographic process shaped by physical and social features of the geographic environment, natural population change, migration processes, socio-economic, and other factors (Káčerová *et al.*, 2014; Li *et al.*, 2019).

In Bosnia and Herzegovina, the level of population ageing is also influenced by geographic location and exhibits spatially uneven patterns. Research by Kadušić *et al.* (2023a) showed that certain municipalities in the western, northwestern, central, and northeastern regions of the country demonstrate clustering in terms of the value of the ageing index and the ageing coefficient, and

suggests that geographical factors play a key role in the ageing process and adverse demographic trends. Similarly, the research of Gekić *et al.* (2019) identified a pronounced demographic polarization between urban and rural municipalities in Bosnia and Herzegovina. In addition, the peripheral and border areas of Bosnia and Herzegovina are faced with a more intensive ageing process, higher emigration rate, and less favourable socio-economic conditions (Avdic & Avdic, 2023; Avdic *et al.*, 2022). Therefore, these findings indicate that the process of population ageing in Bosnia and Herzegovina is not random but spatially determined, with clear grouping patterns influenced by geographic and socio-economic factors.

The concept of spatially uneven population ageing is present and widely researched in numerous countries of the world. In Turkey, Yakar & Özgür (2024) used data on the total population, age and gender features of the population, birth rates, and migration to separate regions concerning the intensity of ageing. In Japan, Inoue & Inoue (2024) introduced the concept of "stages of population ageing" using the data of the elderly population proportion and the elderly population change index at the municipal level to determine ageing clusters. These studies have shown that advanced techniques of spatial analysis and spatial statistics can reveal hidden demographic structures and patterns, and indicate early signs of negative demographic trends in potentially threatened regions.

One of the more effective methods for identifying spatial patterns of demographic phenomena is cluster analysis, which groups spatial units based on the similarity of data of selected variables (Kastreva & Patarchanova, 2021), while in the social sciences, it is recognized as an effective method for classifying territorial units according to the values of demographic characteristics (Rašić-Bakarić, 2007). Among cluster analysis techniques, k-means clustering is a machine learning algorithm particularly popular due to its simplicity, efficiency, and interpretability of results (Ahmed *et al.*, 2020). It is a non-hierarchical multivariate statistical method that groups data into a certain number of clusters so that values in each cluster are more similar than values in other clusters (Hassan *et al.*, 2021).

The number of studies in which k-means clustering was used indicates the relevance of this technique in demographic research. Abbas *et al.* (2020) indicated the effectiveness of the k-means algorithm in identifying spatial patterns of fertility, which is indirectly related to the future dynamics of population ageing in Muzaffarabad (Kashmir). Ismail *et al.* (2016) applied the same technique to estimate the demographic transition in Malaysia, highlighting its simplicity and effectiveness in analyzing demographic data. In particular, the studies of Yakar and Özgür (2024) and Inoue and Inoue (2024) should be highlighted, which indicated the effectiveness of the method in determining different levels of ageing from a spatial aspect. The k-means clustering approach allows, not only mapping the proportion of the old population, but also the understanding of factors that cause spatial patterns of ageing.

However, the efficiency of k-means clustering largely depends on the initial selection of the centroid and the predetermined number of clusters, and the selection of the appropriate number of clusters is crucial for achieving optimal clustering results (Hassan *et al.*, 2021; Matsuga & Sheremet, 2023). Elbow method, Calinski-Harabasz pseudo F-statistic and Tukey's Honestly Significant Difference test are techniques that can be used to determine the optimal number of clusters and their validation (Hassan *et al.*, 2021; Wang & Xu, 2019). The mentioned techniques reduce the subjectivity of the analysis and improve the reliability of data grouping, but they can be sensitive to data distribution, number of clusters, outliers, and other factors.

Spatial-demographic research provides a framework for understanding the spatial dimension of demographic processes. The integration of the spatial aspect with the methods of spatial statistics and cluster analysis enables the determination of complex patterns of demographic development in the research area. Complex administrative arrangements, and complex political, economic, and social conditions in Bosnia and Herzegovina contribute to uneven regional development. Therefore, the results of spatial-demographic research can serve as a basis for creating evidence-based strategies for demographic development of Bosnia and Herzegovina.

3. DATA AND METHODS

According to Anselin (2005), k-means is a clustering algorithm used in data science and machine learning that classifies data into k-distinct clusters based on feature similarities. It is a multivariate non-hierarchical statistical method used for determining groups or clusters by minimizing within-

cluster distance and maximizing between-cluster distance (Fahmiah & Ningrum, 2023). An important step in k-means clustering is the identification of the optimal number of clusters. Different approaches can be used, e.g., the rule of thumb, elbow method, information criterion approach, information-theoretic approach, silhouette method, cross-validation, etc. (Kodinariya & Makwana, 2013).

To understand complex demographic patterns of population ageing in Bosnia and Herzegovina k-means clustering was applied. K-means clustering enables the identification of trends and characteristics that are not apparent when using analytical methods. As stated by Inoue and Inoue, (2024) cluster analysis helps define demographically homogenous groups of ageing by dividing larger areas into smaller and uniform clusters. This way it is easier to understand specific characteristics and trends of population ageing. Moreover, k-means clustering can be performed on multiple indicators or variables, which allows more comprehensive analysis considering various dimensions of the data.

Therefore, k-means clustering was specifically chosen for this study because multiple demographic indicators of ageing can be used in the analysis. It enables the identification of regions with varying levels of ageing allowing comparison between clusters to identify potential causes or factors of the uneven ageing process and complex spatial relationship between demographic processes. Furthermore, it is one of the more practical ways to identify municipalities with extreme ageing trends, while the results of the analysis can be useful to policymakers. However, Chong (2021) and Ahmed *et al.* (2020) noted that k-means clustering has certain limitations, including the necessity of the pre-defined number of clusters, sensitivity to initial positions of centroids, outliers can affect centroids and skew clusters, etc.

The quantitative and exploratory study of spatial disparities of population ageing in Bosnia and Herzegovina involves statistical data from publications and sources of statistical agencies in this country. Ageing coefficient, ageing index, dependency ratio, old-age dependency ratio, and average age were used as indicators of demographic ageing. The ageing coefficient is a share of the population aged 65 and over in the total population, and ageing index is the ratio of the population older than 65 years per 100 young people (0 to 14 years of age). Young-age dependency ratio can be defined as the number of young people (0-14 years) per 100 people of working age, the old-age dependency ratio as the number of people 65 years or older per 100 people of working age, while the sum of both indicators is defined as a total dependency ratio (Harasty & Ostermeier, 2020; Pekarek, 2018). The average age is the arithmetic mean of age within a specific population (Nejašmić, 2005). Data for mentioned indicators were analysed for the period 2013-2023 at the municipal level, and collected from the Agency for Statistics of Bosnia and Herzegovina (BHAS), Institute for Statistics of the Federation of Bosnia and Herzegovina (FZS), and the Republic of Srpska Institute of Statistics (RZSRS). Using official data ensured the reliability and validity of the analysis.

The first step of the analysis was cleaning and preparing data for cluster analysis by removing errors, inconsistencies in the data, and outliers (fig. 1). Bosnia and Herzegovina has several municipalities with a very small population, which affected ageing indicators indexes and the cluster analysis. Therefore, a winsorization of the data was performed after the initial clustering of the data. Winsorization is a statistical technique used to limit the influence of extreme values or outliers on the statistical analysis of the data (Hamadani *et al.*, 2021).

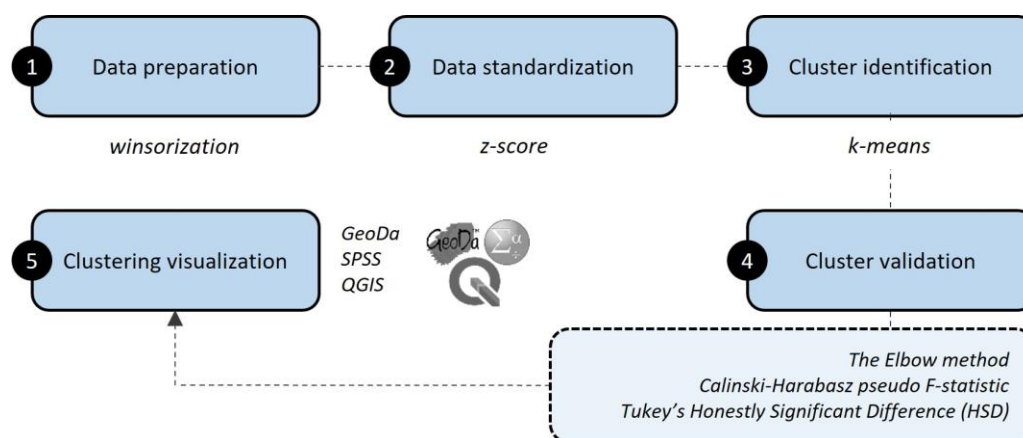


Fig. 1 – Research methodology phases. Colour figure available online.

Fig. 1 – Fases da metodologia da pesquisa. Figura a cores disponível online.

Source: Authors' elaboration

To enhance data accuracy, extreme values in the dataset were replaced with 1st and 99th percentile. Values below the 1st percentile were replaced with that percentile value, and values above the 99th percentile were set to that upper percentile value.

