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ORIGINAL PAPER

GEOSCAPE

Spatial variability of breast cancer in Slovakia examined by means of spatial autocorrelation method

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Abstract

Cancer is one of the leading causes of death in the Slovak population. Breast cancer, one of the most prevalent oncological diseases worldwide, is the primary cause of female mortality. Geographic analyses of the spatial distribution of breast cancer are relatively scarce in Slovak literature. In this article, we assume that, at the local and regional levels in Slovakia, breast cancer exhibits varying frequency, incidence rates, and spatial disparities. We evaluated the spatial incidence patterns of breast cancer in Slovakia at the municipal level using spatial autocorrelation analyses, specifically local Moran's I and Anselin's local Moran's statistics. Our study utilized databases on female-specific mortality rates due to breast cancer, calculated per 1,000 women aged 15 and older, covering the period from 2009 to 2021. During the study period, breast cancer incidence among women showed a statistically significant positive global Moran's index, indicating a tendency toward clustering. According to Anselin's local Moran's I analyses, significant clusters of breast cancer were primarily identified in the western and central regions of Slovakia.

Highlights for public administration, management and planning:

- Breast cancer dominates the structure of cancer-related mortality in women and has shown an increasing trend in Slovakia.
- Mortality rates from breast cancer in Slovakia vary spatially, with the highest values primarily in the western region.
- Identifying high-risk regions based on selected breast cancer indicators is crucial for establishing targeted intervention measures.
- The findings of this study have multiple applications, including their use in annual reports and assisting relevant agencies in implementing effective cancer control and prevention strategies.

Keywords

Slovakia,
Breast cancer,
Medical geography,
Spatial autocorrelation,
Spatial disparities

Received:
18 April 2024
Received in revised form:
1 March 2024
Accepted:
20 March 2025

1 Introduction

The European Union countries are currently going through changes in terms of mortality, which are specific for the respective countries. However, they have a feature in common, which is their dominant position in cancer mortality rate. As stated by Dalmartello et al. (2022) in this context, European Union assumed almost 5.4 million (12 %) deaths due to cancer in the period of 1989 – 2022. In 2022, cancer mortality was to reach 369,000 deaths, which would represent a 23 % share in the total mortality. According to cancer development predictions, in 2023 the situation in the EU is as follows. Malvezzi et al. (2023) estimate 6.5 % reduction in cancer mortality rate for men and 3.7 % reduction for women between 2018 and 2023, which can be considered a positive trend. In some of the cancer types, such breast, colon, lung cancers, we see a growing trend, which is one of the aspects characterising this disease. When analysing this phenomenon, we consider important the spatial differences in the respective regions of the world, as well as the age structure

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of the population (Trama et al. 2022; Stapleton et al. 2018; Bosakova et al. 2018; Autier et al. 2010). After having stabilised the mortality and morbidity due to infectious diseases, the Slovak society became more interested in circulatory system and cancer diseases thanks to the implementation of the National Cardiovascular and Oncological Programme in the 80s (Baráková et al. 2004).

Cancer is the second most frequent cause of death in the Slovak population. At the beginning of the monitored period in 2009, 11,831 inhabitants in total died of cancer. By 2020, there was a significant increase in deaths (increase by 2,024 deaths, which is 17.1 %). This could be affected by the COVID-19 pandemics, which contributed significantly to the total mortality. At the same time, the records show the highest number of deaths due to cancer at the level of 13,805. In 2021, there was a reduction by 1,062 deaths compared to 2020; however, the total mortality was still higher than in 2009. The mortality increased by 8.1 % (962 deaths). During the monitored period, men were dying of cancer more frequently than women. This is documented by the number of deceased males and females. In 2009, at the beginning of the period, 6,708 men and 5,123 women died. By the end of 2021, we saw and increase in the deceased men (7,060) and women (5,733). When it comes to female mortality due to oncological diseases, Slovakia belongs to the European states with average mortality. However, this cannot be said of Slovak men, because the male mortality due to cancer in Slovakia is one of the highest among the countries of Europe. The most frequent types of cancer causing the deaths of Slovak population from 2009 to 2021 were lung cancer, breast cancer, colorectal cancer, pancreatic cancer). For females, breast cancer was dominant, whereas for men, it was the lung cancer.

In line with the above, the aim of the paper is to analyse and evaluate the breast cancer mortality in Slovakia in the period of 2009 to 2021 at the local level. By means of the spatial autocorrelation method, we want to point out the spatial differentiation of the selected disease at the local level. We apply this method to the lowest local level of municipalities and by doing so, we can show and determine distortions. These can be observed when analysing similar variables at the level of larger territorial spatial units in Slovakia, i.e. districts or regions. This phenomenon can be evaluated in terms of time and spatial aspects. At the same time, we will attempt to identify regions highlighted based on the homogeneity criterion, by means of the specific mortality rate due to breast cancer calculated per 1,000 women aged 15+ in Slovakia. In relation to the issue discussed in the paper, we ask the following research question: Is breast cancer in Slovakia spatially differentiated or is it only concentrated in some of the regions?

2 Theoretical framework

Breast cancer is one of the most frequent oncological diseases in the world. In the developed countries, it is the second most frequent cause of death after lung cancer, and it represents more than 30 % of newly occurring types of cancer incurred by women (Ferlay et al. 2020). The International Agency for Research on Cancer (IARC) statistics show that out of the total number of 19.3 million new female cancer patients in 2020, breast cancer was the most frequent cancer type for women. Estimates state that 2.3 million new breast cancer cases represent almost 12 % of the overall number of newly diagnosed cases (Sung et al. 2021). Breast carcinoma is globally the most frequently diagnosed malignant disease, which is, at the same time, the most frequent cause of female deaths due to oncological diseases.

Breast cancer remains the most frequent cause of female deaths due to oncological diseases in Slovakia. Mortality due to breast cancer is still high in Slovakia and it exceeds the average of the European Union by more than 20 %. In spite of the fact that preventive programmes and campaigns help raising the awareness and promote early diagnostics, Slovakia is lagging behind the European Union. It concerns mainly two indicators, screening participation and early diagnostics rate.

In Slovakia and its regions, oncological diseases represent the second most significant group of mortality causes after cardiovascular diseases in terms of incidence and the impact on the overall mortality rate (Dokupilová & Šprocha 2023). In terms of incidence, we can identify a slightly growing trend from the beginning of the 21st century (Šprocha 2022). Research of spatial disparities of cancer incidence is a relatively new subject of interest in Slovakia, focusing on the specifics in relation to risk factors. Káčerová & Šprocha (2020) analyse this phenomenon in relation to the age structure and higher risk of death of elderly people due to this cause. Spatial aspect of the selected types of oncological diseases in the Central Europe has been researched by several authors (Vilinová 2020; Vilinová et al. 2017; Kažmer & Križan 2010; Palencia et al. 2020; Hübelová 2014). In addition, Tomášek & Tomášková (2009) are addressing the issue of mapping in high resolution, present-

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ing the most frequently applied models in the field of spatial epidemiology. According to Šprocha (2021), the specific circumstances of the pandemic year of 2020 significantly affected and, to a certain extent, changed the evolution of mortality rate in Slovakia as we know it. COVID-19 itself had a direct impact on one hand, as it was significantly reducing the life time, however, on the other hand we can assume indirect effects as well, considering the atypical year-on-year evolution in some of the cardiovascular system diseases. These effects were not visible in cancer mortality.

