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Assessment of population ageing using the statistical method of spatial autocorrelation: a case study of Nitra Region (Slovakia)

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Abstract. This case study presents a comprehensive analysis of the issue of population ageing in the municipalities of the Nitra Region, which in 2022 had the second highest proportion of people of post-productive age (19.5%) among regions in Slovakia and has long been the region with the oldest population in Slovakia. Changes in the age structure of the region's population are monitored in three time periods (1996–2004, 2005–2013, 2014–2022). This case study provides new and relevant findings on differentiations in population ageing at the local level within the region monitored. In this paper, we address the issue of population ageing through spatial statistics using the spatial autocorrelation method, where the observed indicators comprised both simple and more complex rates of population ageing. Changes in ageing were observed across all three monitored periods. More pronounced ageing was recorded in the most recent period, 2014–2022, which was reflected in this period by increased values of indicators confirming the economic ageing of the population.

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1. Introduction

Population ageing causes intensive changes in demographic behaviour that appeared in Europe in the end of the 20th and beginning of the 21st century. The latest World Population Prospects 2022 report (United Nations Department of Economic and Social Affffairs, 2022) on ageing of the world's population clearly points to the dynamization of this phenomenon in the 21st century, with increases in the numbers and proportions of seniors in almost every country in the world. Europe is particular in this respect, having long had the oldest population in the world. Currently, people aged 60 and over make up almost a quarter of Europe's total population, with an increase of almost 35% expected by 2050. In the European Union, about 70 million people will reach the age of 60 between 2020 and 2029, while only about 55 million will reach the age of 20, which is the average age of young people entering the labour market (Loichinger et al., 2015). In the countries of Western Europe, the population started to age already in the 1970s. According to the authors Kashnitsky, Beer and Wissen (2018), all European regions are experiencing accelerating ageing, but this process exhibits considerable regional disparities.

In developed countries, cohorts of women born after the Second World War have experienced a shift in fertility to later ages, with a concomitant decline in fertility levels (Sobotka et al., 2011). Lower fertility, childbearing and marriage rates, higher ages at marriage and at childbirth, higher incidence of cohabitation, higher divorce rates and a higher proportion of children born out of marriage are all part of the demographic behaviour typical of the second demographic transition (Kocourková, 1998; Sobotka, 2008; Krejčí et al., 2011; Reher, 2011; Sanchez-Barricarte & Fernandez-Carro, 2009).

Since the 1990s, Slovakia has been experiencing dynamic demographic development and changes in the reproductive behaviour of the population. Typical features of this development include a significant decline in fertility and birth rates, their stabilisation at a low level, alongside a gradual improvement in mortality rates and increase in life expectancy, which together bring about a gradual ageing of the population. Slovakia is moving from its current position as a relatively "young" country in Europe to one of the oldest populations in the European area (and probably also in the world) (Šprocha, 2015). Population development in Slovakia was influenced by common history of the Eastern Socialist Bloc. Isolation from the countries of Western and Northern Europe caused differences in demographic behaviour. This radical change in demographic behaviour was characterised by a decrease in the fertility level, an increase in median age of women at childbirth, and many other factors that intensified population ageing (Sobotka, 2008; Krajňáková & Vojtovič, 2017). In post-communist countries, the decrease in fertility was also a result of rapidly developing urbanisation. Former communist regimes in these countries implemented policies aimed at increasing the birth rate (direct child benefit, maternity benefit, preferential benefits for families with children in the allocation of state-owned apartments, establishment of nurseries for children up to 3 years of age, etc.), which has been called the "Eastern European Reproductive Pattern" (Sobotka, 2011). Central European countries differed in the onset of the second demographic transition. Whereas the Czech Republic and Hungary were earlier in approaching the countries of Western Europe in terms of type of reproductive behaviour, this process was delayed in Poland and Slovakia. Slovakia are Poland have some of the lowest fertility rates in Europe, the highest increase in life expectancy, particularly intensive population ageing and large emigration abroad. The consequences of the above demographic processes are considered to pose a major challenge for the social policy of local governments of individual states (Gołata & Kuropka, 2016).

According to McHugh (2006) and Plane and Rogerson (1991), population ageing is the result of several population processes that shape the age structure of the population. In contrast to the numerous phenomena that concern only a certain part of the population, such as marriage, divorce, fertility, education, etc., the formation of the age structure and its changes relate to all inhabitants of the population. The complexity of the age structure of the population is also reflected in its multiple relationships with many other demographic and social phenomena. The development of basic population processes such as fertility, mortality and migration is reflected in the age structure (Fors et al., 2021; Tavares, 2022). The age structure of the population and the processes of its formation can be considered one of the most important demographic and social phenomena. According to Marin and Zaidi (2010), the size of the productive-age population in the Europe declined after 2012 – and even more after 2017, when employment growth no longer compensated for this overall trend and the effect of population ageing became dominant. Offsetting the decline in the productive-age population and the increase in post-productive-age population will be a major challenge. Similar opinions are also presented by Nagarajan et al. (2019), who argue that the ageing of the population has serious implications for the labour force worldwide, especially in developed countries, and that labour shortages are increasingly becoming a societal problem. According to Nagarajan and Sixsmith (2023), the current working population will live longer and healthier lives than previous generations, which, combined with the current decline in the labour force, means that older persons are expected to participate in the labour market. Therefore, governments in developed countries have responded to this problem by raising retirement ages, which is an appropriate strategy to overcome the decline in labour supply. However, ageing societies also present opportunities in the context of addressing employability and ability to work given the dramatic demographic changes in the workforce across Europe (Deeg & Wahl, 2012). Basic economic inputs – volume of labour, labour productivity and the capital stock – are affected by ageing societies. The volume of labour in an ageing society declines. The number of workers decreases compared to the number of retirees; society has the same number of consumers but fewer workers (Börsch-Supan, 2010). This means that labour productivity decreases in an ageing society; thus, older workers are less productive. Increasing the retirement age thus implies the need to help older workers to be more productive in the labour market. Shoven and Goda (2008) present the view that the senior population has great potential for overcoming the problem of labour shortages. National government policies need to adjust to the fact that, with each additional year, a given age is associated with a higher remaining life expectancy and a lower mortality risk.

Population ageing is also a key risk for Europe's future. The Old Continent has to face increasingly strong new demographic trends and seek effective strategies to address them. The increased number of people of post-productive age brings increased need for specialised health professionals, increased numbers of long-term care facilities and preventive programmes aimed at improving the health status of the elderly (Kiniorska et al., 2023). Advances in public health and medical technology, together with improvements in living conditions, mean that people are living longer and, in many cases, healthier lives than ever before, even at older ages (Izekenova et al. 2015; Leszko, Zając-Lamparska & Trempala 2015; Alders & Schut 2019; Klusmann & Kornadt 2020; Kauppi et al. 2021; and others).