The second step of the analysis was standardization of the data which is necessary for effective cluster analysis and significantly affects the identification of clusters (Nogueira & Munita, 2020, 2021). Z-score standardization is a statistical technique used to transform the data into a standardized normal distribution (Al-Mekhlafi *et al.*, 2024), and it is applied in this study to manage diverse scales of ageing indicators to ensure that indicators equally contribute to the distance calculations used in k-means clustering algorithm. Therefore, standardization equalizes the influence of variables with different units and scales, preserves the distance structure, and maintains the distribution of the data.

The next step in the analysis was cluster validation since k-means clustering requires a predefined number of clusters (fig. 1). The Elbow method, Calinski-Harabasz pseudo F-statistic, and Tukey's Honestly Significant Difference (HSD) test were used as the statistical validation techniques to determine the optimal number of clusters. The analysis was performed in GeoDa and SPSS by testing various alternatives between 2 and 5 clusters. Although the Elbow method has certain limitations and can be subjective in determining the optimal number of clusters (Morissette & Chartier, 2013), it is a widely utilized technique for determining optimal number of clusters in k-means clustering by identifying the point where the sum of squared distances between points and cluster centroids shows no significant decrease (Marisa *et al.*, 2023; Matsuga & Sheremet, 2023).

The Elbow method can be applied by plotting the sum of squared errors (SSE) against the number of clusters (k) and identifying the point where the SSE starts to decrease (Fahmiyah & Ningrum, 2023; Hassan *et al.*, 2021). Calinski-Harabasz pseudo F-statistic or Calinski-Harabasz Index can be useful in identifying the optimal number of clusters, especially when combined with other techniques (Wang & Xu, 2019; Zhang & Li, 2013). It is a measure used in cluster analysis to identify the significance and quality of clusters by comparing the ratio of between-cluster dispersion (how separated identified clusters are) to within-cluster dispersion (how similar or close data points are within a cluster), and higher values of F-statistic indicate more distinct and well-separated clusters (Ashari *et al.*, 2023; Hassan *et al.*, 2021).

After the identification of the optimal number of clusters, a post-hoc analysis was conducted using Tukey's Honestly Significant Difference (HSD) test to validate the difference between cluster means (Wang, 2024). Tukey's HSD test is a post-hoc statistical test used to make pairwise comparisons between means of different clusters after the analysis of variance is performed, and the assumption of equal variances is met. According to Yakar and Özgür (2024), this test is used after the analysis of variance indicated that there are significant differences between clusters' means. This test calculates the difference between each pair of means and compares it to a critical value that is based on the number of clusters, the total number of observations, and the desired confidence level. This test is useful in determining how identified clusters are significantly different from one another, and validating the relationship and findings in data by confirming that the results are statistically significant and not the result of random chance.

The presented methodological framework ensures the reliability of the research findings and provides a foundation for future research analysis of population ageing. The results of the clustering will be visualized in GeoDa, QGIS, and SPSS using maps, charts, and tables allowing for a clearer understanding of the ageing spatial patterns in Bosnia and Herzegovina and the application of k-means clustering in the analysis of population ageing.

4. RESULTS

4.1. Demographic Characteristics of Bosnia and Herzegovina

Bosnia and Herzegovina is a Southeast European country with access to the Adriatic Sea along a 21.2 kilometres coastal stretch in the area of the Neum Bay. Its main administrative, educational, political and healthcare centre is the capital city of Sarajevo. Bosnia and Herzegovina represents a unique case within the European space, having undergone profound and multidimensional transformations over the past three decades.

The dissolution of Yugoslavia and the subsequent war from 1992 to 1995 acted as both direct and indirect catalysts for significant shifts in the country's demographic and socioeconomic

development. This period was marked by an induced demographic transition, resulting in persistently low and, more recently, negative natural population change rates, as well as an intensive wave of emigration, particularly pronounced in the recent period. The transition from a planned to a market-based economy has brought numerous structural challenges. Bosnia and Herzegovina's current development is further shaped by complex European integration processes, the limited functionality of its administrative-territorial organization and socioeconomic spatial disparities, all of which make it a compelling subject for demographic and socioeconomic analysis.

With a Gross Domestic Product (GDP) per capita of approximately 7500 USD in 2022 (Agency for Statistics of Bosnia and Herzegovina [BHAS], 2023), the country is categorized as upper middle income; however, ongoing issues such as high youth unemployment, depopulation and population ageing, as well as the pressing need for the reorganization of health and education infrastructure, pose the relevance of such research for much needed policymaking measures. Analysing spatial disparities in population ageing contributes not only to the national planning agenda but also offers significant insight for broader European strategies aimed at eliminating the asymmetric impacts of demographic ageing across regions with diverse historical, political and institutional legacies.

Bosnia and Herzegovina has been witnessing significant demographic changes in the first decades of the 21st century (Avdić *et al.*, 2022; Gekic *et al.*, 2020). Those changes are characterized by decreasing birth rates, increasing death rates, emigration of the young population, and intensive population ageing (Gekić *et al.*, 2019; Kadušić *et al.*, 2023b). A primary cause of population ageing in numerous world countries is a significant decline in fertility rates, which are below replacement levels, and the increase in life expectancy, caused by improvements in healthcare and living conditions (Li *et al.*, 2019; Zhang *et al.*, 2022). The analysis revealed similar demographic trends in Bosnia and Herzegovina in the period 2013-2023. In this period in Bosnia and Herzegovina, fertility rates continued decreasing from 37.5‰ to 34.9‰, mortality rates increased from 10.1‰ to 10.5‰, and average age increased from 39.6 to 42.5 years (table I).

Table I – Basic demographic indicators in Bosnia and Herzegovina in 2013 and 2023.

Quadro I – Indicadores demográficos básicos na Bósnia e Herzegovina em 2013 e 2023.

Demographic indicator	2013	2023
Birth rate (‰)	8.7	7.7
Mortality rate (‰)	10.1	10.5
Natural population change (‰)	-1.4	-2.7
Fertility rate (‰)	37.5	34.9
Total fertility rate (TFR)	1.276	1.182

Source: Authors' elaboration based on BHAS, FZS, RZSRS (2013-2024)

The data presented in table I indicate that the birth rate has been declining, while the mortality rate has been increasing in the period from 2013 to 2023. The negative rate of natural population change ranged from -1.4‰ to -2.7‰, the total fertility rate declined from 1.276 to 1.182, while the average age of mothers at the birth of their first child rose from 26.69 to 28.13 years.

According to Gekić *et al.* (2019), the demographic development of Bosnia and Herzegovina in the early 21st century is marked by depopulation and adverse population ageing, accompanied by pronounced spatial, regional, and urban-rural polarization. Population ageing is a demographic process with significant spatial disparities. As observed by Basile *et al.* (2023) population ageing varies across regions, while Yakar and Özgür (2024) noted that urban and rural areas very often exhibit different ageing patterns, and according to Wan *et al.* (2022) findings, spatiotemporal differences in population ageing are mostly caused by socio-economic and environmental factors.

Descriptive statistical analysis of ageing indicators pointed to adverse demographic ageing trends in Bosnia and Herzegovina during the study period. Table II presents the data on basic ageing indicators in Bosnia and Herzegovina in a period from 2013 to 2023.

A notable trend is that all ageing indicators show a consistent increase in this period. Ageing coefficient increased from 14.4% to 19.2%, ageing index from 93.5% to 141.8%, the dependency ratio from 42.5% to 48.5%, the old-age dependency ratio from 20.5% to 28.4%, and the average age increased from 39.6 to 42.5 years, indicating advanced demographic ageing at the national level, highlighting the increase in the share of the elderly in the total population of Bosnia and Herzegovina.

To visualize the changes in the ageing process in Bosnia and Herzegovina, data for three key ageing indicators (ageing coefficient, ageing index and dependency ratio) are classified in QGIS into three groups (fig. 2, fig. 3 and fig. 4).

Table II – Ageing coefficient, ageing index, dependency ratio, old-age dependency ratio and average age in Bosnia and Herzegovina (2013-2023).

Quadro II – Coeficiente de envelhecimento, índice de envelhecimento, taxa de dependência, taxa de dependência dos idosos e idade média na Bósnia e Herzegovina (2013-2023).

Year	Ageing coefficient	Ageing index	Dependency ratio	Old-age dependency ratio	Average age
2013	14.4	93.5	42.5	20.5	39.6
2014	14.8	97.7	42.7	21.1	39.9
2015	15.3	101.8	43.1	21.7	40.3
2016	15.3	105.9	43.4	22.3	40.6
2017	16.0	110.3	43.9	23.0	40.8
2018	16.6	115.5	44.9	24.1	41.1
2019	17.2	120.5	45.8	25.0	41.4
2020	17.8	126.5	46.8	26.1	41.7
2021	18.1	130.2	47.2	26.7	41.9
2022	18.6	135.1	47.8	27.5	42.2
2023	19.2	141.8	48.5	28.4	42.5

Source: Authors' elaboration based on BHAS, FZS, RZSRS (2013-2024)

Classification of ageing coefficient, ageing index, and dependency ratio values suggest significant changes in ageing in period from 2013 to 2023 (figs. 2, 3 and 4). It is visible that ageing is present in a large part of Bosnia and Herzegovina, and significantly varies across time and space. Data visualized in figure 2 suggest that most of the municipalities of Bosnia and Herzegovina have reached the moderate and advanced stage of ageing by 2023, and only a few municipalities have an early-stage ageing coefficient, which varies between 7.3% and 14.6%. The value of ageing index also indicates highly adverse demographic trends in Bosnia and Herzegovina, as well as spatial disparities in demographic development.