Recently, we have witnessed a shift in the subject of research on these issues from national and regional spatial level to intra-regional and local level in the international research literature. The research of spatial disparities of breast cancer mortality rate is relatively well elaborated in the international literature. Most of the studies were focusing on the observation of disparities in breast cancer mortality rate with respect to spatial disparities (Khosla et al. 2023; Schulz et al. 2022; Mobley et al. 2021; Froelicher et al. 2021; Scott et al. 2017; Basavegowda et al. 2016). In addition to the spatial aspect, the research focuses on the factors influencing occurrence of this diseases to a certain extent.

According to IARC WHO, the main risk factors affecting breast cancer are the following. Female gender – although this cancer can affect males, this type of cancer is more frequently affecting females. Women have 100 times higher risk than men. Older age – the probability of the breast cancer is increasing with age. Females past the age of 55 face a higher risk of invasive carcinoma. Genetic predisposition – it is estimated that 5 – 10 % of carcinomas are caused by genetic mutations transferred from the parent to offspring. It is mainly the genetic mutation in genes BRCA1 and BRCA2. Positive family anamnesis – women with a first-degree relative (mother, sister, daughter) suffering from breast cancer face the risk almost twice as high as the women without any positive family anamnesis. If there are two first-degree relatives, the risk is approximately three times as high.

Socioeconomic factors present a risk factor in the development of breast cancer (Lundqvist et al. 2016). According to Coughlin (2019), these factors have a significant impact on the occurrence of this disease. In all race groups, there is a tendency of positive correlation between the cancer and socioeconomic standing. On the other hand, low socioeconomic standing is related to a higher risk of aggressive breast carcinoma, as well as to late diagnostics and worse experiencing of the disease. There are well-documented differences in the experiencing of the breast cancer based on the socioeconomic standing, race, education, poverty, health insurance availability, and preventive care. In addition to socioeconomic factors, we could also focus our attention on other factors, such as access to healthcare, lifestyle, dietary habits, ethnic origin, family anamnesis, age, reproduction factors, physical activity, and hormonal treatment. The above determinants can significantly affect the risk of breast cancer occurrence. Detailed view on some socioeconomic factors confirmed adverse influence on the development of this oncological disease. For example, poor women have the breast cancer diagnosed in its late stages and their experience throughout the disease is worse. In this social class, it is the consequence of inadequate health insurance but also of poor access to healthcare. Numerous studies were researching the relation between breast cancer and the socioeconomic standing through selected indicators, such as poverty, income, and education (Kish et al. 2014; Feinglass et al. 2015).

Education is a significant socioeconomic factor affecting breast tumour mortality rate. Examples can be found in the studies from the USA (Barcelo et al. 2021), England (Rashid et al. 2023), and an international study (Mackenbach et al. 2017). For example, in the cohort study, Strand et al. (2005) found that there is a higher mortality due to breast tumour among the Norwegian women with higher education than among those with lower education. Al-Rammahy et al. (2024) studied the differences in the cancer occurrence, diagnostics stage, and survival rate in the respective districts in relation to the differences in education levels in Oslo in Norway. Positive association between the education and mortality due to breast cancer was demonstrated in the research from other countries, as well. In Belgium, for example, there were significant differences in breast cancer occurrence, the share of mortality among other causes, and specific mortality 5 years after the disease had been diagnosed according to the education levels. The results of the study show higher occurrence of breast cancer among women with higher education (Gotink et al. 2024). Cancer epidemiology is increasingly recognising the impact of socioeconomic standing (SES) on the development of this disease. The impact is seen in the occurrence of breast cancer and in the mortality. We point to the studies elaborated in other European countries, namely Denmark and Spain, as examples. We observe a different trend between the occurrence of breast cancer and mortality, which reflects a different socioeconomic breakdown of new cases of breast cancer and deaths due to breast cancer (Danø et al. 2003; Pedraza-Flechas et al. 2020). Some studies also mention relation and association of higher breast cancer occurrence with the so-called western lifestyle (life westernisation). These are, for example, the studies of Youlden et al. (2012), DeSantis et al. (2015), Pfeiffer et al. (2018), Lei et al. (2021). Similarly, they also emphasise other factors (such as sedentary occupation, lack of physical activity, unhealthy dietary style, first pregnancy at an older age, lower number of childbirths, etc.) which increase the risk of this disease. Starting with the nineties of the last century, significant changes occurred in the clinical manifestation and coping with breast cancer as a result of mammographic screening, provision of effective hormonal therapies, chemotherapies, progress in radiotherapy and surgery medicine. According to Barclay et al. (2024-08), changes in the occurrence of breast cancer among the women in the United Kingdom significantly reflect the success of screening programmes, because they are provided more often. It decreases synchronously with the age of eligibility to such programmes. The results of the research provide evidence that the women's overall experiencing of the breast cancer has improved between 2020 and 2021. It reflects the success of screening programmes, early diagnostics, and improvement in treatment. Breast cancer is also affected by genetic and environmental factors. Targeted prevention strategies against these risk factors, such as the group of environmental factors, should be always adopted in advance. It is a diagnosis that goes through a process of several levels and the pathogenesis of this disease has not been adequately clarified yet (Xia et al. 2022). Some studies are focusing on documenting the association of this disease with the quality of the environment, which could be included in the group of environmental factors. As an example, we offer the articles by authors who studied the topic in the context of air pollution (Burwell et al. 2023; Amadou et al. 2023). The degree of development of the countries is considered yet another determinant, which is associated with the development of this diseases in various studies. For example, Sung et al. (2021) claim that the occurrence of breast cancer is high in the developed countries. Almost a half of breast cancer cases and more than a half of deaths happen in the developing countries. Considering the financial burden in the developing countries, clinical examination of the breast is an effective way of diagnosing breast cancer at an early stage. Breast cancer is a disease that can be prevented and in the developed countries, there are adequate medical resources available, which can protect the population from this disease, such as mammographic examination. Even though not all risk factors have been definitely confirmed by studies (e.g. the impact of dietary habits is not clear), they are considered as potentially related to the occurrence of this disease.

3 Methodology

Based on the nature of available data and the applied analytical approach, the paper belongs to retrospective analytical studies in terms of methodology. Such studies are typical for spatial-oriented area, but they are also an important part of the epidemiological research.

For the purposes of the analysis, we used recalculated specific female mortality rates due to breast cancer. We will use the specific mortality rate due to breast cancer calculated per 1000 women aged 15+. Considering the territorial nature of the published data, the basic regional unit selected is the village. The respective analytical perspective was applied separately for four time periods (2009–2012, 2013–2016, 2017–2021, and 2009–2021).

The monitored periods were divided in such a way as to provide comparable time intervals (except for the last one, which includes summary assessment). The chosen system of assessment periods monitors natural chronological continuance. Every period represents a certain time section which can be easily interpreted. Such division allows gradual assessment of the development throughout the whole monitored period. The division of the periods was designed to include comparable time range in every time period to ensure consistency in the assessment.

