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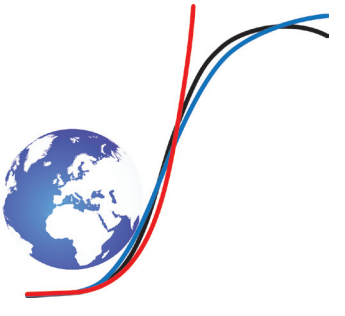

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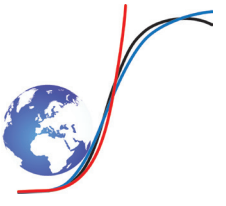

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"POPULATION DYNAMICS AND RISING TEMPERATURES IN SERBIA REGIONAL ASPECT"

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A**bstract:** Serbia is experiencing severe demographic challenges alongside significant environmental pressures. Both components of population dynamics—natural increase and migration balance—have contributed to a declining population trend. Simultaneously, Serbia is expected to be heavily impacted by climate change, particularly in terms of rising average temperatures. Using cluster analysis, this study identifies homogeneous areas within Serbia based on population dynamics and climate parameters. Employing 10 key variables, Serbian municipalities were classified into four distinct clusters. The capital, Belgrade, stands out as a 'heat island' with the highest immigration rates, while municipalities in Eastern, Southeastern, and partially Western Serbia—predominantly hilly and mountainous regions—exhibit more favorable climatic conditions but suffer from severe demographic decline (depopulation, negative migration balance, and negative natural increase). This analysis raises an essential question for future research: Will the intensification of climate change and the worsening environmental conditions in the capital alter migration patterns, directing populations toward regions characterized by lower environmental stress and reduced exposure to climate extremes in Serbia? This study establishes a strong foundation for further research within the POPENVIROS project, which aims to explore the relationship between population dynamics and climate change in Serbia. Identifying homogeneous regions—one of the primary objectives of this paper—will facilitate the mapping of specific areas that require deeper investigation into the complex interactions between demographic trends and climate change.

Keywords: POPENVIROS, population dynamics, rising temperatures, climate changes, cluster analysis, municipalities of Serbia.

Apstrakt: Srbija se suočava sa ozbiljnim demografskim izazovima uz značajne ekološke pritiske. Obe komponente dinamike stanovništva, prirodni priraštaj i migracioni saldo, doprinose opadajućem trendu broja stanovnika. Istovremeno, očekuje se da Srbija bude ozbiljno pogođena klimatskim promenama, naročito porastom prosečnih temperatura

vazduha. Koristeći klaster analizu, ova studija identifikuje homogene oblasti u Srbiji na osnovu dinamike stanovništva i klimatskih parametara. Na osnovu 10 ključnih varijabli, opštine u Srbiji su klasifikovane u četiri različita klastera. Glavni grad, Beograd, izdvaja se kao „toplotno ostrvo" sa najvišim stopama imigracije; opštine na istoku, jugoistoku i delimično zapadu Srbije (pretežno brdsko-planinska područja) imaju povoljnije klimatske uslove, ali ih istovremeno karakterišu i izuzetno nepovoljni demografski trendovi (depopulacija, negativan migracioni bilans i negativan prirodni priraštaj). Ova analiza postavlja ključno pitanje za buduća istraživanja: da li će intenzifikacija klimatskih promena i pogoršanje ekoloških uslova u prestonici promeniti migracione obrasce, preusmeravajući stanovništvo ka područjima sa nižim ekološkim stresom i manjom izloženošću klimatskim ekstremima? Ova studija postavlja osnovu za dalje istraživanje u okviru projekta POPENVIROS, koji ima za cilj da istraži odnos između dinamike stanovništva i klimatskih promena u Srbiji. Identifikacija homogenih regiona, kao jedan od osnovnih ciljeva rada, omogućiće mapiranje specifičnih oblasti koje zahtevaju dublje razmatranje složenih interakcija između demografskih trendova i klimatskih promena.

Ključne reči: POPENVIROS projekat, populaciona dinamika, porast temperature, klimatske promene, klaster analiza, opštine Srbije.

INTRODUCTION

Serbia has been experiencing significant demographic challenges, including depopulation, an aging population, low fertility rates, and emigration. Over the past decade, the country's population has declined by more than 600,000, reaching approximately 6.6 million in 2022. The natural increase rate—reflecting the balance between births and deaths—turned negative in 1992 and has been steadily decreasing ever since, reaching -7.0 per 1,000 inhabitants in 2022. Alongside this, a negative migration balance has further contributed to depopulation, with estimates ranging between 15% and 26% (Nikitović, 2022).

Over the past few decades, environmental challenges have become an increasing global concern (Funk et al., 2020). While population dynamics influence the environment and climate, they are also affected by environmental changes. The severe impacts of climate change and related hazards are being felt worldwide. It is widely acknowledged that climate change is largely anthropogenic, and the continuous deterioration of environmental conditions significantly affects individual and population well-being (Lutz, 2010). Serbia is expected to be among the regions most affected by climate change, particularly in terms of rising average temperatures. Between 1950 and 2017, temperatures showed a consistent upward trend, while annual precipitation remained largely unchanged, though its distribution, frequency, and intensity shifted (Đurđević et al., 2018). Since the mid-20th century, the average temperature has increased

by 0.36°C per decade, with climate projections estimating a total rise of between 2°C and 4.3°C by 2100 (Božanić & Mitrović, 2019; Janković et al., 2019). Extreme weather events are becoming more frequent and intense due to rising temperatures. Approximately 57% of Serbia's territory is at risk from heatwaves, droughts, floods, forest fires, and other climate-related hazards (Dragićević et al., 2011; Mirić et al., 2024).

In response to the challenges Serbia is facing, the POPENVIROS project—"Population Dynamics under Environmental Challenges in Serbia"—was recently developed. Funded by the Science Fund of the Republic of Serbia, the project aims to quantify the impact of environmental challenges on fertility, mortality, and migration in the country.