In recent decades, population ageing has become an important topic of scientific research in individual European countries, including Slovakia. Since the 1950s, the proportion of seniors in Slovakia has gradually increased from less than 7% to 17.9% today (2022). In terms of relative share of seniors in regions, first place belongs to Trenčín Region (19.9%) and the second highest share is in Nitra Region (19.5%). These are the regions with the oldest population in the long term, which is also documented by the average age of the population being 43.4, which is the highest of the Slovak regions. We study population ageing in Slovakia on a model area, which is the Nitra Region.

The aim of the study was to present population ageing in three development stages (1996–2004, 2005–2013, and 2014–2022) at the level of municipalities of the Nitra Region. For a comprehensive analysis of population ageing in Slovakia, it is necessary to examine this demographic process at different hierarchical levels and to highlight regional disparities. In our study, we analyse population ageing at the lowest level (local) using the method of spatial autocorrelation. To assess the degree of spatial autocorrelation of the observed traits, we used the local Moran's coefficient of spatial autocorrelation. We tested the null hypothesis H0, that is, there is no spatial autocorrelation based on the values of the observed traits of ageing, against the alternative hypothesis H1, that is, there is spatial autocorrelation based on the values of the observed traits of ageing.

2. Materials and methods

The age structure of the population and the processes of its formation constitute a relatively complex demographic phenomenon. The complexity and importance of the population age structure are also reflected in the extensive set of methods and techniques by which they are studied. To analyse the ageing process, we have chosen a group of indicators that use comparisons of different age categories (more complex measures of population ageing) – the ageing index, the old-age dependency ratio, the economic dependency ratio, the Billeter´s index, and single-component indicators such as the share of population in post-productive age and the median age. The above indicators were examined using the spatial autocorrelation method (Moran's coefficient of spatial autocorrelation), which deals with the statistical analysis of spatial phenomena. Applying this method to the study of population ageing yielded new knowledge about trends and differentiations of population ageing at the local level (municipalities) of the Nitra Region, which has long maintained its status as the region with the oldest population. The above statistical method has not yet been applied in geographic work to assess population ageing.

One measure that has been given great weight in the study of population ageing is Billeter´s index (B_i) (Billeter, 1954), which is defined as the ratio of the difference between the population *P* aged 0–14 and 65+ and the population in productive age of 15–64 (Eq. 1). If it reaches negative values, the population aged 65+ is more numerous, thus indicating a higher level of ageing.

$$B_i = \frac{P_{(0-14)} - P_{(65+)}}{P_{(15-64)}} x100 \quad (1)$$

A second frequently used indicator is the ageing index (Ai), which measures the number of P 65+ per 100 people aged 0–14. The higher the ageing index (Is>100), the older the population (Eq. 2).

$$A_i = \frac{P_{(65+)}}{P_{(0-14)}} x100 \quad (2)$$

The economic dependency ratio (Dr) measures the ratio of the sum of the population P aged 0–14 and 65+ to the productive population aged 15–64. The higher the index, the higher the dependency ratio of burden placed on the productive population by the non-productive population (Eq. 3).

$$D_r = \frac{P_{(0-14)} + P_{(65+)}}{P_{(15-64)}} x100 \quad (3)$$

The old-age dependency ratio (Oadr) measures the burden of the productive part of the population P aged 15–64 on the elderly aged 65+. The higher the old-age dependency index, the higher the number of persons of post-productive age per person of productive age (Eq. 4).

$$O_{adr} = \frac{P_{(65+)}}{P_{(15-64)}} x100 \quad (4)$$

Spatial statistics, as one of the quantitative statistical methods, deals with the statistical synthesis of spatial phenomena. The methods of spatial statistics are encountered in geography, but also in many other scientific disciplines, e.g. in economics, sociology, biology, archaeology, ecology, etc. Spatial statistics differ from other statistical methods primarily because they work with dependent variables. This makes the models more realistic. Spatial statistics uses spatial autocorrelation as a measure of the relationship between phenomena or events separated by certain spatial or time periods. Spatial autocorrelation, or spatial dependence, can be defined as a particular relationship between the spatial proximity among observational units and the numeric similarity among their values; positive spatial autocorrelation refers to situations in which the nearer the observational units, the more similar their values (and vice versa for its negative counterpart) (Lee, 2017). In our case, the variable is each of our six ageing indicators, which were evaluated in different periods 1996–2004, 2005–2013, and 2014–2022. If similar phenomena or attributes are closer in space, we speak of positive spatial autocorrelation. If there is a clustering of significantly different values, we speak of negative spatial autocorrelation. If the data are localised in space such that close values are not correlated in any way, the values analysed are statistically insignificant. The essence of spatial autocorrelation is the proposition that, if the values of an observed trait for each pair of regions of a given space are uncorrelated, then there is no spatial autocorrelation of the observed trait in the system of regions. This statement is based on Tobler's "first law of geography" (Tobler, 1970), according to which "everything is related to everything else, but near things are more related than distant things". According to Getis (2008) and Getis and Ord (2010), spatial autocorrelation can also be understood as mapped variables exhibiting a spatial structure due to their geographical proximity. According to Gregory et al. (2009), spatial autocorrelation assesses the relationship of a single variable in space and time within a single observation. In the context of applied methodology, statistical methods that are usually used for continuous data are Moran's index and Geary's coefficient. Geary's coefficient assesses only positive spatial autocorrelation, unlike the local Moran's statistic, so in our paper we analysed the variables under study using Moran's index. The following applies for Moran's index (Eq. 5):

$$I = \frac{n\left(\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})\right)}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\right)\left(\sum_{i=1}^{n}(x_i - \bar{x})^2\right)} \quad (5)$$

where *n* is the number of spatial units (the number of all municipalities in the Nitra Region), x_i is the value of the variable in municipality *i* (observed indicators), *x* is the arithmetic mean for the given variables, and w_{ij} is the spatial weight. The values of Moran's index (*I*) range from (–1) (perfect variance) to (+1) (absolute correlation). The closer the value of *I* is to 1, the more positive the spatial autocorrelation; the closer the value of *I* is to (–1), the more negative the spatial autocorrelation. The statistical significance of Moran's index of spatial autocorrelation in the different spatial units of the analysed area needs to be verified (Fotheringham et al., 2002). We test the null hypothesis (H_0), that is, there is no spatial autocorrelation between the values of observations at n spatial units. The test statistic Z_I for verifying the statistical significance of Moran's coefficient I has an asymptotically normalised distribution and is given by the relation (Eqs. 6, 7, 8):

$$Z_I = I - \frac{E(I)}{\sqrt{V(I)}} \tag{6}$$

where

$$E(I) = -\frac{1}{n-1} \quad \text{and} \tag{7}$$

$$V(I) = E(I)^2 - E(I)^2 \tag{8}$$

are the mean values and variance of Moran's coefficient I.