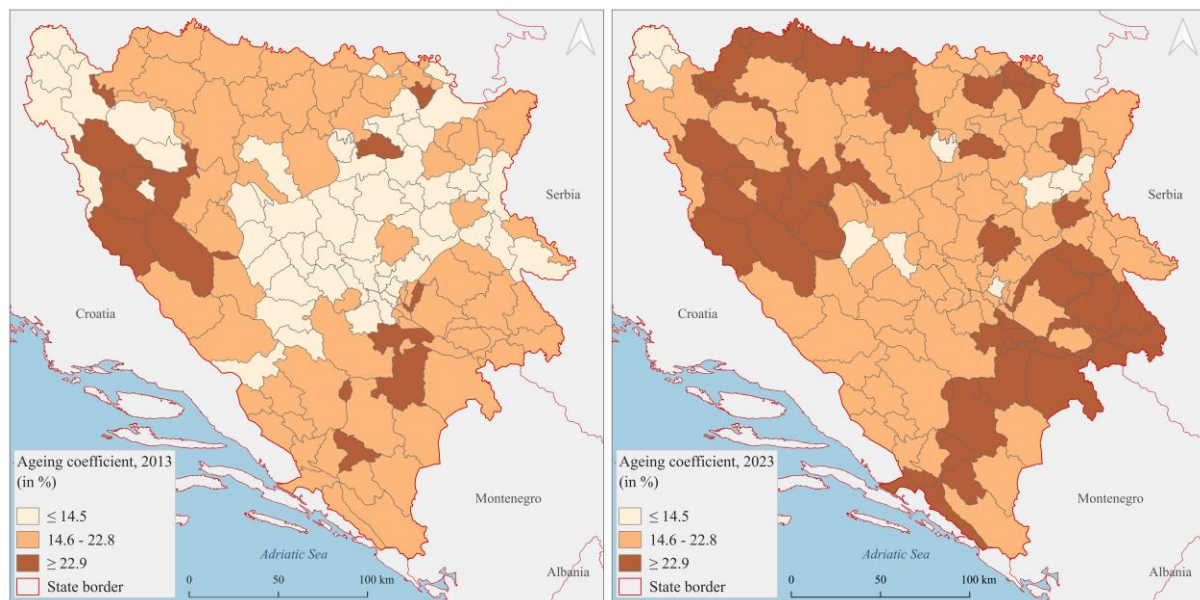


Fig. 2 – Spatial distribution of ageing coefficient in Bosnia and Herzegovina, 2013 and 2023. Colour figure available online.

Fig. 2 – Distribuição espacial do coeficiente de envelhecimento na Bósnia e Herzegovina, 2013 e 2023. Figura a cores disponível online.

Source: Authors' elaboration

Figure 3 shows that the value of this index exceeds 100% in many municipalities across the country. Data presented in figure 4 indicate that the dependency ratio increased in a large number of municipalities of Bosnia and Herzegovina in the researched period. All mentioned ageing indicators reveal temporal and spatial changes in the ageing process across Bosnia and Herzegovina in the period from 2013 to 2023. Over researched period, numerous municipalities have transitioned to moderate or advanced stages of ageing, with notable spatial differences.

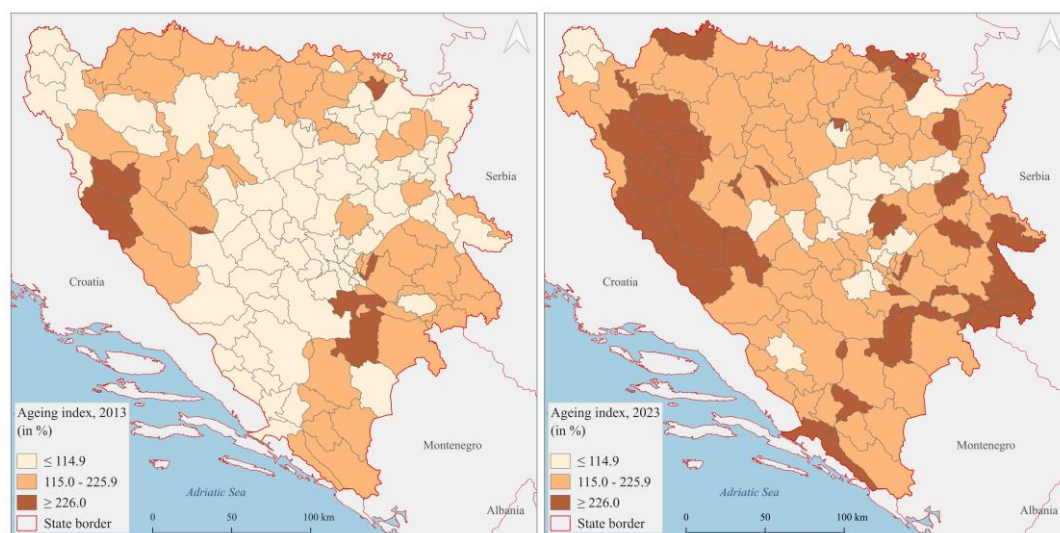


Fig. 3 – Spatial distribution of ageing index in Bosnia and Herzegovina, 2013 and 2023. Colour figure available online.

Fig. 3 – Distribuição espacial do índice de envelhecimento na Bósnia e Herzegovina, 2013 e 2023. Figura a cores disponível online.

Source: Authors' elaboration

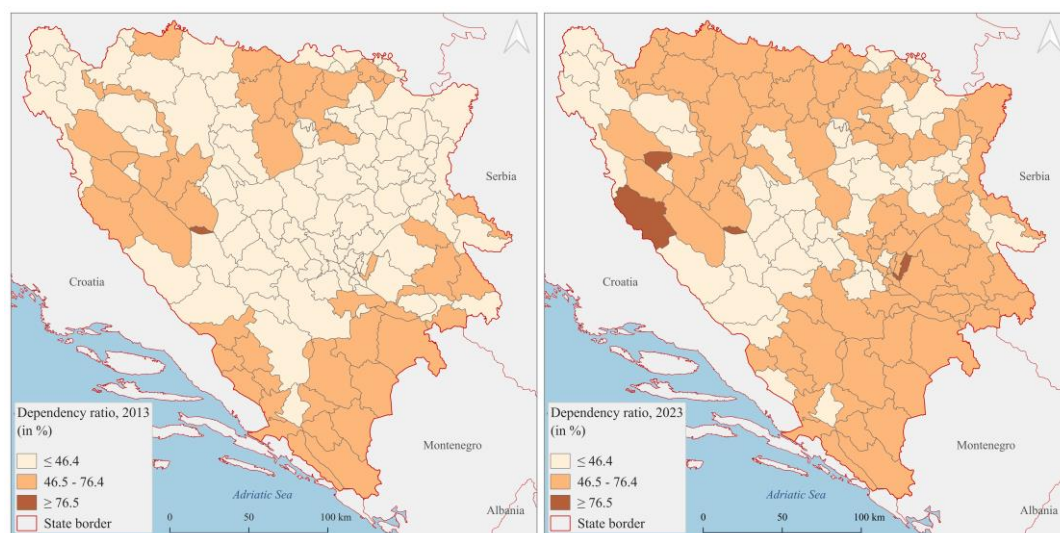


Fig. 4 – Spatial distribution of dependency ratio in Bosnia and Herzegovina, 2013 and 2023. Colour figure available online.

Fig. 4 – Distribuição espacial da taxa de dependência na Bósnia e Herzegovina, 2013 e 2023. Figura a cores disponível online.

Source: Authors' elaboration

4.2. Cluster Analysis of Population Ageing in Bosnia and Herzegovina

Performed cluster analysis, with the following statistical validation techniques, indicated several interesting observations and outcomes related to spatial patterns of population ageing during

the study period in Bosnia and Herzegovina. To determine the optimal number of clusters with different levels of ageing in the Bosnia and Herzegovina Elbow method, the Calinski-Harabasz F-pseudo statistic, and Tukey's Honestly Significant Difference (HSD) test were applied. To define the optimal number of ageing clusters in Bosnia and Herzegovina SSE was determined for 2k (324.28), 3k (215.18), 4k (164.71), and 5k (130.26). Therefore, the optimal ageing clusters in Bosnia and Herzegovina are three. However, according to Inoue and Inoue (2024) and Hassan *et al.* (2021) one of the challenges of the Elbow method is the difficulty in precisely identifying the elbow point. Therefore, additional statistical tests, Calinski-Harabasz pseudo F-statistic and Tukey's HSD test were performed to validate identified three ageing clusters. Calinski-Harabasz pseudo F-statistic was determined for every variable or ageing indicator in the defined three clusters.

Calinski-Harabasz Index is used to assess the quality of clustering by measuring the ratio of the sum between-cluster dispersion to within-cluster dispersion (Wang, 2024). It assesses the quality of the clustering by evaluating how well identified clusters are separated, and how compact data within clusters are. Higher values of the Calinski-Harabasz pseudo F-statistic indicate better clustering with well-separated and compact clusters.

