Available online at www.gi.sanu.ac.rs

Journal of the Geographical Institute “Jovan Cvijić” SASA 61(3) (151-167)

Original scientific paper UDC: 911.3:007
DOI: 10.2298/IJGI1103151B

SPATIAL MODELLING OF POPULATION CONCENTRATION USING GEOGRAPHICALLY WEIGHTED REGRESSION METHOD

Branislav Bajat[1], *Nikola Krunić***, *Milan Kilibarda* *, *Mileva Samardžić – Petrović**

* Faculty of Civil Engineering at University of Belgrade
** Institute for Architecture and Urban Planning of Serbia, Belgrade

Received 13 April 2011; reviewed 5 August 2011; accepted 25 October 2011

Abstract: This paper presents possibilities of applying the geographically weighted regression method in mapping population change index. During the last decade, this contemporary spatial modeling method has been increasingly used in geographical analyses. On the example of the researched region of Timočka Krajina (defined for the needs of elaborating the Regional Spatial Plan), the possibilities for applying this method in disaggregation of traditional models of population density, which are created using the choropleth maps at the level of statistical spatial units, are shown. The applied method is based on the use of ancillary spatial predictors which are in correlation with a targeted variable, the population change index. For this purpose, spatial databases have been used such as digital terrain model, distances from the network of I and II category state roads, as well as soil sealing databases. Spatial model has been developed in the GIS software environment using commercial GIS applications, as well as open source GIS software. Population change indexes for the period 1961-2002 have been mapped based on population census data, while the data on planned population forecast have been used for the period 2002-2027.

Key words: Geographically weighted regression, population change index, dasymetric method, GIS, open source, Timočka Krajina

Introduction

The use of maps in demographic analyses is inevitable when assessing spatial aspects of demographic changes and movements and their interactions with the environment. Data on population are processed based on the census conducted by states at regular time intervals, most often once in a decade. Census data of different levels of territorial units, which are published in tabular form as the results of the processing of gathered data, have been publicly available for a long time. In the Republic of Serbia, the data are normally presented on the level of census designation places (by aggregation of census and statistical districts data),

[1] Correspondence to: bajat@grf.bg.ac.rs

in the USA those are census blocks, and in Great Britain enumeration districts. Demographic census data are mapped as statistical surfaces (DeMers, 1999) and most often presented on choropleth maps (Harvey, 2008), i.e. maps, which consist of a number of individual estimated uniform surfaces, separated by a clear, crisp boundaries.

The major drawback of choropleth method is the assumption of a homogeneous distribution of population within a spatial unit used as cartographic unit, which is not the case in reality (Tobler, 1979). Actually, the model based on a choropleth map is a result of aggregation of data obtained in census districts. The data, like population density, will in such case result in surfaces which do not envisage presentation of uninhabited regions, although they do exist in reality. The only way to overcome this problem, with the aim of making the demographic data modeling as real as possible, is to use spatial bases which indicate the degree of space usage and spatial contents, as well as to take into account the natural factors which are in correlation with spatial distribution of population.

Dasymetric mapping method is one of the possible approaches to solving of this problem, dividing the modeled space into zones of higher homogeneity degree, thus reflecting more truthfully the variations in a statistical layer, with support of additional variables and their correlations. Mennis (2003) defines dasymetric mapping as a process of distribution (disaggregation) of spatial data per smaller spatial units, more suitable for analysis, using additional/auxiliary data, in order to produce a finer distribution of population or other spatial phenomena.

Application of this method dates back to the 19th century, and the first cartographer who used this technique was George Julius Poulett Scrope in 1833, mapping the classes of global population density. The Russian geographer Tian-Shansky, who described the method in 1911 and whose map of European Russia population distribution was published in 1923 (Bielecka, 2011), is most frequently referred to as the first author of a dasymetric map. However, John Kirtland Wright was the first one who introduced this method and the origin of the word “dasymetry” in English language, in 1936, explaining it as “density measuring”. In that paper, he pointed out the advantages of dasymetric mapping regarding to standard thematic or choropleth maps. Although the choropleth mapping was practiced an entire century before Wright, the neologism “choropleth”, meaning ‘value-by-area’ method, is still attributed to him (Jarcho, 1973, Maantay, Maroko, & Herrmann, 2007).

In the course of time, the techniques of dasymetric mapping have been improved and multiplied by means of various data disaggregation or interpolation methods. Outline of methods used in dasymetric mapping may be found in the paper written by a group of authors, Maantay et al. (2007). In addition to mentioned methods, the spatial interpolation is referred as one of existing spatial data disaggregation tools. However, the major drawback of the spatial interpolation method lies in the fact that through this method the spatially continual surfaces are obtained, so that regions which are in reality uninhabited get the value (although minimal) indicating the presence of population.

