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MODELLING THE SPATIAL DISTRIBUTION OF VOJVODINA'S POPULATION BY USING DASYMETRIC METHOD

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Cartographic presentation of heterogeneity/homogeneity in the spatial distribution of population is still a major problem in modern geography, and other geo-sciences as well. The traditional method of thematic or choropleth mapping rarely gives satisfactory results. This paper analyzes the applicability of dasymetric mapping method for the modelling of spatial distribution of population. Although it is a relatively old method, it becomes widely used following the development of computer technology, GIS and satellite imagery, and its applicability is increasing in social, economic and other sciences and disciplines. After showing the basis and development of dasymetric mapping, the authors present possible application of this method in the population distribution modelling of Vojvodina.

Key words: dasymetric mapping, population distribution, spatial planning, Vojvodina.

INTRODUCTION

The traditional choropleth map creates an impression of uniform distribution of a phenomenon in space, although it most often varies in the specific geographic area. Thus, the boundaries of spatial units affect abrupt changes in values of the mapped phenomenon. In order to solve this problem, it is necessary to create the new, so-called *statistical surfaces*, which model the space heterogeneity, thus simulating variations of the observed phenomenon in the specific geographic area. To achieve greater precision in distributing the phenomenon, additional/ancillary data (predictors) are used, namely, spatial relationships between the data and variables are to be determined.

One of the approaches in solving this problem is a dasymetric mapping method by which the distribution of modelled space into zones of higher degree of homogeneity is made, whereby the variations in statistical surfaces are more realistically depicted with the support of additional variables and their mutual relationships. Mennis (2003) defined the dasymetric mapping as a process of spatial data distribution (deaggregation) by smaller and, for the analysis, more suitable spatial units using additional/ancillary data in order to make the population distribution or other spatial phenomena in a more refined way. Although it is most frequently used to model distribution of population, the dasymetric mapping may also, theoretically, be used in deaggregation of any quantitative variable dependent on geographical/spatial units, such as statistical and territorial political units of various hierarchical level (from the census round, statistical settlement, district, and region), but also in deaggregation of geographic entity with specific ecological features such as, for example, flood-prone areas.

Although used for more than two centuries, dasymetric mapping method has still not been standardized like other thematic mapping methods, due to which it is to great extent subjective and without consistent criteria. The most often quoted excuse for this is that the method of making the dasymetric map is rather complicated, that the data used are relatively difficult to obtain, and that the method is also technologically demanding as it employs significant computer resources (Maantay *et al.*, 2007). So far, in Serbia, this method has not been used in demographic studies or somewhere else in thematic cartography.

BASIS AND DEVELOPMENT OF THE DASYMETRY

George Julius Poulett Scrope used rudimental dasymetric technique in 1833 for mapping the population density in various parts of the world. The Russian geographer Semenov-Tyan-Shansky, who described the method in the year 1911 and whose map showing the distribution of population of the European Russia was published in the year 1923, has often been cited as the first author of dasymetric map. However, John Kirtland Wright was the first to describe the method in English language (1936) and explain the origin of the word *dasymetry* as *density measuring*. It his

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paper, he indicated the advantages of dasymetric thematic or choropleth map over the standard one. Although the choropleth mapping was carried out a whole century before Wright, the coined word choropleth denoting the value-by-area method (Jarcho, 1973; Maantay *et al*., 2007) was attributed to him.

The choropleth method is simple to use, easy to read and understand, thus most commonly used in demographic and socio-economic analyses, where the statistical data are related (uniformly distributed) to spatial/territorial units. The major drawback is a so-called MAUP (Modifiable Areal Unit Problem) problem emerging when the results of spatial analysis are substantially changed due to the change of boundaries of mapped units or levels of statistical data aggregation.

In this paper, further evolution of dasymetric mapping is shown through the development of the method, techniques and use of ancillary data (Maantay *et al*., 2007).

DASYMETRIC MAPPING METHOD

Although the final aim of dasymetric mapping is to obtain a map which would in a most realistic way depict spatial distribution of population, its implementation methodology is based on a variety of concepts. Summary of concepts on which dasymetric mapping is based are given below.