Spatial autocorrelation is relatively frequently used in professional research. In the 1940s, Cruickshank highlighted the existence of positive spatial autocorrelation in the relative cancer mortality rate in England and Wales (Cliff et al. 2008). Identifying clusters of districts with statistically higher and lower mortality rates opened and opportunity to focus the research on the respective areas. At the same time, there was an effort to detect the effects of local environmental factors contributing to higher or lower cancer mortality rates. For this reason, spatial analyses of cancer data are currently often used in the applied practice globally. This is documented by the work of Wang & Wan (2022), Wang et al. (2017), Mahdavifar et al. (2016), Al-Ahmadi & Al-Zahrani (2013). According to Boscoe et al. (2004), spatial analyses are used mainly to know the relationship between geography and health. Spatial autocorrelation is one of such methods. This method is applied to breast cancer cases byAl-Hashimi & M. Nori Mahmood (2021), Zhou et al. (2015), Vieira et al. (2008). We will use the spatial autocorrelation method to evaluate the specific female mortality rate due to breast cancer in Slovakia. We will perform the analyses for four time periods (2009–2012, 2013–2016, 2017–2021, and 2009–2021). The respective data were processed by means of mathematical methods and visualised by means of cartographic methods and ArcGIS software. For the purpose of evaluating the prevalence of the phenomenon in question and its subsequent comparison with other geographic entities, relative rates evaluated in the context of time and space were used in the paper. As the basis for the processed data, we used the data provided by the Statistical Office. If similar phenomena or attributes occur closer in the space, it is positive spatial autocorrelation; if there are clusters of significantly different values, it is negative spatial autocorrelation. If the data are localised in the space in such a way that close values are not related in any way, the analysed values are statistically insignificant. In the context of applied methodology, the statistical methods that are commonly used for continual data are the Moran's index and Geary's coefficient. According to Odland (1988), effectiveness of the Moran's index is usually a little better than that of Geary's coefficient. Different from the local Moran's statistics, Geary's coefficient only assesses the positive spatial autocorrelation; therefore we analysed the variable by means of Moran's index in the paper. The following is true for the Moran's index:

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

The values of the Moran's index (I) move along the scale – 1 (perfectly scattered) to + 1 (absolutely correlating). The closer the I value is to 1, the more positive spatial autocorrelation is indicated; the closer the I value is to -1, the more negative spatial autocorrelation is indicated. There can be various degrees of spatial autocorrelation in the same data set; there can be even the positive and negative autocorrelation in the same data set at the same time. In the global measure, the Moran's test examines if there is a spatial autocorrelation for the respective set of regions or territories. Further development shifted the mentioned global spatial autocorrelation test to the series of local indicators called LISA (Local Indicators of Spatial Association) for the detection of local clusters of positive and negative association developed by Anselin. According to Anselin (1995), there can be five different scenarios within LISA.

1. Locations with high values and similar neighbours: (high–high), also known as "hot spots", depicting the scenario of positive spatial autocorrelation,
2. Locations with low values and similar neighbours: (low–low), also known as "cold spots", also depicting the scenario of positive spatial autocorrelation,
3. Locations with high values and neighbours with low values: (high–low), potential "spatial outliers", i.e. potential spatial outlying values symbolising negative spatial autocorrelation,
4. Locations with low values and neighbours with high values: (low–high), again "spatial outliers", expressing negative spatial autocorrelation,
5. Places with no significant local spatial autocorrelation.

Moran's index and Anselin's statistics are the key tools in spatial disparity analysis, as they allow identifying global patterns, as well as local anomalies. These methods provide a better understanding of where the problems are concentrated and help plan the intervention methods to resolve the problems more effectively. In the area of public health, for example, they can localize the areas with high rate of diseases (such as cancer, cardiovascular diseases, diabetes). Identifying problematic regions is important for effective intervention in the future. Before analysing the spatial autocorrelation, it was necessary to create a spatial weighting scheme, which greatly affects the final values of autocorrelation statistics in terms of methodology. To calculate the weighting scheme, co-ordinates of the municipalities were used as related to the co-ordinates system S-JTSK. In our case, the weighting scheme is generated by means of criteria based on the neighborhood, specifically the "Queen" type neighborhood, where the critical value is not specified, and the contiguity is defined by one common point on the boundary of two spatial units. It is important to emphasise that the size of the Moran's I criterion does not indicate statistical significance. Statistical significance of calculated values rejecting zero hypothesis about non-existent spatial autocorrelation was verified by means of permutation method within the GeoDa programme, where all values are considered statistically significant at significance level 1 %.

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Permutation method is an important tool in GeoDa for the testing of spatial hypothesis and for the discovering of patterns in geographic data. The number of permutations used in an analysis depends on the desired accuracy of the result and computation possibilities. In a software such as GeoDa, 999 permutations are standardly used, which is considered sufficient to acquire reliable and accurate p-values. With 999 permutations, the minimum possible p-value is 0.001, which provides a high level of accuracy when testing statistical significance.
To analyse the detection of spatial clusters, we used the local version of Moran's I criterion, which defines the level of autocorrelation of the spatial statistical quantity between a given point in the space and its surroundings. The respective indicator is suitable to localise the units with relevantly high (i.e. above-average) or low (i.e. below-average) values (the so-called positive spatial autocorrelation) or sudden level breaks in the spatial distribution of the phenomenon (negative spatial distribution). The statistical interference of all three applied indicators (general G-statistics, Moran's I criterion, as well as local Moran's I) is based on the Z-statistics concept calculation. The analysis of the spatial clustering and detection of spatial clusters is defined as follows:

Moran´s I:

$$I = \frac{N}{\sum\limits_{ij}^{NN} w_{i,j}} \frac{\sum\limits_{ij}^{NN} w_{i,j}\left(X_i - \bar{X}\right)\left(X_j - \bar{X}\right)}{\left(X_i - \bar{X}\right)^2} \quad (2)$$

$$i, j = 1, ..., N = 57; ij$$

Local Moran´s

$$I_i = \frac{X_i - \bar{X}}{s_i^2} \sum_{j}^{N} w_{i,j}\left(X_{ij} - \bar{X}\right) \quad (3)$$

$$S_i^2 = \frac{\sum_1^N \left(X_j - \bar{X}^2\right.}{N-1} - \bar{X}^2 \quad (4)$$

$$i, j1, \ldots, N = 57; i \neq j$$

Getis-Ord

$$G = \frac{\sum_{ij}^{NN} \sum_{i,j} X_i X_j}{\sum_{ij}^{NN} X_i X_j} \quad (5)$$

$$i, j = 1, \ldots, N = 57; i \neq j$$

4 Results

Throughout the whole monitored period of 2009–2021, breast carcinoma was the most frequently diagnosed oncological disease among the women in Slovakia. Every year, there are about 3,300 cases diagnosed and more than 1,000 deaths of this diseases recorded. Incidence, i.e. occurrence of this disease, increases after 40 years of age when more than 90 % of the cases are diagnosed. Among women aged 30–39, there are more than 130 cases diagnosed a year. Almost 20 % of cases are diagnosed in clinical stages III and IV, i.e. in locally advanced and metastatic stage when the prognosis is less favourable for the patients in most of the cases. In 2013 and 2014, every third patient was diagnosed in the 1st clinical stage of the disease, which is optimistic. At the beginning of the millennium, it was approximately every fourth patient (Berta et al., 2024).
During the monitored period of 2009–2021, mortality due to breast cancer in Slovakia was developing with an increasing trend, except for the year of 2014. The absolute number of people deceased with this diagnosis is documented in Fig. 1A. In total, 12982 women died of this disease. Between 2009 and 2021, the gross mortality rate increased from 26.8 ‰ in 2009 to 36.0 ‰ in 2021.
This increase indicates aggravation of the situation, although there were some variations between the years. The data show increasing severity of the breast cancer issue in Slovakia. Although there were some reductions in some years, the long-term trend indicates the need for more intensive preventive measures and the need for improvements in the approach to treatment. A significant increase in the breast cancer mortality rate was observed between 2009 and 2013. After the increases in mortality in the previous years, slight reductions were seen in 2014 and 2019. After 2017, the values have been relatively stable, without any dramatic changes (Fig. 1B).

