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CARTOGRAPHIC METHODS FOR VISUALIZING DEMOGRAPHIC INDICATORS

Abstract: The cartographic method for visualizing demographic indicators on thematic maps primarily aims to focus on analysis, through a comparison of the presented numerical values, in order to determine the essential characteristics of the indicators in relation to the level of data aggregation and the area of reference territorial units. The nature of quantitative data, through the procedures of classification and generalization, is followed by the choice of cartographic method. Different maps obtained from the same dataset, as a result of the application of different cartographic methods, can present numerical data on interval and semioscale scale. The comparison shows that the choice and applied method determine the level of information (volume and quality) obtained from the map. The spatial distribution of demographic indicators graphically represented on the map must be clear and serve the research objective.

Keywords: cartographic method, demographic indicator, thematic map, information, analysis, comparison

Introduction

Visualization of demographic indicators requires an adequate choice of cartographic method in order to obtain their accurate presentation. The choice of method depends on the research goal and the type of tasks to be solved. The relationship between the type of data and the choice of cartographic method, and thus the type of thematic map in relation to its purpose, is a fundamental question that arises in the initial phase of mapping. The level of research into demographic characteristics requires and determines the degree of methodological complexity of the cartographic presentation, and therefore the amount of information that can be obtained from the map. At the same time, the thematic map should not be overloaded with content and an unnecessary combination of cartographic methods.

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Ingram (2025) emphasizes that thematic maps should be simple in design, focusing on a particular variable. A thematic map, by definition, deals with one theme, and despite the possibility of creating a bivariate map (e.g., applying the method of signs or cartographic diagrams in combination with a choropleth – using symbols and a colored surface), is a more adequate display of individual features of the mapped phenomenon on separate, analytical maps. This highlights the function of the map and simplicity as the primary feature of effective thematic maps (Dent et al., 2009).

A map is one of the most effective ways to present spatial and attribute data. Through visualization on maps, geospatial relationships between mapped indicators can be seen. In addition to their importance in the research and analysis of spatial data, maps enable the presentation of the synthesis and comparison of analyzed spatial data. In this regard, the choice of the type of data used to create the map is important. The choice of cartographic method to be used in relation to the type of data is also important from the aspect of temporal comparison - the presentation of the same area and topic for different time periods (Kraak, Ormeling, 2020). In other words, the essence of choosing a method is to display the characteristics of the data being visualized as accurately as possible. Gładzowski et al. (2015) emphasize that cartographic visualization is a process that includes the processing and analysis of spatial data and their presentation in accordance with the methodology of cartographic representation and the processing technology used. In addition to the choice of cartographic method, the process includes the generalization and processing of source data.

The number of attribute components of the data (from one or more data sets for one or more temporal sections) requires data transformation, i.e. their conversion into cartographic forms that are defined by the properties of the methods to be applied. Research requirements also define the number of thematic maps, in order to view certain characteristics of phenomena more comprehensively, express their regularities of distribution and trend of changes through the application of several different cartographic methods through a series of maps. Maps with thematic-oriented data are a source of information that can serve as a basis for designing different types of maps (Losang, 2011, Vondrakova et al. 2011 & Bac-Bronowicz et al., 2018). As stated by Dent et al. (2009), each individual map is only one of many possible cartographic representations of a variable from the dataset. In this context, the present paper showcases three mapping methods (symbol method, cartographic diagram method and choropleth) of selected numerical values of indicators (population, area and population density) through a series of 7 maps. The paper presents the possibilities of mapping the same indicator by choosing 2 different cartographic methods. The comparison shows that the choice and applied method determine the level of information to be obtained from the map, depending on the purpose and objective of the research. In this context, the form of cartographic presentation on thematic maps primarily aims to focus on analysis, through a comparison of the presented numerical values, in order to determine the essential characteristics of the indicator in relation to the level of data aggregation and the area of reference spatial units.

The aim of the present paper is to elaborate the content of the map by adequately choosing the cartographic method, which enables analysis through three levels:

I – Informative about the thematic content of the map, which provides insight through a specific and immediate visual representation of the mapped type of indicator of a specific phenomenon using a selected, adequate cartographic method. Based on the map key, information and knowledge about the map as a whole is obtained.

II – Cognitive through obtaining information about the size of the indicator of the mapped phenomenon. It is based on the analysis of the type of scale of the indicator of the phenomenon, which is a foundation that facilitates the comparison of the obtained numerical information.

III – Interpretation, analysis, comparison and ascertainment of knowledge about the intensity, dynamics, characteristics, tendency, regularities and laws of the spatial distribution of the presented indicator of a specific phenomenon.

Research Methodology

Thematic maps facilitate the visualization of the spatial-temporal aspect of numerical – statistical data. In order to correctly present statistical data on a map, it is necessary to choose an appropriate cartographic method in relation to the data theme and type of data. The selected theme can be graphically represented on a map in various ways. In addition to the type of data, the choice of method is also influenced by the level of data aggregation, i.e. the size of the reference spatial unit to which the data relate (region, area, municipality). Bac-Bronowicz et al. (2018), point out that the accuracy of the representation, in addition to the choice of method, is also determined by the size of the reference area expressed through the scale of the base map.

The aim of the present paper was to showcase the Population Census data using different cartographic methods and to highlight the impact of the type of data (absolute and relative), at the same level of data aggregation, on the volume and type of information obtained when presented using different methods. The paper presents 3 methods of the thematic indicators mapping: the symbol method, the cartographic diagram method and the choropleth method. Data visualization using the selected methods was performed in relation to the type of quantitative data: absolute (total) and relative (derived, mathematically calculated) at the municipality level, as a reference spatial unit.

The determination of the scope of the thematic map content arises from the theme to be presented and which had defined the content and scale of the base map. Out of the elements of the base map content, only the boundaries of municipalities are presented, as adopted reference spatial units. The map of the administrative-territorial division of the Republic of Serbia (municipality level) that was used and prepared for use in the GIS software, as a basis for the work, was taken from the Administrative Units Register of GeoSerbia, Open Data of the National Spatial Data Infrastructure (<https://opendata.geosrbija.rs/>). The boundaries of the reference, administrative-territorial units are the municipal boundaries of the Bor area: (Bor, Kladovo, Majdanpek, Negotin) and the Zaječar area (Boljevac, Zaječar, Knjaževac, Sokobanja). Official data from the Population Census for the period 1981-2022 were used to create the thematic content of the maps (<https://popis2022.stat.gov.rs/sr-Latn/popisni-podaci-eksel-tabele/>). Maps on which the symbol method and the cartographic diagram method were applied were created in AutoCAD (base map scale 1:1250000), and the choropleth maps were created in QGIS (base map scale 1:2500000).

Comparative maps are presented using the symbol method: Number of inhabitants of the municipalities of the Bor and Zaječar areas, in 1991 and 2022. Data classification (absolute values) was performed using the equal interval method into 5 classes, unified for

both datasets. In relation to the class range, the sizes of the symbols were conditionally scaled (proportional graded scale).

