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SPATIAL ASPECTS OF DEMOGRAPHIC PROCESSES IN SERBIA

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Changes in the trends, distribution and structures of the population identified through censuses (such as the changes in total population, gender, educational, age and other structures) are crucial for understanding spatial phenomena and processes like urbanization. Numerous urban geography studies researching the development of systems of settlements in former Yugoslavia, which carried on in Serbia, were the foundation for a singular theoretical and methodological framework for researching spatial phenomena and processes focused precisely on the understanding of dynamic changes in the structures of the population and their territorial manifestation. Other than in scientific research, this approach found direct application in spatial and urban planning, when defining the measures directing demographic development, arrangement of urban functions, formation of a system of settlements, planning infrastructure development, etc. More recently, this theoretical and methodological framework was enhanced using GIS technologies, which allow for the integration of spatial and statistical data and provide for a powerful analytical tool. Data integration has spurred new research on the correlation between demographic and spatial phenomena and the mutual relationships and influences between spatial and demographic development. This paper presents an overview of existing research on the mutual influence between population development trends and spatial changes manifest through the fluctuations in the intensity of built-up areas, population density, infrastructure development, etc. A model of population distribution was created by using selected census statistical data and correlating them with phenomena in actual geospace. Emphasis is placed on the significance of using this and similar models in further research on the population's impact on the environment, directing economic development, protection in emergency situations, and numerous other areas.

Keywords: *population, spatial data, regression analysis, GIS, Serbia*

Introduction

Understanding the rules of population distribution and the related population trends, seen in the changes in total population, population density, demographic and socioeconomic structures and characteristics of a given popula-

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tion, etc., is constantly the focus of researchers' interest. More recently, with the growing use of GIS technologies and tools in research, development of statistical methods and models, rising accessibility to open data, in particular spatial data, the number of studies primarily focused on the spatial manifestation of demographic processes has been on the rise. This paper has that focus as well – its main hypothesis is that the direction of demographic development may be predicted by following spatial and geographic changes and processes. The aim of the paper is to identify the minimum number of basic spatial indicators that can explain the phenomenon of population distribution in a specific territory in an optimal way.

The research is based on facts, thoroughly explained both in theory and using methods of urban geography and regional sciences, which are based on the fact that the (economic) activity and mobility of the population of an area creates spatial and functional relations and links, determining the level of development of the overall infrastructure, manner of land use and arrangement of a territory and its overall organisation.

These activities, along with cause-and-effect changes in total population (and population density) form centres in actual geospace, and zones of (high) concentration of functions, capital *and information* around them, whereas depressions with poorly developed functions that do not ensure a satisfactory quality of life to their scarce populations form outside them. This kind of polarised development is based on certain principles that have been scientifically explained in Yugoslav and Serbian schools of urban and regional geography (Vresk, 1990; Tošić, 2012). At the core lies the imbalance between centre and periphery that spurs economic development, with the polarisation at the same time being its consequence and function. Development in geographic space is uneven, and the mutual interactions of economic units lead to the formation of a hierarchical structure of that space. The imbalance is ubiquitous due to the circulation of innovation, internal and external economic effects, decision-making processes, etc.

Concentration zones are connected with infrastructure systems that are geographically/topographically predisposed, and these links, known as development axes, are secondary concentration zones. They contribute to the agglomeration of multiple centres and zones of concentration into a metropolis.

All seemingly new and modern phenomena occurring in cities and their systems of settlements (urban sprawl, gentrification, smart/green concept development, etc.) resulted from the above mentioned processes, which differ only in terms of the location and manner of their manifestation. The key to understanding them lies in the examination of cause-and-effect links between spatial and demographic development, in the broadest sense. Mutual cause-and-effect links manifest most prominently in the relation between cities and their surroundings, and Tošić and Nevenić (2007: 297) underline the complexity of

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their influence: "… through their activities, cities affect regional integration and the differentiation of a naturally and environmentally, socio-economically, settlement-wise and demographically, physiognomically and functionally heterogeneous space, creating specific spatial systems…"

Numerous studies were conducted in Serbia on the link between demographic and spatial development. The research presented in this paper was influenced the most by the following studies: a) link between demographic development and changes in the manner of land use (Krunić, et al., 2014; Krunić, Gajić, 2016); b) applications of GIS tools and geostatistical models in the prediction of population distribution in Serbia and its regions (Bajat et al., 2009; Bajat et al., 2011a; 2011b; 2011c); c) dasymetric mapping (Bajat et al., 2011d; Bajat et al., 2011e; Krunić et al., 2011; Krunić et al., 2015a); d) modelling population density in urban areas (Bajat et al., 2013); e) spatial and functional relationships and links in urban regions and settlement networks (Krunić, 2012; Krunić et al., 2013); f) spatial manifestation of daily urban systems (Tošić et al., 2009a, 2009b), etc.