The test is based on comparison of the Z_I-score and the corresponding probability value p. The higher the value of the Z_I-score, or the further it is from 0, the higher the confidence level, i.e., the phenomenon under study is autocorrelated. If the null hypothesis H_0 (that there is no spatial autocorrelation of differentiation of ageing based on the values of the observed traits) is not confirmed, we accept the hypothesis H_1 – that there is spatial autocorrelation of the distribution of ageing based on the values of the observed traits, or the spatial differentiation based on the values of the observed traits is not random.

In this paper, we calculated Moran's spatial autocorrelation coefficient using a GIS program to obtain the Z_I values and the corresponding p-value, which is the probability with which the phenomenon under analysis is the result of a random process. If the calculated p value is sufficiently low ($p<0.05$ or $p<0.01$), we reject the tested hypothesis H_0 at the significance level of 0.05 or 0.01, respectively, meaning that Moran's coefficient of spatial autocorrelation is not statistically significant. Otherwise, we cannot reject the tested hypothesis and confirm hypothesis H_1. It should be further noted that we have assumed homogeneity when calculating the general characteristics of spatial autocorrelation. In the case in which this assumption is not met, a situation may arise in which the global statistic erroneously reports the absence of spatial autocorrelation in the analysed dataset, even though in reality there is a strong positive autocorrelation in one part of the location and a strong negative autocorrelation in another part of the location. Therefore, for the above reasons, it is appropriate to use Local Indicators of Spatial Association (LISA), which relate to a specific location to identify autocorrelation. LISA analysis, developed by Anselin (1995), is essentially the local equivalent of Moran's I criterion because the sum of all indicators is proportional to the global value of Moran's statistic. LISA analysis is closely related to the Moran diagram, through which the basic results of spatial autocorrelation analysis can be represented. To the original values of the variable on the horizontal axis and the calculated mean values from neighbouring units on the vertical axis, the slope of the regression line corresponds to the value of the Moran's I criterion. The statistical significance of the calculated values rejecting the null hypothesis H0 (of no spatial autocorrelation) was verified using the permutation method in GeoDa program. According to Anselin (1996), five different scenarios can occur in the LISA analysis on the study area: 1. localities with high values and with similar values of neighbouring units: (high-high), also known as "hot spots", illustrating the scenario of positive spatial autocorrelation; 2. localities with low values and with similar values of neighbouring units: (low-low), also known as "cold spots", illustrating a scenario of positive spatial autocorrelation; 3. localities with high values and with low values of neighbouring units: (high-low), potentially "spatial outliers", symbolising negative spatial autocorrelation; 4. localities with low values and with high values of neighbouring units: (low-high), "spatial outliers" expressing negative spatial autocorrelation; 5. localities with no important local spatial autocorrelation.

As mentioned above, spatial autocorrelation is applicable in several scientific disciplines, but it is mostly used in the field of geography, which is confirmed by works of geographers such as Slavík, Grác and Klobučník (2020), Petrucci and Salvati (2020), Lima et al. (2020), Kim et al. (2019), Netrdova and Nosek (2017), Vojteková et al. (2019) and others.

3. Nitra Region in Slovakia and Europe

The Slovak Republic (Slovakia) is a landlocked country in Central Europe. It has an area of 49,036 km² and a population of 5.4 million (2022). It is bordered by the Czech Republic to the north-west, Austria to the south-west, Poland to the north, Ukraine to the east and Hungary to the south. The Nitra Region is located in the western part of Slovakia and is one of the eight regions of

Slovakia within the administrative division of the country (Fig. 1). Nitra Region borders Hungary to the south, Trenčín Region to the north, Trnava Region to the west and Banská Bystrica Region to the east. According to the territorial administrative division, the Nitra Region is further divided into seven districts: Komárno, Levice, Nitra, Nové Zámky, Šaľa, Topoľčany and Zlaté Moravce. There are 16 towns and 338 rural municipalities. Its area is 6,343.7 km², which represents 12.9% of the total area of Slovakia. At 1,551.1 km², Levice is the largest district in the region, as well as in Slovakia. On the other hand, the smallest district is Šaľa, with an area of 355.9 km². As of 31 December 2022, the population of the Nitra Region was 670,696, which represents 12.4% of the total population of Slovakia. The population density is 106 inhabitants per km². The population density is highest in the Nitra district (189 inhabitants per km²), which is also hosts the regional capital Nitra. The lowest population density is in the district of Levice (70 inhabitants per km²) (Statistical Office of the Slovak Republic, 2023). The southernmost point of Slovakia is located in the municipality of Patince in the Komárno district.

4. Results

For a comprehensive analysis of population ageing in Slovakia, it is necessary to examine this demographic process at different hierarchical levels and to highlight regional disparities. In our study we analyse population ageing at the lowest (i.e., local) level. Several published papers in Slovakia (Mládek & Káčerová 2008; Mládek, Káčerová & Stankovičová 2018; Šprocha et al. 2018; and others) document that the population of Slovakia has been ageing for more than the last two decades and that, since 1989, this ageing has accelerated. For our analysis, we set three time periods (1996–2004, 2005–2013, and 2014–2022). The initial year 1996 is the first year for which municipality-level data are available for the study area, and 2022 is the year of the most recent data. Based on the use of methods that compare different age categories of the population, we have cartographically interpreted and textually evaluated population ageing in the Nitra Region using the method of spatial autocorrelation, including Moran's coefficient of spatial autocorrelation.

Fig. 1. Delimitation of the Nitra Region within Slovakia and Europe
Source: own data processing in ArcGis 10.2.2 (2026)