Using the method of map diagrams, series of numerical values of demographic indicators were presented through the procedures of semioscale construction of symbols. By adjusting the scale of the symbols, the intensities of the phenomena mapped in the present paper were graphically presented and compared. Depending on the type of data (absolute and/or relative values) and the selected reference data (max, min or average value), the form of cartographic presentation was aligned with the methods of semioscale presentation of series of numerical values of selected demographic indicators (Jovanović et al., 2024). The methodology of semioscale mapping is based on the approach defined by Sretenović (1980; 1982/83; 1989 & 2014), according to which "semioscale is a conditional mathematical relationship between a certain metric of a symbol (s) and the value of an indicator (g) of the state of a phenomenon in a characteristic change intersection ($1:i, 1:I$)", and is calculated based on the following parameters:

g – a series of numerical values of the content indicator that is being mapped (it can be either absolute or relative value) with an appropriate series of geometric symbols;

G – the base numerical value of the indicator, which is selected depending on the purpose of the research (can be: max, min, mean value or some other selected or calculated characteristic value from the series of numerical values of the indicator – g);

S – the value of the base scalar of the symbol (it is chosen conditionally, as the optimal value for the base value of the indicator – G , which also defines the base symbol on the map);

s – the value of the scalar or surface metric of the selected symbol, which represents individual values from the series of numerical indicators (g) of the content that is being mapped;

t – scalar reducer (for linear dimensioning), or T – surface reducer (for surface dimensioning);

i – scalar denominator of semioscale ($1:i$) in linear dimensioning of the symbol; or I – surface denominator of semioscale ($1:I$) in surface dimensioning of the symbol. The denominator of semioscale ($1:i$ and $1:I$) represents the number of units of measurement of the indicator value (g) represented by the scalar unit of the symbol (1 mm), or the surface unit of the planimetric symbol (1 mm^2).

c – coefficient of the planimetric geometric symbol. In relation to the selected symbol, the corresponding coefficient of the geometric shape is applied (Sretenović, 1980; 1982/83; 1989 & 2014).

According to the cited literature, in the semioscale mapping procedure applied in the present paper, parameter values are calculated using the following formulas:

scalar semioscale	$t = \frac{G}{s},$	$s = \frac{g}{t},$	$i = \frac{G}{S}$
surface semioscale	$T = \frac{G}{S^2},$	$s = \sqrt{\frac{g}{T}},$	$I = c^2 \cdot \frac{G}{S^2}$

Using the map diagram method, the present paper produced the following semioscale maps: Comparison of the population of municipalities in the Bor and Zaječar areas, 1991-2022 (absolute values), Comparison of the population growth/decline index of municipalities in the Bor and Zaječar areas 1991-2022 compared to 1981 (relative values), and Comparison of the population, area, and population density in 2022 (absolute and relative values).

The choropleth method had presented comparative maps of the population density of municipalities in the Bor and Zaječar areas by Census years (1991 and 2022). This required the selection of an adequate data classification method, which would be unified for both Censuses in order for the maps to be comparable (the same number and ranges of classes with the same threshold values). The procedure for selecting a classification method required the prior creation of a series of comparative maps, specifically for the Censuses, which presented data grouped according to different classifications. Of the 7 classifications offered by the QGIS software, 4 methods were selected as the most frequently used: natural breaks (Jenks), equal intervals, quantiles and standard deviation. In relation to the data and properties of the methods, the number of classes was determined for each method separately. Based on the analysis of the resulting series of maps and the data diagrams created for both Census years, the equal intervals method was used. The equal intervals method enables a clear and comparable display of uniformly grouped data for both Census years (optimal number and range of classes, with the same threshold values), and thus the clarity of spatial differences between municipalities.

Results and Discussion

Starting from the fact that the cartographic method includes the procedures of transition from data to forms of meaningful graphic representation – a map, the following questions arise: both visually in terms of content and in terms of graphic form, to present to users the spatial distribution of a certain phenomenon accurately, informatively, simply and attractively (Żyszkowska, 2016; Korycka-Skorupa & Gołębiowska, 2020). Therefore, the form of information presentation is based on the synthesis of decisions: how (using an adequate cartographic method and graphic variables), what (which spatial data should be displayed), to whom (type of user) and in what way it will be effective (Kraak & Brown, 2001).

The nature of quantitative data, through the procedures of classification and generalization, is followed by the choice of cartographic method. The applied method defines the scope and quality of information provided by the map. Visual perception and interpretation of the mapped indicator requires its clear graphic identification with the symbols and color used on the map. This means that they represent the content that is thematically assigned to them on the map in a certain graphic form (type and size of the symbol, color/shade), thus their function holds a clear informational expressiveness both in an overview (qualitative) and metric (quantitative) sense.

Symbol Method

Quantitative mapping methods show the spatial aspects of numerical data (Dent et al., 2009). This group of methods includes the symbol method. By placing symbols, data are positioned in geographic space, i.e., a representation of the spatial distribution of indicators is provided, while visual variables of the symbols indicate their intensity, characteristics and structure. In the present paper, this method is used to present the population of the Bor and Zaječar areas by municipality for two Census years (1991 and 2022). By comparing these maps, spatial and temporal changes are observed.

The choice of method had defined the form (absolute values) and scope (dataset) of Census data (Table 1). Data classification is conditioned by the values and distribution of data from both datasets (Census data 1991 and 2022). For proper interpretation, i.e. comparison,

it was necessary to include the values of both datasets and combine them, in order to determine the data classification method that is relevant for cartographic presentation and further analysis of the indicators. The unified data classification method, as well as the number and ranges of classes for both Census years, also enables harmonized scaling of symbols for the same values. Dobson (1973) states that when determining class intervals, one should be guided by the rule that there is the greatest degree of internal homogeneity within classes and a high degree of heterogeneity between classes. The choice of the equal intervals method (achieving the same values and class threshold for both Census years) enabled the comparison of the number of inhabitants. The data classification was carried out within 5 classes, and the size of the class range was determined by the distribution of data by municipalities from both Censuses. The threshold values of the intervals were rounded in order to obtain a uniform distribution of indicator data that is characteristic of the applied equal intervals method.

According to the unified classification and defined class ranges, the size of the symbol was also determined. Using a geometric symbol – a circle, the values are conditionally scaled in relation to the absolute values of the indicator in ascending order. The size of the symbol allows for a visual comparison of the indicator values through class intervals, represented within the spatial unit (municipality) to which it refers. By choosing the method of equal intervals in 5 classes for representing absolute values for both time series, it was possible to obtain comparative analytical maps from the spatial and temporal aspects using the symbol method (Fig. 1). The continuous range of indicator classes is followed by a proportionally continuous size of the symbol. With this method, as stated by Slocum et al. (2008), the symbols are not mathematically scaled and do not reflect real relationships in the data; instead, they are perceptually scaled (proportionally on a degree scale) in order to visually reflect the intensity and tendency of the phenomenon. Graded maps (or range symbol maps) use a set of symbols (proportional to the number of classes) to clearly distinguish each class among the others. This achieved a clear level of visual comparability of data on the spatial distribution and unevenness of the population of the municipalities of Bor and Zaječar areas according to the 1991 and 2022 Population Censuses. This map is analytical in nature and allows for spatial and temporal comparison of numerical values.