As one of the ways to overcome the problem of the choropleth population density mapping, the semioscale[2] cartographic modeling of population density is also used (Janić-Siridžanski, Jovanović, & Živković, 2007). In Serbia, however, the dasymetric method for population disaggregation has not been used for practical purposes so far. The possibility of using dasymetric method for the purpose of assessing “daily“ and “night“ population in the territory of Vojvodina has been presented in a recently published paper written by a group of authors (Krunić, Bajat, Kilibarda, & Tošić, 2011) in which three land use classes have been used, while the data from the CORINE[3] 2000 land cover spatial database has been used as a basic layer for disaggregation (Nestorov & Protić, 2009).

The present paper considers the possibility of using the geographically weighted regression (GWR) interpolation method for the needs of dasymetric mapping. The geographically weighted regression method is a relatively new method used in spatial modeling (Fotheringham, Brunsdon, & Charlton, 2002). Although this method is useful in a wide range of applications, it is interesting that it has had widest practical application in the mass assessment of real property (Crespo, Fotheringham, & Charlton, 2007; Hanink, Cromley, & Ebenstein, 2010).

Increasing application of this technique is based on using the GIS database processing tools, as well as on a variety of publicly available databases on the Internet. Data processing has been made by using open-source programming language R, while data pre-processing and visualization of the obtained results, was done in the commercial ArcGIS software environment.

[2] metric representation of numerical values of mapped features by using metric of geometric figures (Sretenović, 1980)
[3] COoRdinate INformation on the Environment (abbrev.)

Geographically Weighted Regression Method

The geographically weighted regression is based on a basic linear regression model:

$$y_i = \beta_0 + \sum_{k=1}^{m} \beta_k x_{ik} + \varepsilon_i, \quad i = 1,...n \tag{1}$$

where term y_i is related to a variable to be determined, x_{ik} (k=1,…m) is a set of independent variables (predictors), and ε_i and is a residual term (the difference between the assessed and the “real” value) on i-th location (Bourennane, King, & Couturier, 2000). The regression coefficient β is usually determined using the least squares method (Perović, 2005). A multiple regression is based on prediction value model based on ancillary variables (predictors) which are in correlation with it. Thereby, it also implies a spatial stationarity of a variable to be determined. Geographically weighted regression model enables the regression coefficient β to vary spatially depending on geographic coordinates, which satisfies the assumptions of the Tobler's first law of geography according to which „Everything is related to everything else, but near things are more related to each other ” (Miller, 2004), thus more realistically describing the spatially non-stationary phenomena:

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{m} \beta_k(u_i, v_i) x_{ik} + \varepsilon_i, \quad i = 1,...n \tag{2}$$

where the pair (u_i, v_i) denotes coordinates in i-th location, $\beta_k(u_i, v_i)$ is a regression coefficient on the same location, x_{i1}, x_{i2},…,x_{im} are the the explanatory variables (predictors) on i-th location, while ε_i and is a residual or model error. Estimation of regression coefficient is given in a matrix form:

$$\hat{\beta}(i) = (X^T W(i) X)^{-1} X^T W(i) y \tag{3}$$

where W(i) is a matrix of weighting coefficient on i-th location, defined in such way that data closer to interpolated value have greater weight.

$$W(i) = diag[w_{i1}, w_{i2}, ..., w_{in}] \tag{4}$$

w_{ij} is a weighting coefficient of j sample used for estimation on the i-th location. The most frequent form of weighting functions is given in terms of Gaussian curve:

$$w_{ij} = \exp\left[-\frac{d_{ij}^2}{2b^2}\right] \tag{5}$$

Where d_{ij} is a distance between i location and sample on j location, while parameter b is a range to be determined (Figure 1). In case that the spatial distribution of sampled variables is spatially homogeneous, this parameter is taken as a constant value, while in case that the samples are of spatially different density, a spatially variable (adaptive) parameter of the range should be used.

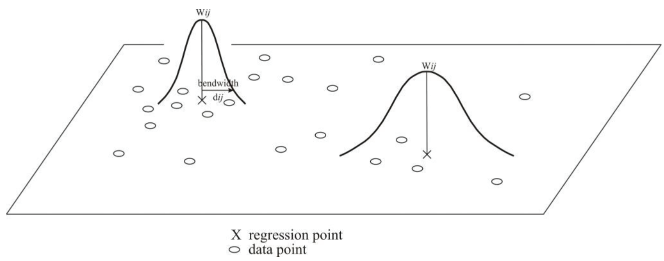

Figure 1. Weighting function w_{ij}

The presented model has been applied to test the data using open-source programming language R using module *spgwr* for geographically weighted regression (Bivand, Pebesma, & Rubio, 2008), prediction and simulation of spatial data, as well as the *sp* module, which enables spatial data manipulation in the R language (Pebesma, 2004). The results obtained in the R package may be easily converted into any of the standard GIS formats, thus enabling the additional manipulation, analysis and visualization of results in commercial GIS software.