The F-values presented in table III are all relatively high and indicate significant between-cluster variance compared to within-cluster variance. This confirms that the identified ageing clusters are well separated. Variables with higher F-values (ageing coefficient, old-age dependency ratio, and average age) contribute more to the separation of clusters than those variables with lower F-statistic (ageing index and dependency ratio). Moreover, p-values for all ageing indicators are <0.05, which confirms that the differences in means between clusters for each ageing indicator are statistically significant.

Table III – Calinski-Harabasz pseudo F-statistic for selected ageing indicators in Bosnia and Herzegovina, 2023.

Quadro III – Pseudo-estatística F de Calinski-Harabasz para Indicadores de Envelhecimento Seleccionados na Bósnia e Herzegovina, 2023.

Variable	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
Ageing coefficient	57.160	2	.198	140	289.108	.000
Ageing index	41.773	2	.418	140	100.049	.000
Dependency ratio	41.479	2	.422	140	98.355	.000
Old-age dependency ratio	56.196	2	.211	140	265.714	.000
Average age	50.773	2	.289	140	175.716	.000

Source: Authors' elaboration

After analysis of variance has been performed and F-statistic was determined, the post-hoc Tukey's Honestly Significant Difference (HSD) test was applied, given that the assumption of equal variances was met (table III). Post-hoc test results presented in table IV confirm that the absolute difference between clusters' means is greater than a critical value, and consequently, the difference between clusters can be considered statistically significant. Pairwise comparisons between clusters show statistically significant differences in population ageing indicators at the 0.01 level. These results confirm distinct clusters with significant differences in ageing variables between all pairs of clusters.

The results of k-means clustering and the results of performed cluster validation tests indicate that the clustering was effective in capturing ageing patterns, and identified clusters are valid and useful for further population ageing analysis in Bosnia and Herzegovina. Visualization of clusters performed in GeoDa and QGIS indicates three distinct clusters with different levels of population ageing in Bosnia and Herzegovina.

Figure 5 shows three ageing clusters in Bosnia and Herzegovina with different levels of ageing. Cluster 1 represents the highest values across all variables or advanced levels of ageing. Cluster 2 represents the lowest values across all ageing indicators or municipalities with a lower stage of ageing. Cluster 3 represents medium values across all ageing indicators or municipalities with a moderate level of ageing. The ratio between the cluster sum of squares (494.825) to the total sum of squares (710) is 0.6969, which indicates that about 69.69% of the variance in the data is explained by the performed clustering.

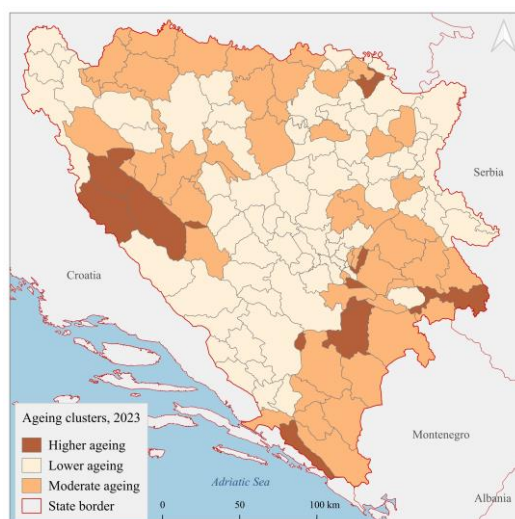


Fig. 5 – Ageing clusters in Bosnia and Herzegovina, 2023. Colour figure available online.

Fig. 5 – Clusters de envelhecimento na Bósnia e Herzegovina, 2023. Figura a cores disponível online.

Source: Authors' elaboration

Table IV – Tukey's Honestly Significant Difference (HSD) test for ageing indicators in Bosnia and Herzegovina, 2023.

Quadro IV – Teste de Diferença Honestamente Significativa (HSD) de Tukey para Indicadores de Envelhecimento, 2023.

Dependent Variable	(I) Cluster Number of Case	(J) Cluster Number of Case	Mean Difference (I-J)	Std. Error	Sig.	99% Confidence Interval	
						Lower Bound	Upper Bound
Ageing coefficient	1	2	2.77167552*	.12893786	.000	2.3898064	3.1535446
		3	1.51414493*	.13444899	.000	1.1159538	1.9123361
	2	1	-2.77167552*	.12893786	.000	-3.1535446	-2.3898064
		3	-1.25753060*	.08035499	.000	-1.4955141	-1.0195470
	3	1	-1.51414493*	.13444899	.000	-1.9123361	-1.1159538
		2	1.25753060*	.08035499	.000	1.0195470	1.4955141
Ageing index	1	2	2.61735020*	.18737233	.000	2.0624185	3.1722819
		3	1.97062270*	.19538108	.000	1.3919719	2.5492735
	2	1	-2.61735020*	.18737233	.000	-3.1722819	-2.0624185
		3	-.64672750*	.11677177	.000	-.9925649	-.3008901
	3	1	-1.97062270*	.19538108	.000	-2.5492735	-1.3919719
		2	.64672750*	.11677177	.000	.3008901	.9925649
Dependency ratio	1	2	2.28709437*	.18831284	.000	1.7293772	2.8448115
		3	1.14395877*	.19636180	.000	.5624034	1.7255141
	2	1	-2.28709437*	.18831284	.000	-2.8448115	-1.7293772
		3	-1.14313560*	.11735790	.000	-1.4907089	-.7955623
	3	1	-1.14395877*	.19636180	.000	-1.7255141	-.5624034
		2	1.14313560*	.11735790	.000	.7955623	1.4907089
Old-age dependency ratio	1	2	2.78878816*	.13335480	.000	2.3938376	3.1837387
		3	1.58668744*	.13905471	.000	1.1748557	1.9985191
	2	1	-2.78878816*	.13335480	.000	-3.1837387	-2.3938376
		3	-1.20210072*	.08310766	.000	-1.4482367	-.9559647
	3	1	-1.58668744*	.13905471	.000	-1.9985191	-1.1748557
		2	1.20210072*	.08310766	.000	.9559647	1.4482367
Average age	1	2	2.69469286*	.15587505	.000	2.2330452	3.1563406
		3	1.60554375*	.16253753	.000	1.1241641	2.0869234
	2	1	-2.69469286*	.15587505	.000	-3.1563406	-2.2330452
		3	-1.08914911*	.09714244	.000	-1.3768512	-.8014470
	3	1	-1.60554375*	.16253753	.000	-2.0869234	-1.1241641
		2	1.08914911*	.09714244	.000	.8014470	1.3768512

Source: Authors' elaboration. *. The mean difference is significant at the 0.01 level

These results suggest moderate to good clustering results since almost 70% of the variability of the data can be explained by the differences between clusters, while the remaining 30% is the variability due to differences within the clusters. This indicates well-separated and effective clusters that capture a substantial portion of the total variance in the data.

It can be seen from the data in table V that the performed clustering reported significantly different ageing levels in identified clusters. In Cluster 1 ageing coefficient varies from 29.3 to 38.6%, the ageing index from 252.5 to 799.0%, the dependency ratio from 53.1 to 90.0%, the old-age dependency ratio from 44.9 to 72.9%, and the average age from 48.7 to 54.7 years. This cluster consists mostly of rural municipalities with small populations, which have the most adverse population ageing trends or advanced ageing. Cluster 1 comprises 14 cases, and is the least represented ageing cluster which includes municipalities Bosansko Grahovo, Donji Žabar, Drvar, Istočni Mostar, Istočni Stari Grad, Glamoč, Kalinovik, Kupres-RS, Novo Goražde, Pelagićevo, Petrovac, Ravno, Rudo and Trnovo-RS.

Table V – Descriptive statistics of ageing indicators by identified ageing clusters in Bosnia and Herzegovina, 2023.

Quadro V – Estatísticas Descritivas dos Indicadores de Envelhecimento por Grupos de Envelhecimento Identificados na Bósnia e Herzegovina, 2023.

Cluster Number of Case		Ageing coefficient	Ageing index	Dependency ratio	Old-age dependency ratio	Average age
Cluster 1 Higher ageing	Mean	33.1	517.6	69.7	56.3	51.2
	N	14	14	14	14	14
	Std. Deviation	2.8262	185.0829	12.8918	8.6885	1.9544
	Sum	462.6	7246.5	975.1	787.7	716.5
	Minimum	29.3	252.5	53.1	44.9	48.7
	Maximum	38.6	799.0	90.0	72.9	54.7
Cluster 2 Lower ageing	Mean	17.8	145.4	44.5	25.8	42.1
	N	79	79	79	79	79
	Std. Deviation	2.4652	46.4090	5.2802	4.1064	1.8609
	Sum	1405.1	11484.2	3514.1	2035.9	3326.9
	Minimum	12.8	77.9	32.9	17.4	38.4
	Maximum	21.7	295.8	57.3	32.7	45.9
Cluster 3 Moderate ageing	Mean	24.7	237.4	57.1	38.9	45.8
	N	50	50	50	50	50
	Std. Deviation	2.3091	107.7602	7.5785	5.0382	1.6784
	Sum	1235.5	11867.4	2853.1	1945.8	2288.8
	Minimum	21.0	141.5	32.9	27.8	42.7
	Maximum	28.9	799.0	72.7	49.2	49.2

Source: Authors' elaboration

On the other side, Cluster 2 includes municipalities with the lowest values of ageing indicators or municipalities that are in the lower stadium of ageing. In Cluster 2 ageing coefficient varies from 12.8 to 21.7%, the ageing index from 77.9 to 295.8%, the dependency ratio from 32.9 to 57.3%, the old-age dependency ratio from 17.4 to 32.7%, and the average age from 38.4 to 45.9 years. This cluster consists large number of urban municipalities of Bosnia and Herzegovina, including Banja Luka, Bihać, Bijeljina, Doboj, Gračanica, Gradačac, Mostar, Sarajevo, Široki Brijeg, Zenica etc. However, it is also visible that the entire Bosnia and Herzegovina is facing adverse ageing trends, except for a very small number of municipalities that have trends that are more favourable.