4.1. Moran's coefficient of spatial autocorrelation of the Nitra Region

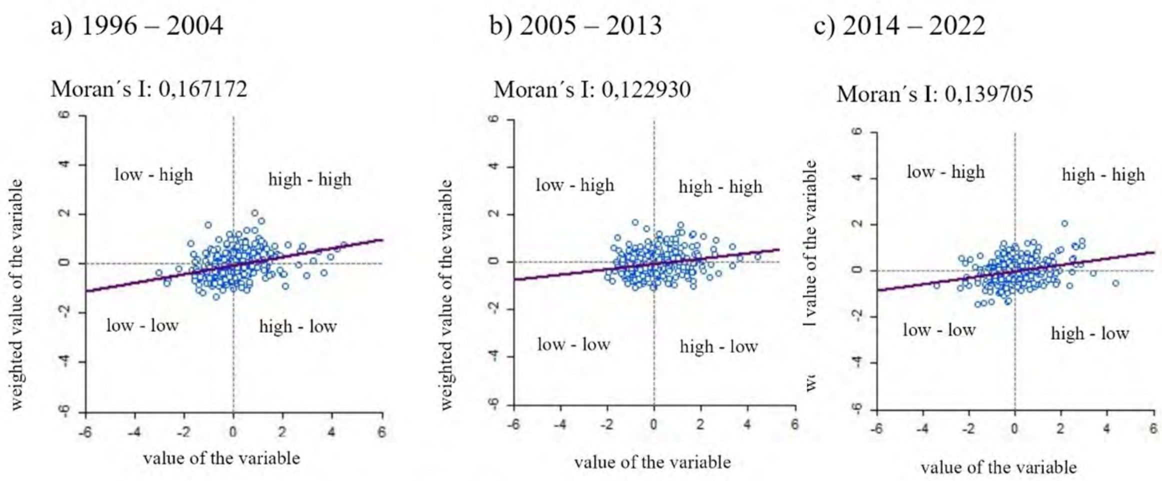
To assess the degree of spatial autocorrelation of observed traits, we used the local Moran's coefficient of spatial autocorrelation, which we calculated using the ArcGIS 10.2.2 program. We tested the null hypothesis H_0, i.e. there is no spatial autocorrelation based on the values of the observed traits of ageing, compared to the alternative hypothesis H_1 that there is spatial autocorrelation based on the values of the observed traits of ageing. Based on the calculations of all examined indicators of ageing for the three observation periods, we found that there is a spatial autocorrelation between the examined indicators, confirming the hypothesis H_1. Based on the above findings, we applied Moran's coefficient to the selected indicator of population ageing – the old-age dependency ratio. The achieved values of Moran's coefficient of spatial autocorrelation *I*, probability *p*-values and Z_I values are presented in Table 1.

Since the *p*-value is less than 0.01 in all observed traits, at the significance level of 0.01, we reject the null hypothesis H_0 and accept the alternative hypothesis H_1 that there is spatial autocorrelation based on the values of observed traits. For all observed traits, we tested the statistical significance of Moran's coefficient of spatial autocorrelation using a Moran scatter plot (Fig. 2). The quadrants in the Moran scatter plot indicate the contribution of each type of spatial dependence in generating the calculated value of the Moran coefficient. Based on Figure 2, the spatial autocorrelation is largely characterised by spatially clustered high values, i.e. high values of the observed variables (the H–H quadrant), and spatially clustered low values, i.e. low values of the observed variables (the L–L quadrant). Membership in the H–L and L–H quadrants indicates spatial "outliers", i.e. locations where the values of observed features were significantly higher or lower recorded compared with neighbouring units.

Table 1. Testing of spatial autocorrelation on example of the old-age dependency ratio in the periods 1996–2004, 2005–2013, and 2014–2021

Old-age dependency ratio	*I*	*p*	Z_I
1996 – 2004	0.167172	0.000	5.352256
2005 – 2013	0.122930	0.000	3.948996
2014 – 2022	0.139705	0.000	4.477179

Source: Statistical Office of the Slovak Republic, 2023, own data processing



Source: ArcGIS 10.2.2, compiled by the author

Fig. 2. The Moran scatter plots of the index of old-age dependency ratio for the years: a) 1996 – 2004, b) 2005 – 2013, c) 2014 – 2022

Source: Statistical Office of the Slovak Republic, 2023, own data processing in ArcGis 10.2.2

4.2. Population ageing in Nitra Region municipalities, expressed by spatial autocorrelation

Since the local Moran's correlation coefficient is statistically significant, as shown on the example of the old-age dependency ratio, we were interested to know which localities (municipalities) express the spatial autocorrelation of the incidence of population ageing in the Nitra Region. We found that, in the first observation period of 1996–2004 (Fig. 3), 56 municipalities of the Nitra Region showed positive autocorrelation (HH, LL), which represents 15.8% of all municipalities of the region. This means that the population in these municipalities is ageing most intensively. In none of the municipalities was the significance of all six analysed indicators confirmed simultaneously (the proportion of people of post-productive age, average age, ageing index, old-age dependency ratio, index of dependency ratio, Billeter´s index). The significance of five indicators was confirmed in eight municipalities, the significance of four indicators in ten municipalities, the significance of three ageing indicators in seven municipalities, and only a maximum of two indicators confirmed population ageing in 31 municipalities. In the first period, the population was ageing most intensively in those municipalities of the Nitra Region where up to five indicators confirmed population ageing. These are four municipalities in the Nitra district, of which the municipalities of Malé Zálužie and Kapince share a common administrative border. They are small municipalities with a steady natural and migratory population decline. In both villages, ageing is expressed by values of Billeter´s index, the proportion of people of post-productive age, and the old-age dependency ratio. The dependency ratio and average age have a lower weight in both municipalities. In the remaining two municipalities in the Nitra district – Dolné Lefantovce and Bádice, which are located in the north-eastern part of the district – up to five indicators proved population ageing. Billeter´s index has the lowest weight and, compared with the other indicators, does not show statistical significance. The situation is similar in the Zlaté Moravce district, namely in the town of Zlaté Moravce and in the municipality of Žitavany. Ageing is also intense in the municipalities of Jabloňovce (Levice district) and Bruty (Nové Zámky district). In these two rural municipalities, ageing is confirmed not only by one indicator, namely the old-age dependency ratio, which testifies to the economic ageing of the population, but by all other monitored indicators. Population ageing is less intense in those municipalities where only four out of six ageing indicators are significant. These are ten municipalities in the Nitra Region that are scattered across the districts of Nitra, Nové Zámky, Topoľčany, Levice and Zlaté Moravce. The most significant indicators are the proportion of people of post-productive age and the old-age dependency ratio, which confirmed ageing of the population in all these municipalities. In the municipalities of Biskupová (Nitra district), Bohunice (Levice district), Trávnica, Šarkan and Leľa (Nové Zámky district), the influence of the indicators of the dependency ratio and average age on population ageing was not confirmed. Average age does not affect population ageing in the municipalities of Vlkas (Nové Zámky district), Domadice (Levice district) and Tovarníky (Topoľčany district), and old-age dependency ratio values are not significant for population ageing in the municipalities of Machulince (Zlaté Moravce district) and Žirany (Nitra district). Seven municipalities of the Nitra Region have a positive autocorrelation in three indicators of ageing, which are mutually significant and which prove population ageing. The most intensive influence is again shown by share of people in post-productive age and the index of old-age dependency ratio; the least intensive influence is shown by the average age and the dependency ratio. The remaining two indicators – the ageing index and average age – confirm population ageing only on average. The municipalities are located in three districts – Nitra, Nové Zámky and Levice. Among the municipalities, two district towns are also represented – Nitra and Nové Zámky. In both district towns, population ageing was not confirmed by the ageing index or by average age. Population ageing was also least confirmed by indicators reflecting economic ageing of the population – i.e., old-age dependency ratio and dependency ratio. The ageing index and Billeter´s index were the indicators that most markedly expressed population ageing in the municipalities of the region (Štitáre, Hontianske Trsťany, Žemliare, Kuraľany, Kět). In the Nitra Region, there are still 31 municipalities with positive autocorrelation, in which at most two indicators are significant and confirm population ageing. In the remaining municipalities, there is a negative autocorrelation, or population ageing is not confirmed.