Table 1. Population, area and population density of municipalities in the Bor and Zaječar areas in 1991 and 2022

Municipalities of the Bor and Zaječar areas	Population		Area (km ²)	Population density (people per sq. km)	
	1991	2022		1991	2022
1. Bor	59900	40845	856	70,0	47,7
2. Kladovo	31881	17435	629	50,7	27,7
3. Majdanpek	27378	14559	932	29,4	15,6
4. Negotin	59559	28261	1090	54,6	25,9
5. Zaječar	72763	47991	1069	68,1	44,9
6. Boljevac	19384	10184	828	23,4	12,3
7. Knjaževac	44036	25341	1202	36,6	21,1
8. Sokobanja	21948	13199	525	41,8	25,1
AVERAGE	42106	24727	891,4	46,8	27,5

Source: Opštine i regioni u Republici Srbiji, 2024, Beograd: RZS & Uporedni pregled broja stanovnika 1948, 1953, 1961, 1971, 1981, 1991, 2002, 2011. i 2022. godine. Beograd: RZS

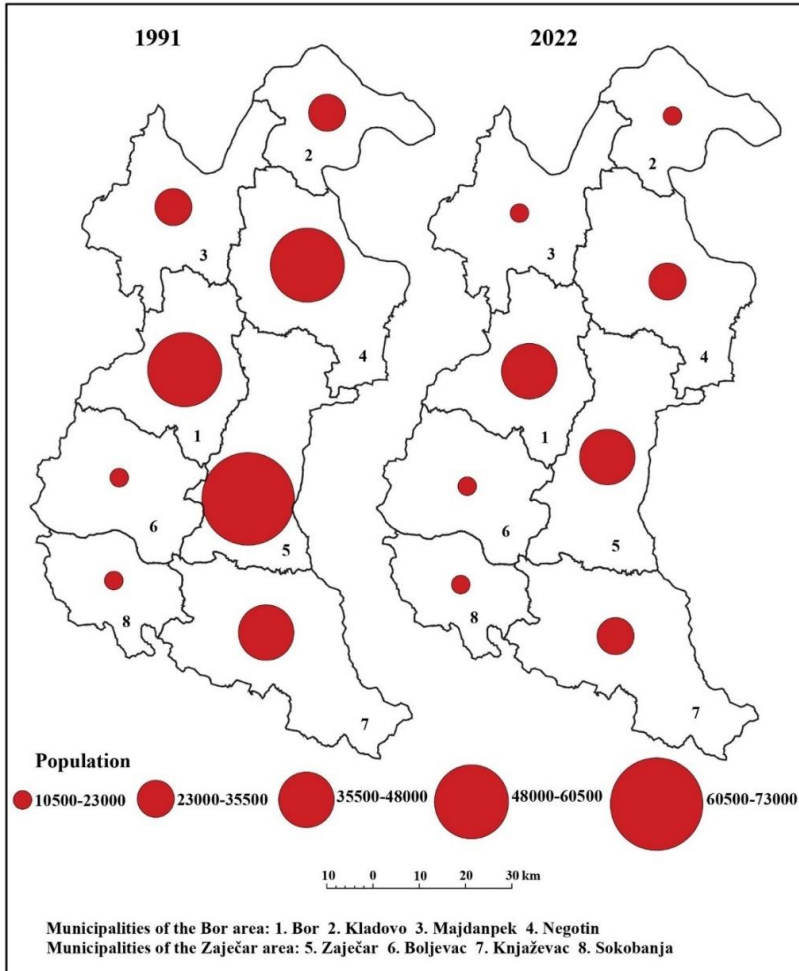


Fig. 1. Population of municipalities in the Bor and Zaječar areas, 1991 and 2022 (Source: Base map - Administrative-territorial division of the Republic of Serbia (<https://opendata.geosrbija.rs/>) & authors: thematic content of the map)

Map Diagram Method

The map diagram method enables the visualization of source (raw data obtained directly from the Census) as well as processed data (through transformation of the initial data). Using various graphical solutions, i.e. using graphical variables, the map diagram method displays the variability of the intensity of the mapped phenomenon (spatially and temporally). Determining the size of individual values, numerical differences and relationships between them by applying this method increases the informative value of the map.

A continuous map diagram can present absolute (Fig. 2) and relative data (Fig. 3) within the reference spatial units to which they refer. Representing a series of numerical values of indicators with a diagram (a series of parallel rectangles), through the process of semioscale linear scaling, a summarized map diagram is obtained. The map Comparison of the population of municipalities in the Bor and Zaječar areas (Fig. 2) presents the total, absolute values for the time period of 1991 – 2022. The comparison of the variability of the

values in the selected Census years was carried out using semioscale. An example is given by comparing the dynamics of the increase/decrease in the population in relation to the maximum value from the dataset for all 4 years of the Census. That is, the variability of the population value of all municipalities in the Bor and Zaječar areas throughout all Census years is compared with the population of 1 municipality, which had the maximum value in a certain year of the Census (Table 2). In the example given in the present paper, the maximum population value was in the municipality of Zaječar in 1991 (72763 inhabitants). This value is designated in the semioscale mapping process as the base value of the indicator (G), for which the value of the linear scalar of the symbol (base scalar S = 20.0mm) by which it is represented is conditionally determined. This determines the base value of the symbol, which in this case is the largest symbol on the map because it represents the greatest value. The values of the other linear scalars (s) are calculated using the scalar reducer (t). This allows the other symbol scalars (s) to be mathematically dimensioned, which represent all the values of the numerical values of the indicator (g) (Fig. 2). According to the nature of the content, the map is analytical and provides a display of the spatial distribution of the indicator in the period of 1991 – 2022 and the variability of the intensity in relation to the maximum value of the phenomenon.

In the map diagram method, it is important to determine the optimal diagram sizes (in this case, linearly scaled values of the length of the rectangle), in order to provide clear graphical presentation the lowest and highest values of the indicator that is being mapped. Depending on the range of occurrence data and the scale of the map base, a conditional value of the linear base scalar is chosen, and then the other scalars are metrically dimensioned in relation to it. So that all other scalar values are reduced to the base (maximum) value, in order to visualize the same data to facilitate a clear comparison. With semioscale mapping, through this example of scaling, the diagram sizes are proportional to the values of the indicator being mapped. Depending on the purpose of the research, the base value can be taken as the maximum and minimum or the mean value or any other value from a series of numerical values of the indicator (e.g. the number of inhabitants of a selected municipality in a certain year of importance for the research). The focus of the research determines the choice of the base value against which the scaling will be performed. By applying the semioscale to determine the size of the diagram, it becomes possible to read the value of each diagram on the map. This is achieved by constructing a semioscale, which is an integral part of the map key. The numerical values of the indicators can be read on the semioscale or mathematically calculated from the map using the denominator of the semioscale (i).