In many cases population ageing is associated with declining fertility rates, increasing life expectancy, and emigration (Yakar & Özgür, 2024), and these have been important factors of population ageing in Bosnia and Herzegovina in the last decades (Kadušić & Smajić, 2019; Kadušić *et al.*, 2015). As already stated, in Bosnia and Herzegovina fertility rates have decreased from 37.5‰ to 34.9‰ in researched period, and lowest fertility rates and highest average age correlate with the values of ageing indicators in municipalities of Cluster 1 (Bosansko Grahovo, Donji Žabar, Pelagićevo, Novo Goražde, Istočni Mostar itd.) (BHAS, 2024). Migration also plays a significant role in population ageing in Bosnia and Herzegovina. According to data of Ministry of security of Bosnia and Herzegovina in 2023 about 2777 persons emigrated from Bosnia and Herzegovina to foreign countries, out of which 85% of them emigrated to Croatia, Austria, Germany and Slovenia. Data of Institute for Statistics of the Federation of Bosnia and Herzegovina indicate that on average about 3731 people emigrated from

Bosnia and Herzegovina every year in the period 2013 to 2023 (FZS [Federation of Bosnia and Herzegovina], 2024). According to the same source most of the emigrants from the Federation of Bosnia and Herzegovina, for example, are aged from 20 to 40 years (45.7%).

5. DISCUSSION

There is an increased interest in researching the phenomenon of population ageing, the causes and consequences of this process at the global (Guerin *et al.*, 2015; Li *et al.*, 2019; Sabri *et al.*, 2022) and national level (Cristea *et al.*, 2021; Jemna & David, 2021; Milena, 2022). Studies such as that conducted by Li *et al.* (2019) and Bucher (2014) showed that ageing rates are growing consistently on all continents, with Europe experiencing the highest pace of ageing.

Wan *et al.* (2022) findings reveal that socioeconomic and environmental factors are the main cause of global ageing, with significant geographical disparities. Research have shown spatiotemporal variation in population ageing (Li *et al.*, 2019; Wan *et al.*, 2022; Zhang *et al.*, 2022), and a considerable amount of literature has been published on spatial disparities of population ageing in many world countries (Jukic & Khan, 2015; Reynaud *et al.*, 2018; Wu *et al.*, 2021).

Inoue and Inoue (2024) provided a quantitative analysis of Japan's ageing population and introduced a new concept of stages in the population ageing process, Kočanová *et al.* (2023) reported relationships and patterns of ageing in European Union countries, and Chen *et al.* (2019) determined spatial disparities in population ageing across various regions in China. All these studies provided insights into various aspects of population ageing, including causes, consequences, and spatial differences.

Various methods have been used to analyze spatial disparities in population ageing, each offering unique insights and application (Kočanová *et al.*, 2023; Zhang *et al.*, 2022), and in recent years k-means clustering has been applied in several studies on the demographic variables, including population ageing (Inoue & Inoue, 2024; Yakar & Özgür, 2024). For instance, Yakar and Özgür (2024) identified ageing regions in Turkey using k-means clustering.

The aforementioned studies indicate that population ageing is a demographic trend that affects many world countries, including Bosnia and Herzegovina. Conducted population ageing studies in Bosnia and Herzegovina by Gekić *et al.* (2019) and Kadušić *et al.* (2016) indicate a significant increase of elderly in the total population. According to Pijalović *et al.* (2018) and Bošnjak (2016) elderly population is expected to increase in the future which will put additional pressure on the pension system, affecting economic growth and public spending. Since population ageing is a process with pronounced spatial differences, this study aimed to determine spatial disparities in population ageing, determine whether there is a grouping of population ageing data, record the municipalities that are in the advanced stage of ageing, and identify factors of spatial differences in population ageing in Bosnia and Herzegovina.

Previous studies of demographic development in Bosnia and Herzegovina have focused on demographic trends in general, and only a few studies have treated the issue of population ageing (Gekić *et al.*, 2019; Kadušić *et al.*, 2016), while Kadušić *et al.* (2023a) performed spatial analysis of population ageing in Bosnia and Herzegovina using spatial autocorrelation method. Therefore, this study aimed to provide a more comprehensive analysis of multiple ageing indicators using k-means clustering. Since one of the shortcomings of the k-means clustering method is determining the optimal number of clusters (Matsuga & Sheremet, 2023), the Elbow method is used for the identification of clusters (Hassan *et al.*, 2021), while Calinski-Harabasz pseudo F-statistic and Tukey's Honestly Significant Difference test were used to validate identified clusters (Fahmiyah & Ningrum, 2023; Hassan *et al.*, 2021).

The results of this study contradict the assumption that demographic ageing in Bosnia and Herzegovina is uniform across different regions (Kadušić *et al.*, 2016), unlike neighbouring Croatia where the ageing process is more spatially consistent (Nejašmić & Toskić, 2013). This highlights the need for targeted interventions to address spatial disparities of ageing in Bosnia and Herzegovina. The clustering of data on ageing coefficient, the ageing index, dependency ratio, old-age dependency ratio, and average age, for the period from 2013 to 2023, has revealed clusters with different values of analyzed ageing indicators. The entire Bosnian population is facing significant ageing with different levels of ageing across different areas of this country. Three clusters were identified with lower, moderate, and advanced ageing. These clusters indicate areas where the population is ageing more

rapidly and the necessity for targeted policy interventions. As stated by Litra (2014) increase of the elderly in the total population puts a growing demand on the healthcare and pension system, and pressure on the public finances and the social system of a country. Since similar trends are evident in Bosnia and Herzegovina, many studies indicate an urgent policy change to ensure adequate living standards for the elderly and the economic stability of the country (Bošnjak, 2016; Pijalović *et al.*, 2018).

According to Avdic & Avdic (2023) and Kadušić *et al.* (2023b), spatial disparities in demographic and socio-economic trends in Bosnia and Herzegovina are mostly caused by social, economic, and political factors. The most significant factors of uneven demographic development of Bosnia and Herzegovina are socio-economic factors (unemployment rate, unemployment rate of highly educated population, net salary, number of inhabitants per doctor, migration, etc.), political-social factors (political instability, social injustice, lack of trust in institutions, general feeling of insecurity), psychological factors (attitude of younger generations towards marriage, family, personal and professional ambitions, feminization of migration), administrative division of Bosnia and Herzegovina, urban-rural polarization, etc. (Begović *et al.*, 2020; Efendić, 2016; Jahić *et al.*, 2024).

Adverse population ageing is particularly present in Cluster 1, or in rural municipalities that are founded after the Dayton Peace Agreement, and are situated along the administrative entity border within Bosnia and Herzegovina. However, this research identified an exception to this general rule. Municipalities such as Tešanj, Teslić, Doboj, Doboj Jug, Doboj Istok, etc., despite being situated along entity lines, have more favourable demographic ageing trends. This implies that socio-economic factors like population size, human resources, unemployment rate, the unemployment rate of the population with a university degree, net salary, number of inhabitants per medical doctor, etc., play a significant role in demographic development in Bosnia and Herzegovina. Socioeconomic factors affect the living standard of the population and cause the emigration of the younger population to highly developed European countries (Efendic, 2016; Efendic *et al.*, 2023; Lukić-Tanović & Marinković, 2024). As stated by Kadušić *et al.* (2023b) and Gekic *et al.* (2020) emigration of young and educated individuals aggravates the population ageing by reducing the proportion of the younger population.

Unfortunately, one of the limitations of this study is the availability of official statistical data on the demographics of Bosnia and Herzegovina. The last population census in Bosnia and Herzegovina took place in 2013, and consequently, there are no available demographic data on a settlement level. To carry out the clustering of data on the ageing process in Bosnia and Herzegovina, data on the municipal level were used, which contributes to the generalization of the data and can affect the clustering results. Furthermore, it was not possible to perform a spatial analysis of emigration by municipalities because there is no systematic and continuous monitoring of this demographic phenomenon in all areas of Bosnia and Herzegovina. The Republic of Srpska Institute of Statistics does not record and publish data on emigration by municipalities. However, existing data and recent studies all point that emigration is a serious issue for the present and future demographic development of Bosnia and Herzegovina (Avdić *et al.*, 2022; Gekic *et al.*, 2020).