4.1 Analysis of the spatial autocorrelation breast cancer in Slovakia

The use of spatially referential data on breast cancer female mortality in the municipalities of Slovakia offers the understanding of spatial-analytical relations in interest. By means of the spatial autocorrelation method, clusters of regions with respect to the studied indicator can be defined. The LISA method provides more accurate and detailed information about spatial autocorrelation than the indices frequently used for this spatial analysis within

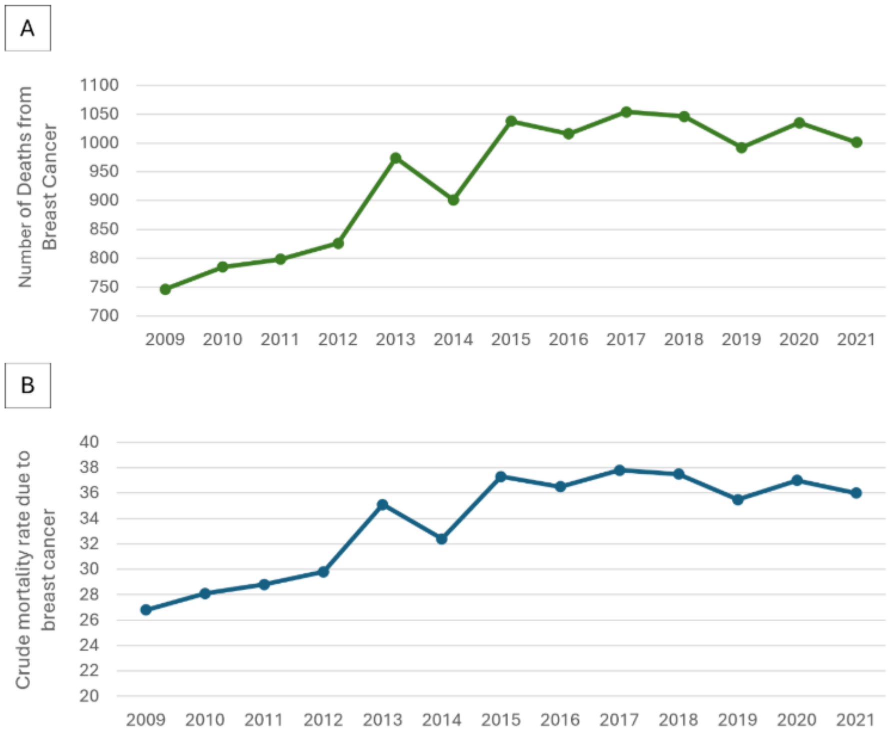

Fig. 1 A Trend of breast cancer mortality in Slovakia (2009-2021) (Statistical office of the Slovak Republic (DATAcube) 2022; own work). B – Trend of crude mortality rate due to breast cancer in Slovakia (2009-2021) (Statistical office of the Slovak Republic (DATAcube) 2022; own work)

the studied territory, and it is a significant specific addition to the global analysis. Identifying and introducing correct variables in space and time can reveal micro-regional differentiation of the studied territory. Based on the differentiation results, we can deduce the consequences of the studied phenomenon (Slavík et al. 2011). When evaluating the spatial autocorrelation of breast cancer in the studied periods of 2009–2012, 2013–2016, 2017–2021, 2009–2021, we identified locations with various intensity of specific mortality rate due to breast cancer. It is demonstrated in the form of positive or negative spatial autocorrelation. When analysing the specific mortality rate due to breast cancer in the respective periods, we can identify municipalities with mosaic pattern of representation by respective quadrants. The phenomenon is described in Figs. 2−5. Moran's diagrams for the specific mortality rate due to breast cancer covering the studied periods indicated values ranging from 0.005 to 0.049. This means that we recorded slightly positive spatial autocorrelation (Fig. 6).

The low values of Moran's index present an important result, indicating weak spatial correlation. This phenomenon can be caused by several factors. For example, uneven spatial distribution of data; if the analysed values do not have a strong spatial pattern (e.g., concentration of similar values in certain areas), autocorrelation will be naturally weak. The type of spatial phenomenon can be another reason behind the low index values. This means that some phenomena may not show strong spatial correlation, such as socioeconomic data, where other factors may play a role, such as cultural or historical differences. We assume that this effect is manifested in the monitoring of the breast cancer mortality. Another reason behind the low Moran's index values, which we identify, consists in the fact that there are several overlapping trends (e.g. local clusters in otherwise evenly distributed data); this can result in weak autocorrelation.

The respective value indicates the clustering of similar values of standardized breast cancer mortality rate (high–high, low–low). As mentioned above, global Moran's index itself does not detect various degrees of spatial relations within a single data set. Deeper analysis by means of LISA and the respective diagram by its quadrants imply that clustering concerns mainly locations with high values surrounded by similar neighbors, the so-called hot spots in the high–high quadrant. In a smaller extent, the global Moran's index of positive spatial autocorrelation was influenced by the so-called

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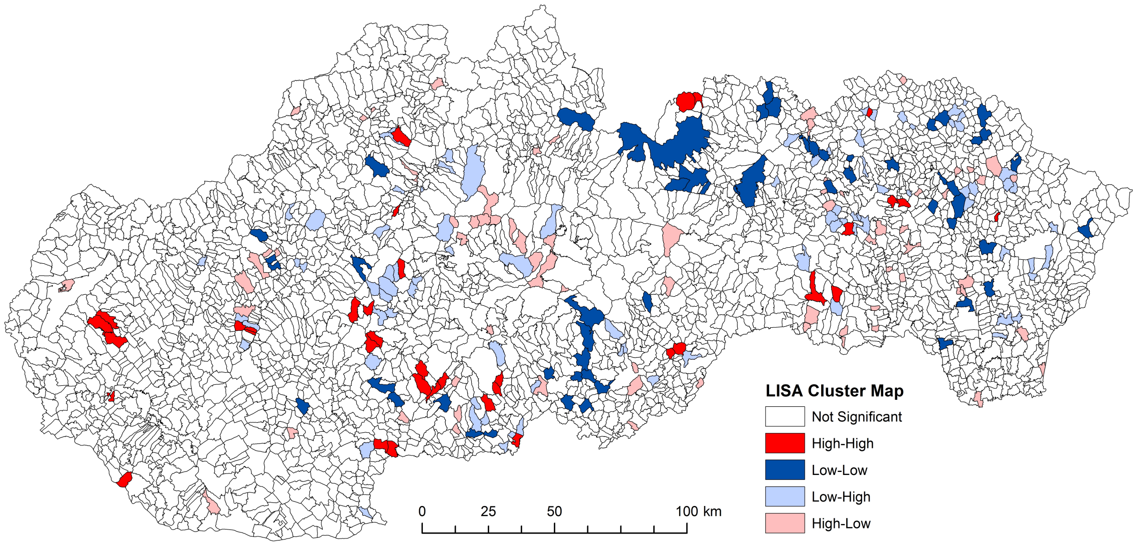

Fig. 2 Regionalization of Slovakia based on the LISA analysis for specific death rate of women due to breast cancer by age-specific 15 + per 1 000 women (2009−2012) (Statistical office of the Slovak Republic (DATAcube) 2022; own work)