Method

The most frequent problem in the research of the mutual relationship between space and population is identifying population distribution in real geospace based on available statistical and spatial data, given that the population is in no way settled homogeneously. An additional problem stems from the scope of administrative/territorial/statistical units, which, besides the actually built-up space belonging to the settlement, also contain other uninhabited spaces. This leads to wrong assessments of population distribution, density and intensity, and an inability to establish the directions of population movements, functional links between settlements, etc.

The development of methods aimed at more accurate mapping of population distribution has a long history (Bajat et al., 2011d). These procedures are today known as dasymetric mapping. The dasymetric procedure uses various approaches in disaggregating statistical data, along with predictors, and relies both on simple statistical methods and on advanced geostatistical models, machine learning techniques, etc.

Most dasymetric models exhibit deficiencies when modelling extreme population density values, since they overestimate low-population-density areas and underestimate high-population-density areas. To overcome this problem, Cockx and Canters (2015) used the Flanders–Brussels region to propose a model based on spatial non-stationarity by comparing global (OLS), regional (rule-based) and local (geographically weighted) regression and included as predictors the information on address type (residential, mixed or commercial zone), household size and demographic and residential characteristics. It was found that the regional model that incorporates address type and household size information is the best solution for improving dasymetric mapping.

Mennis (2015) uses dasymetric mapping in an assessment of the population living in proximity to hazardous air pollutant releases (Philadelphia, Pennsylvania) in small urban areas. Use of the dasymetric model was justified by comparing census tract-level and dasymetric data, which include additional predictors (through a combination of demographic data and urban plan data).

By introducing new sets of data that do not relate merely to the manner of using land and the land cover (as had been the case in most approaches until then), Stevens et al. (2015) defined a semi-automated method, which creates maps that are not only more accurate than most other methods, but also represent variability in population density as it relates to multiple biophysical and social features across the landscape. Their model uses the "Random Forest" (RF) method, which yields a flexible weighting algorithm, thus improving the accuracy of the model in every grid cell.

Tenerelli et al. (2015) emphasise the significance of using fine scale population distribution information in the context of providing support to risk management and emergency response. They disaggregated the residential population from a local level census at the level of single building blocks, based on a dasymetric approach using an urban land use map as ancillary information. Similar studies were carried out in Serbia to determine the vulnerability of the population to floods (Bajat et al., 2012; Bajat et al., 2015; Krunić et al., 2015b).

The study by Jia and Gaughan (2016) confirms the hypothesis that the integration of land cover data, information on cadastral parcels and some demographic indicators increases the accuracy of grid cells in population distribution models. They improve the existing high-resolution gridded population surface (HGPS) by including data on numerous types of land use, ownership, household characteristics and types of residence.

Li et al. (2015) disaggregated population census data at the level of a small spatial unit (1x1 km grid) for Hungary. A dasymetric approach was used to predict the spatial distribution of population in different age groups by distinguishing residential preferences (in relation to accessible social, economic and green amenities) and land use data.

Wei et al. (2017) used a dasymetric modelling approach to establish the extent of urban sprawl and detect the related demographic changes based on a macro-regional analysis of 28 cities. In addition to census data, they

https://doi.org/10.2298/STNV1802023K

used a series of Landsat satellite imagery to establish the manner of land use.

An interesting approach to population distribution modelling was taken in the study by Liu et al. (2018), who compared data on the population recorded by mobile phone base stations and land use data. The key methodological challenge here was the fact that mobile base stations have no stable boundaries of service area, and their spatial distribution is uneven. This was resolved using a model where the phenomenon's intensity drops as the distance increases (distance-decay function). They also shed a light on the strong relationship between the number of mobile phone users and the type of nearby land use. This method is useful for identifying urban centrality, employment subcentres and population fluctuation over space and time, etc.

Zoraghein and Leyk (2018) used a dasymetric method to overcome problems when comparing high-detail census data at lower levels in cases when census boundaries change. In addition to census data, also used were data on residential parcels, housing types, road/street network and land cover classes.