Table 2. Population of municipalities in Bor and Zaječar areas years 1991 – 2022

Municipalities of the Bor and Zaječar areas	Census year				Scalar value (s / mm)			
	1991	2002	201	2022.	1991	2002	2011	2022
1. Bor	59900	55817	48615	40845	16,5	15,3	13,4	11,2
2. Kladovo	31881	23613	20635	17435	8,8	6,5	5,7	4,8
3. Majdanpek	27378	23703	18686	14559	7,5	6,5	5,1	4,0
4. Negotin	59559	43418	37056	28261	16,4	11,9	10,2	7,8
5. Zaječar	72763	65969	59461	47991	20,0	18,1	16,3	13,2
6. Boljevac	19384	15849	12994	10184	5,3	4,4	3,6	2,8
7. Knjaževac	44036	37172	31491	25341	12,1	10,2	8,7	7,0
8. Sokobanja	21948	18571	16021	13199	6,0	5,1	4,4	3,6

Source: Upporedni pregled broja stanovnika 1948, 1953, 1961, 1971, 1981, 1991, 2002, 2011 i 2022. godine Beograd: RZS & authors - data processing

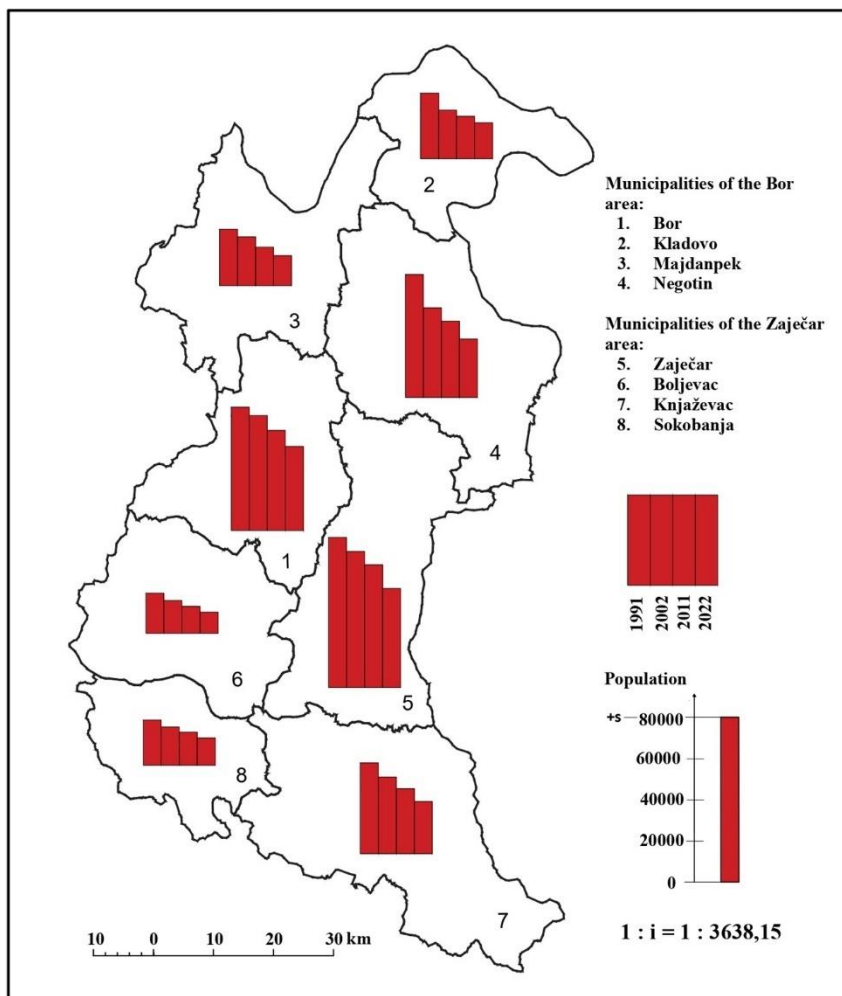


Fig. 2. Comparison of population of municipalities in Bor and Zaječar areas, years 1991 – 2022
 (Source: Base map - Administrative-territorial division of the Republic of Serbia
 (<https://opendata.geosrbija.rs/>) & authors: thematic content of the map)

In addition to absolute values, the map diagram method presents the relative values of the indicator. The method is suitable in cases when it is necessary to present data that can have both positive and negative values while maintaining the same scaling of the values (Table 3). It allows the intensity of the phenomenon to be represented by a linear scalar (the side of the rectangle), and the position of the sign with the application of color to represent positive and negative values. On the map Comparison of the population growth/decline index of municipalities of the Bor and Zaječar areas for the period of 1991 - 2022 compared to 1981 (Fig. 3), the values of this indicator are presented in a semioscale manner. The graphical representation of the dynamics of the phenomenon (intensity and temporal variability) is based on the fact that on a horizontal line corresponding to the index value of 100 (the value for 1981, against which all indices are calculated) and which marks the zero beginning, diagrams with positive values are drawn above, and diagrams with negative values below that line. The use of red (increase) and blue (decrease) colors makes the map

more graphically stylized. In order to mathematically represent the variability of the intensity of the mapped phenomenon (spatially and temporally) as accurately as possible, the diagrams are constructed in semioscale. Semioscale mapping involves adopting a base value (G) from a series (dataset) of indicators. The dataset includes all index values for all municipalities and for all Census years. The processed data (indexes) are then converted into a simpler form of that indicator by generalization and the index variation intensities ($g = \Delta i$) are obtained, which are then cartographically shaped. Depending on the purpose of the research, the maximum, minimum or any other value from a series of numerical indicator values can be selected (e.g. the value of the index variation intensity of a selected municipality in a certain year of significance for the research). In the present paper, the minimum value of the index variation intensity was chosen as an example (Bor municipality, $\Delta i = 1.2$ for year 2002/1981). In the following procedure, the minimum value of the index variation intensity is given a conditional symbol size ($S = 0.3$ mm). This dimensioning of the base symbol is done, which in this case will also be the smallest symbol on the map because it represents the lowest value. By calculating the scalar reducer (t), the other symbol scalars (s) are mathematically determined. This enables a clear and mathematically based graphical representation of the comparison of the population growth/decline index. The key of the map content constructed in this way contains, in addition to the graphical scale of the base map, a series of diagrams with the years to which they refer, the semioscale bar and the denominator of the semioscale (i). The map conceptualized in this manner methodologically belongs to the group of continuous complex diagram maps, on which the values of the indicators in relation to the selected base indicator are read and recalculated through the procedures of semioscale mapping. According to the nature of the content, the map is analytical.