In the period 2005–2013 (Fig. 4), positive autocorrelation was typical for 43 municipalities in the Nitra Region; all indicators were significant for each other in one municipality – Trávnica in the district of Nové Zámky – all of them showing population ageing. Five out of six indicators confirmed population ageing in eight municipalities, which represents 21% of positively autocorrelated municipalities. In seven municipalities (Kapince, Malý Lapáš and Žitavce in the Nitra district, Lula, Domadice and Kuraľany in the Levice district, Podhájska in the Nové Zámky district), the indicator expressing economic ageing of the population – the dependency ratio – had insignificant evidence of population ageing, and, in one municipality (Radava in the Nové Zámky district), average age was an insignificant indicator that was the least indicative of population ageing. In Kapince municipality, there was no change compared to the previous period, meaning that the population had started to age already in 1996. The population is also ageing less intensively in municipalities where only four out of six ageing indicators are significant. This group of municipalities is the least represented in the region, with five municipalities (Malé Zálužie, Veľké Zálužie and Štitáre in the Nitra district; Pozba

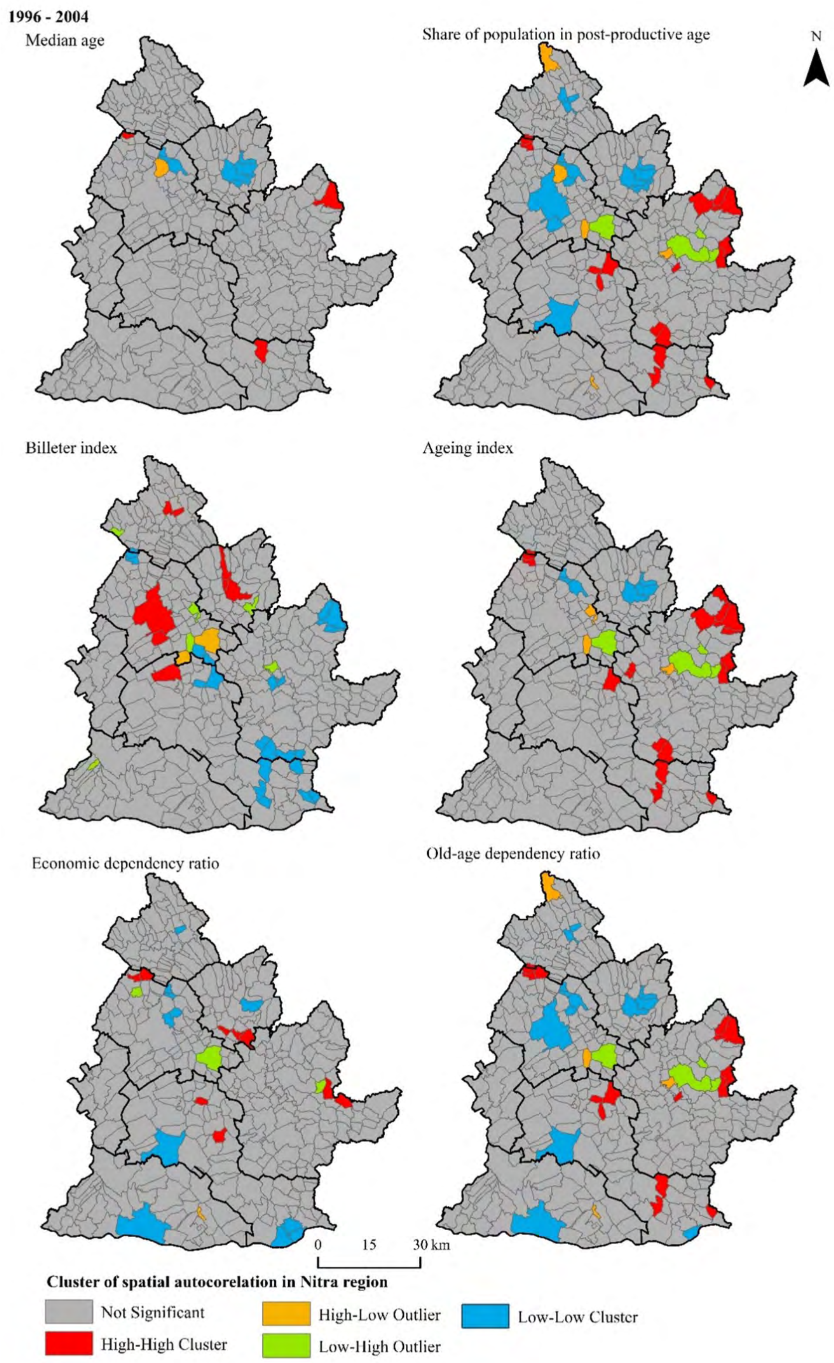


Fig. 3. Spatial autocorrelation of the Nitra Region for the examined indicators of population ageing in the period 1996–2004
Source: Statistical Office of the Slovak Republic, 2023, own data processing in ArcGIS 10.2.2

