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Article

Spatiotemporal Patterns of Cancer among Women in Central Serbia: Relevance for Risk-Informed Health Planning

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ABSTRACT

Malignant diseases are among the most prevalent health conditions affecting the female population in the Republic of Serbia. This study provides an overview of the most common malignant diseases – cancers in women in the central part of Serbia from 1999 to 2021, including breast, cervical, uterine, colorectal, bladder, ovarian, pancreatic, lung, and bronchial cancers from a geographic perspective. The spatial hot spots were identified using the well-known Getis-Ord Gi* statistic. New and consecutive hot spots for lung and bronchus cancer incidence were detected in Zlatiborski, Moravički, Mačvanski, and Beogradski counties, with oscillating and sporadic hot spots in the others. Consecutive hot spots for lung and bronchus cancer mortality were identified in Beogradski, Kolubarski, Podunavski, and Šumadijski counties, while oscillating hotspots were identified in Braničevski and Pomoravski counties. New hotspots for ovarian cancer incidence were concentrated in Zlatiborski and Moravički counties, whereas cold spots for uterine cancer incidence were identified in Kolubarski, Šumadijski, and Mačvanski counties. Pancreatic cancer incidence exhibited consecutive and sporadic patterns across multiple regions, while bladder cancer incidence showed widespread hot spots. The results provide valuable evidence on regions most severely affected and underscore the necessity of targeted preventive and intervention strategies. This analysis contributes to improving public health outcomes in Serbia and offers a model for similar studies in other countries.

KEYWORDS

Cancers, women, Central Serbia, Hot Spot Analysis

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1. Introduction

Cancer is the second most common cause of death among women globally (Gareis, 2021; Torre et al., 2017). Understanding the geographic patterns of cancer incidence, mortality, and prevalence is the first step in addressing global cancer disparities (Kamangar et al., 2006). Recent studies have increasingly demonstrated that spatial analysis can provide valuable support for health risk management by identifying geographic concentrations of disease, service inequalities, and areas requiring targeted public health intervention (Djebari & Bestandji, 2025; Al-Ramlawi et al., 2025; Akter et al., 2023; Kaur, 2020; Premović et al., 2025). Data from the GLOBOCAN 2020 Project indicate that breast, cervical, ovarian, and uterine cancers are among the ten most common cancers affecting women globally (Sung et al., 2021; Yi et al., 2021; Tomić et al., 2025). In 2022, breast cancer, along with tracheal, bronchial, and lung cancers, was the most prevalent among women worldwide. Colorectal cancers ranked third among the most common cancers (World Cancer Research Fund). From a broader disaster risk management perspective, risk-informed planning and resilience-oriented approaches are essential for strengthening health systems and communities in the face of spatially uneven health burdens and complex institutional challenges (Okpan et al., 2025; Cvetković et al., 2025).

The study by Williams et al. (2016) explored how geographic variation affects breast cancer stage at diagnosis, with attention to race/ethnicity and socioeconomic factors (Williams et al., 2016). DuBois et al. (2024) analysed cancer incidence disparities in the USA. Maryanaji (2020) studied climatic and geographic impacts on breast cancer in Iran. Cervical cancer clusters in Los Angeles County were identified using the Getis-Ord Gi statistic in ArcGIS (Shin, 2022). Sokale et al. (2024) mapped cervical cancer clusters in Texas, where incidence and mortality exceed national rates, while Shrestha et al. (2018) researched cervical cancer prevalence, incidence, and mortality in low- and middle-income countries. Olson et al. (2016) assessed screening programs and barriers like cost, awareness, geography, and cultural factors. Han (2020) studied metastatic breast cancer mortality hot spots among Black women in the USA. Tatalovich et al. (2015) investigated late-stage breast cancer incidence across eight U.S. states for targeted interventions. Jiang et al. (2023) analysed cancer survival rates and spatial distribution in Shandong Province, China.

The World Cancer Research Fund places Serbia among countries with high cancer incidence; in 2022, it ranked 60th globally for newly diagnosed cancer cases among women (19,129 cases) and 57th in cancer-related mortality (Kričković et al., 2025a; Kričković et al., 2025b). Cancer research in Central Serbia has primarily focused on medical and statistical analyses (Sipetic-Grujicic et al., 2013; Mihajlović et al., 2013; Ilic et al., 2013; Naumović et al., 2015; Markovic-Denic et al., 2014; Ignjatović et al., 2021; Nikolić et al., 2023; Jovanović et al., 2017). This study is among the first geographic-medical analyses of cancer in Central Serbia. Few studies in Serbia have applied this approach (Micić et al., 2013; Micić, 2016; Kričković et al., 2022; Mihalj et al., 2024; Kričković et al., 2025a; Kričković et al., 2025b).

This study did not explore the causes of cancers in women but focused on presenting an overview of the geographic and medical patterns of these diseases in Central Serbia. The medical geographic information systems field has proven invaluable for gaining a broader perspective on public health (Musa et al., 2013). Spatial analysis can pinpoint locations with notable variations in disease risk. The objective of this study is to examine the spatiotemporal distribution of eight types of cancer-breast, cervical, uterine, colorectal, bladder, ovarian, pancreatic, and lung and bronchial cancers in the female population, using twenty-three years of data (1999 to 2021) across eighteen counties in the central part of Serbia. The spatial dimension of the research was addressed using the Hot Spot Analysis to detect statistically significant clusters of high and low values. By integrating GIS with epidemiological data, the study aims to provide insights that could support future public health strategies, resource allocation, and targeted prevention efforts.