Table 3. Comparison of the population growth/decline index of municipalities in the Bor and Zaječar areas, 1991 – 2022 compared to 1981

Municipalities of the Bor and Zaječar areas	Growth/decline index number of population				Intensity of index variation (Δi)				Scalar value (s / mm)			
	1991/1981	2002/1981	2011/1981	2022/1981	1991/1981	2002/1981	2011/1981	2022/1981	1991/1981	2002/1981	2011/1981	2022/1981
1. Bor	106,0	98,8	86,1	72,3	6,0	1,2	13,9	27,7	1,5	0,3	3,5	6,9
2. Kladovo	95,5	70,7	61,8	52,2	4,5	29,3	38,2	47,8	1,1	7,3	9,5	11,9
3. Majdanpek	102,8	89,0	70,2	54,7	2,8	11,0	29,8	45,3	0,7	2,7	7,5	11,3
4. Negotin	93,1	67,9	57,9	44,2	6,9	32,1	42,1	55,8	1,7	8,0	10,5	14,0
5. Zaječar	94,9	86,0	77,5	62,6	5,1	14,0	22,5	37,4	1,3	3,5	5,6	9,4
6. Boljevac	88,8	72,6	59,6	46,7	11,2	27,4	40,4	53,3	2,8	6,8	10,1	13,3
7. Knjaževac	90,3	76,2	64,5	51,9	9,7	23,8	35,5	48,1	2,4	6,0	8,9	12,0
8. Sokobanja	93,8	79,4	68,5	56,4	6,2	20,6	31,5	43,6	1,5	5,2	7,9	10,9

Index calculation based on data from Source: Uredni pregled broja stanovnika 1948, 1953, 1961, 1971, 1981, 1991, 2002, 2011 i 2022. godine Beograd: RZS (<https://popis2022.stat.gov.rs/sr-Latn/popisni-podaci-eksel-tabele/>) & authors - data processing

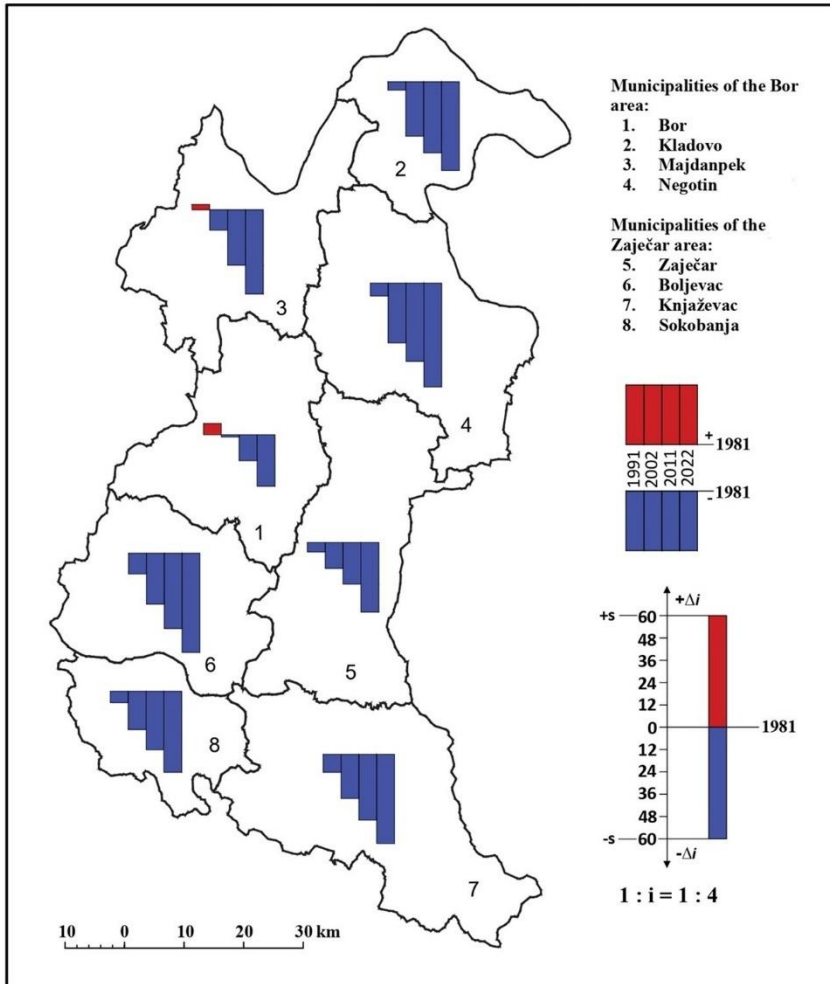


Fig. 3. Comparison of the population growth/decline index of municipalities in the Bor and Zaječar areas, 1991 – 2022 compared to 1981 (Source: Base map - Administrative-territorial division of the Republic of Serbia (<https://opendata.geosrbija.rs/>) & authors: thematic content of the map)

Numerous studies require a more comprehensive presentation of different, interconnected indicators of one or more phenomena in order to enable their comparison. Using the map diagram method, in addition to the same indicators by Census year, it is possible to simultaneously present more quantitative data of related indicators of different types (absolute and relative). The most commonly used structural diagrams are those in which the value of the phenomenon (absolute indicator) is represented, for example, by the size of a circle, and the interior of the circle is divided in relation to the participation of individual structural elements of the phenomenon (relative indicators). In addition to these, common structural diagrams (e.g. percentage participation share in the total value), which are used to provide information on the structural division of a certain phenomenon in a reference spatial unit, diagrams are also used to display 2 or 3 variables, which are interconnected but expressed in different values.

The present paper showcases a diagram with a three-element data structure, which refers to indicators between which there is a correlation. The data are previously processed in order to present them in a cartographic form in a methodological sense. The simultaneous display of different types of indicators and in different units of measurement (for the same Census year), in a way that comparability is mathematically and visually achievable, is achieved by the semi-dimensional mapping process. The possibility of graphical comparison is based on the division of a circle into 3 circular segments (each having 120°). Information about the value of the phenomenon is provided by scaling the size of each individual radius, in relation to the type of indicator represented by the particular circular segment. The map diagram showcased in the present paper Comparison of the number of inhabitants, area and population density in 2022 is complex in terms of the nature of the content. The dataset includes all values of the indicators that are mapped for that Census year. It consists of: the number of inhabitants (absolute value expressed in thousands), area (absolute value expressed in km²) and population density (relative value expressed in people per sq. km). In order for the data to be mutually comparable, it is necessary that their values are reduced to mean values for all municipalities of the Bor and Zaječar areas during the data generalization phase (Table 4). The mean values obtained for all of the three indicators (P = 24726.9 inhabitants, F = 891.4 km², A = 27.5 people per sq. km) represent their base values (G) and are scaled by the same value, i.e. for all three indicators the base scalar is the same (S = 5.0mm). The base scalar represents the radius of the circle marked on the map with a dashed line. For further cartographic data processing, it is necessary to calculate the value of the surface reducer for each indicator separately (T_P, T_F, and T_A), based on which the final result is obtained as scalars (s) - the radii of circular sections, separately for each series of indicators. The data of all indicators processed in this manner, through generalization procedures, were converted into a form that is being cartographically shaped (Fig. 4). The applied methodology facilitates the metricity of all of the three indicators presented (their total values) through their semioscale denominators (I_P, I_F, and I_A) given within the map key. They indicate that the diagrammatic sections are presented in an area scale in relation to the indicators. This methodological procedure facilitates usage of the map for: - direct comparability of the 3 interconnected indicators within each municipality; - clear comparability of the indicators and deviations from the mean value of the entire mapping area; and - comparability of individual indicators between reference spatial units.