This paper, developed during the initial phase of the project, aims to identify homogeneous areas in Serbia based on population dynamics and climate parameters. Given the significant demographic and climatic variations across the country, as outlined in the Background section, this analysis is particularly important. The study offers several key advantages. First, it incorporates a comprehensive set of parameters reflecting all three components of population dynamics—fertility, mortality, and migration—alongside multiple climatic variables. Second, by examining these demographic and climatic factors at the municipal level, the study considers locally specific conditions, recognizing that distinct demographic and climatic characteristics influence the population-environment relationship and shape localized political responses to mitigate the demographic consequences of climate change. Third, from a broader perspective, this paper establishes a strong foundation for further research within the project, focusing on the interplay between population dynamics and climate change in Serbia. Identifying homogeneous regions will facilitate the mapping of specific areas that require deeper analysis of the connections between demographic trends and climate change.

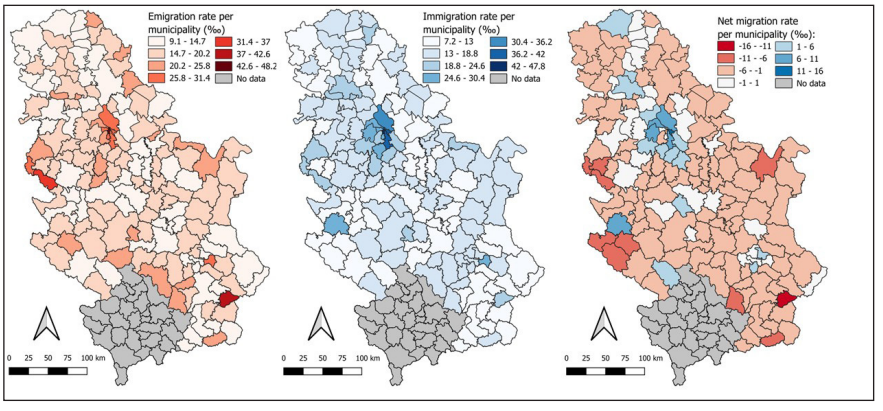
BACKGROUND

Total depopulation

Serbia's population has been steadily declining for over three decades. Estimates indicate that the total population has been decreasing at a consistent rate of approximately 300,000 people per decade. Over the past ten years alone, the population has shrunk by nearly 8%. The rate of natural increase first turned negative in 1992 and has been in continuous decline, averaging around -9 per 1,000 inhabitants between 2011 and 2022. At the beginning of the 21st century, in addition to the negative natural increase, a

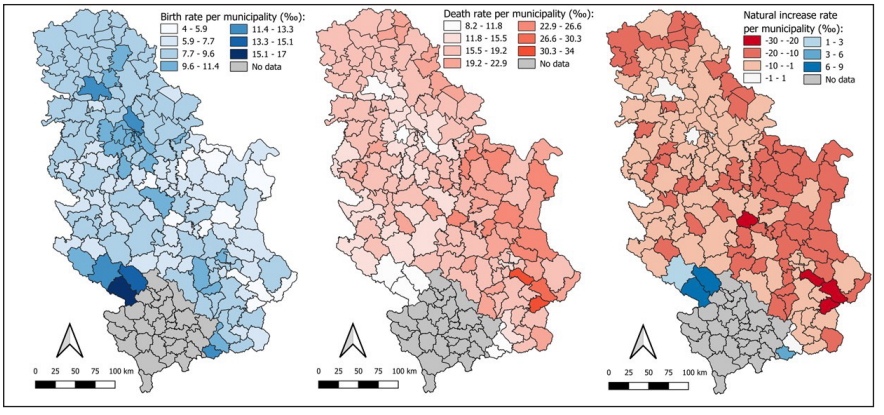
negative migration balance also began contributing to the overall population decline. Between 2011 and 2022, the migration balance stood at -1.8‰, further exacerbating demographic challenges.

Regional disparities in natural increase and migration balance are highly pronounced. The Belgrade region is the only area with a positive population growth rate, primarily due to internal migration driven by the attractiveness of the Belgrade metropolitan area (Nikitović et al., 2015). However, significant intra-regional differences exist, particularly between central and peripheral municipalities. Beyond Belgrade, municipalities with major regional centers—especially Novi Sad, Niš, and Kragujevac—exhibit either a positive or neutral migration balance. Belgrade and Novi Sad, home to Serbia's leading universities, also serve as financial, administrative, economic, and cultural hubs, forming the country's uniquely fast-growing metropolitan area (Antonić, 2022). Conversely, nearly 130 municipalities in Serbia recorded a negative migration balance between 2011 and 2022 (Map 1). Biological depopulation is widespread, with 162 municipalities experiencing negative natural increase during the same period. In some municipalities in southern Serbia, the natural increase rate has reached an alarming -25‰ or lower, particularly in areas such as Crna Trava and Gadžin Han. Only five municipalities in the southwest, predominantly inhabited by Bosniaks—one of the few ethnic groups in Serbia with a total fertility rate still well above the replacement level (Rašević, 2015)—recorded a positive natural increase rate (Map 2).



Map 1. Emmigration, immigration and net migration rate in the period 2011-2022 in Republic of Serbia

(Source: Demographic data: Republic Institute of Statistics, https://data.stat.gov.rs/*; Municipalities and Republic of Serbia borders: Republic Geodetic Authority,* https://a3.geosrbija.rs/ *Software used for analyses: QGIS 3.36.3)*



Map 2. Natality, mortality and natural increase rate in the period 2011-2022 in Republic of Serbia