Case Study Area Of Timočka Krajina

The data referring to geographic-demographic characteristics of surveyed area were collected for the requirements of Regional Spatial Plan of Timočka Krajina (IAUS, 2010a).

Position and Main Features of the Region

The region covered by the Spatial Plan occupies the eastern part of the Republic of Serbia and covers the territories of the Zaječar and Bor administrative districts. In physical-geographic terms, it covers most of the Timok basin, part of lower Podunavlje and the zone of its hilly-mountainous hinterlands, the upper - spring zone of the Pek river watershed and upper and mid part of the Sokobanjska Moravica watershed. The Timočka Krajina region is surrounded by the Republic of Romania in the north, the Republic of Bulgaria in the east, the

Niš and Pirot administrative district in the south, and Braničevo and Pomoravlje administrative district in the west.

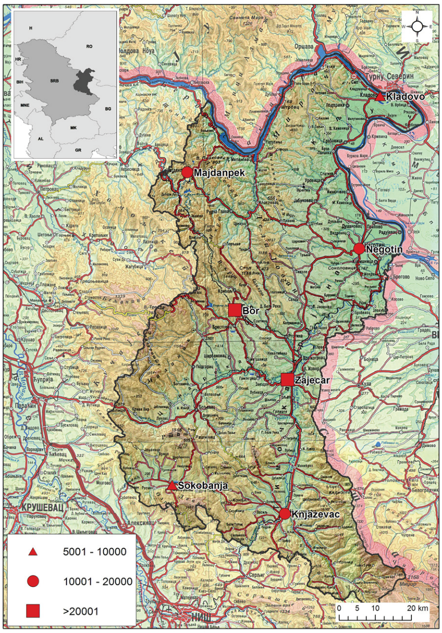

Figure 2. Researched region position

The Spatial Plan region belongs to underdeveloped and both economically and demographically depressive, specific-purpose regions: the region of the Pan-European transport corridor VII „Danube“ and contact area between Pan-European infrastructure corridors X in the west and IV in the east; the region with outstanding hydropower potentials (Hydropower and Navigation System Djerdap); an agricultural-cattle breeding and forest region; natural and tourist attractions (development of tourism on the Stara Planina mountain and on the Danube); water springs ranked national or regional ones, etc.; a region with significant reserves of mineral resources and developed mining industry (Mining and Smelting Complex „Bor“), etc.

The region covered by the Spatial Plan, over total area of 7,130 km^2 (about 8% territory of the Republic of Serbia), covers the territories of Bor, Negotin, Kladovo and Majdanpek municipalities of the Bor administrative districts (3,507 km^2) and the city of Zaječar and Knjaževac, Sokobanja and Boljevac municipalities of the Zaječar administrative districts (3,623 km^2).

Population and Settlements

The population of the Spatial Plan region numbers around 284,100 inhabitants, i.e. 3.8% total population of the Republic (Statistical Office of the Republic of Serbia, 2003.), with constantly declining tendency in all census periods since 1948. Average population density is 40 p/km^2, which is less than a half of the republic average (85 p/km^2).

During the period between 1948 and 2002, the total number of the population[4] in the region covered by the Plan decreased by about 2,800 people, or 1%. In the same period, the population of the Bor administrative district increased by 16%, while the total population of the Zaječar administrative district decreased by 17%. In the both of these administrative districts, the population grew during the period between 1948 and 1961. In the Zaječar administrative district, population began to decline after 1961, while in the Bor administrative district, similar trend was recorded after 1981. Because of constant population decline in both districts after 1981, in 2002 the total population of the region covered by the Plan was less compared to 1948 as registered using both new and old census methodology. During the period between 1981 and 1991, when the population of Timočka Krajina began to decline, the population growth was recorded in municipalities of Bor and Majdanpek (6% and 3%, respectively). However, in the last inter-census period (1991–2002), based on the new census methodology, the population of the region covered by the Plan decreased from about 317,400 to 284,112 people, or by about 33,300 people (10,5%), somewhat more in the Zaječar administrative district (10,8%) than in the Bor administrative district (10,2%). All municipalities/towns in the region covered by the Plan were depopulated during the last inter-census period. Amongst them, only the Bor municipality and the town of Zaječar have recorded population decline by less that 10%, while in all other municipalities and towns, the situation was much worse. In addition to permanent population, based on the difference in the population count obtained according to the old and the new 2002 census methodology, it may be observed that another about 30,750 people of the region covered by the Plan worked or lived abroad longer than a year, which was much more compared to about 19,500 of them in 1991 (IAUS, 2010b).

[4] We used old censuses methodology to compare census data of the year 2002. with former censuses data, according to which, in addition to the permanent population in the country, all citizens who have worked or lived (as a family members) abroad were also included. According to the new methodology, which has been applied from the year 2002., in addition to the resident population, only people working or staying abroad less than one year as well as foreign citizens who work or stay as a family members in our country for over a year are included in census data.