Table 4. Comparison of population, area and population density in 2022

Municipalities of the Bor and Zaječar areas	Indicators			Scalar value (s / mm)		
	Population P	Area F	People per sq. km / A	P (s ₁ / mm)	F (s ₂ / mm)	A (s ₃ / mm)
1. Bor	40845	856	47,7	6,4	4,9	6,6
2. Kladovo	17435	629	27,7	4,2	4,2	5,0
3. Majdanpek	14559	932	15,6	3,8	5,1	3,8
4. Negotin	28261	1089	25,9	5,3	5,5	4,9
5. Zaječar	47991	1070	44,9	7,0	5,5	6,4
6. Boljevac	10184	828	12,3	3,2	4,8	3,3
7. Knjaževac	25341	1202	21,1	5,1	5,8	4,4
8. Sokobanja	13199	525	25,1	3,7	3,8	4,8
AVERAGE	24726,9	891,4	27,5	5,0		

Source: Opštine i regioni u Republici Srbiji, 2024, Beograd: RZS ; Uporedni pregled broja stanovnika 1948, 1953, 1961, 1971, 1981, 1991, 2002, 2011 i 2022. godine Beograd: RZS & authors - data processing

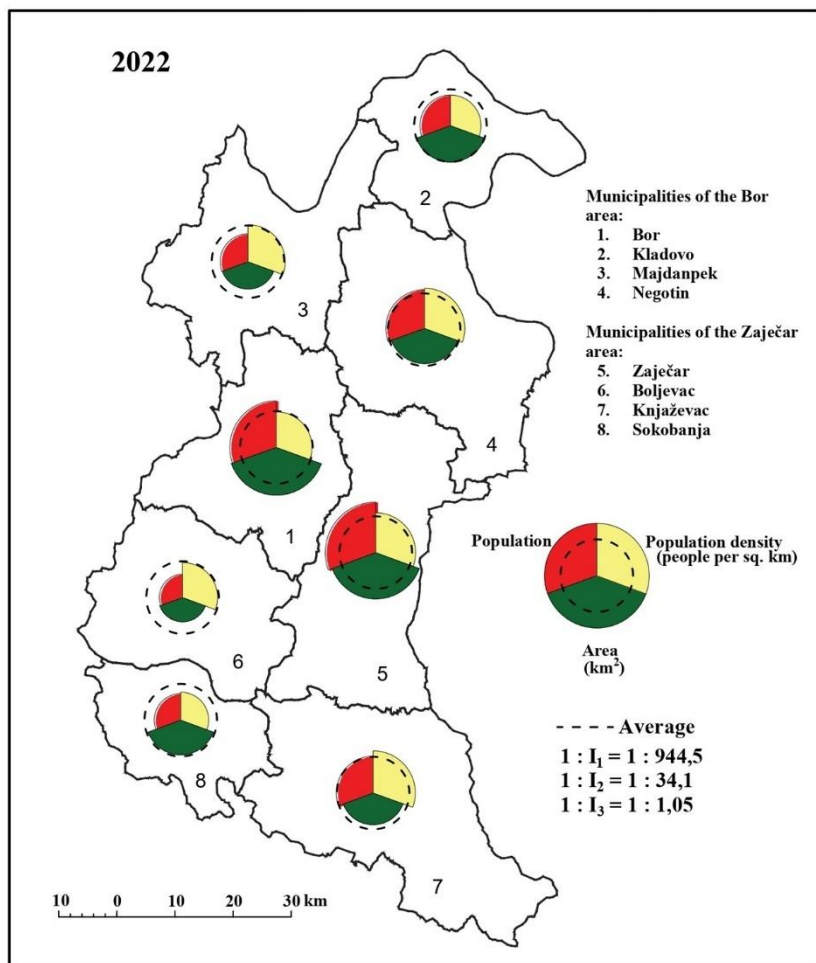


Fig. 4. Comparison of population, area and population density of municipalities of Bor and Zaječar areas in 2022 (Source: Base map - Administrative-territorial division of the Republic of Serbia (<https://opendata.geosrbija.rs/>) & authors: thematic content of the map)

Choropleth Method

The choropleth method is used only to display the values of relative indicators, and only those that are based on the relationship between two interconnected and conditioned phenomena (Pieniążek & Zych, 2020). The data being mapped always refer to the total area of the selected level of the reference spatial unit. The choropleth method represents an indicator whose values are classified into interval classes, with defined boundaries of individual intervals. Determining the number of classes is equivalent to the degree of generalization of the dataset. The display of spatial variability of indicators (e.g. population density) is conditioned by the level of data aggregation (size of the reference space unit – region, area, municipality) and the degree of generalization during data processing (choice of data classification method when defining classes and their boundary values). The choropleth method displays values from a single dataset, individually for a selected Census year, by hue or saturation of color within defined reference spatial units (e.g. municipalities).

The goal of applying the method in the present paper is to select an adequate classification method that would be used to produce analytical comparative choropleth maps of population density of municipalities of the Bor and Zaječar areas for 2 Census years (1991 and 2022) (Table 1 & Fig. 8). The procedure for selecting a classification method that would be relevant for cartographic presentation and further analysis of indicators from 2 datasets (2 Census years) requires a prior cartographic presentation of indicators using multiple classification methods, through a series of maps, specifically for each Census year. That is, the analysis and assessment require the presentation of complementary overviews on multiple maps, in order to select a method that provides the best grouping of the data. The present paper presents the population density choropleth maps of the municipalities of the Bor and Zaječar areas (at the municipality level) individually for 2 datasets – 2 Census years (1991 and 2022) using 4 methods of class separation: A) the method of natural breaks / (Jenks classification); B) equal intervals; C) the quantile method; and D) standard deviation. By applying these 4 classification methods, cartographic visualization clearly shows the differences in the presentation of the same population density data (from 2 datasets by Censuses) when using different methods of determining classes, their range and number (Fig. 5 and Fig. 6). Analyzing the maps for both Census years, differences in the size of the range, boundary values and number of classes are observed. These differences were defined by different methodological procedures for determining classes and ranges of indicator values in relation to the Census year. In order for the data to be clearly comparable and to be presented as such on a map, it was necessary to choose a method in the following procedure that would provide a unified classification of data for both Census years. The procedure for selecting a classification method included: 1) transformation and generalization of tabular statistical data, collectively from both datasets, into relevant classes to be mapped; 2) diagrammatic presentation of population density values for both Census years; and 3) analysis of the assessment of the choice of method.

The diagrams had graphically presented the difference between individual population density values and deviations from the mean values. The diagrammatic presentation provides precise information on which classification method is adequate for comparing population densities for both Census years (number and ranges of classes, class threshold values, deviations from the mean value). By processing the data, analyzing them based on the obtained cartographic representations, using 4 methods of determining classes for both Census years (Fig. 5 and Fig. 6) and a diagrammatic representation of the dynamics of population density (Fig. 7), it has been concluded that the application of the method of equal intervals, with 5 classes of the same threshold values, was adequate for comparison. The cartographic visualization of this demographic indicator, through the unification of classes for both Census years, clearly and specifically showed its distribution – both spatially and temporally (Fig. 8). This resulted in comparative choropleth maps, where the visual presentation of the data provided a clear picture of the overall spatial distribution and compared individual values of population density by municipality based on the range of classes. Also, by comparing two analytical choropleth maps of population density for different Census years, temporal changes were observed.