Areal Interpolation. Areal interpolation method is defined as data transfer from the so-called source (spatial) unit to the target unit. The ratio of the variable's value to surface area of the spatial unit is determined under assumption that phenomenon is spatially-homogeneous. The obtained ratio is assigned to the target unit, and the variable's value is determined in relation to its surface area. This method is most often used in measuring the population density. Indeed, the major drawback is precisely in the assumption that phenomenon is spatially-homogeneous on the entire area of the spatial unit.

Binary model - Filtered Areal Weighting. This method is based on areal weighting coefficient added to ancillary data, thus obtaining a new layer used as a filter or mask. These filter/mask data are most often the land use/land cover data obtained by remote sensing, that indicate inhabited and uninhabited land areas (therefore the name „binary model"). Through applying the filters/masks, the population data are distributed by spatial units belonging to the category of inhabited land area. However, the model has two key drawbacks. First, the model still assumes a homogenous population density within inhabited areas. Second, the fact that uninhabited areas still have certain population is neglected. Through further improvement of the method, a essentially refine model has been used, whereby more realistic data have been obtained.

Utilisation of land use and land cover data as ancillary predictors. The possibilities provided by the use of ancillary data in defining spatial distribution of population have been indicated already in the previous model. These data are obtained either from the data in vector format, e.g. CORINE, (Bielecka, 2005), or from raster data, such as satellite and orthophoto images (Mennis, 2003; Sleeter, 2004). Drawbacks in implementation of these data have also been indicated, primarily those related to prices and time required for their collection, volume of raster data and difficulties in their processing, as well as difficulties in separating inhabited from uninhabited areas.

Three-Class Method and Limiting Variable Method. Both approaches represent further improvement of binary method. Through the three-class method, based on land use categories, a percentage share of class is assigned to the total population counts in the given area (the known example is that the class of urban land is assigned e.g. 70%, agricultural/forest/non-urban land is assigned 20%, while 10% belongs to forest land (Eicher and Brewer, 2001). Indeed, the percentage share is determined on a case-by-case basis and by expert knowledge. It has been noticeable that this method still „suffers" from the problem of separating urban areas from other areas, as well as that it homogenizes density within classes.

The limiting variable method differs from the previous method therein the maximum probable population density value for the class is assigned to each class. When the modelled density value exceeds the limit value, the population is distributed into other classes. Nevertheless, the problem of heterogeneity in population distribution within the classes is not solved. Furthermore, the procedure of determining the limiting variable itself may lead to wrong limit values, thus significantly influencing the results of mapping. (Mennis, Hultgren, 2005).

Image Texture Analysis Method. Population distribution modeling is carried out using high resolution satellite images, thus determining the ratio between the population densities according to census data and raster texture. Spatial units thus obtained are called homogeneous urban patches (HUP) and are determined by image analysis through which the differences between these patches are maximized, while differences within each patch are minimized. Albeit this method has demonstrated high correlation between the modelled density and image texture, it is still barely efficient for implementation in practice.

Statistical Approach – Regression Analysis. Some authors have used statistical techniques in dasymetric approach, such as areal patch-point interpolation or regression analysis of correlation between population density and land use (Bielecka, 2005).

Heuristic Sampling Method. Mennis (2003) used the combination of dasymetric mapping, advanced three-class method and empirical sampling based on satellite images to model the population distribution independently of data from spatial/statistical units. Population within group of block was classified into individual grid cells based on two factors: a) relative difference in population density regarding to rank of urbanization (low, high, non-urbanised), and b) the proportion of urban area in the total surface area of the block group. This method, although significantly improving the previous models, revealed certain drawbacks in implementation for the densely inhabited urban areas, which makes its implementation in planning and analyses impossible. Variations within block groups may not be adequately perceived by using this method.