2. Methods

2.1. Data set

Information on cancer cases was compiled from official, publicly accessible publications of the Institute of Public Health of Serbia, "Dr. Milan Jovanović Batut", specifically "Cancer Incidence and Mortality in Central Serbia from 1999–2015" and "Malignant Cancers in the Republic of Serbia 2016-2021" (Kričković et al., 2025b). This analysis used standardized female mortality and incidence rates, excluding uterine and bladder cancer mortality because statistical data were insufficient for the entire study period. Malignant tumours were classified based on the World Health Organization's (WHO) disease classification. Tumours classified as "in situ" (codes D00-D09) were excluded from the registry (Institute of Public Health of Serbia "Dr Milan Jovanović Batut", 2023; Kričković et al., 2025a; Kričković et al., 2025b).

2.2. Study area

Central Serbia, located in the central part of the Balkan Peninsula, comprises the region of Serbia excluding its Autonomous Provinces (AP), with a total area of 55,947 km² (Bačević et al., 2024). This region, with a population of 4,906,773, includes 18 counties- Beogradski, Borski, Braničevski, Jablanički, Kolubarski, Mačvanski, Moravički, Nišavski, Pčinjski, Pirotski, Podunavski, Pomoravski, Rasinski, Raški, Šumadijski, Toplički, Zaječarski, and Zlatiborski (RZS, 2023; Kričković et al., 2025a; Kričković et al., 2025b). According to the 2022 census, 2,520,534 were women (Statistical Office of the Republic of Serbia, 2023; Kričković et al., 2025b). Several geographic features define the natural boundaries of the study area: 1) the Drina River to the west; 2) the Sava and Danube rivers to the north; 3) the Balkan and Rhodope Mountains to the east; and 4) the southern and south-western borders are delineated by the North Macedonia's state border and the provincial boundary with the AP Kosovo and Metohija, extending to the Montenegro state border (Bačević et al., 2024; Radaković et al., 2018). The location of the study area within Serbia and Europe is depicted in Figure 1.

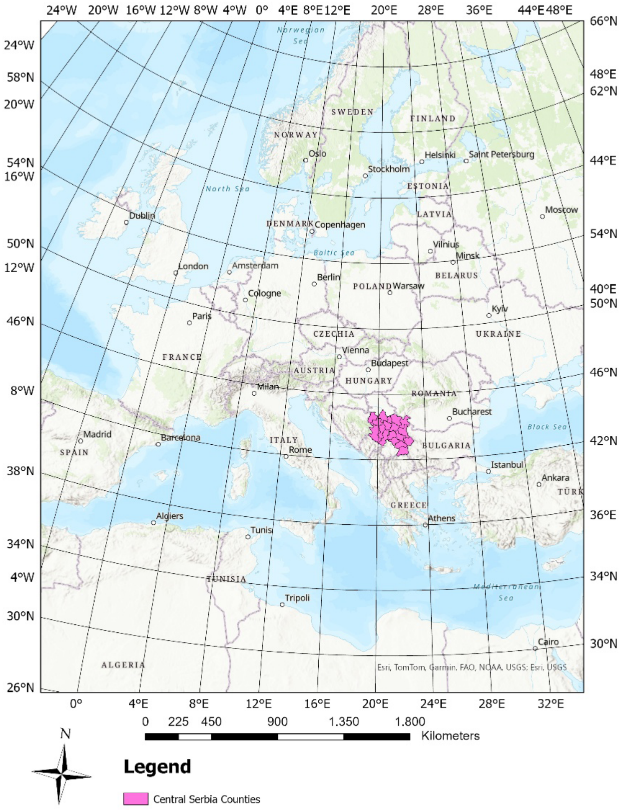

Figure 1. Study area in Europe and the Republic of Serbia.

2.3. Hot spot analysis (HSA)

HSA is a spatial mapping and analytical method focused on identifying clusters of spatial occurrences. The occurrences are mapped as points, each corresponding to the location of a specific event or object (Columbia University's Mailman School of Public Health, n.d.). This method was employed to examine the spatial and temporal distribution of cancer incidence and mortality among women in Central Serbia. The Getis-Ord Gi* statistic is employed to identify spatial clusters, revealing areas with high concentrations (hot spots) or low concentrations (cold spots) of a particular feature. This is reflected in the so-called z-values and the statistical significance indicated by the p-values. This spatial analysis helps detect significant patterns in the data, enabling a better understanding of spatial distributions (Pacific Northwest National Laboratory, n.d.). HSA utilizes the Gi statistic that can be calculated as (Getis, Ord, J. K., 1992; Ord, J. K., Getis, 1995; Kričković et al., 2024; Kričković et al., 2025a):

$$G_i^* = \frac{\sum_{j=1}^{n} \omega_{i,j} x_j - \bar{X} \sum_{j=1}^{n} \omega_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} \omega_{i,j}^2 - \left(\sum_{j=1}^{n} \omega_{i,j} \right)^2 \right]}{n-1}}} \quad (1)$$

Where is the spatial autocorrelation (spatial dependency) statistics of an event i over the n events, the term x_j defines the magnitude of the variable x at the events j over all n, and the term $w_{i,j}$ defines the weight value between the events i and j that represents their spatial interrelationship (Kumari, Pandey, 2020; Vizuete-Jaramillo et al., 2022; Kričković et al., 2023; Kričković et al., 2024; Kričković et al., 2025a) and

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (3)$$

The Statistics consider the magnitude of each feature in the dataset in the context of its neighbours' values (Kričković et al., 2024; Getis, Ord, J. K., 1992; Ord, J. K., Getis, 1995; Kumari, Pandey, 2020; Vizuete-Jaramillo et al., 2022; Kričković et al., 2023; Kričković et al., 2025a).

3. Results

The HSA parameters for lung and bronchus cancer mortality and incidence rates by county are presented in Table 1.

Table 1. Parameters of the HSA for lung and bronchus cancer by county from 1999 to 2021 (z-score, p-value).