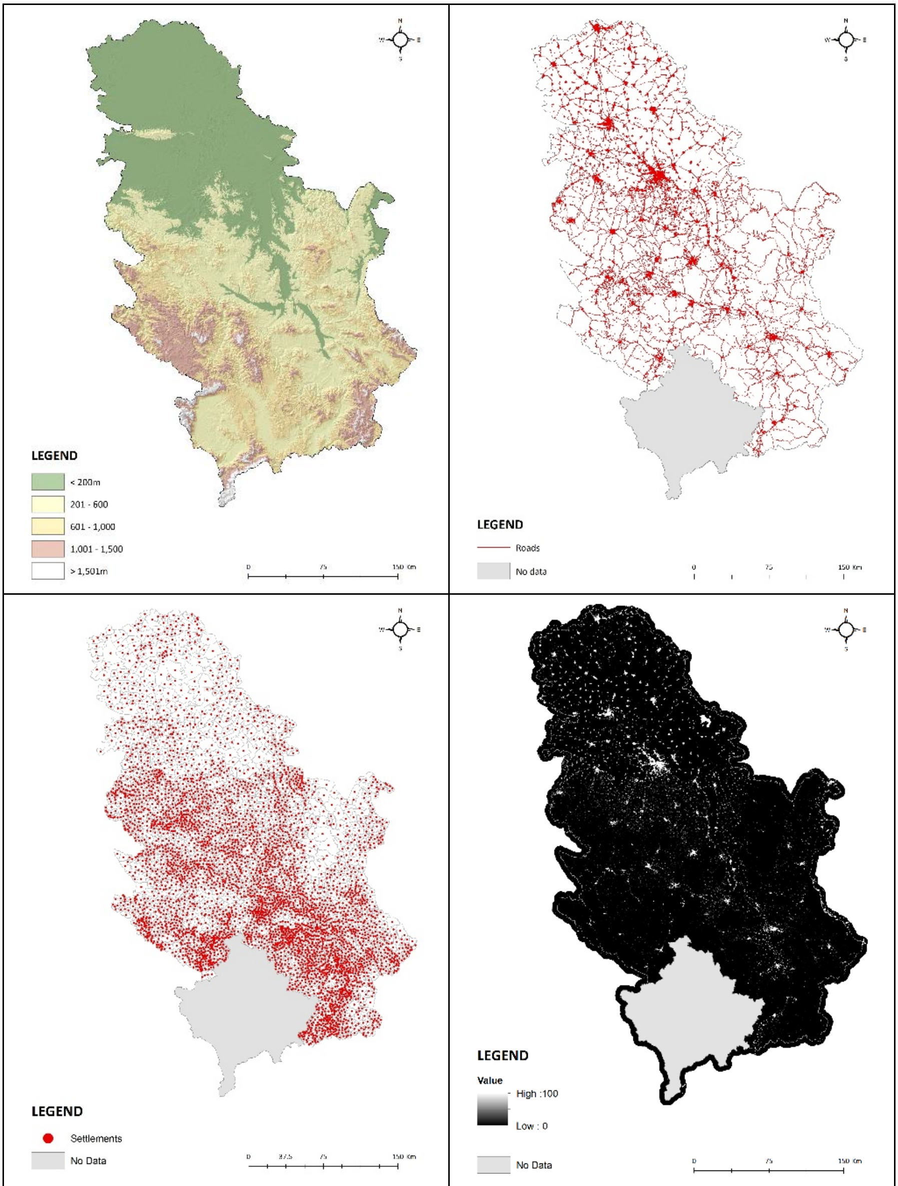
Aiming to contribute to further research on the links between space and population, this paper explores the influence of certain spatial components on population distribution in Serbia. Research results should help define appropriate models that would, based on a small set of easily available geodata, integrated with statistical population data, be used to assess the total population in a given territory, and to assume its number and distribution in the future.

This study covers the territory of the Republic of Serbia. According to the 2011 Census of population, without data available for the territory of the Autonomous Province of Kosovo and Metohija, Serbia had 7,186,862 inhabitants, with the average population density of 92 per km^2. The research was conducted at the level of 4,721 statistical settlements (Map 1). The analysis is based on official statistical census data and on open geospatial data.

Data on total population according to the 2011 census relate to the level of settlements. In addition to absolute population numbers, the following data were used: age (population aged 15 to 64) and educational structure (population with high education), changes in total population from 1961 to 2011, active employed population and the share of the total number of daily migrants in active employed population (SORS 2013a; 2013b; 2018).

Data relating to the territory of statistical settlements were taken from the Register of Spatial Units of the Republic Geodetic Authority in vector format (*shp) in the form of polygons. To prepare the statistical data layer, centroids of settlements were defined, and were assigned appropriate spatial and statistical attributes.

Map 1.
Overview of spatial data: Relief (top left), Road network (top right), Statistical settlements and their centroids (bottom left) and Intensity of built-up areas (bottom right)



Source: Authors' interpretation of the used geodata (EEA 2012: 2016, Geofabrik 2018).

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Transport accessibility is considered one of the key components of spatial and demographic development. For the purposes of this paper, accessibility to a settlement was expressed as the density of the road network in a 5 km radius from the centroid of every statistical settlement. Open spatial data from the OpenStreetMap base in the vector format (*shp) were used (Geofrabik, 2018). Based on the attributes of geospatial data that relate to the category of roads, significant roads were selected – state and local roads, and uncategorised roads, pedestrian and bicycle paths were eliminated.

Numerous studies linked altitude to population distribution (Krunić et al., 2015; Gajić, Krunić, 2015). To establish the average altitude of settlements, the EU-DEM (European Digital Elevation Model) terrain model was used, which was developed by the EEA (European Environment Agency) as part of the Copernicus program, and is available in GeoTIFF format in the spatial resolution of 25 m (EEA, 2016).

Finally, to accurately determine the position of actually built-up parts in the scope of a statistical settlement, and the intensity of built-up areas, raster data on land that became impervious to water for anthropogenic reasons (Burghardt, 2006) for 2012 in 100 m resolution was used.