Kernel Density Surface from Population-Weighted Census Centroids. Numerous variations of surface-generating methods are used to model a population layer by kernel density. Rather than mapping population by zones, by spatial units of the statistical services (census/statistical units), this method entails creating a vector layer of population density by interpolating the population number within enumeration district - (ED) centroid, often used for representing census data in the United Kingdom (Martin, 2006). A kernel window is moved over the cells contained in these centroids, and the population number at each centroid is distributed to the cells in the kernel window by a distance-decay model. An early iteration of this method had the drawback that the total surface population number by cells was not always identical to the population counts in the census data. This drawback was overcome by distributing the population number to cells within the centroid's original zonal boundaries, thus highlighting the pycnophylactic property of the method[2].

[2] The pycnophylactic method means that, after reaggregation, modelled values have the same values as initial/original value (Tobler, 1979).

Use of Other Types of Ancillary Data - Street-weighted Interpolation. Realizing that the use of other types of ancillary data, such as those on land use and others, did not offer the possibility for sufficiently precise population density modelling, particularly in densely populated urban areas, some researchers (as stated by Maantay *et al*., 2007) used in their studies the street network data to determine interpolation weighting coefficient. By comparing the obtained results with the areal-weighted coefficients, they found that the applied method was better and that, in modelling the total population number, yielded by 20% more precise results.

Cadastral-based expert dasymetric system - CEDS. Maantay *et al.* (2007) used cadastral data as predictors for large-scale dasymetric mapping. The expert system was used to select which cadastral data, as ancillary variables, would best depict the true population number. Modelled population always retained its pycnophylactic property, this being rarely achieved by the previous methods. According to the authors, the greatest advantage of the CEDS method was that it could make high resolution population distribution in densely urbanized and heterogeneously inhabited urban blocks with high precision. The techniques implied the use of data on housing zones and housing units, with the support of tax data, by parcels. Selection between housing zones and housing units was made by the expert system. The results were checked against the census data and other dasymetric techniques in order to improve the method.

Despite the utilized dasymetric model, the reliability of obtained results depends most of all on the lineage and quality of input spatial data and GIS layers (Joksić and Bajat, 2004).

Global databases on dasymetric mapping - based population distribution

Mapping the spatial population distribution is today increasingly implemented in a number of projects and researches at the global level. One of such examples is a LandScan database which has been developed by the Oak Ridge National Laboratory (ORNL) within the Global Population Project for the needs of assessing the population vulnerability after disastrous events at the global level (Dobson *et al*., 2000). The LandScan database is a dasymetric model of population distribution in a grid format, based on available census data for each country, where the population distribution probability for each grid cell (size 1×1 km) is calculated based on parameters, such as purpose of the land use, slope of the terrain, vicinity of communications, night light, etc.

The Special Report on Emission Scenarios (SRES) is a similar project showing the assessment of spatial distribution of population for the period 1990-2100 (Bengtsson *et al*., 2006). This map is a long-term projection of world population for the needs of projects related to climate change and water resources assessment. A database of similar purpose is the Gridded Population of the World version 3 (GPWv3) of resolution of 2.5 minutes by geographic coordinates (e.g. latitude-longitude) based on projection of population for 2015 (Balk and Yetman, 2004). It is very important to underline that all of these mentioned databases are available on the Internet (*open-access*).

DASYMETRIC MAPPING OF VOJVODINA

The dasymetric method was used to model spatial distribution of population of Vojvodina aiming at obtaining statistical surfaces which would more convincingly show heterogeneity/homogeneity of the Province's population density. The obtained statistical surfaces were additionally used to model differences between the so-called „daily" and „night" population. The counts of „night" population in this model was equal to the population counts registered by their place of residence. The „daily" population is the population who usually stay in the settlement during working days, made up of enumerated population to/from which daily migratory population (workers and pupils/students) is added/deduced, depending on whether the settlement is of migratory character or immigration character. The layers from the 2000 CORINE database were used as ancillary data.