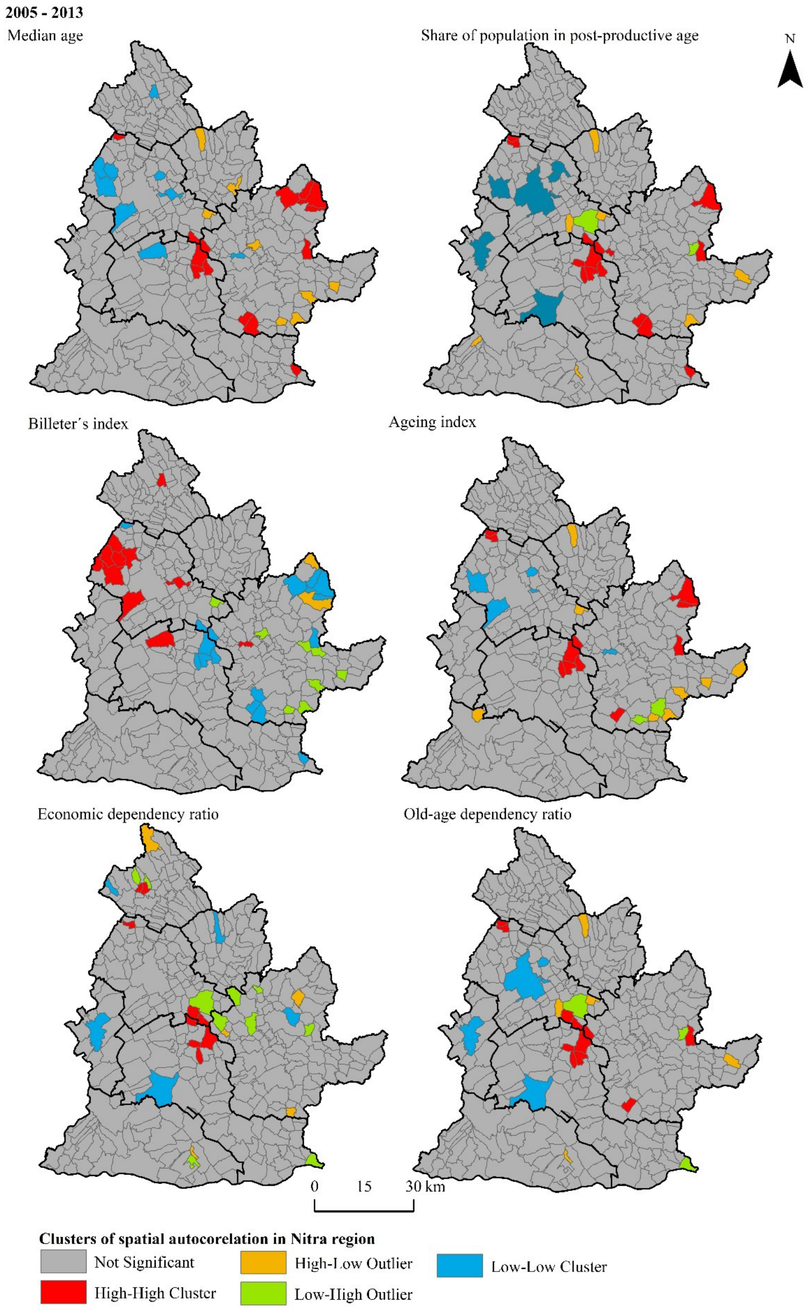


Fig. 4. Spatial autocorrelation of the Nitra Region for the examined indicators of population ageing in the period 2005 – 2013
Source: Statistical Office of the Slovak Republic, 2023, own data processing in ArcGIS 10.2.2

in the Nové Zámky district; and Jabloňovce in the Levice district). In these municipalities, population ageing was most markedly confirmed by the ageing index, the proportion of people of post-productive age, Billeter´s index and average age, whereas population ageing is not influenced at all by the indicators related to the economic ageing of the population. Eight municipalities in the Nitra Region have a positive autocorrelation in three indicators of ageing, and in each municipality the significance of the indicators manifests in different ways. In the municipalities of Cabaj-Čápor (Nitra district), Pečenice and Bajka (Levice district) population ageing was confirmed by almost all indicators except for the indicators reflecting population ageing in the economic sense and the single-component indicator of the proportion of persons in post-productive age. In the municipalities of Keť (Levice district), Leľa and Vlkas (Nové Zámky district) the situation is similar – higher values reflecting ageing were reached by the ageing index and less significant was the share of persons of post-productive age. The situation in the ageing of the population is opposite in the towns of Šaľa and Nové Zámky, where population ageing was mostly confirmed by higher values of the dependency ratio, the old-age dependency ratio and the share of persons of post-productive age. In the Nitra Region, there are another 24 municipalities with a positive autocorrelation, in which there are only two indicators that are significant and reflect population ageing. In the remaining municipalities there is a negative autocorrelation, or population ageing is not confirmed there.

More significant changes in population ageing in the region occurred only in the last reference period 2014–2022 (Fig. 5). There was a positive autocorrela-

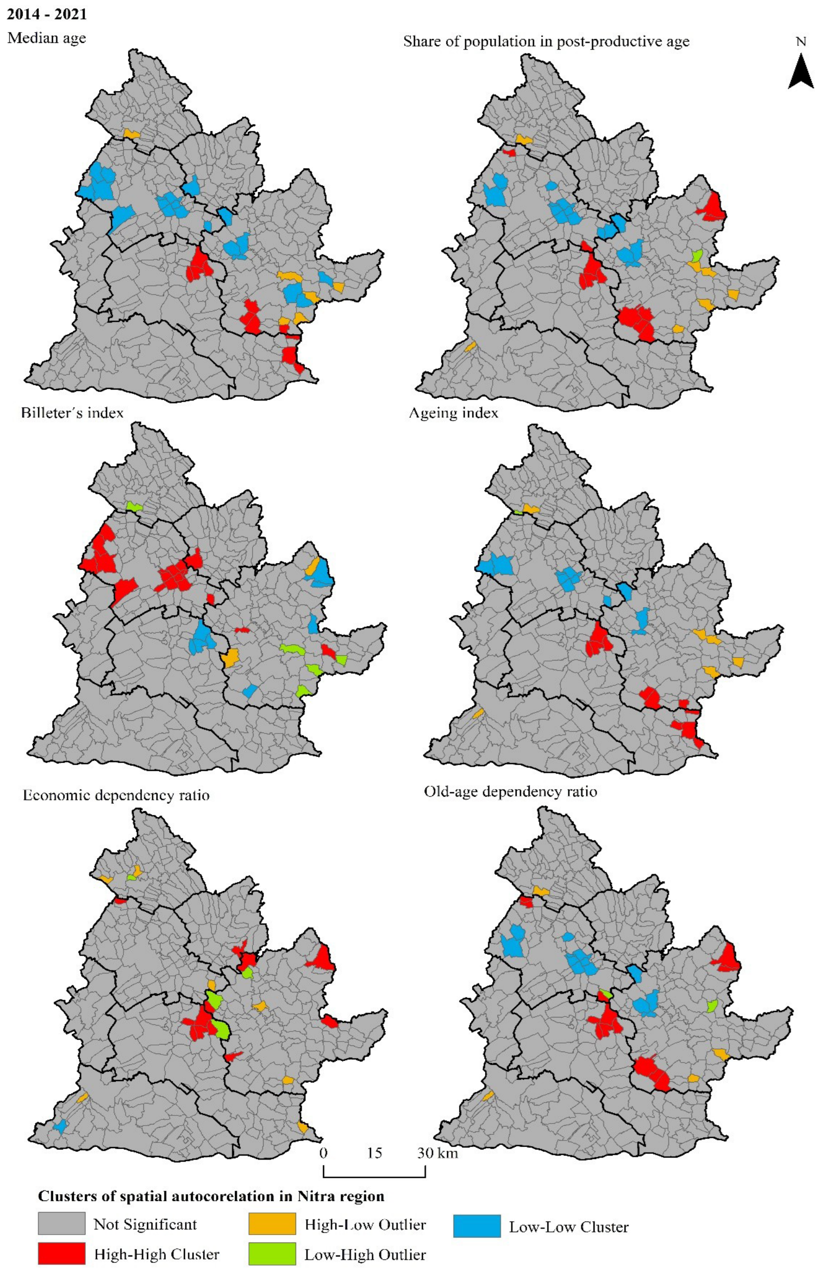


Fig.5. Spatial autocorrelation of the Nitra Region for the examined indicators of population ageing in the period 2014–2022
Source: Statistical Office of the Slovak Republic, 2023, own data processing in ArcGIS 10.2.2