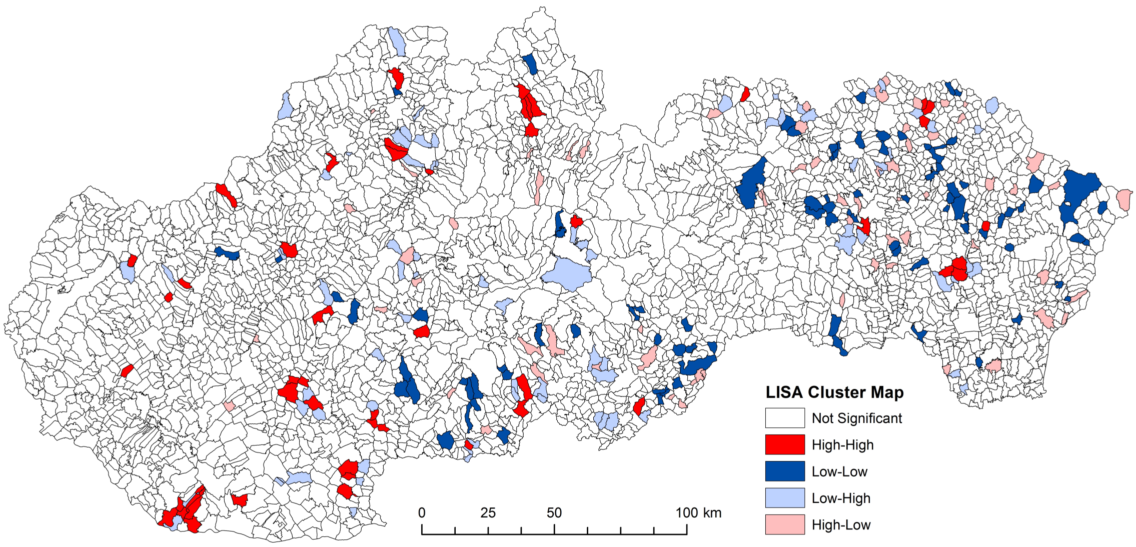

Fig. 3 Regionalization of Slovakia based on the LISA analysis for specific death rate of women due breast cancer by age-specific 15+per 1 000 women (2013−2016) (Statistical office of the Slovak Republic (DATAcube) 2022; own work)

cold spots, i.e. locations with low breast cancer mortality rates surrounded by similar neighbors, in the low–low quadrant. The reasons for the spatial differentiation of this phenomenon are closely related to several factors, which are difficult to identify precisely. Since oncological diseases belong to multi-factorial diseases, specifying the factors that present a high risk for the occurrence of the disease can be challenging. Direct correlation with risk factors cannot be specified unambiguously. In spite of that, the most significant factors which affect the occurrence of the disease can include the quality of the environment (Michaeli & Boltižiar 2010; Michaeli et al. 2021), lifestyle, age structure of the population, poverty rates, and others. We think that the occurrence of high breast cancer mortality rates does not depend on the degree of regional development.

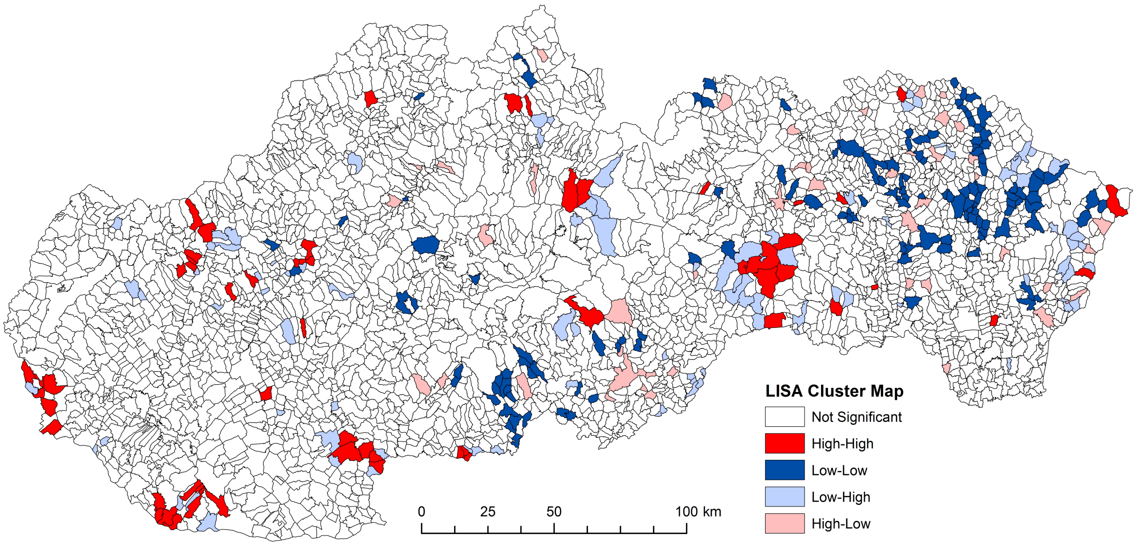

Fig. 4 Regionalization of Slovakia based on the LISA analysis for specific death rate of women due to breast cancer by age-specific 15 + per 1 000 women (2017-2021) (Statistical office of the Slovak Republic (DATAcube) 2022; own work)

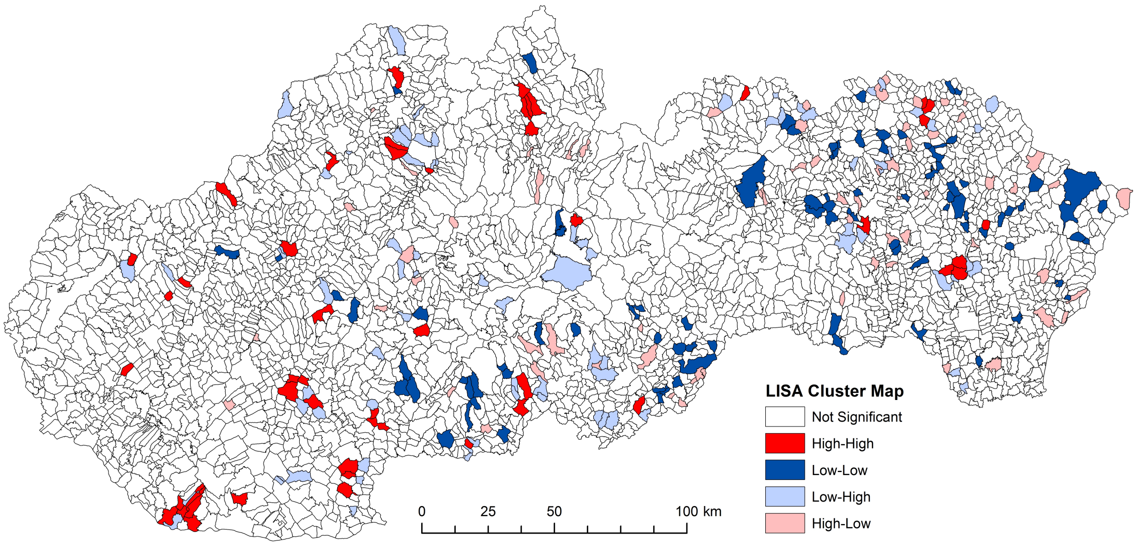

Fig. 5 Regionalization of Slovakia based on the LISA analysis for specific death rate of women due to breast cancer by age-specific 15 + per 1 000 women (2009−2021) (Statistical office of the Slovak Republic (DATAcube) 2022; own work)

4.2 Analysis of the specific mortality rate due to breast cancer in Slovakia

Specific breast cancer mortality rate in Slovakia shows significant spatial disparities. These disparities are affected not only by regional position but also by changes in time periods. The development in mortality rate indicates that in some areas, especially the regions of East and Central Slovakia, this indicator stayed on low values on long-term basis, whereas in the western parts of Slovakia, it was growing. The period of 2009–2012 shows low mortality rate in the municipalities of the East and Central Slovakia. There were 1852 municipalities, in which there were no deaths due to breast cancer. This can indicate better prevention, lower incidence, or lower availability of diagnostics in these regions (Fig. 7). In 2013–2016, there was an increase in the specific breast cancer mortality rate with the increase being most significant in the municipalities of the West Slovakia. The spatial distribution changed in the municipalities of the Cen-