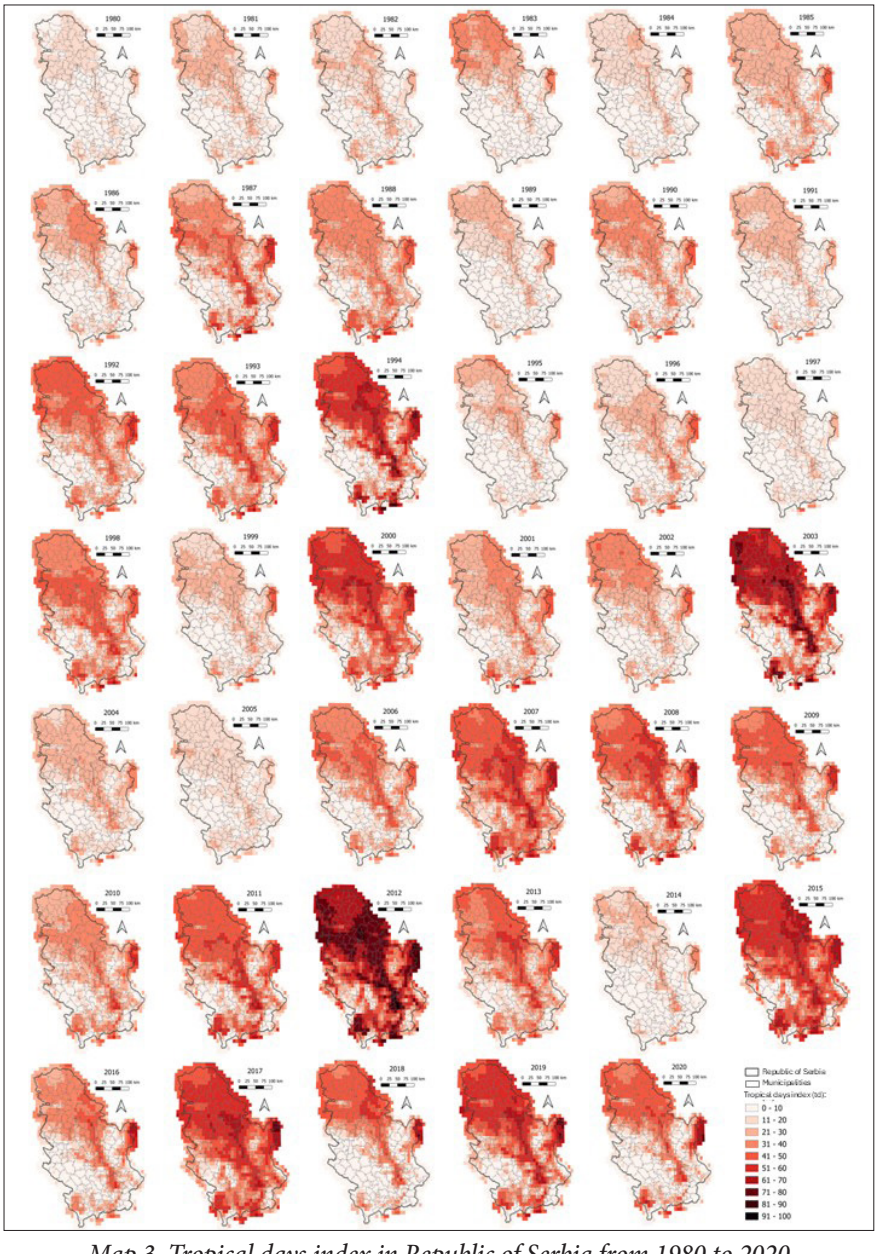
(Source: Demographic data: Republic Institute of Statistics, https://data.stat.gov.rs/*; Municipalities and Republic of Serbia borders: Republic Geodetic Authority,* https://a3.geosrbija.rs/ *Software used for analyses: QGIS 3.36.3)*

Unfavorable climate conditions

The average temperature trend in Serbia has shown a steady increase of 0.36°C per decade from 1961 to 2017. However, between 1981 and 2017, the rate of warming intensified to 0.60°C per decade (Đurđević et al., 2018). Milovanović (2015) found that the rise in air temperature is most pronounced in Belgrade, which functions as an urban heat island, registering temperatures approximately 1.1°C higher than its surroundings. Over the past decade, the average air temperature in Belgrade municipalities has exceeded 13°C, whereas in some municipalities in Western Serbia—such as Ivanjica, Prijepolje, Nova Varoš, and Novi Pazar—it has remained below 9°C. In certain areas, including Sjenica and Tutin, temperatures have even dropped below 8°C. The Vojvodina region follows Belgrade, with all municipalities recording an average air temperature above 12°C over the last decade. Meanwhile, 23 municipalities located in the mountainous areas of western and southeastern Serbia have maintained an average air temperature below 10°C.

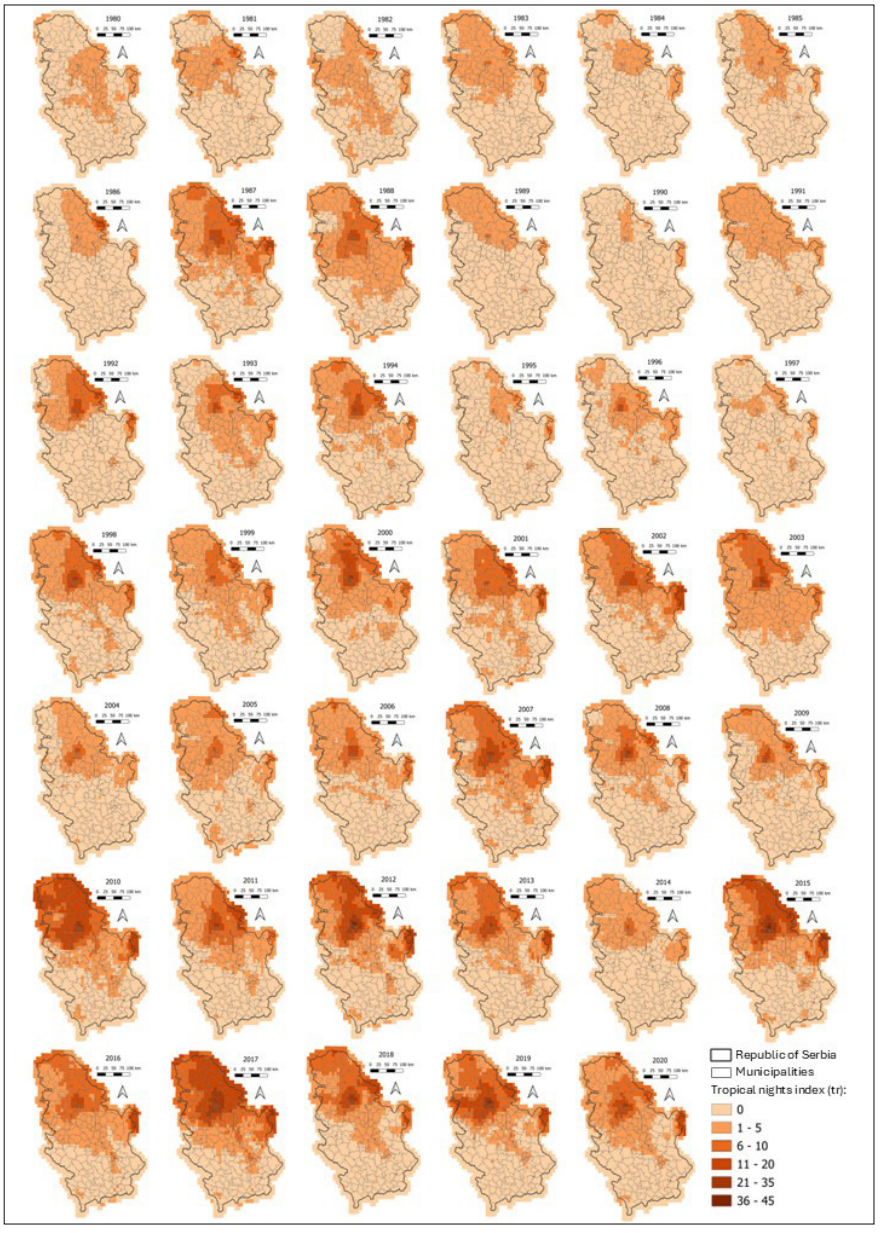
An analysis of data from the Digital Climate Atlas of Serbia reveals an upward trend in the frequency of tropical days and tropical nights in the Republic of Serbia. Of the ten years with the highest number of tropical days during the observed period, five occurred in the last decade, while nine were recorded in the past two decades (Map 3). Similarly, six of the ten years with the highest number of tropical nights took place in the last decade,