Although data on emigration could not have been included in the analysis, the results obtained by this study indicate significant spatial differences in demographic trends in Bosnia and Herzegovina, including population ageing. This study is a novelty in a spatial approach to analyze multiple ageing indicators and identify spatial disparities in demographic ageing in Bosnia and Herzegovina. Furthermore, a 70% ratio of the between-cluster sum of squares to the total sum of squares indicates that k-means clustering was effective in capturing the structure of the data on ageing indicators.

Although the applied methodology proved suitable for deriving clusters of demographic ageing, it is important to emphasize that clustering reveals spatial patterns but does not quantify underlying causes. Therefore, future research should, among other aspects, focus on identifying and analyzing the factors driving such spatial manifestations. The partially limited spatial resolution may affect the accuracy of classification, as municipal boundaries, used as the primary statistical units, constrain the ability to capture intra-local variations in demographic ageing. Additionally, temporal limitations must be acknowledged, arising from the absence of regular population censuses in Bosnia and Herzegovina and the lack of an up-to-date population register.

To enhance the analytical framework of future studies on population ageing in Bosnia and Herzegovina, several methodological refinements are proposed. One important direction involves the incorporation of spatial contiguity into the clustering process. While k-means clustering effectively groups units based on attribute similarity, it does not account for geographic proximity, which is an important dimension in spatial demography. Therefore, the application of spatially constrained

hierarchical clustering (SCHC) methods, as proposed by Anselin (2020), could improve the identification of demographically coherent and spatially contiguous clusters. Such an approach would generate more policy-relevant regional delineations for spatial planning and targeted interventions. In addition, the application of geographically weighted clustering could prove particularly valuable in detecting local variations in ageing structures. Given the demographic complexity of Bosnia and Herzegovina, where adjacent municipalities often exhibit vastly different demographic profiles due to historical, socio-economic and administrative factors, this technique would allow for more localized and context-sensitive analysis of ageing patterns.

When it comes to data preprocessing, future research should continue to employ techniques such as winsorization or natural logarithm transformation to address the influence of outliers. These outliers frequently correspond to small municipalities established in the post-war period through the new administrative organization of the country. Due to their low population base and atypical demographic structures, these municipalities pose specific challenges in spatial statistical analysis and require detailed methodological approach. Ideally, such municipalities should be the focus of separated demographic case studies to better understand their actual conditions.

It would be beneficial to compare the results of quantitative clustering with existing official typologies or classifications, or to validate findings using qualitative methods. This would enhance the interpretability and credibility of the identified clusters. Furthermore, the inclusion of data at lower administrative levels, such as settlements, would greatly increase the resolution and analytical precision of spatial ageing studies. However, due to the absence of disaggregated demographic data after the 2013 census, such analyses remain limited. Additionally, the inclusion of migration data and the implementation of comparative studies with neighboring countries would provide a broader regional perspective, allowing for contextualization of demographic ageing trends within the wider post-socialist and post-conflict spatial development of this part of Balkans.

The findings of the study are significant for future planning of demographic development in Bosnia and Herzegovina since they point to the need to create and implement regional demographic development strategies. In the coming period, it is necessary to define and implement measures of population policy by applying various financial and social measures. This includes developing programs for the revitalization of rural areas through investments in infrastructure, agriculture, and other local economic activities that could reduce emigration. Improving working conditions and reducing unemployment among young population, should be addressed through the creation of new jobs and the implementation of programs supporting self-employment and entrepreneurship.

A strategy for return of Bosnian emigrants should be developed, incorporating tax incentives, subsidies for starting new business and recognition of qualifications acquired abroad. Furthermore, immigration should be promoted by creating policy that would attract immigrants to Bosnia and Herzegovina through temporary or permanent residence. Bosnia and Herzegovina needs balanced regional development strategies that consider the geographic and demographic specificities of each region and municipality.

Therefore, in the forthcoming period it is necessary to conduct case studies and research spatial demographic disparities through the systematic collection and analysis of data on demographic data at regional and municipal level. These insights will serve as a foundation for formulating effective and regionally responsive demographic development strategies.

6. CONCLUSIONS

This study emphasizes the use of k-means clustering in determining spatial disparities in population ageing in Bosnia and Herzegovina providing valuable insights into demographic challenges facing this country. The results of k-means clustering revealed three distinct clusters with different levels of ageing, which correlate with underlying demographic, socioeconomic, and political factors. Key socioeconomic factors, affecting this demographic process, include unemployment rate, the unemployment rate among highly educated population, net salaries, etc. These are accompanied by political and social factors such as political instability, social injustice, lack of trust in institutions, and general feeling of insecurity. Psychological factors also play a significant role, especially the attitudes of young generations towards marriage and family, personal and professional ambitions. These factors aggravate rural-urban polarization contributing significantly to the uneven demographic development of Bosnia and Herzegovina, causing disparities in population ageing. Uneven socio-economic

development in Bosnia and Herzegovina causes emigration of young population from underdeveloped rural to developed urban areas, and the emigration of young people abroad.

Cluster analysis identified that municipalities in rural and less economically developed areas of Bosnia and Herzegovina experience higher levels of ageing. These regions are characterized by significant emigration and lower fertility rates, which aggravates the challenges of the pension and healthcare system, putting pressure on the economic stability of the country. On the other hand, municipalities with lower levels of ageing are mostly located in urban and economically more developed areas, with larger share of young population and higher fertility rates.

Therefore, the k-means clustering approach proved to be an effective tool for identifying spatial disparities in population ageing in Bosnia and Herzegovina. The classification of municipalities based on ageing indicators enabled a better understanding of spatial differences in the ageing process. Moreover, cluster analysis of ageing indicators provided a visualization of ageing disparities, facilitating data interpretation for future strategists and spatial planners. Future research could incorporate additional socioeconomic variables to gain a more comprehensive understanding of factors that contribute to spatial disparities in demographic development and population ageing. Future studies could also explore interdependencies between demographic and socioeconomic development using advanced spatial statistical methods, such as geographically weighted clustering. This approach would contribute to more precise and effective policy recommendations aimed at addressing the challenges of population ageing in Bosnia and Herzegovina.

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AUTHOR CONTRIBUTIONS

Alma Kadušić: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft preparation, Writing – review and editing, Visualization, Supervision. **Mariana Lukić Tanović:** Conceptualization, Methodology, Validation, Resources, Writing – review and editing, Visualization, Supervision. **Nedima Smajić:** Resources, Writing – review and editing, Visualization, Supervision. **Aida Avdić:** Resources, Writing – review and editing, Visualization, Supervision.

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REFERENCES

- Abbas, S. A., Aslam, A., Rehman, A. U., Abbasi, W. A., Arif, S., & Kazmi, S. Z. H. (2020). K-means and k-medoids: Cluster analysis on birth data collected in city Muzaffarabad, Kashmir. *IEEE Access*, 8, 151847-151855. <https://doi.org/10.1109/ACCESS.2020.3014021>
- Agency for Statistics of Bosnia and Herzegovina (2024). *Demography 2023. Demographic Bulletin TB 02*. Sarajevo: Agency for statistics of Bosnia and Herzegovina. https://bhas.gov.ba/data/Publikacije/Bilteni/2024/DEM_00_2023_TB_1_BS.pdf
- Agency for statistics of Bosnia and Herzegovina (2023). *Gross Domestic Product by Production, Income, and Expenditure Approach. Thematic Bulletin TB 01*. Sarajevo: Agency for statistics of Bosnia and Herzegovina. https://bhas.gov.ba/data/Publikacije/Bilteni/2025/NAC_00_2023_TB_1_BS.pdf
- Ahmadov, E.Y. (2023). Comparative analysis of k-means and fuzzy c-means algorithms on demographic data using the PCA method. *Problems of Information Technology*, 14(1), 15-22. <http://doi.org/10.25045/jpit.v14.i1.03>