To establish the relationship between total population on the one hand, and other demographic, statistical and spatial data on the other, the multiple linear regression (MLR) method was used. This approach is well-known and frequently used, both to determine the relationships and links between a dependent variable and multiple independent variables, and to identify significant indicators influencing the independent variable (Rawlings et al., 1998). It is also used to predict and assess the variation of phenomena based on other phenomena (Kleinbaum et al., 1988). In this research, the method was used with a view to accurately determine the relationships between total population and determined predictors.

Table 1.
Descriptive statistics for chosen independent variables

Variables	**Mean**	**Std. Deviation**
Total population	1,522.32	8,516.06
Population change index	65.38	85.25
Average altitude (m a. s. l.)	470.21	330.12
Intensity of built-up areas (Sum of SSD* pixel values)	3,082.24	9,970.10
Road density network (km per km^2)	0.59	0.73
Share of population aged 15-64 in total population (%)	58.42	14.65
Share of population with high education (%)	2.27	2.71
Share of daily migrants in total employed population (%)	48.40	224.20
Source: Authors' calculation. * SSD - Soil sealing degree		

The first step constituted the selection of indicators (variables) considered to have a potential impact on the overall population (Table 1). Particular attention was paid to indicators reflecting changes in Serbia's geospace. Initially, there were 7 spatial statistical indicators, but after the correlation analysis and the establishment of every variable's significance in the set model, it was found that three spatial variables (intensity of built-up areas, average altitude, road network density) were the most significant in the regression analysis. The relationship between these variables was further considered in the regression model. Values of spatial variables were obtained using GIS tools. The Statistical Package for Social Sciences (SPSS) was used for the processing, analysis and modelling of statistical data.

Results

The obtained results confirm the hypothesis on the interdependence between spatial and demographic indicators. Multiple correlation coefficient R equals 0.921, pointing to a linear correlation between the original values of the dependent variable (Total population) and the model of the predicted value of the dependent variable. The coefficient of determination (R^2) shows that 85% of the variability of the dependent variable may be explained by the regression model. The value of the adjusted determination coefficient (0.849) shows a favourable relation between the dependent variable and independent variables. Analysis of variance (ANOVA) has a significant value – 0.000, indicating that the regression model is statistically reliable. Standardised values of β coefficients suggest that the greatest share in the regression model is held by the intensity of built-up areas, followed by road network density and average altitude. Based on the value of the t-statistic and the accompanying significance values (Sig. <0.05), it may be concluded that the observed variables have a significant statistical contribution to the prediction of the dependent variable (Table 2).

Table 2.
Coefficients

Variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-3198.079	103.386		-30.933	0.000
Avg. altitude	2.992	0.153	0.116	19.551	0.000
SSD* SUM	0.725	0.006	0.849	123.430	0.000
Road_density	1824.471	80.819	0.157	22.575	0.000

Source: Authors' calculation. *SSD - Soil sealing degree

Map 2 shows residual standard deviation. Under-predicted values (where the actual population exceeds the population estimated by the model) are