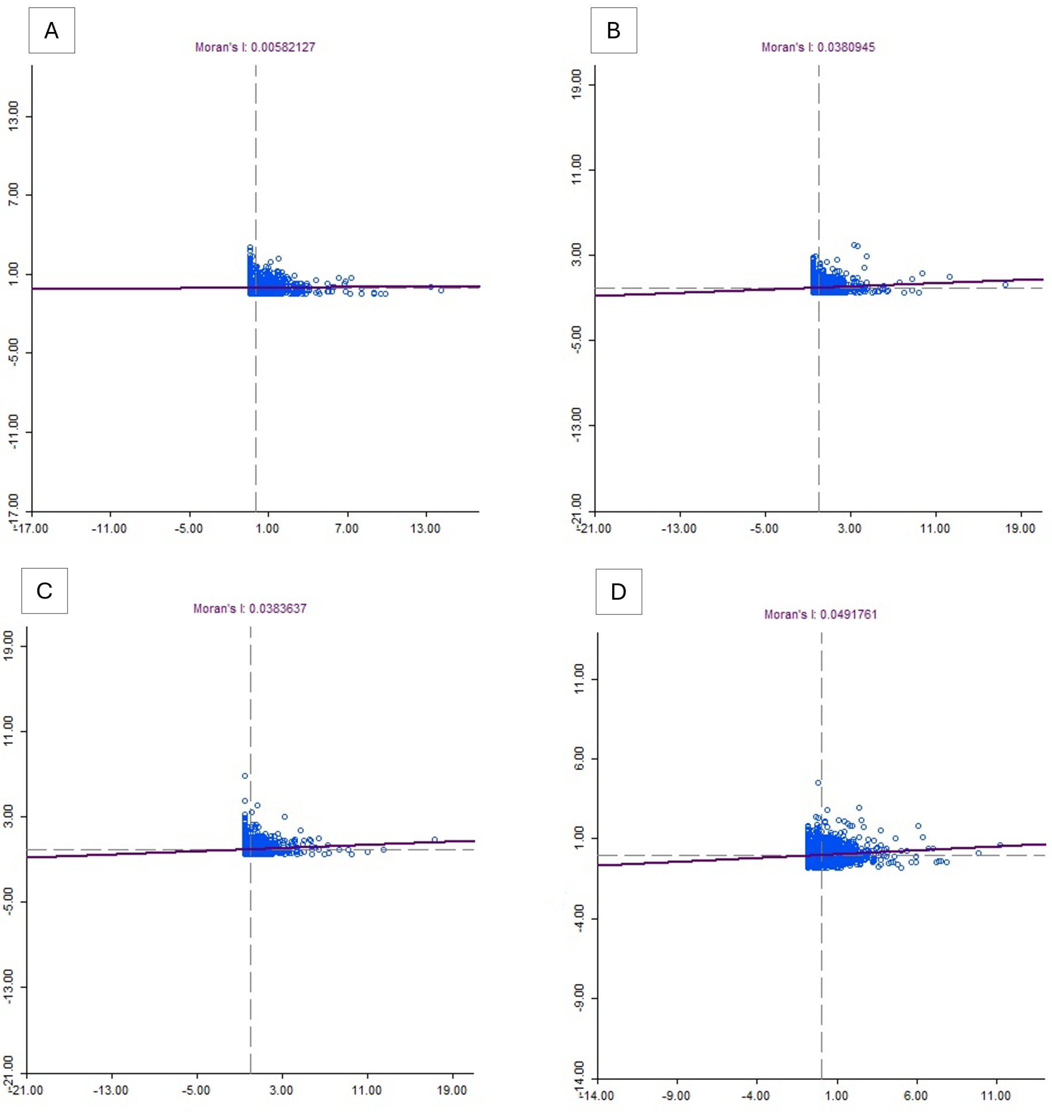

Fig. 6 A – Moran's diagram for specific death rate of women on breast cancer by age-specific 15 + per 1 000 women (2009–2012). B – Moran's diagram for specific death rate of women on breast cancer by age-specific 15 + per 1 000 Women (2013–2016). C – Moran's diagram for specific death rate of women on breast cancer by age-specific 15 + per 1000 Women (2017–2021). D – Moran's diagram for specific death rate of women on breast cancer by age-specific 15 + per 1 000 Women (2009–2021)

tral and East Slovakia where there were municipalities with zero mortality rate previously. The mortality centre moved to the western parts of the country. At the same time, the number of municipalities, where deaths due to breast cancer were recorded, grew. This change could be related to the better availability of diagnostics and healthcare; however, it can also reflect aggravation of environmental situation or other socioeconomic factors in the areas in question. Aging of the population, as another factor in the West Slovakia, can increase the risk of mortality due to this oncological disease (Fig. 8). In the period of 2017–2021, the trend of growing number of municipalities where mortality due to breast cancer was recorded continued. During this period, breast cancer mortality was recorded in 1332 municipalities in total. The highest mortality rate values were concentrated in the western and south-western parts of Slovakia, which confirms the trend observed in the previous period. This spatial concentration can be associated with the higher rate of urbanisation, different lifestyle, socioeconomic factors and different accessibility of healthcare services (Fig. 9). In the overall assessment of the period of 2009–2021 (Fig. 10), we can state that the breast cancer mortality was recorded in 2,150 municipalities of Slovakia, which represents about 73 % of all municipalities of Slovakia. There were only 777 municipalities (31.1 %), where no mortality was recorded on account of this disease. Most of these municipalities were situated in the eastern regions of Slovakia, which is aligned with the previous observations from the respective time periods. This can indicate the lower incidence or lower rate of diagnostics.