County	Lung and bronchus cancer					
	Incidence			Mortality		
	Pattern	z	p	Pattern	z	p
Beogradski	Consecutive Hot Spot	5.81	6.24×10^{-9}	Consecutive Hot Spot	5.65	1.59×10^{-8}
Borski	Oscillating Hot Spot	5.76	8.54×10^{-9}	No Pattern Detected	4.54	5.56×10^{-6}
Braničevski	Oscillating Hot Spot	5.97	2.33×10^{-9}	Oscillating Hot Spot	4.75	2.00×10^{-6}
Jablanički	No Pattern Detected	5.28	1.28×10^{-7}	No Pattern Detected	4.44	9.12×10^{-6}
Kolubarski	Sporadic Hot Spot	5.76	8.54×10^{-9}	Consecutive Hot Spot	5.28	1.28×10^{-7}

Mačvanski	Consecutive Hot Spot	5.55	2.92×10^{-8}	No Pattern Detected	5.34	9.46×10^{-8}
Moravički	New Hot Spot	5.76	8.54×10^{-9}	No Pattern Detected	4.97	6.86×10^{-7}
Nišavski	Oscillating Hot Spot	5.70	1.17×10^{-8}	No Pattern Detected	5.07	3.96×10^{-7}
Pčinjski	No Pattern Detected	5.28	1.28×10^{-7}	No Pattern Detected	4.44	9.12×10^{-6}
Pirotski	Oscillating Hot Spot	5.65	1.59×10^{-8}	No Pattern Detected	4.44	9.12×10^{-6}
Podunavski	Sporadic Hot Spot	5.76	8.54×10^{-9}	Consecutive Hot Spot	5.13	2.97×10^{-7}
Pomoravski	Oscillating Hot Spot	5.15	2.58×10^{-7}	Oscillating Hot Spot	5.28	1.28×10^{-7}
Rasinski	Oscillating Hot Spot	3.17	1.53×10^{-3}	No Pattern Detected	4.91	9.00×10^{-7}
Raški	No Pattern Detected	4.54	5.56×10^{-6}	No Pattern Detected	4.60	4.32×10^{-6}
Šumadijski	Sporadic Hot Spot	5.65	1.59×10^{-8}	Consecutive Hot Spot	5.15	2.58×10^{-7}
Toplički	Oscillating Hot Spot	3.96	7.45×10^{-5}	No Pattern Detected	5.44	5.31×10^{-8}
Zaječarski	No Pattern Detected	5.55	2.92×10^{-8}	No Pattern Detected	4.65	3.35×10^{-6}
Zlatiborski	New Hot Spot	5.76	8.54×10^{-9}	No Pattern Detected	4.97	6.86×10^{-7}

For the incidence rates of lung and bronchus cancer, new hotspots were identified in two counties: Moravički ($z=5.76$, $p=8.54 \times 10^{-9}$) and Zlatiborski ($z=5.76$, $p=8.54 \times 10^{-9}$). Additionally, two counties were recognized as consecutive hotspots: Mačvanski ($z=5.55$, $p=2.92 \times 10^{-8}$) and Beogradski ($z=5.81$, $p=6.24 \times 10^{-9}$). Oscillating hotspots were found in seven counties: Borski ($z=5.76$, $p=8.54 \times 10^{-9}$), Braničevski ($z=5.97$, $p=2.33 \times 10^{-9}$), Nišavski ($z=5.70$, $p=1.17 \times 10^{-8}$), Pirotski ($z=5.65$, $p=1.59 \times 10^{-8}$), Pomoravski ($z=5.15$, $p=2.58 \times 10^{-7}$), Rasinski ($z=3.17$, $p=1.53 \times 10^{-3}$), and Toplički ($z=3.96$, $p=7.45 \times 10^{-5}$). Kolubarski ($z=5.76$, $p=8.54 \times 10^{-9}$), Podunavski ($z=5.76$, $p=8.54 \times 10^{-9}$), and Šumadijski ($z=5.65$, $p=1.59 \times 10^{-8}$) counties were identified as sporadic hotspots. No pattern was detected in the hotspot analysis of lung and bronchus incidence for the counties of Jablanički, Pčinjski, Raški, and Zaječarski. The findings of this analysis are visually represented in Figure 2a.