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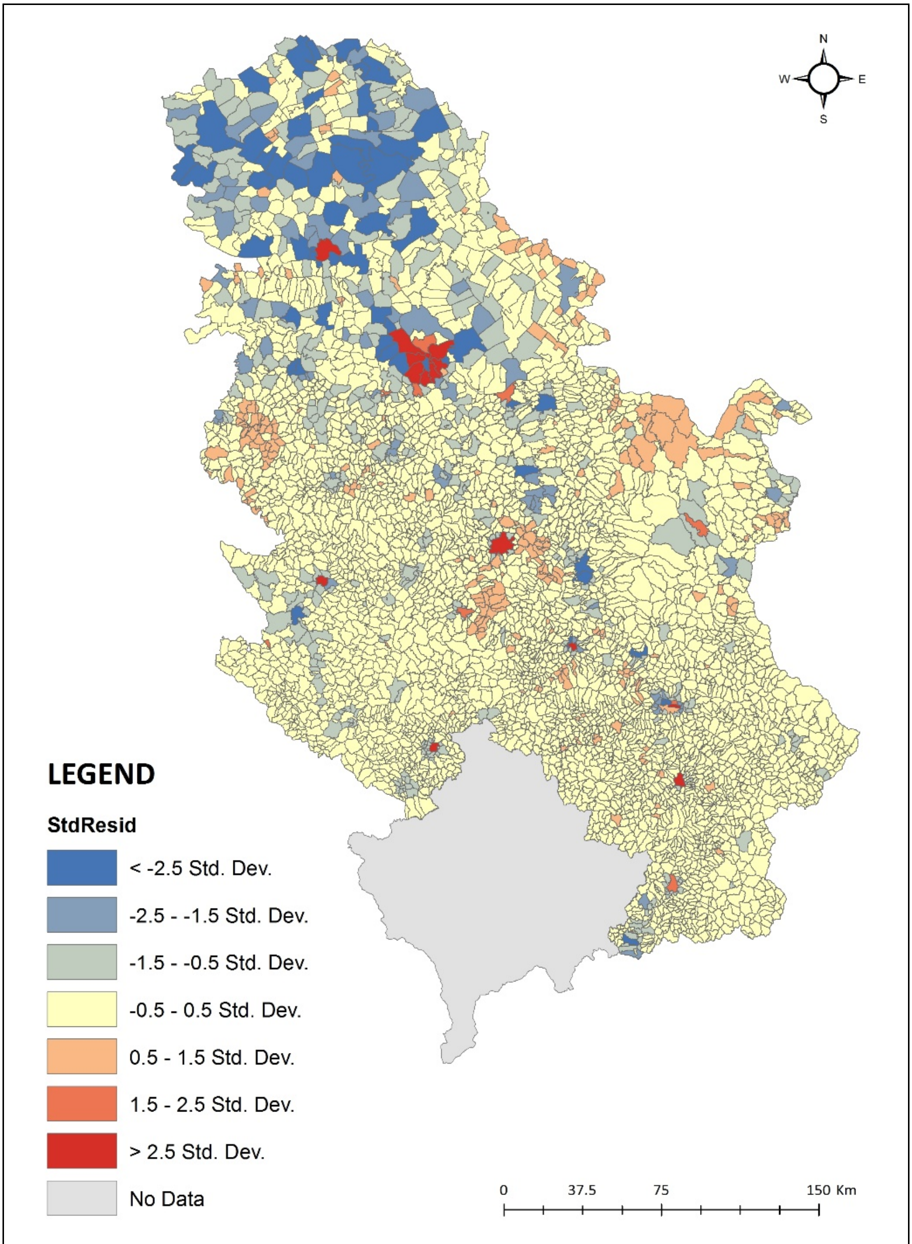
marked in white, while over-predicted values are marked in black. The total number of settlements with residual standard deviation above the tolerance band is 103, or 2.8% of the total number of observed settlements.

Map 2.
Total population in the function of spatial phenomena (residuals)



Source: Authors' calculation based on the 2011 census data (SORS 2013a).

Discussion

The research used the multiple linear regression method to identify links between spatial and demographic indicators and their influence on the overall population of Serbia. Several regression models were developed during the research. They had included more variables (population change index, share of population aged 15-64 in total population, share of daily migrants in total employed population, and share of population with high education), but after establishing the influence of each variable, only three were selected. The selected variables largely recognise the complexity of spatial and demographic relations that influence the overall population.

Similar conclusions were found in a study by Gajić et al. (2018) that explored the possibilities for the delimitation of rural and urban areas in Serbia using multivariate analysis. Principal component analysis (PCA) was used to identify the links between physical geography indicators and socioeconomic indicators, and 4 components were identified that influence the delimitation of rural and urban areas in Serbia. Spatial indicators were defined (e.g. average altitude, land use) and their relations to demographic indicators were established, while proving that these indicators have a significant impact in the explanation of the overall variance of the proposed model. Factor analysis and cluster analysis were further used to confirm the results obtained with the PCA method, leading to the identification of five types of land that may be constitute a basis for the delimitation of rural and urban areas in Serbia.

On the other hand, the greatest deficiencies of the multiple linear regression method used here are seen precisely in the areas where the complexity of spatial and demographic processes is the most pronounced (e.g. areas with high population density). Still, this is consistent with previous studies that used built-up areas to map population distribution (Krunić et al, 2015a). The influence of road network density and average altitude is considerably lower, which may in particular be seen in plains, where the use of the model encounters the greatest errors. A very high coefficient of determination of the applied model is a solid foundation for further research, modelling and prediction of demographic processes. However, spatial stationarity should not be neglected, as it is one of the main preconditions for using multiple linear regression, where parameters are calculated as average values at all locations (Mou et al., 2017). The focus of further studies will move in the direction of using models that are more locally sensitive, such as those that are obtained using geographically weighted regression (GWR). A preliminary analysis shows that this method explains around 92% of the dependent variable's value.

https://doi.org/10.2298/STNV1802023K

Conclusion

In recent decades, spatial and demographic analyses have been a prevalent topic in numerous studies and publications, mainly owing to the wide array of possibilities provided by GIS tools and various statistical software packages combined with the ever more available and high quality geospatial data (Chi, Zhu, 2008).

The results obtained by this paper additionally explain the mutual links between demographic and spatial phenomena and may substantially help other researchers in the definition of more reliable models for the assessment of total population and population distribution in Serbia. The main hypothesis of the paper was confirmed, suggesting that demographic phenomena and processes may only be understood with a good understanding of their geographic context. On the other hand, it is clear that all spatial and structural changes in settlements are the result of the activities of the population and its overall development.

Regression analysis in this paper ensures positive initial results in the identification of the main directions of movement of the population in Serbia and the relations between spatial and demographic variables. In addition to the above, the obtained results have a wide practical application, and may be significant for analyses and projections in spatial and urban planning, environmental protection, socioeconomic disciplines, etc., wherever population is a factor of spatial changes.