- Ahmed, M., Seraj, R., & Islam, S.M.S. (2020). The k-means algorithm: A comprehensive survey and performance evaluation. *Electronics*, 9(8), 1295. <https://doi.org/10.3390/electronics9081295>
- Al-Mekhlafi, A., Klawitter, S., & Klawonn, F. (2024). Standardization with zlog values improves exploratory data analysis and machine learning for laboratory data. *Journal of Laboratory Medicine*, 48, 215-222. <https://doi.org/10.1515/labmed-2024-0051>
- Anselin, L. (2020). *GeoDa Workbook: Spatial Clustering (Lab 9d)*. GeoDa Center for Geospatial Analysis and Computation. https://geodacenter.github.io/workbook/9d_spatial4/lab9d.html
- Anselin, L. (2005). *Exploring Spatial Data with GeoDaTM: A Workbook*. Center for Spatially Integrated Social Science.
- Ashari, I.F., Nugroho, E.D., Baraku, R., Yanda, I.N., & Liwardana, R. (2023). Analysis of elbow, silhouette, Davies-Bouldin, Calinski-Harabasz, and rand-index evaluation on k-means algorithm for classifying flood-affected areas in Jakarta. *Journal of Applied Informatics and Computing*, 7(1), 95-103. <https://doi.org/10.30871/jaic.v7i1.4947>
- Avdic, A., & Avdic, B. (2023). Center and Periphery in Bosnia and Herzegovina-Social and Spatial Indicators of Regional Disparities. *Folia Geographica*, 65(2), 103-126. <https://www.foliageographica.sk/unipo/journals/2023-65-2/693/>
- Avdić, A., Avdić, B., & Zupanc, I. (2022). Socio-demographic analysis of border regions of Bosnia and Herzegovina. *Acta Geographica Slovenica*, 62(3), 7-19. <https://doi.org/10.3986/AGS.10859>
- Basile, R., Basso, S., Miccoli, S., Reynaud, C. (2023). Ageing population in Italy: a space-time analysis. *Rivista Italiana di Economia Demografia e Statistica*, LXXVI(2), 77-88. <https://www.rieds-journal.org/rieds/article/view/99/91>
- Begović, S., Lazović-Pita, L., Pijalović, V., & Baskot, B. (2020). An investigation of determinants of youth propensity to emigrate from Bosnia and Herzegovina. *Economic research-Ekonomska istraživanja*, 33(1), 2574-2590. <https://doi.org/10.1080/1331677X.2020.1754267>
- Bošnjak, N. (2016). The Pension System of Bosnia and Herzegovina: Problems and Perspectives. *European Journal of Multidisciplinary studies*, 1(2), 186-194. <https://doi.org/10.26417/ejms.v1i2.p186-194>
- Bucher, S. (2014). Selected indicators of population ageing in the world: Trends, impacts and consequences. *Geographica Pannonica*, 18(2), 26-33. <https://scindeks-clanci.ceon.rs/data/pdf/0354-8724/2014/0354-87241402026B.pdf>
- Chen, Y., Bouferguene, A., Shen, Y., & Al-Hussein, M. (2019). Difference analysis of regional population ageing from temporal and spatial perspectives: a case study in China. *Regional Studies*, 53, 849-860. <https://doi.org/10.1080/00343404.2018.1492110>
- Chong, B. (2021). K-means clustering algorithm: a brief review. *Academic Journal of Computing & Information Science*, 4(5), 37-40. <https://doi.org/10.25236/AJIS.2021.040506>
- Cristea, M., Noja, G.G., & Thalassinou, Y. (2021). Population ageing and welfare dissimilarities within the European Union: a new approach based on cluster analysis. *Facta Universitatis, Series: Economics and Organization*, 18, 17-27. <https://doi.org/10.22190/FUEO201226003C>
- Efendic, A. (2016). Emigration intentions in a post-conflict environment: evidence from Bosnia and Herzegovina. *Post-Communist Economies*, 28, 335-352. <https://doi.org/10.1080/14631377.2016.1166800>
- Efendic, A., Husić-Mehmedović, M., & Turulja, L. (2023). Emigration in Bosnia and Herzegovina: Empirical Evidence from the Last Two Decades. *Central and Eastern European Migration Review*, 12(2), 53-72. <https://doi.org/10.54667/ceemr.2023.18>
- Fahmijah, I., Ningrum, R.A. (2023). Human Development Clustering in Indonesia: Using K-Means Method and Based on Human Development Index Categories. *Journal of Advanced Technology and Multidiscipline*, 2(1), 27-33. <https://e-journal.unair.ac.id/IATM/article/view/45070>
- Federation of Bosnia and Herzegovina (2024). *Population migration 2023. Statistical Bulletin 375*. Institute for statistics of FBiH. <https://fzs.ba/wp-content/uploads/2024/02/Migracije-2023.pdf>
- Gabor, V.R., Iftimoaei, C., & Baci, I.C. (2022). Population Ageing. Romania in a European Context. *Romanian Journal of Population Studies*, 16(2), 81-110. <https://doi.org/10.24193/RJPS.2022.2.04>
- Gekić, H., Bidžan-Gekić, A., Mirić, R., & Drešković, N. (2019). Spatial differentiation of the age structure of a population in Bosnia and Herzegovina. In Macedonian Geographical Society (Ed.), *Proceedings of International Scientific Symposium New Trends Geography* (pp. 215-226). October 3-4, 2019, Ohrid, Republic of North Macedonia. <https://doi.org/10.37658/procgeo19215g>
- Gekic, H., Bidzan-Gekic, A., Miric, R., & Reményi, P. (2020). Hidden geographies of population implosion in Bosnia and Herzegovina. *European Journal of Geography*, 11, 47-64. <https://doi.org/10.48088/ejg.hgek.11.2.47.64>

- Gnjatovic, J.S., Devedzic, M. (2016). Certain characteristics of population ageing using a prospective approach: Serbia as a case study. *Vienna Yearbook of Population Research*, 14, 89-106. <http://www.jstor.org/stable/26506084>
- Guerin, B., Hoorens, S., Khodyakov, D., & Yaqub, O. (2015). *A growing and ageing population: Global societal trends to 2030. Thematic report 1*. RAND Corporation. https://www.rand.org/pubs/research_reports/RR920z1.html
- Hamadani, A., Ganai, N.A., Raja, T., Alam, S., Andrabi, S.M., Hussain, I., & Ahmad, H.A. (2021). Outlier removal in sheep farm datasets using winsorization. *Bhartiya Krishi Anusandhan Patrika*, 36(4), 334-337. <https://doi.org/10.18805/BKAP397>
- Harasty, C., & Ostermeier, M. (2020). *Population ageing: Alternative measures of dependency and implications for the future of work*. ILO Working Paper No. 5. International Labour Organization.
- Hassan, I.H., Abdullahi, M., & Ali, Y.S. (2021). Analysis of Techniques for Selecting Appropriate Number of Clusters in K-means Clustering Algorithm. In *Proceedings of the International Conference on Computing and Advances in Information Technology (ICCAIT 2021)* (pp. 90-96), November 15-17, 2021, Ahmadu Bello University, Zaria, Nigeria. <https://icait.com.ng/2021/>
- Inoue, T., & Inoue, N. (2024). The Future Process of Japan's Population Aging: A Cluster Analysis Using Small Area Population Projection Data. *Population Research and Policy Review*, 43, 58. <https://doi.org/10.1007/s11113-024-09903-5>
- Ismail, K., Nayan, N., & Ibrahim, S.N. (2016). Improving the tool for analyzing Malaysia's demographic change: Data standardization analysis to form geo-demographics classification profiles using k-means algorithms. *Malaysian Journal of Society and Space*, 12(6), 34-42. <https://core.ac.uk/download/pdf/84306815.pdf>
- Jahić, H., Hadžiahmetović-Milišić, N., Dedović, L., & Kuloglija, E. (2024). Diagnosing the Issue: Understanding and Combating Medical Brain Drain in Bosnia and Herzegovina. *Naše gospodarstvo/Our economy*, 70, 12- <https://doi.org/23.10.2478/ngoe-2024-0008>
- Jakovljevic, M., Cerda, A.A., Liu, Y., García, L., Timofeyev, Y., Krstic, K., Fontanesi, J. (2021). Sustainability challenge of Eastern Europe-historical legacy, belt and road initiative, population aging and migration. *Sustainability*, 13(19), 11038. <https://doi.org/10.3390/su131911038>
- Jakovljevic, M., & Laaser, U. (2015). Population aging from 1950 to 2010 in seventeen transitional countries in the wider region of South Eastern Europe. *South Eastern European Journal of Public Health*, 3(1), 1-12. <https://doi.org/10.12908/SEEPH-2014-42>
- Jemna, D.-V., & David, M. (2021). Determinants of ageing in Romania. Evidence from regional-level panel analysis. *CES Working Papers*, 13(1), 17-32. <https://ideas.repec.org/a/jes/wpaper/y2021v13i1p17-32.html>
- Jukic, M., & Khan, H.T. (2015). Spatial pattern of structural ageing in eastern Croatia: evolution and explanations. *International Journal of Ageing and Later Life (IJAL)*, 9(2), 53-78. <https://doi.org/10.3384/ijal.1652-8670.2015.159253>
- Jurun, E., Ratković, N., & Ujević, I. (2017). A cluster analysis of Croatian counties as the base for an active demographic policy. *Croatian Operational Research Review*, 8(1), 221-236. <https://doi.org/10.17535/crorr.2017.0014>
- Káčerová, M., Ondačková, J., & Mládek, J. (2014). Time-space differences of population ageing in Europe. *Hungarian Geographical Bulletin*, 63(2), 177-199. <https://doi.org/10.15201/hungeobull.63.2.4>
- Kadušić, A., & Smajić, N. (2019). Primary-school-age population change in the Federation of Bosnia and Herzegovina: The effects of demographic factors. *Stanovništvo*, 57(2), 49-70. <https://doi.org/10.2298/STNV1902049K>
- Kadušić, A., Smajić, S., Kunosić, S., & Smajić, N. (2023a). Geospatial analysis of population ageing in Bosnia and Herzegovina. *Geographica Pannonica*, 27(1), 38-49. <https://doi.org/10.5937/gp27-41960>
- Kadušić, A., Smajić, S., & Smajić, N. (2023b). The patterns of depopulation in Bosnia and Herzegovina: Spatial autocorrelation analysis. *Geografski Pregled*, 48, 85-100. <https://doi.org/10.35666/23038950.2023.48.85>
- Kadušić, A., Suljić, A., & Mešanović, D. (2015). Fertility rates in Tešanj Municipality (Bosnia and Herzegovina) in the second half of the 20th and the beginning of 21st century. *Geographica Pannonica*, 19, 50-57. <https://doi.org/10.5937/GeoPan1502050K>
- Kadušić, A., Suljić, A., & Smajić, N. (2016). The demographic ageing of population in Bosnia and Herzegovina: causes and consequences. *Revija za geografiju - Journal for Geography*, 11(1), 41-52. <https://doi.org/10.18690/rg.11.1.3951>
- Kastreva, P., & Patarchanova, E. (2021). Creating Spatial Models of Demographic Processes Using Cluster Analysis for Demographic Policy Planning in Bulgaria. *Journal of Settlements & Spatial Planning*, 12(2), 119-130. <https://doi.org/10.24193/JSSP.2021.2.05>
- Kočanová, D., Kováč, V., Serzhanov, V., & Buleca, J. (2023). Differences and similarities in patterns of ageing society in the European Union. *Economics and Management*, 26(1), 45-64. <https://doi.org/10.15240/tul/001/2023-1-003>