The Autonomous Province of Vojvodina is located in the northern part of the Republic Serbia and occupies an area of 21,506 km^2, or somewhat more than 25% of the territory of Serbia. It has population of 2,031,992 (according to the 2002 Census, about 27% of the total population of the country, excluding the data for Kosovo and Metohija), with population density of approximately 94 people per km^2. Administratively, it consists of seven districts comprising of 45 municipalities/cities. The territory of Vojvodina is comprised of 449 cadastral municipalities with 467 settlements, out of which 48 are urban ones, while other settlements are mainly rural, and more rarely the mixed ones (according to the methodology of the Republic of Serbia Statistical Office – RZS).

In Vojvodina, out of 912,000 active population, 227,162 are daily migrants, or about 25% (*Table 1*); 159,862 (70,4%) are employed daily migrants, while 67,300 (29,3%) are students and pupils. 72,840 of daily migrants (32,1%) are from urban settlements, while 154,322, or almost 68%, from other settlements, which is typical for urban system in which central positions dominate. According to place of

*Table 1. Daily migrants in 2002**

		Total	Employed	Work in		Total no. of pupils and students	Pupils	Students	Go to schools in	
				other settlement in the same municipality	other municipa-lity and the R. Serbia				other settlement in the same municipality	other municipa-lity and the R. Serbia
Vojvodina	ttl	227,162	159,862	103,250	55,303	67,300	45,940	21,360	30,929	35,810
	%	100	70.37	64.59	34.59	29.63	68.26	31.74	45.96	54.04
Urban settlements	ttl	72,840	47.615	23,440	23,589	25,225	11,233	13,992	5,548	19,421
	%	32.07	65,37	49.23	49.54	34.63	44.53	55.47	21.99	78.01
Other settlements	ttl	154,322	112,247	79,810	31,714	42,075	34,707	7,368	25,381	16,389
	%	67.93	72,74	71.10	28.25	62.52	82.49	17.51	60.32	39.68

**data on migrants from categories: "in other republic or foreign country" as well as "unknown", have not been taken into consideration, the total of 1309 inhabitants.*

migration, and at the level of the entire Province, migrations within municipality dominate, where about 2/3 of daily migrants move into other municipalities. As for urban settlements, however, the same share of daily migrants move within municipalities and into work centres in other municipalities. As for other settlements, local work centres dominate, where about 71% of workers move within municipality. This indicates that there is a formed hierarchy in the work center network of Vojvodina. Daily commuting creates specific spatial forms and relations between centres known as „Daily urban systems". These systems become very important issue in the spatial planning (Tošić *et al.*, 2009).

The share of pupils and students in daily migrations is about 30% (68% pupils, 32% students). Here, the difference between urban and other settlements is also pronounced: for urban settlements, the number of pupils and students is approximately the same (46% and 54% respectively), while for other settlements, the share of pupils is dominant compared to the share of students (82.5% and 17.5% respectively). The analogy in place of migration is also pronounced, where, similar to workers, the pupils and students from urban settlements more commonly migrate into other municipal/ urban centres (22% and 78% respectively), while those from other settlements opt more for municipal/urban central settlements (60%:40%).

Table 2: Comparative overview of the 2002 Census population count by previous and new census methodology

Region	2002 Census population numbers, by new census methodology	2002 Census population numbers, by previous census methodology	Difference in population number	Change index
Vojvodina	2,031,992	2,098,779	-66,787	96.8
Bačka	1,079,889	1,108,339	-28,450	97.4
Banat	616,202	642,733	-26,531	95.9
Srem	335,901	347,707	-11,806	96.6

Table 3: Comparative overview of daily/night population for some typical settlements

Settlement	City/municipality	Settlement type	Number of night population	Number of daily population	Change	Change index
Novi Sad	Novi Sad	urban	191,405	221,765	30,360	115.9
Kać	Novi Sad	other	11,166	8,945	-2,221	80.1
Sombor	Sombor	urban	51,471	55,878	4,407	108.6
Čonoplja	Sombor	other	4,359	4,019	-340	92.2
Kikinda	Kikinda	urban	41,935	46,435	4,500	110.7
Mokrin	Kikinda	other	5,918	5,026	-892	84.9