5 Discussion and conclusion

Breast cancer is among the most spreading oncological diseases in the world, and it is the second most frequent cause of deaths in the developed countries. Slovakia is no exception; this disease is the most frequent cause of deaths due to oncological diseases among women. The topic of spatial disparities in breast cancer is widely discussed and elaborated in detail in academic literature. It is documented by studies from various countries. The mortality due to this disease is the most frequently used indicator in the analysis and description of this issue. As an example, we highlight some studies, which discussed this issue (Torres-Román et al. 2023; Khosla et al. 2023; Qi et al. 2023; Clemons et al. 2022; Schulz et al. 2022; Mobley et al. 2021; Froelicher et al. 2021), In the Slovak conditions, such detailed research of breast cancer on a regional and local level was missing, which created a good premise to carry out new research in this area. In addition to the spatial aspect, significant role is played by other factors which contribute to the occurrence of breast cancer to a certain extent. The development of this disease is significantly influenced by the factors of socioeconomic standing, such as unemployment, poverty rate, life in marginalised groups, income, education level, and others. Their impact on the development of breast cancer has been discussed in many studies in the world, such as Mobley et al. (2012), Al-Rammahy et al. (2024), Gotink et al. (2024), Pedraza-Flechas et al. (2020), Coughlin (2019), Lundqvist et al. (2016). In the Slovak conditions, this topic is very important because the respective regions show significant differences in socioeconomic indicators. The areas with higher unemployment and poverty rates, as well as with higher presence of marginalised communities, can face poorer accessibility of healthcare and lower participation in preventive examinations. These disparities can contribute to late diagnosing of the disease and higher mortality rate, as mentioned in the studies (Kish et al. 2014; Feinglass et al. 2015). In the research of spatial variability of breast cancer in Slovakia, it is thus important to consider the socioeconomic factors, which can significantly influence its occurrence and impacts on the respective groups of population. Evidence is provided in the studies focusing on the correlation between breast cancer and socioeconomic status. For example, education level and health literacy levels aggravate the differences in health and affect the breast cancer screening rates (Jiang et al. 2023). Several research showed an increased mortality rate among women with higher education. The probable reason behind the higher mortality in this group of women is the accumulation of risk factors resulting from a higher emphasis on the education and career (Dong & Qin 2019; Al-Rammahy et al. 2024; Strand et al. 2005). With regards to some areas of Slovakia, we believe it can be related to higher breast cancer mortality values. The map outputs provided imply several pieces of information, whether in terms of content or spatial aspect of regional differentiation of breast cancer mortality. When assessing the results of territorial differentiation of gross breast cancer mortality rate, we can conclude that its dominance and higher values are localised mainly in the western part of Slovakia. The so-called western lifestyle (life westernisation) can be one of the potential factors of breast cancer development in these areas. The significance of this factor in breast cancer occurrence is highlighted in the studies of Pfeiffer et al. (2018) and Lei et al. (2021). Based on the economic development of the West Slovakia we could assume lower breast cancer mortality rate; however, this assumption was not confirmed. Breast cancer is a disease, which is usually associated with the higher quality of life and better provision of healthcare. Spatial disparities in the occurrence of the monitored disease described in this paper disconfirmed this claim. The quality of the environment is one of the possible factors which can contribute to the development of this disease in the monitored area. Its importance in relation to breast cancer was emphasised in the work of Burwell et al. (2023). In the effort to analyse spatial distribution of breast cancer in Slovakia, we used the spatial autocorrelation techniques. Specific techniques – global and local. They currently belong to frequently used spatial analyses of cancer data in the applied practice. The method was applied by several authors on the example of breast cancer, e.g. Kadhim Hussein (2024), Wang & Wan (2022), Montazeri et al. (2020), Al-Hashimi & M. Nori Mahmood (2021). Our results detected significant ge-

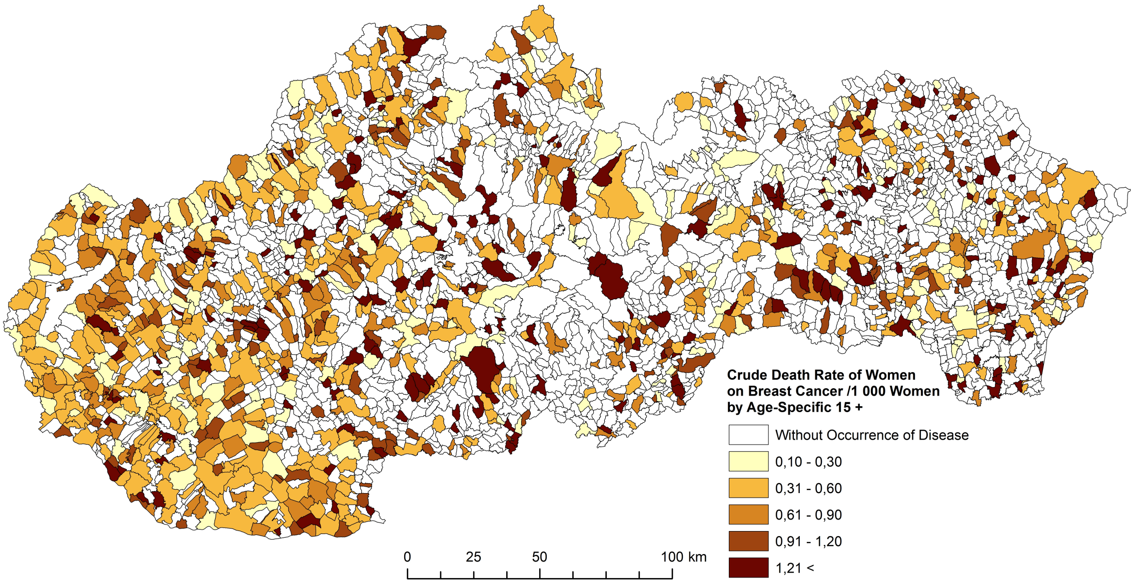

Fig. 7 Specific Rate Death of Women on Breast Cancer by Age-specific 15+per 1 000 Women (2009–2012) (Statistical office of the Slovak Republic (DATAcube) 2022; own work)

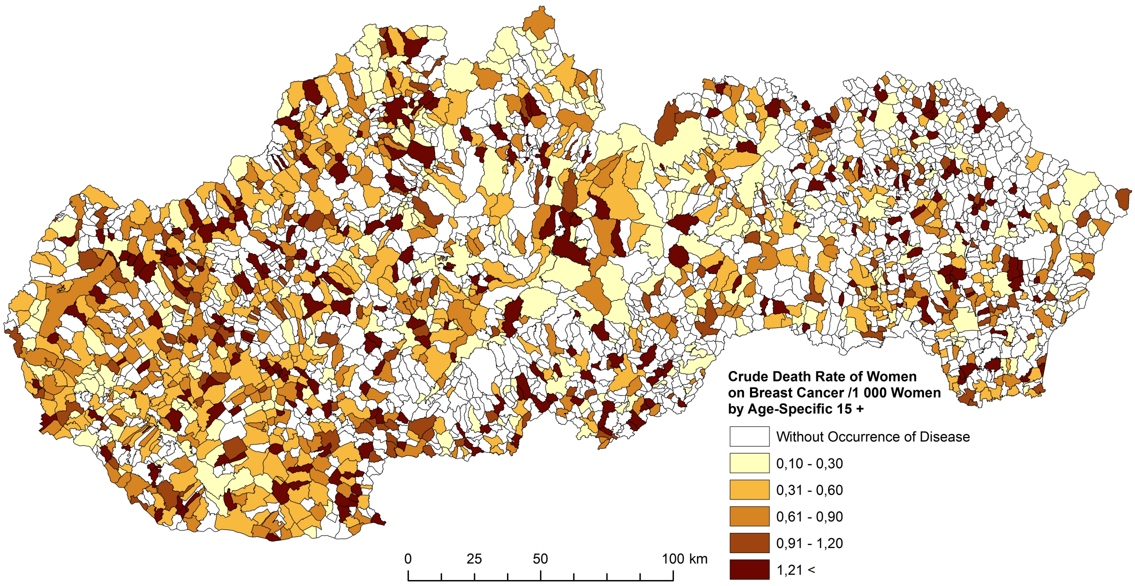

Fig. 8 Specific Rate Death of Women on Breast Cancer by Age-specific 15+per 1 000 Women (2013– 2016) (Statistical office of the Slovak Republic (DATAcube) 2022; own work)

ographic differences in the occurrence of the disease between the regions of Slovakia. The values of local indexes indicate the presence of significant clusters, with the clusters being concentrated mainly in the western and central part of the country. Breast cancer is a significant global health issue, which affects millions of people every year. It is a multifaceted disease, in which various risk factors and diagnostic approaches play a key role in its understanding and management. Progress in the diagnostic techniques allowed earlier detection and improved the outcomes of treatment. Mammography, together with state-of-the-art technologies, such as magnetic resonance and molecular testing, are crucial in the process. Early diagnosing of breast cancer allows for fast intervention and potentially improves the prognosis for the patients. Continuing research is focusing on the identification of new risk factors, perfection of screening methods, and development of targeted therapies.