with nine out of ten occurring in the past twenty years (Map 4). Across the entire territory of the Republic of Serbia, the highest number of tropical days between 1980 and 2020 was recorded in 2012, reaching 55.23, while the greatest number of tropical nights, 5.22, occurred in 2010. These values for the Republic of Serbia were derived in QGIS as mean values calculated from all raster pixels within the dataset, which has a spatial resolution of ~ 10 × 10 km.



Map 3. Tropical days index in Republic of Serbia from 1980 to 2020

(Source: Digital Climate Atlas of Serbia, https://atlas-klime.eko.gov.rs/eng/files, *Municipalities and Republic of Serbia borders: Republic Geodetic Authority,* https://a3.geosrbija.rs/ *Software used for analyses: QGIS 3.36.3)*



Map 4. Tropical nights index in Republic of Serbia from 1980 to 2020

(Source: Digital Climate Atlas of Serbia, https://atlas-klime.eko.gov.rs/eng/files*, Municipalities and Republic of Serbia borders: Republic Geodetic Authority,* https://a3.geosrbija.rs/ *Software used for analyses: QGIS 3.36.3)*

Table 1 presents the Serbian municipalities with the highest total number of tropical days and nights during the period 2011–2020. Notably, nine of the ten municipalities with the greatest total number of tropical nights are located in Belgrade, necessitating a separate listing for the ten municipalities with the highest total number of tropical nights outside the capital. Within Belgrade, more than 260 tropical nights were recorded in Stari Grad, Savski Venac, and Zvezdara over the ten-year period. In contrast, the number of tropical nights observed outside Belgrade was significantly lower, with only three municipalities—Opovo, Zrenjanin, and Pančevo—exceeding 130 tropical nights. Regarding tropical days, the highest total numbers between 2011 and 2020 were recorded in Kostolac (545.33), Stari Grad (533.5), and Požarevac (532.12).

Table 1. Top ten municipalities in Republic of Serbia per total number of tropical days and nights from 2011 to 2020

Top ten municipalities	No. of tropical days 2011-2020
Kostolac	545.33
Stari grad	533.5
Požarevac	532.18
Smederevo	520.7
Kovin	519.2
Pančevo	519.05
Opovo	517.67
Lapovo	517.5
Palilula (Beograd)	516.31
Sečanj	515.17

Top ten municipalites	No. tropical nights 2011-2020
Stari grad	279.5
Savski venac	270.5
Zvezdara	261.25
Vračar	243
Novi Beograd	236.5
Palilula (Beograd)	200.08
Rakovica	196
Čukarica	186
Opovo	165.32
Voždovac	154.17

Top ten municipalities (Belgrade excluded)	No. tropical nights 2011-2020
Opovo	165.32
Zrenjanin	148.17
Pančevo	132.37
Stara Pazova	122.73
Kovačica	117.21
Obrenovac	115.11
Plandište	107.23
Vršac	100.82
Pećinci	100.43
Sečanj	97.42

Source: Digital Climate Atlas of Serbia, https://atlas-klime.eko.gov.rs/eng/files
Software used for analyses: QGIS 3.36.3

DATA AND METHOD

As stated in the Introduction, this paper aims to identify homogeneous areas based on population dynamics and climate parameters over the past decade. Specifically, the objective is to group all 168 municipalities in Serbia into homogeneous regions according to population trends and climate changes observed during this period.

The population dynamics variables analyzed in this study include birth rates, death rates, immigration rates, and emmigration rates across municipalities in Serbia from 2011 to 2022. These data were sourced from the open data portal of the Republic Institute of Statistics: https://data.stat.gov.rs/.

The climate change variables analyzed in this study include average air temperature, the average number of registered tropical days, and the average number of registered tropical nights in municipalities across Serbia from 2011 to 2022. Data on daily temperatures, averaged at the annual level, were sourced from the Digital Climate Atlas of Serbia: https://atlas-klime.eko.gov.rs. One of the reasons why temperature, and not precipitation, was chosen as a climate change parameter is that earlier studies identified temperature as a variable whose impact on health (and consequently on birth and death rates) is direct (Zhao et al., 2021; Ballester et al., 2023; Ebi et al., 2021), unlike other forms of climate change, which influence health indirectly—through effects on living standards and existential security. Moreover, in Serbia, the devastating impact of extreme precipitation is perceived as minor compared to the direct impact of temperature when evaluating a favorable climate. On the other hand, as highlighted in previous sections, Serbia is one of the regions most affected by rising air temperatures.