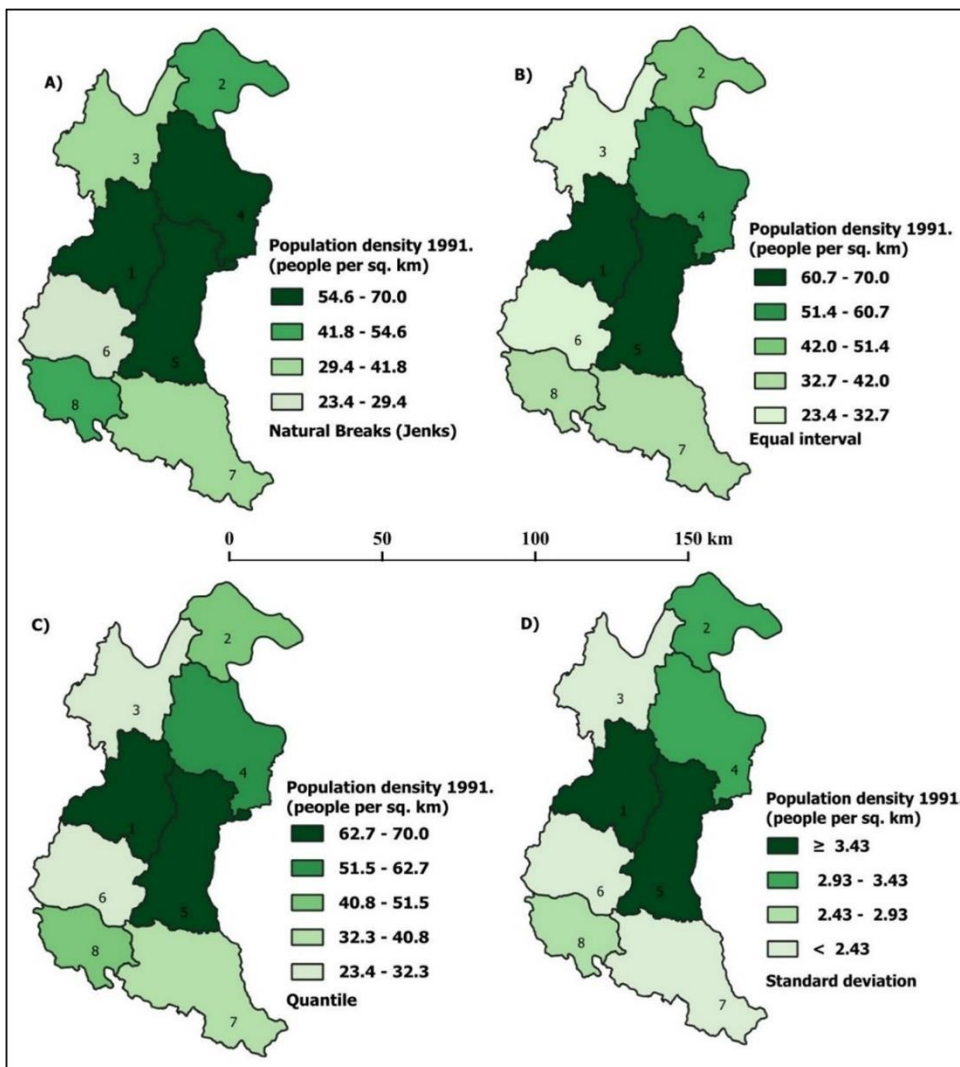


Fig. 5. Population density of municipalities in the Bor and Zaječar areas, year 1991 (Municipalities: 1. Bor, 2. Kladovo, 3. Majdanpek, 4. Negotin, 5. Zaječar, 6. Boljevac, 7. Knjaževac, 8. Sokobanja) (Source: Base map - Administrative-territorial division of the Republic of Serbia (<https://opendata.geosrbija.rs/>) & authors: thematic content of the map)

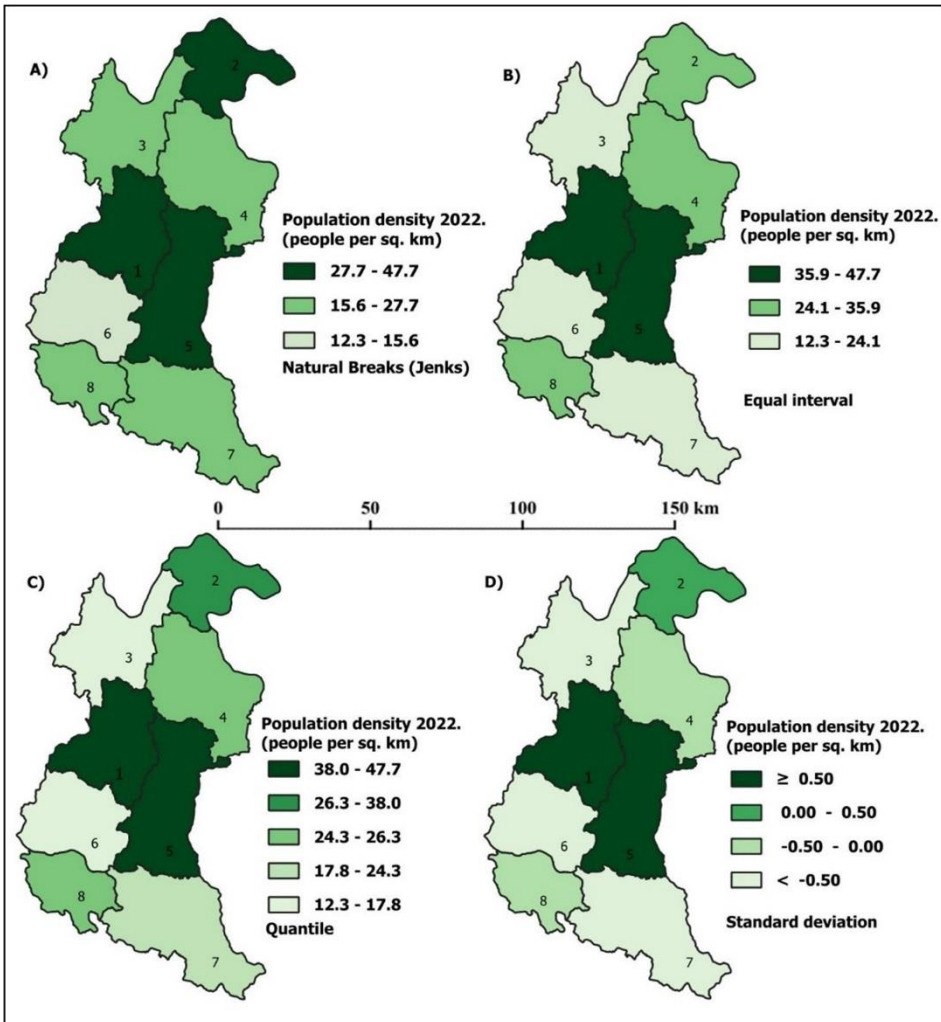


Fig. 6. Population density of municipalities in the Bor and Zaječar areas, year 1991 (Municipalities: 1. Bor, 2. Kladovo, 3. Majdanpek, 4. Negotin, 5. Zaječar, 6. Boljevac, 7. Knjaževac, 8. Sokobanja) (Source: Base map - Administrative-territorial division of the Republic of Serbia (<https://opendata.geosrbija.rs/>) & authors: thematic content of the map)