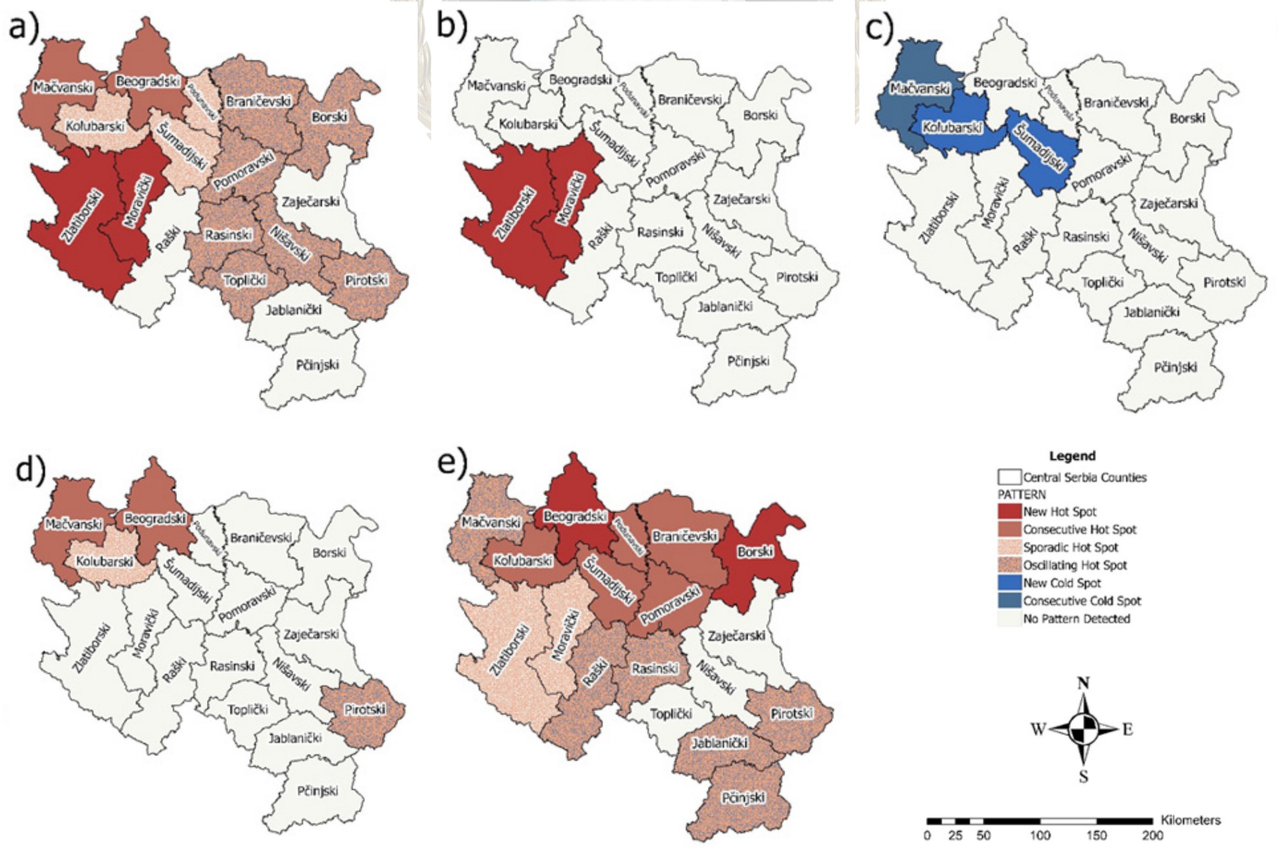

Figure 2. HSA in women incidence rates for:
a) lung and bronchus, b) ovarian, c) uterine, d) pancreatic, and e) bladder cancer.

Consecutive hot spots for lung and bronchus cancer mortality rates were recorded in four counties – Beogradski (z=5.65, p=1.59x10^{-8}), Kolubarski (z=5.28, p=1.28x10^{-7}), Podunavski (z=5.13, p=2.97x10^{-7}), and Šumadijski (z=5.15, p=2.58x10^{-7}), while oscillating hot spots were recorded in Braničevski (z=4.75, p=2.00x10^{-6}) and Pomoravski (z=5.28, p=1.28x10^{-7}) counties. In other counties, no patterns were detected in this analysis (Figure 3).

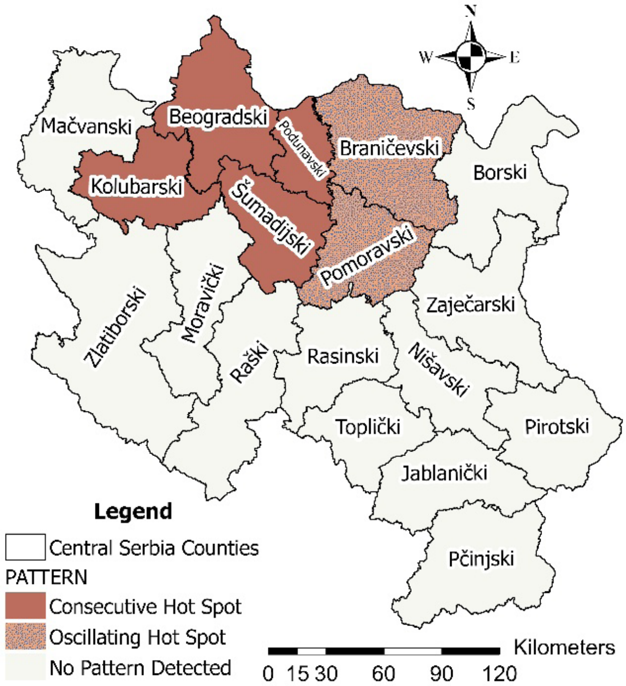

Figure 3. HSA in women's lung and bronchus cancer mortality rates.

The HSA parameters for ovarian cancer mortality and incidence rates by county are presented in Table 2.

Table 2. Parameters of the HSA for ovarian cancer by county from 1999 to 2021 (z-score, p-value).

County	Ovarian cancer					
	Incidence			Mortality		
	Pattern	z	p	Pattern	z	p
Beogradski	No Pattern Detected	2.80	0.01	No Pattern Detected	-1.16	0.25
Borski	No Pattern Detected	4.02	5.92x10^{-5}	No Pattern Detected	2.35	0.02
Braničevski	No Pattern Detected	4.38	1.16x10^{-5}	No Pattern Detected	2.09	0.04
Jablanički	No Pattern Detected	2.54	0.01	No Pattern Detected	1.00	0.32
Kolubarski	No Pattern Detected	3.65	2.65x10^{-4}	No Pattern Detected	-1.32	0.19
Mačvanski	No Pattern Detected	2.75	0.01	No Pattern Detected	1.06	0.29
Moravički	New Hot Spot	4.12	3.74x10^{-5}	No Pattern Detected	-0.05	0.96
Nišavski	No Pattern Detected	1.37	0.17	No Pattern Detected	1.85	0.06
Pčinjski	No Pattern Detected	2.54	0.01	No Pattern Detected	1.03	0.30
Pirotski	No Pattern Detected	2.96	3.08x10^{-3}	No Pattern Detected	1.59	0.11
Podunavski	No Pattern Detected	2.54	0.01	No Pattern Detected	-0.32	0.75
Pomoravski	No Pattern Detected	3.49	4.90x10^{-4}	No Pattern Detected	0.37	0.71

Rasinski	No Pattern Detected	2.85	4.34×10^{-3}	No Pattern Detected	1.74	0.08
Raški	No Pattern Detected	1.80	0.07	No Pattern Detected	0.48	0.63
Šumadijski	No Pattern Detected	2.51	0.01	No Pattern Detected	-1.35	0.18
Toplički	No Pattern Detected	1.27	0.20	No Pattern Detected	2.11	0.03
Zaječarski	No Pattern Detected	4.49	7.13×10^{-6}	No Pattern Detected	2.27	0.02
Zlatiborski	New Hot Spot	4.12	3.74×10^{-5}	No Pattern Detected	-0.05	0.96

It is evident that for ovarian incidence rates, new hot spots were recorded in two counties: Moravički ($z=4.12$, $p=3.74 \times 10^{-5}$), and Zlatiborski ($z=4.12$, $p=3.74 \times 10^{-5}$). In the remaining counties, spatial patterns were absent for both incidence and mortality rates.