Additionally, the analysis includes socio-economic parameters that reflect the overall quality of life, health, and agricultural conditions in Serbian municipalities. These parameters include the Human Development Index (HDI), health status, and the proportion of agricultural land. HDI data for Serbian municipalities were obtained from the open data portal of the Team for Social Inclusion and Poverty Reduction in Serbia: https://socijalnoukljucivanje.gov.rs/indeks. The index ranges from 1 to 100, with higher values indicating better living conditions in a given municipality. The highest quality of life is observed in Belgrade municipalities (index above 60), whereas the lowest is found in municipalities in Eastern and Southern Serbia, such as Gadžin Han and Crna Trava (below 40). Information on health status is based on the subjective assessment of the population's health, derived from the European Health Interview Survey conducted in Serbia in 2019. The analysis utilizes the percentage of residents who rated their health as 'good' or 'very good.' The data reveal significant spatial variations in subjective health assessments, which may be influenced by differences in the population's age structure. In Belgrade, 73% of residents assess their health positively, while in other regions, the average stands at approximately 64%. The lowest percentage is observed in Eastern and Southern Serbia, the demographically oldest region, where around 60% of the population rates their health as 'good' or 'very good'. Data on agricultural land were obtained from the Copernicus portal (https://land.copernicus.eu/en/dataset-catalog). The lowest share of agricultural land is recorded in central Belgrade municipalities, such as Vračar, Stari Grad, and Savski Venac (0%), followed by Novi Beograd and Zvezdara (below 20%). Conversely, 100 municipalities report a share of agricultural land exceeding 75%, with 22 municipalities surpassing 90%. Nearly 90 of these municipalities belong

to the Vojvodina region, Serbia's most agricultural area. Additionally, four municipalities from the Šumadija and Western Serbia regions (Šabac, Bogatić, Vladimirci, and Ub) and nine municipalities from the Eastern and Southern Serbia regions (Smederevo, Smederevska Palanka, Malo Crniće, Žitorađa, Lapovo, Žabari, Svijalnac, Batočina, and Velika Plana) also exhibit a high proportion of agricultural land.

The inclusion of socioeconomic parameters in this analysis is based on the premise that climate change affects human populations through various channels, such as changes in livelihoods, agricultural production, land use, economic conditions, health, quality of life, and well-being (IPCC, 2014). These mechanisms likely influence demographic processes—including fertility, mortality, and migration—which, in turn, shape future population size (Muttarak, 2021). Agriculture is particularly vulnerable to climate change, primarily due to droughts, high temperatures, and storms. The decline in agricultural land and yields can drive rural-to-urban migration among working-age individuals, leaving rural areas predominantly inhabited by an aging population. This demographic shift leads to lower fertility rates, higher mortality, and accelerated depopulation (Petrović, 2022). Furthermore, deteriorating environmental conditions threaten traditional livelihoods, exposing people to heightened health risks and concerns over environmental changes. These pressures may force individuals to migrate (Piguet, 2008) or alter their family living arrangements (Testa & De Roso, 2013)

To identify homogeneous areas based on demographic, socioeconomic, and climate parameters, this paper employs cluster analysis. The grouping of 168 Serbian municipalities was conducted using the values of 10 demographic, socioeconomic, and climate indicators observed over the past decade. A non-hierarchical clustering method, specifically K-Means clustering, was applied to structure the dataset into predefined clusters. This method determines the central value of each variable (in this case, the 10 selected parameters) and calculates the distance from this central value to categorize municipalities accordingly. K-means clustering was used in the study because it's an effective method for identifying patterns and similarities within large and complex datasets—like those involving both demographic and climate variables across municipalities. K-means clustering allows to: a) group municipalities into homogeneous clusters based on multiple criteria (e.g., temperature, natural increase, migration balance), b) reveal spatial patterns that may not be immediately visible through individual variable analysis, c) support data-driven decision-making by clearly delineating areas with shared characteristics that may require targeted policy interventions.

Table 2. Variables included in cluster analysis

Group of variables	Variables	Timeframe
Demographic variables	Birth rate	2011-2022
	Death rate	2011-2022
	Immigration rate	2011-2022
	Emmigration rate	2011-2022
Climate changes variables	Average air temperature	2011-2022
	Average number of tropical days	2011-2022
	Average number of tropical nights	2011-2022
Socioeconomic variables	HDI index	2018
	Health status	2019
	Share of agriculture land	2018

Izvor: Authors model concept

RESULTS

The results of the cluster analysis are presented in Table 3 and Map 5. Based on 10 demographics, socioeconomic, and climate parameters, four distinct clusters were identified. The results were interpreted by emphasizing the key characteristics of each cluster.

The cluster analysis revealed that all variables significantly contributed to the grouping of municipalities in the Republic of Serbia (Sig. 0.000). The highest F values indicate that average temperature and agriculture are the most influential parameters (116.33; 314.33), meaning Serbian municipalities differ the most in terms of these two factors. Conversely, the smallest F values (6.18; 6.70) suggest that municipalities exhibit the least variation in the natural components of population dynamics. A common characteristic among nearly all municipalities (162) is a negative natural increase, driven by higher death rates compared to birth rates. While this trend is widespread across Serbia, the decline is particularly severe in clusters 2, 3, and 4, where the natural increase reaches approximately -9‰. In contrast, cluster 1 experiences a slightly less pronounced decline, with a natural increase around -3‰.