tion in 48 municipalities of the Nitra Region, while all six indicators confirmed population ageing in four municipalities. This shows that population ageing is intensifying compared to the previous period. The municipalities (Trávnica, Radava, Podhájska, Pozba) are located in the northern part of the Nové Zámky district and have common administrative borders. Five ageing indicators are significant in nine municipalities of the Nitra Region; ageing is confirmed only by the dependency ratio, and the old-age dependency ratio is significant in one municipality with low positive autocorrelation (LL). All these municipalities are located in the districts of Nitra and Nové Zámky. The municipalities of Golianovo, Veľký Lapáš, Malý Lapáš, Babindol and Dolné Obdokovce in the Nitra district form a cluster of municipalities with a common administrative boundary with a more pronounced ageing population. Other municipalities are irregularly distributed within the districts of Nitra and Nové Zámky. The situation is similar in municipalities where only four indicators point to population ageing. The indicators that reflect how the population is ageing economically have a stronger impact only in municipalities with low positive autocorrelation (LL). In the case of high positive autocorrelation (HH), the ageing index and the average age have the highest impact in the municipalities of Jabloňovce (Levice district) and Klasov (Nitra district). Only four municipalities in the Nitra Region have positive autocorrelation in three out of six indicators; in other municipalities, only two indicators were significant in the case of positive autocorrelation. Other municipalities showed negative autocorrelation or population ageing was not confirmed.

5. Discussion

The population of European countries has aged considerably in recent decades and is undoubtedly among the oldest in the world. The most important factors are improved mortality rates associated with increasing life expectancy and cohort turnover, with an expected decline in the child component. People of reproductive age are having fewer children, and the overall proportion of children and youth is declining, resulting in a corresponding increase in the proportion of older age groups in the population. Other problems of low fertility in Slovakia and in the whole Central European area are seen in the average age at first birth, which is increasing, and this has been contributed to by a decline in reproductive-age population (especially women). Fertility rates (number of children per woman) are falling, and emigration of the reproductive-age population abroad is increasing. According to the authors Molnár and Koczor-Keul (2013), increasing survival in old age has led to an increase in the proportion of the elderly population. We agree with the experts (Requena et al., 2010), that although the increase in life expectancy is a positive process, it is necessary to improve the quality of life of the elderly while also introducing measures to promote the birth rate in Slovakia. This would increase the share of the child component of the population in the society and gradually increase the number of the working-age population. Our research has confirmed a decrease in the share of the population in the pre-productive age group and a gradual increase in the population in the post-productive age group. Whereas post-productive age persons comprised only 13% of the population in the first reference period (1996–2004), by the most recent reference period (2014–2022) this share had increased to as much as 18%.

According to Šídlo, Šprocha and Ďurček (2020), the youngest countries of Europe include Poland, Slovakia, Ireland, Luxembourg and Cyprus. The oldest states, mainly based on prospective indicators, include the Balkan EU member states, Hungary, and the two Baltic states (Latvia and Lithuania). The predicted trend of population ageing suggests that, by the middle of the 21st century, several northern and western European countries could be among the youngest in Europe, while southern European countries, together with Croatia, Bulgaria and Lithuania, will be the oldest.

Other forecasting studies have indicated that Europe's population will age intensively, as documented in our three assessment periods. Ondačková et al. (2018) examined changes in the age structure of the population in four time periods at the level of the capital cities of the Visegrad Four (V4) countries. The authors found that it is only in the second period, 1985–2000, that there is a fundamental change in the age structure of the population, i.e. its radical ageing. Also, according to Káčerová and Nováková (2016), during the period 1980–2012, the age structures of the population of the V4 countries changed significantly in the direction of intensive population ageing. This fact is particularly evidenced by increases in the average age of the assessed populations. At the level of the European countries, the above-mentioned issue was also assessed by Káčerová, Ondačková and Mládek (2012, 2014), Scherbov and Sanderson (2020), Goldstein, Sobotka and Jasilioniene (2009), and others. The increase in the median age of the population was also relevant in our research. Whereas in the period 1996–2004 the median age in the region was 36 years, it rose to 43 years in the period 2014–2022. The projections of population ageing to the level of the V4 countries were also addressed by Repaská (2022), who asserted that the change in the age structure of the population is reflected in an increasing share of older persons in conjunction with a decreasing share of persons of pre-productive and productive age in the total population. Although there are currently two persons aged under 14 for every person aged 65+, this ratio will be reversed by 2050. The ageing situation will continue to worsen by 2050, and ageing will intensify. Its increase will be evident in every NUTS 2 region of the V4 countries.

The results of our research using spatial autocorrelation confirmed the views of the above and other authors dealing with the issue under study. According to Šprocha et al. (2019), from a regional point of view, the south-west and west of Slovakia, the central part of the central Slovak region and the extreme east region are characterised by a higher median age, a high ageing index, a higher proportion of working population and, conversely, a lower proportion of children. The north of central Slovakia and the eastern Slovakia region, with the exception of the extreme east, are characterised by a lower average age and ageing index, a higher proportion of pre-productive population and a lower dependency ratio. Migration to the capital city Bratislava has contributed significantly to the overall population growth in the western part of Slovakia; but in northern and eastern Slovakia, population growth was more strongly influenced by natural movement (Šprocha et al., 2019). Šprocha and Ďurček (2019) identified a younger population in several districts in the east of Slovakia, as well as in several districts in the north. On the other hand, several regions in western and central Slovakia can be classified as among the oldest according to the retrospective and prospective indicators examined. We agree with Káčerová and Bleha (2007) that, despite ageing having been particularly rapid in Slovakia, especially in recent years, the increase in the number and (especially) the proportion of older persons will gradually continue in other European countries as well. Although Slovakia has a relatively young population for Europe, changes in the age structure in the last two decades show that the ageing process is gaining momentum. Bleha, Šprocha and Vaňo (2014) found that, by 2050, the population of Slovakia will decrease by 315,000 people (−5.8%) and increase in average age by seven years (1.5%).