The HSA parameters for uterine cancer mortality and incidence rates by county are presented in Table 3.

Table 3. Parameters of the HSA for uterine cancer by county from 1999 to 2021 (z-score, p-value).

County	Uterine cancer					
	Incidence			Mortality		
	Pattern	z	p	Pattern	z	p
Beogradski	No Pattern Detected	-1.00	0.32	N/A	N/A	N/A
Borski	No Pattern Detected	1.61	0.11	N/A	N/A	N/A
Braničevski	No Pattern Detected	1.16	0.25	N/A	N/A	N/A
Jablanički	No Pattern Detected	0.42	0.67	N/A	N/A	N/A
Kolubarski	New Cold Spot	-2.54	0.01	N/A	N/A	N/A
Mačvanski	Consecutive Cold Spot	-3.78	1.58×10^{-4}	N/A	N/A	N/A
Moravički	No Pattern Detected	0.03	0.98	N/A	N/A	N/A
Nišavski	No Pattern Detected	0.32	0.75	N/A	N/A	N/A
Pčinjski	No Pattern Detected	0.40	0.69	N/A	N/A	N/A
Pirotski	No Pattern Detected	1.37	0.17	N/A	N/A	N/A
Podunavski	No Pattern Detected	-1.85	0.06	N/A	N/A	N/A
Pomoravski	No Pattern Detected	-1.32	0.19	N/A	N/A	N/A
Rasinski	No Pattern Detected	2.80	0.01	N/A	N/A	N/A
Raški	No Pattern Detected	1.19	0.23	N/A	N/A	N/A
Šumadijski	New Cold Spot	-2.22	0.03	N/A	N/A	N/A
Toplički	No Pattern Detected	0	1.00	N/A	N/A	N/A
Zaječarski	No Pattern Detected	3.27	1.06×10^{-3}	N/A	N/A	N/A
Zlatiborski	No Pattern Detected	0.03	0.98	N/A	N/A	N/A

In terms of uterine cancer incidence rates, two counties were identified as new cold spots: Kolubarski ($z = -2.54$, $p = 0.01$) and Šumadijski ($z = -2.22$, $p = 0.03$). In the category, a consecutive cold spot was detected in Mačvanski county ($z = -3.78$, $p = 1.58 \times 10\text{-}4$). Other counties did not exhibit any spatial patterns (Figure 2c). Also, the analysis of mortality was not done due to the lack of statistical data during the analysed period.

The HSA parameters for pancreatic cancer mortality and incidence rates by county are presented in Table 4.

Table 4. Parameters of the HSA for pancreatic cancer by county from 1999 to 2021 (z-score, p-value).

County	Pancreatic					
	Incidence			Mortality		
	Pattern	z	p	Pattern	z	p
Beogradski	Consecutive Hot Spot	5.65	$1.59x10^{-8}$	No Pattern Detected	4.54	$5.56x10^{-6}$
Borski	No Pattern Detected	3.88	$1.03x10^{-4}$	No Pattern Detected	1.74	0.08
Braničevski	No Pattern Detected	4.49	$7.13x10^{-6}$	No Pattern Detected	2.80	0.01
Jablanički	No Pattern Detected	4.28	$1.88x10^{-5}$	No Pattern Detected	2.38	0.02
Kolubarski	Sporadic Hot Spot	4.60	$4.29x10^{-6}$	No Pattern Detected	3.96	$7.40x10^{-5}$
Mačvanski	Consecutive Hot Spot	4.33	$1.48x10^{-5}$	No Pattern Detected	4.70	$2.59x10^{-6}$
Moravički	No Pattern Detected	4.23	$2.38x10^{-5}$	No Pattern Detected	3.51	$4.42x10^{-4}$
Nišavski	No Pattern Detected	4.81	$1.53x10^{-6}$	No Pattern Detected	2.96	$3.09x10^{-3}$
Pčinjski	No Pattern Detected	4.28	$1.88x10^{-5}$	No Pattern Detected	2.38	0.02
Pirotski	Oscillating Hot Spot	4.44	$9.12x10^{-6}$	No Pattern Detected	4.17	$3.01x10^{-5}$
Podunavski	No Pattern Detected	4.49	$7.13x10^{-6}$	No Pattern Detected	3.62	$2.94x10^{-4}$
Pomoravski	No Pattern Detected	4.01	$5.96x10^{-5}$	No Pattern Detected	2.67	0.01
Rasinski	No Pattern Detected	3.70	$2.18x10^{-4}$	No Pattern Detected	0.85	0.40
Raški	No Pattern Detected	4.41	$1.02x10^{-5}$	No Pattern Detected	0.79	0.43
Šumadijski	No Pattern Detected	4.20	$2.63x10^{-5}$	No Pattern Detected	2.96	$3.09x10^{-3}$
Toplički	No Pattern Detected	4.23	$2.38x10^{-5}$	No Pattern Detected	2.64	0.01
Zaječarski	No Pattern Detected	3.64	$2.68x10^{-4}$	No Pattern Detected	2.93	$3.35x10^{-3}$
Zlatiborski	No Pattern Detected	4.23	$2.38x10^{-5}$	No Pattern Detected	3.51	$4.42x10^{-4}$

Regarding pancreatic cancer incidence rates, a consecutive hotspot was detected in the Beogradski (z=5.65, p=1.59x10-8) and Mačvanski (z=4.33, p=$1.48x10^{-5}$) counties. Sporadic hot spot was detected in Kolubarski county (z=4.60, p=$4.29x10^{-6}$). Pirotski county was detected in the category Oscillating Hot Spot (z=4.44, p=$9.12x10^{-6}$) (Fig. 2 d). In the remaining counties, neither incidence nor mortality rates showed detectable patterns.