On the other hand, new questions are opened, which need to be considered to improve the existing model. Future research should explore other models for disaggregation of statistical data and test additional variables, etc. However, it is certain that in the near future, there will be a greater need for spatial information that, besides geographic location, contains the characteristics of the population living in those areas.

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References

BAJAT, B., HENGL, T., KILIBARDA, M., & KRUNIĆ, N. (2011a). Mapping population change index in Southern Serbia (1961-2027) as a function of environmental factors. *Computers, Environment and Urban Systems* 35: 35-44. https://doi.org/10.1016/j.compenvurbsys.2010.09.005

BAJAT, B., KRUNIĆ, N., KILIBARDA, M., & SAMARDŽIĆ-PETROVIĆ, M. (2011b). *Spatial prediction of Human Population Change*. Paper presented at AGILE International Conference on Geographic Information Science, Utrecht, Netherlands, 18-21 April 2011.

BAJAT, B., KRUNIĆ, N., KILIBARDA, M., & SAMARDŽIĆ PETROVIĆ, M. (2011c). Spatial Modelling of Population Concentration Using Geographically Weighted Regression Method. *Journal of the Geographical Institute "Jovan Cvijić"* 61(3): 151-167. https://doi.org/10.2298/IJGI1103151B

BAJAT, B., KRUNIĆ, N., KILIBARDA, M., & SAMARDŽIĆ PETROVIĆ, M. (2011d). Dasimetrijsko modeliranje demografskih parametra u funkciji izrade prostorno planske dokumentacije. In J. Petrić and M. Vujošević (eds.), *Obnova strateškog prostornog mišljenja, istraživanja i upravljanja u Srbiji*, knjiga 1, posebna izdanja (pp. 151-184). Belgrade: IAUS.

BAJAT, B., KRUNIĆ, N., & KILIBARDA M. (2011e): Dasymetric Mapping of Spatial Distribution of Population in Timok Region. *Proceedings of International Scientific Conference "Professional Practice and Education in Geodesy and Related Fields"* (pp. 31-34). Kladovo (Serbia) link

BAJAT, B., KRUNIĆ, N., BOJOVIĆ, M., KILIBARDA, M., & KOVAČEVIĆ, Z. (2012). *Population vulnerability assessment in hazard risk management: A dasymetric mapping approach*. Paper presented at the 2nd Project Workshop on "Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods", Rijeka, Croatia, December 15-17, 2011. link

BAJAT, B., KRUNIĆ, N., & KILIBARDA, N. (2009). Prediction model of spatial population distribution using geostatistics. In M. Vujošević and J. Petrić (eds.), *Regional development, spatial planning and strategic governance*, Thematic Conference Proceedings, Volume 1 (pp. 314-340). Belgrade: Institute of Architecture and Urban & Spatial Planning of Serbia.

BAJAT, B., KRUNIĆ, N., KILIBARDA, M., & SAMARDŽIĆ PETROVIĆ, M. (2013). Dasymetric modeling of population dynamics in urban areas. *Geodetski vestnik* 57 (4): 777-792. DOI: 10.15292/geodetski-vestnik.2013.04.777-792.

BAJAT, B., KRUNIĆ, N., KILIBARDA, M., & SEKULIĆ, A. (2015). Assessment of population vulnerability in risk analysis using dasymetric database of Serbia. In B. Abolmasov, M. Marjanović and U. Đurić (eds.), *2nd Regional Symposium on Landslides in the Adriatic-Balkan Region*, Conference proceedings (pp. 93-96). Belgrade: RESYLAB, Belgrade, University of Belgrade, Faculty for mining and geology.

https://doi.org/10.2298/STNV1802023K

BURGHARDT, W. (2006). Soil sealing and soil properties related to sealing. Geological Society, London, *Special Publications* 266(1): 117–124. https://doi.org/10.1144/GSL.SP.2006.266.01.09

CHI, G., & ZHU, J. (2008). Spatial Regression Models for Demographic Analysis. *Population Research and Policy Review* 27 (1): 17-42. https://doi.org/10.1007/s11113-007-9051-8

COCKX, K., & CANTERS, F. (2015). Incorporating spatial non-stationarity to improve dasymetric mapping of population. *Applied Geography* 63: 220-230. https://doi.org/10.1016/j.apgeog.2015.07.002

EEA (2012). Soil sealing degree (SSD) in TIFF format. (electronic resource). Copenhagen: European Environment Agency (EEA).

EEA (2016). European Digital Elevation Model (EU-DEM), version 1.1. GeoTIFF format. Copernicus (electronic resource). Copenhagen: European Environment Agency (EEA).

GAJIĆ, A., & KRUNIĆ, N. (2015). Noviji pristup u istraživanju urbanih i ruralnih područja u Srbiji. U D. Filipović, V. Šećerov, Z. Radosavljević (ur.), *Planska i normativna zaštita prostora i životne sredine*, zbornik radova (str. 129-135). Beograd: Asocijacija prostornih planera Srbije, Univerzitet u Beogradu – Geografski fakultet.