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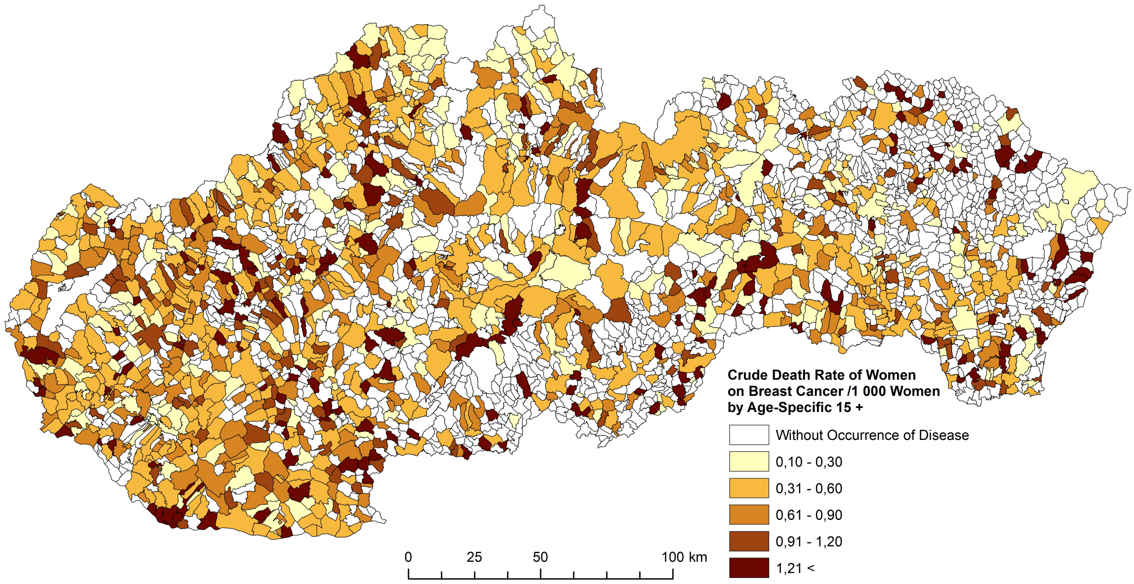

Fig. 9 Specific Rate Death of Women on Breast Cancer by Age-specific 15+per 1000 Women (2017–2021) (Statistical office of the Slovak Republic (DATAcube) 2022; own work)

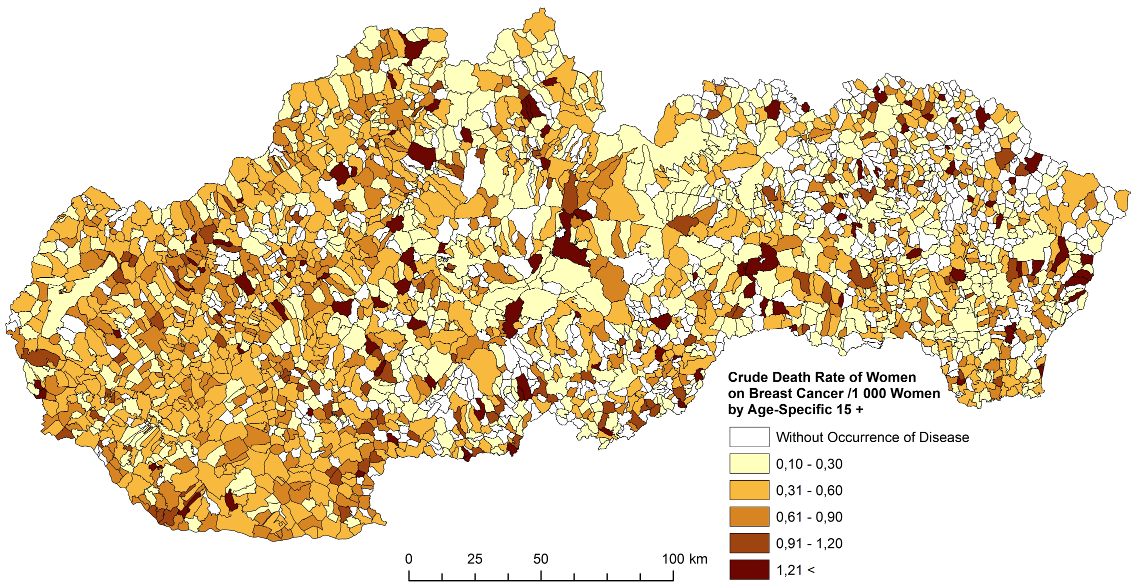

Fig. 10 Specific Rate Death of Women on Breast Cancer by Age-specific 15+per 1000 Women (2009-2021) (Statistical office of the Slovak Republic (DATAcube) 2022; own work)

Promoting awareness, availability of the screening, and global cooperation of experts are important aspects in fighting breast cancer, as they help reducing its influence on the individuals and society (Obeagu & Obeagu 2024; Barclay et al. 2024-08). The treatment of breast cancer in Slovakia has seen significant progress over the last decades. It is reflected in the higher chances of saving the lives of patients with this diagnosis. Whereas in the 90's, cancer was often a death verdict, nowadays with the early diagnostics, the disease can be successfully cured. This improvement was possible thanks to the technological development of diagnostic equipment and the use of cytostatic agents of better quality. According to Berta et al. (2024), Slovakia is actively involved in the European projects and initiatives in the effort to improve the above-average values of oncological diseases. The "Europe Beating Cancer Plan" programme brings the opportunity to cooperate with other member states for the common cause, which is to reduce the mortality and morbidity due to oncological diseases through several systematic steps. For example, in prevention, diagnostics, treatment, research, development, education, and use of new technologies and digitalisation.

Monitoring and assessing the effect of the respective factors, which affect the localisation of breast cancer mortality in Slovakia, is very challenging. Oncological diseases, including breast cancer, usually have a long-term and complex development. Factors affecting mortality are usually not seasonal and episodic. They are long-term and cumulative in nature. According to the experts from among medical doctors, it is a multi-factorial disease, and it is difficult to identify the specific contributors unambiguously. Complex assessment of spatial disparities in breast cancer mortality thus requires an interdisciplinary approach, which includes medical research, epidemiology, demography, public healthcare, and social policy. Such an approach helps better understand the reasons behind the regional differences and design actions, which can help reduce mortality and improve health condition of the population more effectively. The results obtained in this study can be broadly applied in several areas of public and healthcare sectors. They can be included in annual reports and they can help the agencies involved in taking adequate decisions in relation to cancer prevention and control. Identification of problematic regions based on the chosen indicators of breast tumor occurrence is crucial for the design of effective intervention measures in these areas. At the same time, this analysis can serve as the basis for the regional policies focusing on the reduction of regional differences in the approach to healthcare and screening programmes. In this context, it is important to emphasise the importance of a programme for the prevention of this disease, which is the National Oncological Programme and its action plans. They comprise the public health strategy focusing on the reduction of new cancer cases, mortality, and improvement of the quality of life for the patients with cancer. Breast Cancer Screening is one of the important programmes dealing with breast cancer. It is focusing on the target group of women who are 50 to 69 years old, in the time interval of 2 years. The main objective is the early detection of breast cancer. It is done using mammographic examination of the breast. The results of this study can contribute to the improvement in the planning of healthcare services and allocation of resources based on the regional needs. In addition, they can be used within educational campaigns to improve the awareness of the population about the risk factors and importance of early diagnosing. The research can also contribute to the development of new, more effective screening methods and therapeutic approaches, which can concentrate on the specific needs of the respective regions.

Acknowledgments

This research was funded by the grant VEGA 2/0110/25 and VEGA 2/0015/24 of the Scientific Grant Agency of the Ministry of Education, Research, Development and Youth of the Slovak Republic.

Declarations of Conflicting Interests

The Author declares that there is no conflict of interest.

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