The HSA parameters for bladder cancer mortality and incidence rates by county are presented in Table 5.

Table 5. Parameters of the HSA for bladder cancer by county from 1999 to 2021 (z-score, p-value).

County	Bladder cancer					
	Incidence			Mortality		
	Pattern	z	p	Pattern	z	p
Beogradski	New Hot Spot	3.12	$1.83x10^{-3}$	N/A	N/A	N/A
Borski	New Hot Spot	3.17	$1.53x10^{-3}$	N/A	N/A	N/A
Braničevski	Consecutive Hot Spot	2.85	$4.33x10^{-3}$	N/A	N/A	N/A
Jablanički	Oscillating Hot Spot	3.86	$1.15x10^{-4}$	N/A	N/A	N/A
Kolubarski	Consecutive Hot Spot	3.91	$9.28x10^{-5}$	N/A	N/A	N/A
Mačvanski	Oscillating Hot Spot	4.28	$1.88x10^{-5}$	N/A	N/A	N/A
Moravički	Sporadic Hot Spot	4.07	$4.76x10^{-5}$	N/A	N/A	N/A
Nišavski	No Pattern Detected	4.44	$9.12x10^{-6}$	N/A	N/A	N/A

Pčinjski	Oscillating Hot Spot	3.86	1.15×10^{-4}	N/A	N/A	N/A
Pirotski	Oscillating Hot Spot	4.07	4.73×10^{-5}	N/A	N/A	N/A
Podunavski	Consecutive Hot Spot	3.94	8.27×10^{-5}	N/A	N/A	N/A
Pomoravski	Consecutive Hot Spot	4.12	3.79×10^{-5}	N/A	N/A	N/A
Rasinski	Oscillating Hot Spot	3.67	2.40×10^{-4}	N/A	N/A	N/A
Raški	Oscillating Hot Spot	4.07	4.73×10^{-5}	N/A	N/A	N/A
Šumadijski	Consecutive Hot Spot	4.07	4.76×10^{-5}	N/A	N/A	N/A
Toplički	No Pattern Detected	3.99	6.62×10^{-5}	N/A	N/A	N/A
Zaječarski	No Pattern Detected	3.38	7.23×10^{-4}	N/A	N/A	N/A
Zlatiborski	Sporadic Hot Spot	4.07	4.76×10^{-5}	N/A	N/A	N/A

In terms of bladder cancer incidence rates, two counties were identified as new hot spots: Beogradski (z=3.12, p=1.83x10-3) and Borski (z=3.17, p=1.53×10^{-3}). Additionally, sporadic hot spots for bladder cancer incidence rates were identified in the Moravički (z=4.07, p=4.76×10^{-5}) and Zlatiborski (z=4.07, p=4.76×10^{-5}) counties. Consecutive Hot Spot were identified in the Braničevski (z=2.85, p=4.33×10^{-3}), Kolubarski (z=3.91, p=9.28×10^{-5}), Podunavski (z=3.94, p=8.27×10^{-5}), Pomoravski (z=4.12, p=3.79×10^{-5}) and Šumadijski (z=4.07, p=4.76×10^{-5}). Jablanički (z=3.86, p=1.15×10^{-4}), Mačvanski (z=4.28, p=1.88×10^{-5}), Pčinjski (z=3.86, p=1.15×10^{-4}), Pirotski (z=4.07, p=4.73×10^{-5}), Rasinski (z=3.67, p=2.40×10^{-4}), and Raški (z=4.07, p=4.73×10^{-5}) counties were classified in category Oscillating Hot Spot. No pattern in the incidence of bladder cancer was detected across the Nišavski, Toplički, and Zaječarski counties. The analysis of bladder mortality was not conducted due to insufficient statistical data for the analysed time period. No spatial patterns in incidence and mortality rates were detected for colorectal, cervical, and breast cancer in any county; therefore, they are not shown on the maps. The HSA parameters for these three analysed cancers are presented in Tables 1, 2, and 3 in Appendix A.

4. Discussion

The application of HSA in public health and epidemiology has expanded significantly due to advances in GIS technology (Columbia University's Mailman School of Public Health, n.d.). This study identifies regional disparities in cancer incidence and mortality across Central Serbia, revealing new and consecutive hot spots for lung and bronchus cancer in Zlatiborski and Moravički, Mačvanski, and Beogradski counties. In contrast, bladder and pancreatic cancer incidence showed widespread and sporadic clustering. Ovarian cancer hot spots were concentrated in Zlatiborski and Moravički, whereas cold spots for uterine cancer appeared in Kolubarski, Šumadijski, and Mačvanski counties.

Kričković et al. (2025b) examined spatial and temporal trends in incidence and mortality for eight major cancers among women in Central Serbia, aiming to inform targeted prevention and preparedness strategies. They employed the Mann-Kendall trend test and Sen's slope estimator to quantify long-term trends in the most common cancers (Kričković, E. et al., 2025b). Their study shows increasing incidence trends for breast, colorectal, bladder, pancreatic, and lung and bronchus cancers in multiple counties, while decreasing cervical cancer trends (Kričković, E. et al., 2025b). In contrast, the present study complements these findings by identifying the spatial concentration of high-risk areas, contributing to a more comprehensive understanding of cancer distribution and supporting geographically targeted prevention strategies.