The settlement network of the Region is a system of 263 settlements situated in 267 cadastral municipalities. The totals of 11 settlements have the status of urban ones[5], with population of about 152,750 (53.8% of the Spatial Plan region). Average size of a settlement area approximates 26 km^2. Differences among districts are quite pronounced, both in terms of settlements, cadastral communes and size of areas, and the function of centers. In the Bor district, there are 98 cadastral municipalities, with 90 settlements and average size of areas around 35.8 km^2, whereas in the Zaječar district there are 169 cadastral municipalities, 173 settlements, with average size of areas around 21.4 km^2 (IAUS, 2010c).

In the Region, daily migrations have been initiated between suburban villages and municipal/town centers, as well as formation of urban agglomerations with elements of daily urban system. This is particularly prominent in the Bor and Zaječar agglomerations. The settlements along the category I road No. 25 to Negotin and Knjaževac have functionally and physiognomically become suburb of the town of Zaječar. Brestovac has become a suburb of Bor due to its specific morphological environment and mining activities. There is an observable analogy between the development of these agglomerations and the development of agglomerations of other urban settlements in Serbia which are of similar function and demographic size. Development of agglomeration encourages planned, but also partially spontaneous, relocation of plants and companies from urban centers into suburban villages in which new forms of economic and service activities have developed over time. Urban population concentrations and functions in regional and municipal centers, as well as demographic emptying of rural areas resulting from migration or natural increase, and most frequently their combination, have brought about changes in demographic size of settlements. Comparing this situation with the situation from previous censuses, a succession in demographic fragmentation of rural settlements may be noticed.

Population Change Index

The population change index represents the demographics indicator, widely used in demographic analysis and it is one of the initial indicators in spatial planning. It depicts the intensity and rates of population change, which enables the identification of the settlements where the processes of concentration of

[5] The settlements defined as urban ones in accordance to the methodology of the Statistical Office Serbia

population, or on the other hand, the processes of deconcentration / depopulation are presented.

The population change index is obtained based on data from the census of 1961 and 2002 (Statistical Office of the Republic of Serbia, 2003.). It represents the ratio of change in the number of inhabitants in a certain location for an observed period, often between two censuses:

$$I = \frac{P_2}{P_1} \times 100\% \qquad (6)$$

where: I-index value, P_1-population at the beginning of the observed period, P_2-population at the end of the observed period.

Index values range from 0 to n, by which the values lower than 1 (i.e., less than 100% if multiplied with 100%) are considered to be negative, i.e., the number of inhabitants has dropped during the observed period. In the observed example, herein, the index value in the period from 1961 to 2002. The starting year is „statistically“ considered as the year when a massive planned industrialization started followed by mainly uncontrolled urbanization, and especially deagrarization, which led to the formation of spots and zones of intensive concentration of population, economy, transportation and capital. In the case of the Region, the index value ranges from 0 (for settlements that are population-wise totally empty) to 3,62 (or 362% for municipal centers that attracted people from surrounding villages and other parts of former Yugoslavia during the period of intense industrialization).

Projection of population change

The index of change in the number of inhabitants for the period from 2002 to 2027 is based on the planned projection of the Region's population, obtained by analytical method (method of components). (Booth, 2006; O'Neill, Balk, Brickman, & Markos, 2001). The analytical method is based on the fact that the five-year cohorts of population develop over time under the influence of mortality and migrations, and those born during every five-year period form a new cohort. The input data for the population projections by analytical method are: age-sex structure of population according to the last census, probability of survivorship for every cohort according to sex, fertility rate for the cohort of female population in their fertile age, migration balance in the last intercensal period and arrangement of migrants in percentages according to cohorts and sex.

Ancillary predictors

Road network. The database of the Regional Spatial Plan of Timočka Krajina (IAUS, 2010a) based on inputs from referent road system of the Republic of Serbia has been used, as well as available topographic TK100 and TK 200[6] maps. In the Region, there are 8 state roads of I category in total length of about 485 km, as well as 29 state roads of II category in total length of 1000 km. Although the road network in this region is well developed and road surfaces are of good quality, the curve radii and other technical characteristics of roads considerably vary, but may be appraised as bad, as well as an important limiting factor in the development of the region. Based on vector data on road network, the grids (in resolution of 200 m) of Euclidean distances from I and II category roads have been generated (Figure 3.).