- Kodinariya, T.M., & Makwana, P.R. (2013). Review on determining number of Cluster in K-Means Clustering. *International Journal*, 1(6), 90-95. <http://ijarcsms.com/docs/paper/volume1/issue6/V116-0015.pdf>
- Kong, F. (2018). Aging Trend of the World. In T. Hoshi & S. Kodama (Eds.), *The Structure of Healthy Life Determinants. International Perspectives on Aging*, vol. 18. Springer. https://doi.org/10.1007/978-981-10-6629-0_2
- Krisjane, Z., Berzins, M., Krumins, J., Apsite-Berina, E., & Balode, S. (2023). Uneven geographies: ageing and population dynamics in Latvia. *Regional Science Policy & Practice*, 15(4), 893-909. <https://doi.org/10.1111/rsp3.12648>
- Li, J., Han, X., Zhang, X., & Wang, S. (2019). Spatiotemporal evolution of global population ageing from 1960 to 2017. *BMC Public Health*, 19, 127. <https://doi.org/10.1186/s12889-019-6465-2>
- Lillova, K. (2021). Population Ageing and Longevity in Bulgaria (1947-2015). *Население*, 39(2), 205-240. <https://www.cceol.com/search/article-detail?id=995325>
- Litra, A.V. (2014). Economic effects of demographic ageing. Bulletin of the Transilvania University of Brasov. Series V: *Economic Sciences*, 7(56), 2, 229-234. https://webbut.unitbv.ro/index.php/Series_V/article/view/5005/3881
- Lo, V. I. (2023). The Criss-Cross of Ageing and Globalisation. In U. Ghorri, M. Hiscock, L. Parsons & C. Watters. (Eds.), *Globalisation in Transition* (pp. 67-79). Springer. https://doi.org/10.1007/978-981-99-2439-4_6
- Lukić-Tanović, M., & Marinković, D. (2024). Population census in Bosnia and Herzegovina: Between political interests and unfavorable demographic processes. *Zbornik Matice srpske za društvene nauke*, 189, 53-67. <https://doi.org/10.2298/ZMSDN2489053L>
- Marisa, F., Wardhani, A.R., Purnomowati, W., Vitianingsih, A.V., Maukar, A.L., & Puspitarini, E.W. (2023). *Potential customer analysis using k-means with elbow method*. Jurnal Informatika dan Komputer, 7, 307-312. <http://dx.doi.org/10.26798/jiko.v7i2.911>
- Matsuga, O.M., & Sheremet, V. S. (2023). Оцінювання оптимальної кількості кластерів для методу k-середніх на основі кусково-лінійної регресії з одним вузлом [Determining the optimal number of clusters for the k-means method using piecewise-linear regression with one changepoint]. *Актуальні проблеми автоматизації та інформаційних технологій*, 27, 17-24. <http://dx.doi.org/10.15421/432302>
- Milena, S. (2022). Population ageing in selected ex-Yugoslav states. *Zbornik radova Departmana za geografiju, turizam i hotelijerstvo*, 51(1), 1-10. <https://doi.org/10.5937/ZbDght2201001S>
- Ministry for security of Bosnia and Herzegovina, Sector for migration (2024). *Migration profile of Bosnia and Herzegovina for 2023*. Sarajevo. <https://www.msb.gov.ba/PDF/160820244.pdf>
- Morissette, L., & Chartier, S. (2013). The k-means clustering technique: General considerations and implementation in Mathematica. *Tutorials in Quantitative Methods for Psychology*, 9, 15-24. <https://doi.org/10.20982/tqmp.09.1.p015>
- Nejašmić, I. (2005). *Demogeografija: stanovništvo u prostornim odnosima i procesima* [Demogeography: Population in Spatial Relations and Processes]. Školska knjiga.
- Nejašmić, I., & Toskić, A. (2013). Population Ageing in Croatian Border Regions. *Acta Geographica Croatica*, 40, 1-13. <https://hrcak.srce.hr/file/216609>
- Nogueira, A.L., & Munita, C.S. (2021). The effect of data standardization in cluster analysis. *Brazilian Journal of Radiation Sciences*, 9(1A), ENAN / 2019. <https://doi.org/10.15392/bjrs.v9i1A.1324>
- Nogueira, A.L., & Munita, C.S. (2020). Quantitative methods of standardization in cluster analysis: finding groups in data. *Journal of Radioanalytical and Nuclear Chemistry*, 325, 719-724. <https://doi.org/10.1007/s10967-020-07186-6>
- Pekarek, S. (2018). Population aging and economic dependency ratio: Comparative study of the Czech Republic and Slovakia. *Ecoforum*, 7(1), 69-78. <https://ecoforumjournal.ro/index.php/eco/article/view/2084>
- Pijalović, V., Lazović-Pita, L., Peštek, A., & Martinović, D. (2018). The analysis of perceptions and attitudes related to ageing in the Federation of Bosnia and Herzegovina. *Public Sector Economics*, 42, 255-278. <https://doi.org/10.3326/pse.42.3.2>
- Rašić-Bakarić, I. (2007). Uncovering regional disparities-the use of factor and cluster analysis. *Croatian Economic Survey*, 9, 11-34. <https://hrcak.srce.hr/en/file/17906>
- Reynaud, C., Miccoli, S., & Lagona, F. (2018). Population Ageing in Italy: An Empirical Analysis of Change in the Ageing Index Across Space and Time. *Spatial Demography*, 6, 235-251. <https://doi.org/10.1007/s40980-018-0043-6>
- Roszkowska, E. (2018). Comprehensive analysis of the process of population ageing in Poland in the years 1950-2016. Optimum. *Economic Studies*, 92(2), 206-226. <https://doi.org/10.15290/oes.2018.02.92.16>
- Republic of Srpska Institute of Statistics (2024). *Demographic statistics. Statistical Bulletin 2024*. Republic of Srpska Institute of statistics. https://www.rzs.rs.ba/static/uploads/bilteni/stanovnistvo/BiltenDemografskaStatistika_2024_WEB.pdf

- Sabri, S. M., Annuar, N., Rahman, N. L. A., Musairah, S. K., Mutalib, H. A., & Subagja, I. K. (2022). Major trends in ageing population research: a bibliometric analysis from 2001 to 2021. *Proceedings*, 82(1), 19. <https://doi.org/10.3390/proceedings2022082019>
- Wan, Q., Tang, Z., Pan, J., Xie, M., Wang, S., Yin, H. ... Song, C. (2022). Spatiotemporal heterogeneity in associations of national population ageing with socioeconomic and environmental factors at the global scale. *Journal of Cleaner Production*, 373, 133781. <https://doi.org/10.1016/j.jclepro.2022.133781>
- Wang, X., & Xu, Y. (2019). An improved index for clustering validation based on Silhouette index and Calinski-Harabasz index. *IOP Conference Series: Materials Science and Engineering*, 569, 052024. <https://doi.org/10.1088/1757-899X/569/5/052024>
- Wang, Y. (2024). Exploring the Application of Early Childhood Psychological Education Based on K-means Cluster. Analysis. *Journal of Electrical Systems*, 20, 64-71. <https://journal.esrgroups.org/jes/article/view/4290/3136>
- Wu, L., Huang, Z., & Pan, Z. (2021). The spatiality and driving forces of population ageing in China. *PLOS One*, 16, e0243559. <https://doi.org/10.1371/journal.pone.0243559>
- Yakar, M., & Özgür, E.M. (2024). Revealing ageing regions through spatial patterns: the evidence from Türkiye. *Finisterra – Revista Portuguesa de Geografia*, LIX(125), 105-123. <https://doi.org/10.18055/Finis32411>
- Zhang, K., Sun, H., & Li, X. (2022). Aging population spatial distribution discrepancy and impacting factor. *Sustainability*, 14(15), 9528. <https://doi.org/10.3390/su14159528>
- Zhang, Y., & Li, D. (2013). Cluster analysis by variance ratio criterion and firefly algorithm. *International Journal of Digital Content Technology and its Applications*, 7(3), 689-697. <https://doi.org/10.4156/jdcta.vol7.issue3.84>
- Zlotnik, H. (2016). Population Ageing in the Context of Globalization. In D. Sánchez-González & Rodríguez-V. Rodríguez (Eds.), *Environmental Gerontology in Europe and Latin America. International Perspectives on Aging*, vol. 13. Springer. https://doi.org/10.1007/978-3-319-21419-1_3