The results of our study focused on a western region of Slovakia that has long had one of the oldest populations among the country's regions. They confirmed the more intensive population ageing that is evident from previous studies. At the local level, the region's population ageing was confirmed by increasing values of the monitored indicators, in addition to the median age and the share of the population in the post-productive age, and other more complex measures of ageing, such as ageing index, old-age dependency ratio, economic dependency ratio and Billeter´s index. Ageing processes were evident in all the periods under review, with a stronger trend in the last period, 2014–22. In the first two periods under review, ageing is documented by a higher share of population of post-productive age, a higher median age and a higher value of the ageing index. In the last period, we also detected signs of economic population ageing.

We agree with Vaňo, Jurčová and Mészáros (2002) and Mierzejewska and Parysek (2013) that the expected demographic development related to an ageing population will bring many important changes. Society must prepare not only for an increasing proportion of elderly and old people, but also for integration of larger numbers of foreigners (often from culturally very different backgrounds) and increased tensions in intergenerational relations. New approaches in population, family, social, economic and migration policies will be needed to cope with this situation. A similar view is presented in the study by Rees et al. (2012), who discussed the decline in the labour force due to an ageing population. They assessed that 55–70% of European regions will undergo a 10% or greater decline in labour force in the coming years. In most regions of Eastern Europe, the labour force may decline by more than 30%. The decline in labour force in Slovakia has been confirmed by our study, and we found a gradual increase in the burden placed on the productive population by the non-productive population over the periods studied, which is reflected in a decline in population in the productive age group (15–64) and an increase in population in the post-productive age group (65+). In the first reference period 1996–2004, the old-age dependency ratio was 19%; in the last reference period 2014–22, this increased to 25%.

6. Conclusions

In the article, we evaluated population ageing in the model territory of Slovakia in the municipalities of the Nitra Region by means of spatial autocorrelation. This statistical method has not previously been used in works by geographers to evaluate this demographic process. By statistical method, we confirmed intensive population ageing at the local level, finding that all the evaluated indicators were significant. The statistical method applied to the model territory of Slovakia brings new methodological procedures for the study of population ageing; it is beneficial not only methodologically but also professionally for other experts dealing with the issue under study. Our study provides important insights into population ageing in Slovakia in the three study periods 1996–2004, 2005–13 and 2014–2022, representing a research period of almost 30 years. This is a large time period, focused on surveying the ageing of Slovakia's population in a model area of 354 municipalities of the Nitra Region, which is the oldest in Slovakia in terms of indicators for measuring long-term ageing. In the model territory, we presented the direction of ageing of the Slovak population.

The model territory of the Nitra Region has long been one of the oldest regions in Slovakia in terms of the proportion of seniors and the results of the examined indicators. It was confirmed that population ageing is more intensive in the region than in Slovakia as a whole. The values of the monitored indicators measuring the population ageing in the region gradually increased in the individual monitored periods. Based on the results of spatial autocorrelation, we can conclude that the population is ageing in individual municipalities of the region. In the first observed period (1996–2004) and the second period (2005–2013), population ageing was most strongly reflected in the indicators of the share of the population of post-productive age and the average age, which were mutually significant and exhibited positive autocorrelation. The other monitored indicators showed lower basic index values. We found that ageing was more dynamic and confirmed by more indicators confirmed in the last period 2014–2022, in which all six indicators were significant in several municipalities. This means that the population is ageing more significantly here. The indicators reflecting the economic population ageing, which had low weight in the first two periods compared with the other indicators, also started to show higher values. In the coming years, we can expect an increasing number of seniors not only in Nitra Region, but in the whole of Slovakia, as well as increasing values of several indicators measuring the ageing process. Increasing values of indicators measuring economic population ageing (old-age dependency ratio and economic dependency ratio) will bring a further decline in the number of persons on the labour market and an ageing workforce.

The results of our study confirmed that Slovakia is undergoing intense population ageing, which will affect the entire functioning of society, e.g. the labour market, healthcare, social services, the pension system, etc. The study confirmed that the unequal age structure of the population, especially the very low birth rate and fertility of women of reproductive age, contribute to the population ageing. This means that the generation born in the 1960s and 1970s are now aged over 55 and will gradually retire. At younger ages, on the other hand, the less abundant generation born in the 1980s and 1990s will not be adequately replaced in the labour market in the future.

Government policies in Europe need to adapt to the fact that each additional year of age is associated with a higher remaining life expectancy and a lower risk of mortality. The significant improvement in mortality rates that has taken place over the last century has led to an increase in life expectancy and in the elderly population. However, if residents live longer, it is also expected that they will work longer. Therefore, several countries are raising the retirement age. Linking the retirement age to life expectancy will stabilise the number of years spent in retirement for future generations of pensioners. Therefore, countries are gradually developing instruments to promote healthy and active ageing in order to increase employment. Healthy lifestyles and physical activity reduce chronic diseases and increase quality of life. For the most part, programmes aim to prolong the working lives of seniors through engagement in social activities such as older adult education, third-age universities, intergenerational social activities, physical group exercise, and involving seniors in volunteer activities. In the countries, this constant increase in elderly populations and declining birth rates, which is heavily pressuring healthcare and pension systems, has prompted nationwide efforts to focus on these issues. In Slovakia, the statutory retirement age is not fixed: it depends on the year of birth, while for women it also depends on the number of children, and for younger generations it additionally depends on life expectancy. At present, it ranges between 63 and 64. In the Czech Republic, the situation is similar; currently, the retirement age ranges from 64 to 65. In Hungary, the retirement age is the same for both men and women and is set at 65. In Poland, the retirement age differs by gender: 65 for men and 60 for women. However, these measures will mean that, for example, Poland will have the lowest retirement age among the V4 countries, but at the same time, the pension will not be even a quarter of the average wage (Ministry of Finance of the Slovak Republic, 2022). It is therefore essential to improve the quality of life of the elderly, to ensure their active participation in the labour market and, at the same time, to introduce measures promoting fertility. In recent decades, countries have introduced various pro-natalist and pro-family measures to encourage fertility (cash benefits: support for young families through bridal loans, increases in maternity and parental allowances, increases in child allowances, various concessions in the tax system, a system of social guarantees to encourage people to marry and start families, extending maternity leave, etc.).

The issue of population ageing is very broad and serious, but the main topic of public debate remains the choice of pension system, the determination of the retirement age, and the financial burden that pension payments place on the state budget. The main problem is the ratio of economically active to inactive population and the capacity of the economy to provide sufficient resources for the economically inactive part of the population. For society to cope long-term with demographic change, all relevant economic and non-economic factors should be taken into account. These may include the health of the elderly, living standards, security or quality of care. In our opinion, population ageing is a very complex demographic process, the importance and consequences (economic, health and social) of which will continue to grow, and therefore our further research will be directed towards the development of ageing in Slovakia and its regions and the impact of population ageing on society.

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