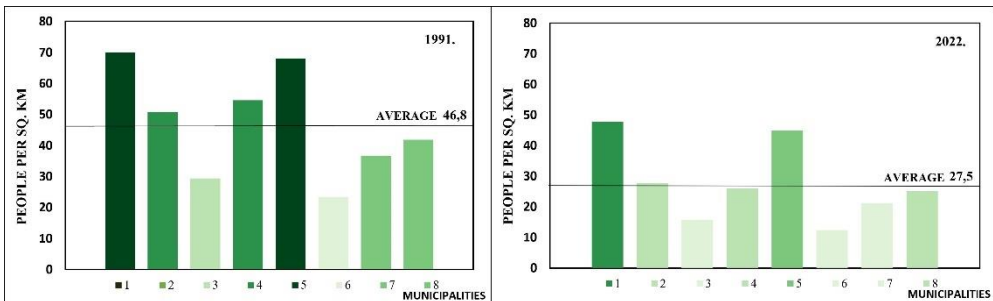


Fig. 7. Population density diagrams of municipalities in the Bor and Zaječar areas, years 1991 and 2022 (Municipalities: 1. Bor, 2. Kladovo, 3. Majdanpek, 4. Negotin, 5. Zaječar, 6. Boljevac, 7. Knjaževac, 8. Sokobanja)

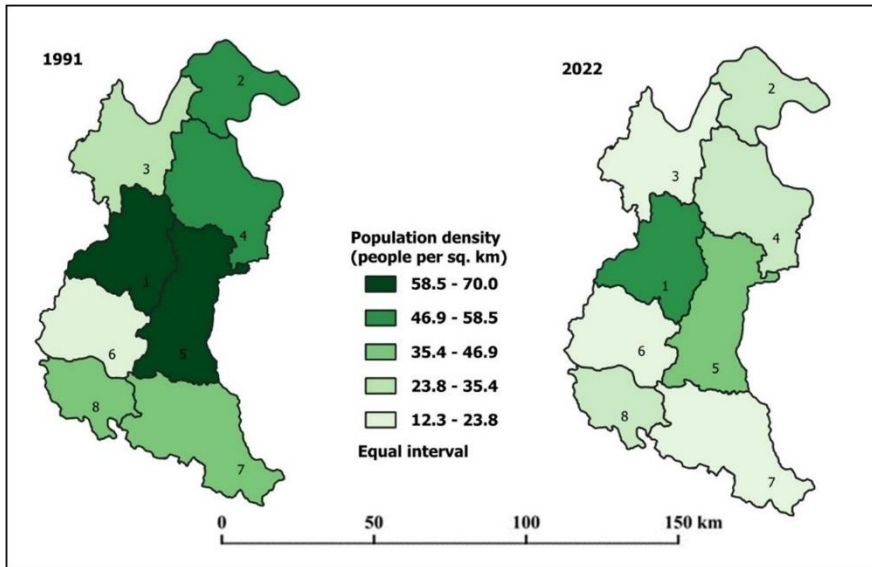


Fig. 8. Population density of municipalities in the Bor and Zaječar areas, years 1991 and 2022 (Source: Base map - Administrative-territorial division of the Republic of Serbia (<https://opendata.geosrbija.rs/>) & authors: thematic content of the map)

Demographic maps are important for studying and researching demographic processes (Abdurakhmonov et al., 2020). They convey a clear message in an unambiguous graphic form and are an essential tool in the initial stages of research, enabling visual thinking where information is explored interactively, in order to form hypotheses about the data being studied (MacEachren, 1994; MacEachren & Kraak, 1997 & Tobón, 2003).

Different types of demographic data and tasks require different methods of analysis and visualization in order to present reality more objectively (Kleinmuntz & Schkade, 1993). Visual expression of data is useful for demographic research both in the initial stages of data analysis and for gaining knowledge and drawing conclusions based on mapped data, i.e. discovering and understanding the information content of a data set. One of the advantages of visualization is that a large amount of data can be presented and easily interpreted. In addition, visualization provides a quick insight into the characteristics of the data (Tobón, 2003).

The theme and purpose of the map determines the type of data presented. Depending on the type and level of data aggregation, they can be presented in different manners, using different cartographic methods. Monmonier (1993) states that each individual map is just one of many methods of cartographic presentation of a variable or dataset. In demographic research, maps are a tool for analysis, and the functional aspect of the map must be respected. Choosing the right method of cartographic presentation is a key issue in the conceptual phase of research (Pieniążek & Zych, 2020). The choice of cartographic method and data processing method determines whether the information from the map will be obtained in a systematized, comparative, metric and overview form, which is important for different types of focused research (Jovanović et al., 2024). The application of different cartographic

methods for visualizing demographic indicators should be aligned with the requirements of the analysis.

The cartographic research method is a method based on obtaining the necessary information with the help of maps for scientific and practical knowledge of the phenomena depicted on them (Субботина & Лядова, 2021). The choice of the method for mapping demographic data depends on the purpose of the map and the need to observe changes over time and compare values between reference units. The functionality that the applied method should provide is viewed from the communicative, operational and cognitive aspects. The communicative function involves the storage and transmission of spatial information. The operational function is associated with solving practical tasks. The cognitive function allows the study of spatial phenomena and the acquisition of new information about them (Saliszczew, 2003 & Głażewski et al., 2015).

Conclusions

Demographic mapping allows for the display of data that has a geographic dimension. Visualizing data from different perspectives allows for the observation and analysis of comparability and temporal variability of data, as well as the detection of spatial patterns, trends, or variations. The focus of demographic maps on the visualization of a specific data set, using various cartographic methods, was intended to convey a clear message about the distribution of a specific variable in relation to the needs of the research.

The choice of method for cartographic representation of demographic indicators should be aligned with the type of data they cover. Data visualization through the display of temporal change should simplify the complexity and abundance of statistical data. This is achieved by processing and classifying data within reference spatial units. The results of processing, transformation and classification of data in mapping are presented in a generalized manner. Different maps obtained from the same dataset, as a result of the application of different cartographic methods, can present numerical data on an interval and semi-scale scale. The comparison shows that the choice and applied method determine the level of information obtained from the map. The spatial distribution of demographic indicators graphically represented on the map must be clear and serve the research objective. By aligning the scale of the base map, thematic content, the degree of data generalization and the selected mapping method, it becomes possible to obtain the spatial distribution, size and changes of indicators (where, what, how much and when?).

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

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