Cluster 1 stands out as the warmest region, with an average temperature of 13.64°C, and the smallest share of agricultural land (14.18%). It is also the only cluster with a positive migration balance. As noted in the Background section, migration growth contributes to the overall population increase in Belgrade, despite the negative natural increase (-3‰), with a death rate of 14.72‰ and a birth rate of 11.10‰. Since this cluster comprises the 17 municipalities of the capital, Belgrade, it is unsurprising that it exhibits the highest immigration rate, driven by intensive construction and urban expansion at the expense of agricultural land and green areas. Some

Belgrade municipalities record migration balances as high as 10‰ (e.g., Surčin, Zemun, Palilula, Voždovac, and Zvezdara), reflecting key migration pull factors such as housing availability, affordability, and accessibility to the city center. However, urban expansion has also contributed to rising temperatures, transforming Belgrade into a 'heat island' within Serbia. Despite unfavorable climate conditions—marked by the highest number of registered tropical days (47.9) and tropical nights (24.6) among all clusters—Belgrade remains the most attractive cluster due to its economic, educational, and cultural significance. Expectedly, these factors correlate with the best quality of life in the capital, as confirmed by the highest Human Development Index (HDI) value (Table 3, Map 5). In summary, *Cluster 1 is characterized by its warm climate, high development level, and favorable demographic trends*.

Cluster 2 encompasses a total of 50 municipalities in Serbia. Based on demographic, climatic, and socioeconomic variables, it ranks just behind Cluster 1. The average temperature in this cluster is approximately 1°C lower than in Cluster 1 (12.6°C). However, it has the highest share of agricultural land, as it includes nearly all municipalities in the Vojvodina region, as well as selected municipalities in Western Serbia and Šumadija—areas traditionally known for their strong agricultural presence. On average, around 82% of the land in Cluster 2 is agricultural, with some municipalities, such as Srbobran, Plandište, and Mali Iđoš, reaching as high as 95%. Additionally, Cluster 2 has an average zero migration balance, meaning that immigration generally equals or exceeds emigration. This trend is attributed to the presence of larger urban centers that attract populations, including Novi Sad, Subotica, Zrenjanin, Vršac, and Vrbas in Vojvodina, Šabac in Western Serbia, and urban municipalities near the capital—such as Pančevo, Inđija, and Smederevo. However, the attractiveness of these centers remains significantly lower than that of Cluster 1 (Belgrade), which is reflected in the lower Human Development Index (HDI) value (48.6 compared to 64.8). Unlike Cluster 1, the negative trend in natural increase is much more pronounced in Cluster 2. The natural increase rate reaches -9‰, leading to overall depopulation, despite slightly more favorable migration trends in the aforementioned urban centers (Table 2, Map 5). In summary, *Cluster 2 is primarily characterized by its dominant agricultural landscape, an intermediate position in terms of population dynamics and climate parameters (falling between Clusters 1 and 3/4)*.

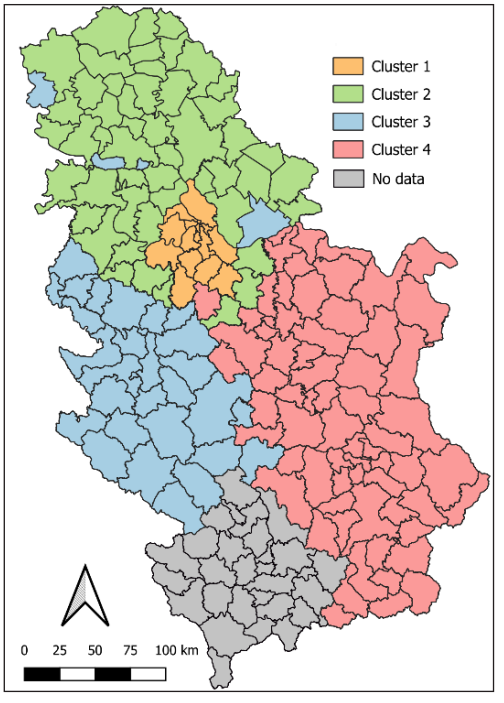
Clusters 3 (33 municipalities) and 4 (68 municipalities) exhibit significantly more favorable climate conditions, as evidenced by lower average temperatures (around 10°C) and fewer registered tropical days (approximately 30) and nights (around 2), compared to Clusters 1 and 2. This may be attributed to the physical-geographical characteristics of these

areas, which are predominantly mountainous, encompassing the Zlatibor, Zlatar, and Kopaonik mountains in the west and Stara Planina in the east. However, these clusters are marked by pronounced population emmigration, with a migration balance of nearly -3‰. This strong outmigration likely reflects the very low quality of life in these municipalities, which is confirmed by the lowest Human Development Index (HDI) values among all clusters. In municipalities such as Nova Varoš, Priboj, Ljubovija in the west and Trgovište in the east, the negative migration balance reaches as low as -10‰. Additionally, Clusters 3 and 4 experience a sharp decline in natural increase (-9‰), meaning both migration and natural demographic trends contribute to overall depopulation. In some municipalities, such as Kosjerić and Osečina in the west and Gadžin Han, Crna Trava, and Žagubica in the east, the negative natural increase surpasses -15‰. These unfavorable demographic trends are primarily due to an aging population, which is further associated with the poorest health conditions among all clusters. Clusters 3 and 4 differ notably in their share of agricultural land. Cluster 3 maintains a high proportion, exceeding 55%, as it integrates several municipalities of Western Serbia—an area traditionally known as the country's most agriculturally active region. Conversely, Cluster 4 primarily consists of municipalities in Eastern and Southeastern Serbia, a region with significantly weakened demographic potential, which remains a major barrier to development (Table 2, Map 5). In summary, *Clusters 3 and 4 are characterized by the most favorable climate conditions, yet they also face the most severe demographic decline, lowest levels of development, poorest health status, and, in the case of Cluster 3, a strong agricultural presence*.