Also, Kričković et al. (2025a) conducted a spatiotemporal and trend analysis of cancer incidence among men in Central Serbia. That HSA identified bladder cancer as a hotspot in the Podunavski and Šumadijski counties (Kričković et al., 2025a). A comparison with our study reveals a similar pattern among women, with bladder cancer also classified as a consecutive hotspot in the same counties. Conversely, no patterns were identified for colorectal cancer in women, while in men, this cancer appeared frequently as a new and oscillating hot spot. Regarding mortality, our analysis showed that lung and bronchial cancer in women formed both consecutive and oscillating hot spots, whilst in men, cold spots were detected, indicating a decline in mortality from this type of cancer. These findings emphasize that combining temporal trend analysis with spatial hot spot detection provides a more robust framework for identifying priority areas for targeted prevention, screening, and resource allocation.

According to Mihalj et al. (2024), mining activities are associated with increased incidence of bronchial cancer in male and female populations. Their findings identified Borski County as having the highest occurrence of lung and bronchial cancer (Mihalj et al., 2024). Consistent with the current analysis, Borski County emerged as an oscillating hotspot, exhibiting pronounced yet temporally variable spatial clustering patterns. It should also be noted that our study covered a longer period and focused exclusively on the female population, which should be considered when comparing the two studies.

The incidence of cervical cancer in low- and middle-income nations is more than ten times greater than in high-income countries, owing to limited access to screening and treatment (Toliman, 2018). Screening has proven effective in reducing morbidity and mortality from breast, cervical, and colorectal cancers (Alford et al., 2015). The decline in the incidence and mortality of these cancers in Central Serbia suggests the impact of preventive measures and early diagnosis. Raising awareness and improving access to healthcare remain crucial (WHO, 2024). HPV vaccination between ages 9 and 14 provides strong protection against cervical and other HPV-related cancers (WHO, 2024). In Serbia, cervical cancer screening is hindered by inadequate public health education, a lack of patient-friendly services, sociocultural attitudes, and traditional gender roles (Marković et al., 2005, 2015). A study by Kešić et al. (2006) found little correlation between education, economic status, and screening awareness, with widespread misinformation persisting.

Lifestyle factors, including high BMI, alcohol consumption, and elevated fasting glucose, contribute to breast cancer mortality (Li et al., 2019; Yi, 2021). Smoking and alcohol use increase breast cancer risk (Lilleborge, 2021; Yi, 2021), while obesity and reduced physical activity heighten uterine cancer risk (Henley et al., 2018; Cote, 2015). Socioeconomic disparities also influence late-stage breast cancer diagnoses, with poverty and low literacy hindering screening participation (Tatalovich et al., 2015; Davis, 2002).

Environmental and occupational risks, such as air pollution and industrial exposure, further impact cancer incidence (Ng et al., 2015; Ekpanyaskul et al., 2010; Sipetić-Grujičić et al., 2013). Although Serbia has introduced tobacco control legislation, more efforts are needed to mitigate risk factors (Mihajlović et al., 2013; O'Rourke & Djukic, 2008). Additional studies are required to investigate the links between alcohol use, smoking, pollution, and cancer incidence in at-risk areas (Kričković et al., 2025a; Kričković et al., 2025b).

Geospatial analysis reveals crucial patterns in cancer distribution, which may be obscured in broader state-level studies (DuBois, 2024). Mapping disease cases aids local and national policymakers in targeting interventions and assessing their impact (Musa et al., 2013; Lovett et al., 2014). A key challenge remains in presenting GIS-based findings in an accessible format for decision-makers (Lovett et al., 2014).

One limitation of this study is the lack of consistent mortality data for certain cancer types, which restricts further analysis (Janković, S. et al., 2007; Kričković et al., 2025a; Kričković et al., 2025b). Nevertheless, the findings offer a valuable foundation for future research on healthcare effectiveness. Enhancing data collection on pathological staging and treatment is crucial for improving cancer prevention, control, and patient outcomes (Jiang et al., 2023). A significant challenge is the absence of comprehensive national data on cancer survival and prevalence in Serbia (Mihajlović et al., 2013). Unlike many other countries, Serbia does not routinely track patient cohorts, limiting epidemiological insights primarily due to financial constraints (Mihajlović et al., 2013). Additionally, cancer registries lack essential clinical data on staging and treatment (Jiang et al., 2023).

Identifying spatial patterns in cancer incidence and mortality supports targeted prevention and provides insights into regional risk factors (Moore et al., 2018). This study may assist Serbia in refining health policies and interventions.

4. Conclusions

This study provides novel insights into the spatial distribution of cancers among women in central Serbia. It identifies areas most at risk for cancer occurrence in women, highlighting the need for further research to investigate the underlying causes in these regions. Addressing this issue would require collaborative efforts from experts across various fields, working together rather than in isolation. Research of this kind can also be applied to other regions and populations worldwide experiencing increased cancer incidence and mortality rates. Such an approach would greatly facilitate the implementation of complex analyses to uncover the causes of cancer in specific areas. Additionally, it would support the prioritisation of public health initiatives, which are key indicators of a society's development.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table 1. Parameters of the HSA for colorectal cancer by county from 1999 to 2021 (z-score, p-value).

County	Colorectal cancer					
	Incidence			Mortality		
	Pattern	z	p	Pattern	z	p
Beogradski	No Pattern Detected	1.61	0.11	No Pattern Detected	-1.43	0.15
Borski	No Pattern Detected	2.27	0.02	No Pattern Detected	-1.24	0.21
Braničevski	No Pattern Detected	2.91	3.67×10^{-3}	No Pattern Detected	-0.42	0.67
Jablanički	No Pattern Detected	3.22	1.27×10^{-3}	No Pattern Detected	-1.95	0.05
Kolubarski	No Pattern Detected	2.30	0.02	No Pattern Detected	-2.01	0.04
Mačvanski	No Pattern Detected	2.80	5.12×10^{-3}	No Pattern Detected	-1.77	0.08
Moravički	No Pattern Detected	3.54	4.02×10^{-4}	No Pattern Detected	-0.79	0.43
Nišavski	No Pattern Detected	3.49	4.88×10^{-4}	No Pattern Detected	-1.80	0.07
Pčinjski	No Pattern Detected	3.22	1.27×10^{-3}	No Pattern Detected	-1.95	0.05
Pirotski	No Pattern Detected	4.07	4.76×10^{-5}	No Pattern Detected	-1.43	0.15