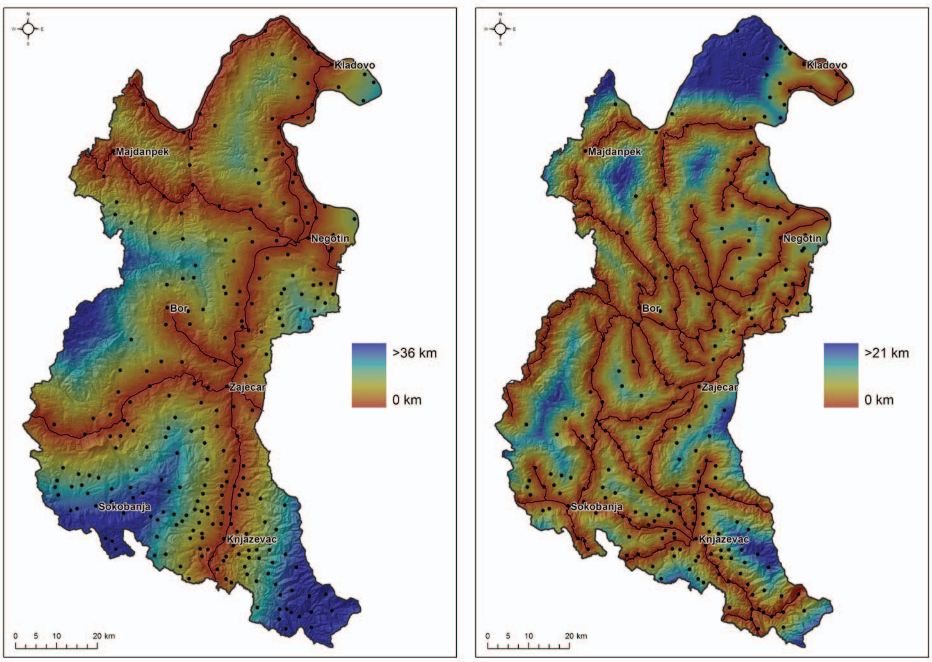

Figure 3. Distances from I category roads (left), from II category roads (right); positions of settlement centers are represented by black dots

[6] maps with scales 1:100000 and 1:200000, corresponding to the situation from the years 1985-87, published by the Military Geographical Institute.

Digital terrain model (DTM). For the data on digital terrain model, the ASTER[7] GDEM global model of Earth's surface, published in the year 2009 (http://asterweb.jpl.nasa.gov/gdem-wist.asp) has been used. The ASTER GDEM data are distributed by the NASA[8] through its Land Processes Distributed Active Archive Center (LPDAAC[9]) free of charge, to the beneficiaries all over the world (Bajat, Samardžić, & Nedeljković, 2010). A format in which all data are distributed is a GeoTIFF with a spatial resolution of 30 m and estimated height accuracy of 20 m. For purpose of this paper, initial data have been reduced to the resolution of 200 m. Based on a digital model within the ArcGIS software environment, a slope grid in the same spatial resolution has been generated (Figure 4.).

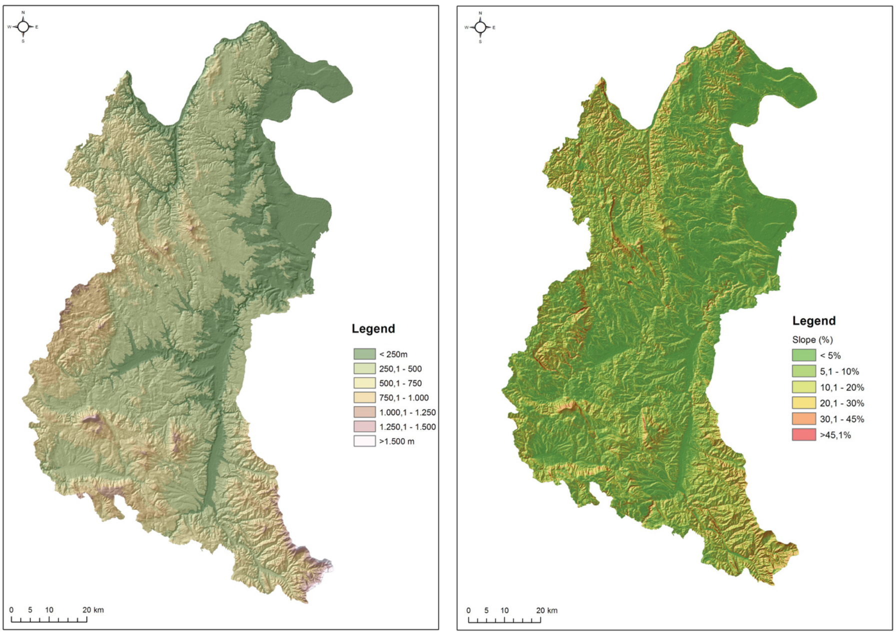

Figure 4. Digital terrain model (left), terrain slope model (right)

Soil sealing database. This database represents yet another free open access database available via Internet. It indicates the land surfaces which have, due to anthropogenic impact, become sealed areas (Burghardt, 2006). As such, they directly reflect the percentage of built-up land given in the scale from 0 to 100

[7] Advanced Spaceborn Thermal Emission and Reflection Radiometer (abbrev.)
[8] National Aeronautics and Space Administration (abbrev.)
[9] Land Processes Distributed Active Archive Center (abbrev.)