GAJIĆ, A., KRUNIĆ, N., & PROTIĆ, B. (2018). Towards a new methodological framework for the delimitation of rural and urban areas: a case study of Serbia. *Geografisk Tidsskrift-Danish Journal of Geography* 118 (2): 160-172. https://doi.org/10.1080/00167223.2018.1503551

GEOFABRIK (2018). Open street map (OSM) road dataset (electronic resource). Karlsruhe: Geofabrik.

JIA, P., & GAUGHAN, A. E. (2016). Dasymetric modeling: a hybrid approach using land cover and tax parcel data for mapping population in Alachua County, Florida. *Applied Geography* 66: 100-108. https://doi.org/10.1016/j.apgeog.2015.11.006

KLEINBAUM, D. G., KUPPER, L. L., & MULLER, K. E. (1988). *Applied Regression Analysis and Other Multivariable Methods* (2nd ed.). Boston: PWS Publishing Co.

KRUNIĆ, N. (2012). Spatial-functional organization of settlements in Vojvodina. *Spatium* 28: 23-29. https://doi.org/10.2298/SPAT1228023K

KRUNIĆ, N., BAJAT, B., KILIBARDA, M., & TOŠIĆ, D. (2011). Modelling the spatial distribution of Vojvodina's population by using dasymetric method. *Spatium* 24: 45-50. https://doi.org/10.2298/SPAT1124045K

KRUNIĆ, N., & GAJIĆ, A. (2016). Recent trends in population dynamics and land cover changes in metropolitan areas. In M. Vujošević, S. Zeković (eds.), *Forms of Urban Growth in Southeast Europe: Transitioning towards Urban Resilience and Sustainability*, Vol. 2 (pp. 65-92). Varna: Varna Free University & Institute of Architecture and Urban & Spatial Planning of Serbia.

KRUNIĆ, N., MAKSIN, M., MILIJIĆ, S., BAKIĆ, O., & ĐURĐEVIĆ, J. (2014). Population Dynamics and Land Cover Changes of Urban Areas. *Spatium* 31: 22-29. https://doi.org/10.2298/SPAT1431022K

KRUNIĆ, N., BAJAT, B., & KILIBARDA, M. (2015a). Dasymetric Mapping of Population Distribution in Serbia Based on Soil Sealing Degrees Layer. In K. Růžičková, T. Inspektor (eds.), *Surface Models for Geosciences. Lecture Notes in Geoinformation and Cartography* (pp. 137-149). Cham: Springer. https://doi.org/10.1007/978-3-319-18407-4_12

KRUNIĆ, N., MILIJIĆ, S., ĐURĐEVIĆ, J., BAKIĆ, O., & KRSTIĆ, V. (2015b). *Dasymetric mapping of flood impact to the population in Serbia*. Paper presented at the 9th World Congress of EWRA "Water Resources Management in a Changing World: Challenges and Opportunities", Istanbul, Turkey, June 10-13, 2015.

KRUNIĆ, N., TOŠIĆ, D., & MILIJIĆ, S. (2013). *Recent changes of spatial and functional organization of urban regions and cities in Serbia*. In A. Gospodini (ed.), Proceedings of the International Conference on "Changing Cities": Spatial, morphological, formal & socio-economic dimensions (pp. 1687-1697). Thessaloniki: University of Thessaly, Department of Planning and Regional Development. link

LI, S., JUHÁSZ-HORVÁTH, L., HARRISON, P. A., PINTÉR, L., & ROUNSEVELL, M. D. A. (2015). Population and age structure in Hungary: a residential preference and age dependency approach to disaggregate census data. *Journal of maps* 12(sup1): 560-569. https://doi.org/10.1080/17445647.2016.1237898

LIU, L., PENG, Z., WU, H., JIAO, H., & YU, Y. (2018) Exploring Urban Spatial Feature with Dasymetric Mapping Based on Mobile Phone Data and LUR-2SFCAe Method. *Sustainability* 10(7): 2432. https://doi.org/10.3390/su10072432

MENNIS, J. (2015). Increasing the Accuracy of Urban Population Analysis with Dasymetric Mapping. *Cityscape* 17 (1): 115-126. https://www.huduser.gov/portal/periodicals/cityscpe/vol17num1/ch9.pdf

MOU, Y., HE, Q., & ZHOU, B. (2017). Detecting the Spatially Non-Stationary Relationships between Housing Price and Its Determinants in China: Guide for Housing Market Sustainability. *Sustainability* 9(10): 1826. https://doi.org/10.3390/su9101826

RAWLINGS, J. O., PANTULA, S. G., & DICKEY, D. A. (1998). *Applied Regression Analysis: A Research Tool* (2nd ed.). New York: Springer-Verlag.