Table 3. Results of the cluster analysis

Variables	Cluster	Mean values per clusters				ANOVA	
		1	2	3	4	F	Sig.
Demographic variables	Birth rate	11,10	8,52	8,10	8,06	6,18	,000
	Death rate	14,72	17,12	17,50	17,76	6,70	,000
	Immigration rate	29,83	15,03	15,14	14,04	36,86	,000
	Emmigration rate	26,67	15,96	16,68	17,63	42,33	,000
Climate changes variables	Average temperature	13,64	12,69	11,84	9,971	116,33	,000
	Average number of tropical days	47,90	45,03	38,02	20,78	91,76	,000
	Average number of tropical nights	24,60	7,47	3,40	1,08	65,33	,000
Socioeconomic variables	HDI index	64,80	48,59	47,36	46,35	15,08	,000
	Health status	72,80	65,50	64,00	63,20	11,86	,000
	Share of agriculture land	14,18	81,11	55,52	29,55	314,33	,000
Total number of municipalities per clusters		17	50	33	68		

Source: author's calculation



Map 5. Municipalities of Republic of Serbia categorized by clusters

(Source: Municipalities and Republic of Serbia borders: Republic Geodetic Authority, https://a3.geosrbija.rs/ *Software used for analyses: QGIS 3.36.3)*

DISCUSSION

This study applies cluster analysis to group Serbian municipalities into homogeneous clusters based on population dynamics and climate change parameters observed over the past decade. The underlying premise is that climate change affects population dynamics through socioeconomic mechanisms; thus, variables related to agriculture, health, and quality of life were included in the analysis (Muttarak, 2021).

Using 10 key variables, 4 demographic, 3 climatic, and 3 socioeconomic, municipalities were classified into four homogeneous clusters. In summary, the typical characteristics of these clusters are as follows: Cluster 1 (comprising 17 Belgrade municipalities): The warmest, most developed, and exhibiting the most favorable demographic trends (immigration-driven growth). Clusters 3 and 4 (33 and 68 municipalities, respectively, mainly in Šumadija, Western Serbia, Eastern, and Southern Serbia): These regions

experience the most pleasant climate but are also the least developed, facing severe depopulation trends. Cluster 3 is strongly associated with agriculture. Cluster 2 (50 municipalities, primarily in Vojvodina and partly in Western Serbia): Characterized by intermediate climate and demographic parameters (situated between Clusters 1 and 3/4) and distinguished by the most prevalent agricultural presence. This classification provides insight into how population dynamics interact with climate and socioeconomic conditions across Serbian municipalities.

The most notable result is the contrast between Belgrade (Cluster 1) and the rest of the country. Despite, Belgrade's challenging climate conditiones this is a primary migration destination. The municipalities of Belgrade stand out as a 'heat island' within Serbia, exhibiting the highest immigration rates and representing the only area experiencing population growth. Despite its elevated average temperature and a significant number of tropical days and nights, Belgrade remains the country's most attractive urban center, currently home to a quarter of Serbia's population. It is obvious that economic opportinities and access to services play a bigger role than environmental stress in migration decisions in Serbia. The paradox lies in the fact that, despite widespread awareness of environmental issues, the capital remains the primary migration destination. Eurostat (2025) data indicate significant differences in self-reported exposure to environmental problems based on the degree of urbanization in both Serbia and the broader European Union. In Serbia—as in many EU countries—more than 20% of the urban population reported being affected by environmental problems, compared to less than 10% of the rural population. This aligns with studies in some EU countries showing that counterurbanization is becoming increasingly pronounced, with a growing number of family households leaving major cities. This trend is largely driven by a rising preference for greener, more spacious, and rural-like environments. Karsten (2020) on the outmigration of family households from the city of Amsterdam, concludes that the primary motivation is closely linked to parents' perceptions of a 'good and healthier childhood environment'. The motivations of families with children leaving Swedish metropolitan areas are closely linked to the type of living environment they choose upon resettlement. Moreover, highly educated individuals are overrepresented among these families, indicating a potential influx of skills and expertise into the receiving regions (Sandow & Lundholm, 2019; 2023). Hansen & Aner (2017) emphasize that the motivations of highly educated individuals to relocate from urban to peripheral areas in Denmark are driven by their preferences for living conditions and local natural amenities. Interestingly, they also tend to view the new location as a permanent home. Whether the worsening environmental conditions and intensifying effects of climate change in Belgrade will alter migration

patterns and drive populations toward environmentally sustainable regions remains an open question for future research.

In contrast, Clusters 3 and 4 experience more favorable climatic conditions—such as lower temperatures and fewer tropical days and nights—yet face both natural and migration-driven depopulation. These areas, primarily located in the mountainous regions of Western and Eastern Serbia, offer environmental potential for more sustainable living. However, economic stagnation and weak infrastructure diminish their attractiveness. This pattern reflects the principle of circular cumulative causation, whereby economic underdevelopment perpetuates further depopulation (O'Hara, 2008).

As highlighted, Cluster 2 is distinguished by its agricultural profile, making the impacts of climate change on agriculture particularly significant. This sector is widely recognized as the primary channel through which climate change influences population dynamics (IPCC, 2014). Notably, rising air temperatures have coincided with a decline of approximately 15% in agricultural land in Vojvodina (Cluster 2) over the past two decades (https://data.stat.gov.rs/). Given that agriculture—highly sensitive to temperature increases—is a main source of livelihood for part of the population, it is reasonable to infer that climate change is contributing, alongside other factors, to the negative demographic trends observed in Cluster 2. The Food and Agriculture Organization (FAO, 2016) underscores the crucial link between agriculture and migration in the context of climate change. It notes that smallholder family farmers, small-scale fishers, forest-dependent communities, and pastoralists are among the most vulnerable to increasingly frequent and intense weather-related disasters. Droughts and associated food price volatility exacerbate poverty and hunger, often compelling people to seek sustainable alternatives elsewhere. Furthermore, a study encompassing 108 countries confirms that climate-induced shocks to agricultural productivity significantly increase emigration, reinforcing a causal relationship between agricultural disruption and migration patterns (Falco, Galeotti & Olper, 2019). This is consistent with findings from Europe, where studies indicate that climate change has already adversely affected the agricultural sector and will likely continue to do so in the future. Shifts in temperature and precipitation patterns, along with extreme weather events, are impacting both crop yields and livestock productivity. For instance, wheat yields in Southern Europe are projected to decline by up to 49% by 2050. This trend may lead to the abandonment of climate-vulnerable farmlands, particularly in Southern Europe (Hristov et al., 2020, Kurnik, 2019).