(Figure 5.). The database is developed by the European Environment Agency (EEA) and available in two spatial resolutions of 20 m and 100 m respectively (http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing-100m-1). For purpose of this paper, the database with a resolution of 100 m has been used, which has been reduced to the resolution of 200 m for the unification with other sets of ancillary predictors.

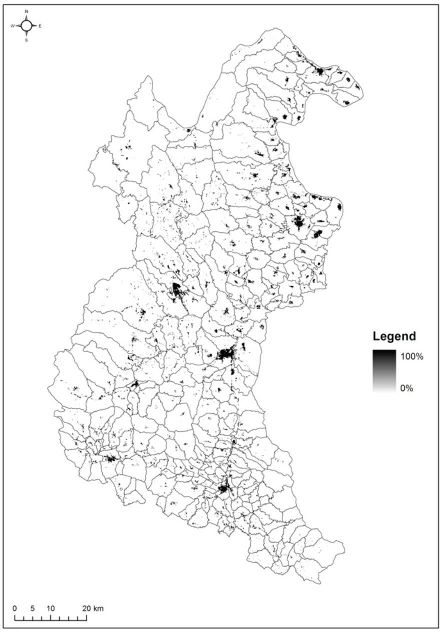

Figure 5. Visual presentation of soil sealing database

Mapping population change index for the researched region of Timočka Krajina

Population change index maps have been created for the considered region using standard choropleth mapping technique and geographically weighted regression. The geographically weighted regression model has been applied using the centers of settlements in the region as locations of sampled variables which have been georeferenced with topographic maps in scale 1:100 000, published by the Military Geographical Institute. Valley settlements are easy to identify since they belong to the type of Timok compact settlements, thus having a clear and recognizable form. However, settlements located in hilly or mountainous areas are most frequently of a scattered type comprising a group of houses and hamlet settlements, so that urban centers in settlements do not exist. In such cases, the greatest group of houses has been positioned, particularly those in which there are public buildings such as schools, churches or cooperatives. Care has been taken that each statistical settlement has only one corresponding point positioned using the TK 100 map, so that it could be assigned the appropriate attributes. These locations have been assigned the population change indexes obtained on the basis of census for the period 1961-2002, as well as population projection data for the period 2002-2027 expressed through population change indexes. Results of choropleth mapping, as well as a model obtained through the geographically weighted regression, are given in figures 6 and 7 respectively.

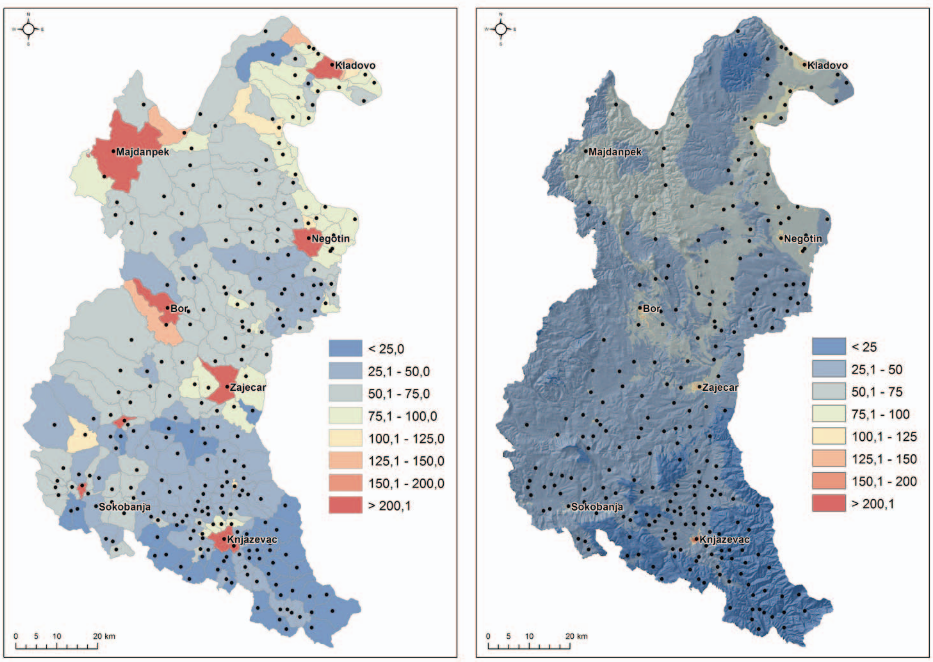

Figure 6. Map of population change index for the period 1961-2002, choropleth presentation (left), geographically weighted regression model (right)

Standard choropleth map of population change index for the period 1961-2002 indicates the population growth in urban centers like Majdanpek, Bor, Zaječar, Negotin, and Kladovo. Such growth is primarily the result of great inflow of rural population resulting from the development of these centers through urbanization and industrialization, and primarily due to development of Mining Smelter Basin „Bor“ and associated complementary economic activities, as well as development in services sector. This has also resulted in index values higher than 200. Should we take into consideration a shorter period, for example from 1961 to 1982, this value would be considerably higher considering that urbanization intensity in this period has been the highest. The major drawback of choropleth map is that it defines parts of the territory on which there are neither housing structures nor human activities as areas with positive population change index. A map generated using the geographically weighted regression shows inhabited zones and zones of human activities in a more realistic way.