SORS (2013a). *2011 Census of Population, Households and Dwellings in the Republic of Serbia. Book No. 02. Age and sex*. Belgrade: Statistical Office of the Republic of Serbia (SORS).

SORS (2013b). *2011 Census of Population, Households and Dwellings in the Republic of Serbia. Book No. 20. Comparative overview of the number of population in 1948, 1953, 1961, 1971, 1981, 1991, 2002 and 2011*. Belgrade: Statistical Office of the Republic of Serbia (SORS).

SORS (2018). Census of Population, Households and Dwellings in the Republic of Serbia. Daily migrants, economically active population who perform occupation and educational attainment, at settlement level. Documentation tables. Belgrade: Statistical Office of the Republic of Serbia (SORS).

STEVENS F.R., GAUGHAN A.E., LINARD C., & TATEM, A. J. (2015). Disaggregating Census Data for Population Mapping Using Random Forests with Remotely-Sensed and Ancillary Data. *PLoS ONE* 10(2): e0107042. https://doi.org/10.1371/journal.pone.0107042

TENERELLI, P., GALLEGO, J. F., & DANIELE, E. (2015). Population density modelling in support of disaster risk assessment. *International Journal of Disaster Risk Reduction* 13: 334-341. http://doi.org/10.1016/j.ijdrr.2015.07.015

TOŠIĆ, D. (2012). *Principi regionalizacije*. Beograd: Geografski fakultet.

TOŠIĆ, D., KRUNIĆ, N., & MILIJIĆ, S. (2009a). Istraživanje prostorne organizacije mreže naselja Južnog pomoravlja u funkciji izrade prostornog plana. *Demografija* 6: 173-194. link

TOŠIĆ, D., KRUNIĆ, N., & PETRIĆ, J. (2009b). Dnevni urbani sistemi u funkciji prostorne organizacije Srbije. *Arhitektura i urbanizam* 27: 35-45.

TOŠIĆ D., & NEVENIĆ, M. (2007). Nodalna regija instrument prostorno-funkcionalne organizacije Srbije. *Zbornik radova Geografskog instituta „Jovan Cvijić“ SANU* 57: 297-307. https://doi.org/10.2298/IJGI0757297T

VRESK, M. (1990). *Grad u regionalnom i urbanom planiranju*. Zagreb: Školska knjiga.

WEI, C., TAUBENBOCK, H., & BLASCHKE T. (2017). Measuring urban agglomeration using a city-scale dasymetric population map: A study in the Pearl River Delta, China. *Habitat International* 59: 32-43. https://doi.org/10.1016/j.habitatint.2016.11.007

ZORAGHEIN, H., & LEYK. S. (2018). Enhancing areal interpolation frameworks through dasymetric refinement to create consistent population estimates across censuses. *International Journal of Geographical Information Science* 32(10): 1948-1976. https://doi.org/10.1080/13658816.2018.1472267

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Prostorni aspekti demografskih procesa u Srbiji

R e z i m e

Promene u strukturama stanovništva koje se prate popisom (kao što su npr. promene u broju stanovnika, polna, obrazovna, starosna i dr. struktura) su od ključnog značaja za razumevanje prostornih pojava i procesa poput urbanizacije. Polazeći od brojnih urbano-geografskih studija razvoja sistema naselja ostvarenih u nekadašnjoj Jugoslaviji, a nastavljenih potom u Srbiji, formiran je jedinstven teorijsko-metodološki okvir istraživanja prostornih pojava i procesa koje u fokusu imaju upravo razumevanje dinamičnih promena u strukturama stanovništva i njihovo teritorijalno manifestovanje. Ovakav pristup je, pored naučnoistraživačkog polja, našao direktnu primenu i u prostornom i urbanističkom planiranju pri definisanju mera usmeravanja demografskog razvoja, razmeštaja gradskih funkcija, formiranja sistema naselja, planiranja razvoja infrastrukture i dr. U novije vreme, ovaj teorijsko-metodološki okvir je unapređen primenom GIS tehnologije koja omogućuje integraciju prostornih i statističkih podataka i obezbeđuje moćan analitički alat. Integracija podataka podstakla je nova istraživanja korelacija demografskih i prostornih pojava, odnosno uzajamnih veza i uticaja prostornog i demografskog razvoja. U ovom radu se daje pregled dosadašnjih istraživanja međusobnog uticaja dinamike razvoja stanovništva i promena u prostoru vidljivih kroz promene u intenzitetu izgrađenosti naselja, gustini naseljenosti, infrastrukturnoj opremljenosti i dr. Korišćenjem odabranih statističkih podataka popisa, i dovođenjem njih u vezu sa pojavama u konkretnom geoprostoru, dat je model prostorne distribucije stanovništva. Naglašava se značaj primene ovog i sličnih modela u daljim istraživanjima uticaja stanovništva na životnu sredinu, usmeravanja ekonomskog razvoja, zaštite u vanrednim situacijama i brojnim drugim oblastima.

Ključne reči: *stanovništvo, prostorni podaci, regresiona analiza, GIS, Srbija*

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