CONCLUSION

This study underscores the complex and regionally differentiated relationship between rising air temperatures and population dynamics in Serbia. Through cluster analysis, Serbian municipalities were grouped into four homogeneous clusters, each reflecting distinct demographic, climatic, and socioeconomic profiles. The findings highlight a stark contrast between Belgrade—an urban "heat island" that continues to attract migration despite environmental stress—and the rest of the country that possess more favorable climatic conditions but face persistent depopulation and economic stagnation. The results confirm that economic opportunities, access to services, and quality of life currently outweigh environmental concerns in shaping internal migration patterns. However, rising temperatures and climate impacts—particularly through agriculture, Serbia's most climate-sensitive economic sector—are emerging as critical factors influencing long-term demographic stability.

Clusters 3 and 4 exemplify the paradox of climate advantage undermined by infrastructural and economic weaknesses, while Cluster 2 illustrates how agricultural decline tied to climate variability may further accelerate rural depopulation. These findings align with broader European trends, suggesting that climate pressures, when combined with socioeconomic vulnerabilities, may intensify migration flows and reshape regional population structures.

The study provides a strong empirical foundation for the POPENVIROS project and future research. By identifying homogeneous regions, it facilitates targeted policy development and deeper exploration of localized climate-demographic dynamics. Future work should incorporate additional climate stressors such as drought and flood risks, while further investigating the interplay between agricultural resilience, environmental sustainability, and migration trends in both rural and urban contexts.

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"POPULACIONA DINAMIKA I RASTUĆA TEMPERATURA VAZDUHA U SRBIJI: REGIONALNI ASPEKT"

Natalija MIRIĆ
Tijana JAKOVLJEVIĆ

SAŽETAK

Tokom poslednje decenije, Srbija se suočava sa sve većim demografskim izazovima — populacija je smanjena za više od 600.000, stope fertiliteta ostaju na jako niskom nivou, stanovništvo intenzivno stari, a emigracija se ubrzava. Od početka devedesitih godina prošlog veka prirodni priraštaj je negativan, a više ljudi napušta zemlju nego što u nju dolazi. Istovremeno, Srbija postaje sve ranjivija na klimatske promene. Porast temperatura i sve češći ekstremni vremenski događaji predstavljaju sve veći rizik po javno zdravlje, poljoprivredu i egzistenciju. Prosečna temperatura u zemlji konstantno raste, a projekcije pokazuju da bi do kraja veka mogla porasti i do 4.3°C. Kao odgovor na ove trendove, pokrenut je projekat POPENVIROS kako bi se istražilo na koji način klimatski i ekološki pritisci oblikuju demografske promene u Srbiji. Ovaj rad je usmeren na identifikaciju klastera opština koje imaju slične demografske, klimatske i socioekonomske karakteristike. Kombinuju se podaci o fertilitetu, mortalitetu, migracijama, temperaturi vazduha, broju tropskih dana i noći, kvalitetu života, samoproceni zdravlja i udelu poljoprivrednog zemljišta. Ovi indikatori pomažu da se stvori sveobuhvatna slika o tome kako se različita područja u Srbiji nose s izazovima — i koji su najranjiviji. U radu se koristi klaster analiza kako bi se grupisale opštine u homogene oblasti, otkrivajući prostorne obrasce koji mogu da posluže kao osnova za kreiranje ciljane politike. Uočen je jasan kontrast između Beograda i ostatka zemlje. Beograd (Klaster 1) ostaje najatraktivnija destinacija u Srbiji uprkos nepovoljnim klimatskim uslovima. On je znatno topliji od ostatka zemlje i predstavlja urbano toplotno ostrvo čija populacija raste zahvaljujući migracionoj komponenti. Prilikom odlučivanja o preseljenju, ljudi daju prednost ekonomskim mogućnostima i pristupu uslugama, čak i kada to podrazumeva život u klimatski nepovoljnijem okruženju. Ova pojava postavlja važno pitanje: da li će ljudi i dalje biti spremni da trpe visoke temperature ako grad nudi posao i infrastrukturu, ili će pogoršanje uslova izazvati migraciju u suprotnom pravcu? S druge strane, planinska područja zapadne, istočne i južne Srbije (Klasteri 3 i 4) imaju blažu klimu sa manje ekstremnih vrućina, ali beleže intenzivnu depopulaciju — kako prirodnu, tako i migracionu. Iako klimatski povoljnija, ova područja nisu dovoljno

privlačna zbog nerazvijene ekonomije i ograničenih javnih usluga čime se propušta prilika da se iskoristi klimatski potencijal. Klaster 2, koji obuhvata veći deo Vojvodine i delove zapadne Srbije, predstavlja „sredinu“ između Beograda i Klastera 3 i 4. Bogat poljoprivredom, ali i sve ranjiviji, suočava se sa sve izraženijim pritiscima usled klimatskih promena. Temperature rastu, a površine pod poljoprivrednim zemljištem su se u Vojvodini smanjile za oko 15% tokom poslednje dve decenije. Ovaj trend prati šire evropske i globalne obrasce. Klimatski šokovi u poljoprivredi sve češće pokreću migracije, posebno iz ruralnih područja. Iako ekonomski faktori za sada imaju veći uticaj na migracije u Srbiji, klimatski uticaji (naročito oni povezani sa poljoprivredom) postaju sve ozbiljniji. Ova rad ukazuje da budući demografski tokovi u Srbiji zavise ne samo od razvoja, već i od toga kako zemlja upravlja klimatskim rizicima, podržava ruralna područja i prilagođava ključne sektore poput poljoprivrede. Ovim se postavlja čvrst osnov za dalje aktivnosti u okviru projekta POPENVIROS, uz jasne smernice za formulisanje politika koje jačaju otpornost najugroženijih oblasti. Otvaraju se i nova istraživačka pitanja — kako stanovništvo doživljava ekološke rizike, kako sačuvati poljoprivrednu održivost, i hoće li u budućnosti ljudi početi da biraju hladnija, zelenija područja za život.

Ključne reči: POPENVIROS projekat, populaciona dinamika, porast temperature, klimatske promene, klaster analiza, opštine Srbije.

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