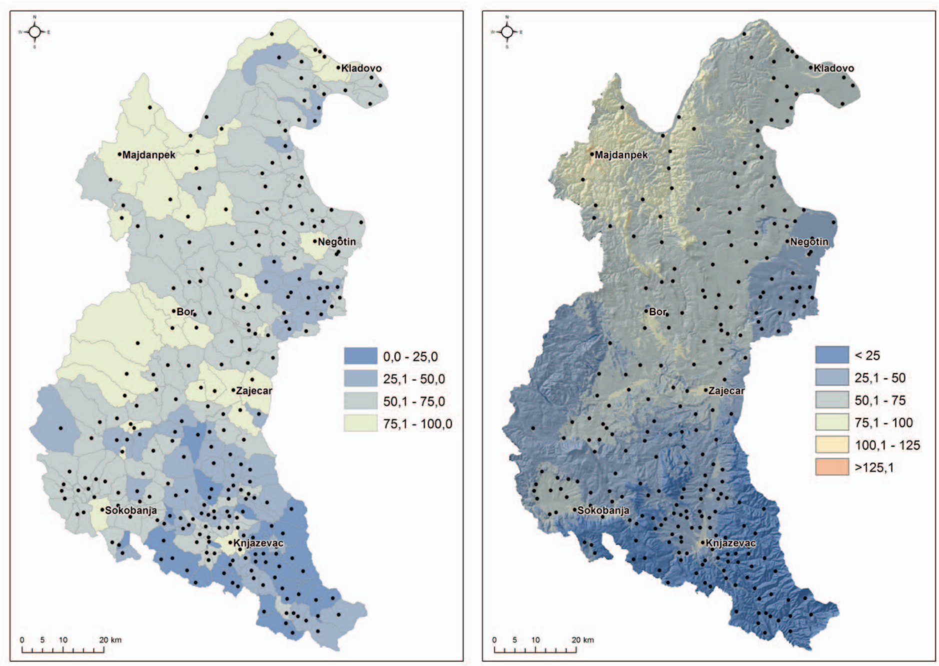

Figure 7. Map of population change index for the period 2002-2027, choropleth presentation (left), geographically weighted regression model (right)

Projection of future population size for the period 2002-2027 generally indicates the trend of depopulation in this region, considering that the scenario of intensive migration from the area covered by the Plan is not envisaged, which conforms to official projection of the Statistical Office of the Republic of Serbia. As in the first mentioned case, the disadvantages which the homogeneous surfaces of choropleth maps have are also evident in the population projection period. Non-homogeneous distribution of settlements in the region has required the application of adaptive range in determining the parameters of weighting functions (formula 5.)

Conclusive considerations

Increasingly available GIS applications, primarily open-source applications, intended for spatial data modeling, create new possibilities in processing and presenting the demographic data. The possibility of combining the demographic and other spatial data which are in correlation is of particular importance. Today, many of these data are available on Internet and sufficiently detailed for usage, not only at the state-level analyses, but also at the regional-level ones. In the present paper, the data on digital terrain model and soil sealing due to effects of human activities obtained via the Internet have been used.

Based on the census data and projection of future population size using the geographically weighted regression, the obtained maps have more realistically presented the spatial distribution of population and spatial concentration intensity of population in the considered periods between 1961 and 2002, and between 2002 and 2027.

The possibility of using the dasymetric modeling of spatial distribution of population, or demographic parameters such as population change index, is wide and important primarily for analyses and projections in spatial and urban planning, risks and vulnerability assessment, hazard management, environmental protection, socio-economic disciplines, etc. One can expect growing interest of scientific and professional community in applying this method, thus significantly improving the methods and models, and even most importantly, achieving a higher level in researching the space, phenomena and processes in the Republic of Serbia.

Acknowledgment:
The paper represents the result of research carried out on projects no. III 47014 and TR 36035, financed by the Ministry of Education and Science of the Republic of Serbia.

References

Bajat B., Samardžić M., Nedeljković Z. (2010). Digital terrain models as topographic layouts for civil engineering design (Digitalni modeli terena kao podloge za projektovanje u građevinarstvu). *Građevinski kalendar*, *42*, 399-453.

Bielecka E. (2011, January 31) *A dasymetric population density map of Poland*. Retreived from http://www.cartesia.org/geodoc/icc2005/pdf/oral/tema5/session%209/elzbieta%20bielecka.pdf

Bivand R., Pebesma E., & Rubio V. (2008). *Applied Spatial Data Analysis with R.* Use R Series. Heidelberg: Springer.