Podunavski	No Pattern Detected	0.71	0.48	No Pattern Detected	-1.58	0.11
Pomoravski	No Pattern Detected	2.96	3.10x10^{-3}	No Pattern Detected	-0.37	0.71
Rasinski	No Pattern Detected	2.22	0.03	No Pattern Detected	-1.82	0.07
Raški	No Pattern Detected	2.99	2.83x10^{-3}	No Pattern Detected	-1.06	0.29
Šumadijski	No Pattern Detected	1.11	0.27	No Pattern Detected	-2.51	0.01
Toplički	No Pattern Detected	2.64	8.27x10^{-3}	No Pattern Detected	-1.64	0.10
Zaječarski	No Pattern Detected	4.12	3.79x10^{-5}	No Pattern Detected	-0.21	0.83
Zlatiborski	No Pattern Detected	3.54	4.02x10^{-4}	No Pattern Detected	-0.79	0.43

Table 2. Parameters of the HSA for bladder cervical by county from 1999 to 2021 (z – z-score, p – p-value).

County	Cervical cancer					
	Incidence			Mortality		
	Pattern	z	p	Pattern	z	p
Beogradski	No Pattern Detected	-3.20	1.39x 10^{-3}	No Pattern Detected	-3.17	1.52x10^{-3}
Borski	No Pattern Detected	-1.58	0.11	No Pattern Detected	-4.25	2.10x10^{-5}
Braničevski	No Pattern Detected	-2.01	0.04	No Pattern Detected	-3.64	2.68x10^{-4}
Jablanički	No Pattern Detected	-0.58	0.56	No Pattern Detected	0.63	0.53
Kolubarski	No Pattern Detected	-3.22	1.27x10^{-3}	No Pattern Detected	-1.96	0.05
Mačvanski	No Pattern Detected	-3.33	8.76x10^{-4}	No Pattern Detected	-2.17	0.03
Moravički	No Pattern Detected	-2.48	0.01	No Pattern Detected	-2.32	0.02
Nišavski	No Pattern Detected	-1.74	0.08	No Pattern Detected	-0.16	0.87
Pčinjski	No Pattern Detected	-0.58	0.56	No Pattern Detected	0.63	0.53
Pirotski	No Pattern Detected	0.16	0.87	No Pattern Detected	-0.32	0.75
Podunavski	No Pattern Detected	-4.12	3.79x10^{-5}	No Pattern Detected	-3.64	2.68x10^{-4}
Pomoravski	No Pattern Detected	-3.54	4.02x10^{-4}	No Pattern Detected	-3.54	4.02x10^{-4}
Rasinski	No Pattern Detected	-2.96	3.10x10^{-3}	No Pattern Detected	0	1.00
Raški	No Pattern Detected	-3.27	1.06x10^{-3}	No Pattern Detected	-2.32	0.02
Šumadijski	No Pattern Detected	-4.28	1.88x10^{-5}	No Pattern Detected	-3.91	9.28x10^{-5}
Toplički	No Pattern Detected	-3.01	2.61x10^{-3}	No Pattern Detected	0.05	0.96
Zaječarski	No Pattern Detected	0.58	0.56	No Pattern Detected	-2.09	0.04
Zlatiborski	No Pattern Detected	-2.48	0.01	No Pattern Detected	-2.32	0.02

Table 3. Parameters of the HSA for breast cancer by county from 1999 to 2021 (z – z-score, p – p-value).

County	Breast cancer					
	Incidence			Mortality		
	Pattern	z	p	Pattern	z	p
Beogradski	No Pattern Detected	2.96	3.10×10^{-3}	No Pattern Detected	0.79	0.43
Borski	No Pattern Detected	2.85	4.34×10^{-3}	No Pattern Detected	-1.85	0.06
Braničevski	No Pattern Detected	2.77	0.01	No Pattern Detected	-1.58	0.11
Jablanički	No Pattern Detected	3.70	2.18×10^{-4}	No Pattern Detected	0.11	0.92
Kolubarski	No Pattern Detected	5.07	3.96×10^{-7}	No Pattern Detected	-0.16	0.87
Mačvanski	No Pattern Detected	3.91	9.28×10^{-5}	No Pattern Detected	0.40	0.69
Moravički	No Pattern Detected	5.60	2.16×10^{-8}	No Pattern Detected	0.95	0.34
Nišavski	No Pattern Detected	3.75	1.77×10^{-4}	No Pattern Detected	-0.16	0.87
Pčinjski	No Pattern Detected	3.70	2.18×10^{-4}	No Pattern Detected	0.11	0.92
Pirotski	No Pattern Detected	3.80	1.43×10^{-4}	No Pattern Detected	-0.11	0.92
Podunavski	No Pattern Detected	1.11	0.27	No Pattern Detected	-2.01	0.04
Pomoravski	No Pattern Detected	2.48	0.01	No Pattern Detected	-1.53	0.13
Rasinski	No Pattern Detected	1.90	0.06	No Pattern Detected	-0.95	0.34
Raški	No Pattern Detected	3.64	2.68×10^{-4}	No Pattern Detected	-1.95	0.05
Šumadijski	No Pattern Detected	3.01	2.61×10^{-3}	No Pattern Detected	-3.17	1.53×10^{-3}
Toplički	No Pattern Detected	2.96	3.10×10^{-3}	No Pattern Detected	0.71	0.48
Zaječarski	No Pattern Detected	3.06	2.19×10^{-3}	No Pattern Detected	-1.90	0.06
Zlatiborski	No Pattern Detected	5.60	2.16×10^{-8}	No Pattern Detected	0.95	0.34

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