Bourennane H., King D., & Couturier A. (2000). Comparison of kriging with external drift and simple linear regression for predicting soil horizon thickness with different sample densities. *Geoderma, 97*, 255–271.

Booth H. (2006). Demographic Forecasting: 1980 to 2005 in Review. *Working Papers in Demography No. 100*. Canberra: The Australian National University.

Burghardt W. (2006). Soil sealing and soil properties related to sealing. *Geological Society, London, Special Publications 266*, 117-124.

Crespo R., Fotheringham A. S. & Charlton M. E. (2007). Application of geographically weighted regression to a 19-year set of house price data in London to calibrate local hedonic price models. *Proceedings of the 9th International Conference on Geocomputation 2007*. Maynooth, Ireland: National University of Ireland Maynooth.

DeMers M. N. (1999). *Fundamentals of Geographic Information Systems*. (2^{nd} ed.). New York, NY: John Wiley.

Fotheringham A. S., Brunsdon C., & Charlton M. (2002). *Geographically Weighted Regression: The analysis of spatially varying relationships*. Chicester: Wiley.

Hanink D., Cromley R., & Ebenstein A. (2010). Spatial variation in the determinants of house prices and apartment rents in China. *The Journal of Real Estate Finance and Economics*, 17-17.

Harvey F. (2008). *A primer of GIS: fundamental geographic and cartographic concepts*. New York, NY: The Guilford Press.

IAUS (2010a). *Regional spatial plan of Timočka krajina, Draft (Regionalni prostorni plan Timočke krajine, Nacrt plana)*. Belgrade: Institute for Architecture and Urban Planning of Serbia.

IAUS (2010b). *Regional spatial plan of Timočka krajina, Documentation, Expertise "Population" (Regionalni prostorni plan Timočke krajine, Dokumentaciona osnova, ekspertiza „Stanovništvo“)*. Belgrade: Institute for Architecture and Urban Planning of Serbia.

IAUS (2010c). *Regional spatial plan of Timočka krajina, Documentation, Documentation Expertise "The Development of the network of settlements" (Regionalni prostorni plan Timočke krajine, Dokumentaciona osnova, ekspertiza „Razvoj mreže naselja“)*. Belgrade: Institute for Architecture and Urban Planning of Serbia.

Janić-Siridžanski M., Jovanović S., & Živković Lj. (2007). Cartographic modeling of the urban and rural population concentration in Serbia (Kartografsko modelovanje koncentracije gradskog i seoskog stanovništva Srbije). *Journal of the Geographical Institute „Jovan Cvijić“ SASA, 56*, 147-158.

Jarcho S. M. D. (1973). Some early demographic maps. *Bull. N. Y. Acad. Med., 49*(9), 837-844.

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.

Maantay J. A, Maroko A. R, & Herrmann C. (2007). Mapping population distribution in the urban environment: the cadastral-based expert dasymetric system (CEDS). *Cartography & Geographic Information Science, 34*(2), 77-102.

Mennis J. (2003). Generating surface models of population using dasymetric mapping. *The Professional Geographer, 55*(1), 31–42.

Miller H.J. (2004). Tobler's First Law and Spatial Analysis. *Annals of the Association of American Geographers, 94*(2), 284–289

Nestorov I, & Protić, D. (2009). CORINE Land Cover Mapping in Serbia (CORINE kartiranje zemljišnog pokrivača u Srbiji). Beograd: Građevinska knjiga.

O'Neill, B. C., Balk, D., Brickman, M., & Markos, E. (2001). A Guide to Global Population Projections. *Demographic Research 4,* 203-288.

Pebesma E. J. (2004). Multivariable geostatistics in S: the gstat package. *Computers & Geosciences 30*(7), 683–691.

Perović, G. (2005). Least Squares (Metod najmanjih kvadrata). Belgrade: Faculty of Civil Engineering

Statistical Office of the Republic of Serbia (2003). Knjige popisa stanovništva, domaćinstva i stanova u 2002. godini. Belgrade: Statistical Office of the Republic of Serbia

Samardžić M., & Milenković M. (2010). Shuttle radar topography mission: Availability of data and the accuracy achieved (Shuttle radar topography mission - dostupnost podataka i ostvarena tačnost). *Bulletin of Serbian Geographical Society, 90*(1), 51-72.

Slocum, T. A., McMaster, R. B., Kessler, F. C. & Howard H. H. (2005). *Thematic cartography and geographic visualisation.* (Part II Mapping Tehniques, Chapter 13 Choropleth Mapping) Upper Saddle River: Prentice Hall.

Sretenović, Lj. (1980). Semi-scale thematic mapping (Semiorazmerno tematsko kartiranje), *Zbornik radova Geografskog zavoda, 27*

Tobler W. R. (1979). Smooth pycnophylactic interpolation for geographical regions. *Journal of the American Statistical Association, 74*, 519-530.