Table 4: CORINE land use classes and one possibility of the assessed percentage value of representation of the number of „night" and „daily" population

Class code	Class name	Percentage of night population	Percentage of daily population
112	Discontinuous urban fabric	87	75
121	Industrial or commercial units	8	15
122	Road and rail networks and associated land	3	2
123	Port areas	1	2
131	Mineral extraction sites	0	1
141	Green urban areas	0	1
142	Sport and leisure facilities	0	1
221	Vineyards	0	1
222	Fruit trees and berry plantations	0	1
243	Land principally occupied by agriculture	0	1
	All other categories	0	0
	Total	100	100

Used data and software

The population count by settlements on the territory of Vojvodina, according to the data of 2002 Census (RZS, 2004), was used as an basic data. The data used here were from the 2002 Census, obtained by the new census methodology which, compared to previous one, did not include the population who stayed abroad longer than 1 year, but enumerated foreign citizen who lived and worked in Vojvodina longer that 1 year. The Table 2 shows the population count obtained both by previous and by new methodology, for Vojvodina as a whole, as well as for its districts of Bačka, Banat and Srem.

The number of workers – daily migrants in 2002, according to unpublished RZS data, was used to determine the number of the so-called „daily population". Using the overview of the number of population who move to/from settlements, the total number of population who move between the settlements was determined. By adding to or deducting from the number of permanent population, the number of „daily" population was determined for each settlement. In this paper, students (most commonly the secondary school ones, and more rarely university students) who migrate daily, were taken as permanent population for the sake of trial model simplicity, although their share was not small (comments given in Table 1). The Table 3 shows the ratio of number of daily to number of night population for some typical urban and other settlements.

For the basic spatial surface of dasymetric modelling, a polygonal overview of cadastral municipality boundaries was used for the territory of Vojvodina as a whole, the total of 447 units. Each cadastral municipality was assigned the data on permanent number of population, number of workers moving into settlements, number of workers moving from the settlements, and number of daily population. Given that the number of cadastral municipalities and statistical settlements did not coincide in about 20 cases (there are 467 settlements), it was necessary to distribute statistical data by cadastral municipalities.

The land use data according to the 2000 CORINE were used as predictors. The subjectively assessed percentage values of the number of represented population were assigned to the land use classes. The land use classes, different values in percentage representation of population were given, to obtain a model of daily oscillations in population number. Table 4 shows percentage representation of population number by land use classes.

The ArcGIS ArcEditor 9x software was used to model data and create maps. The procedures are very simple to perform and mainly based on traditional GIS overlaying analyses.

RESULTS AND DISCUSSIONS

The map of spatial distribution of Vojvodina's population was made by the use of dasymetric mapping. In this paper, a very simple dasymetric method was used with the CORINE land use data as main predictor. Percentage values of population share by land use classes were given arbitrarily. The obtained results were in direct correlation with predictors, while the obtained values of assessed population were in direct function of subjectively determined percentage values of representation, so that they could be significantly manipulated during analysis. The goal of further investigations of the model, as well as for its improvement in local theory and practice should be the adjustment of the initial model in order to eliminate, or minimize, the subjectivity and uncertainty in modelling.

However, the most important contribution to making the dasymetric map of Vojvodina is a complete change in visualization of demographic phenomena in the specific geo-space, compared to traditional choropleth maps. Dasymetric mapping essentially alters perception of researchers and analysts. The long-established perception of the conception of population density is also changing, because modelled values obtained by dasymetric method indicate much greater values per surface unit, as well as their greater non-uniformity. For the sake of example, the population density in Novi Sad reaches more than 7,000 people/km^2, or more than 70 people/ha, which is many times greater value than a common conception of about 450 people/km^2 (when total population of the city and its total surface area are considered). Functional relationships and inter-dependence in the settlement network (at regional and sub-regional level), on the one hand, and functioning of the city as a work centre (of spatial distribution of functions within the settlement itself), on the other hand, was indicated by modelling daily population oscillations between and within settlements.

Figure 1 shows the traditional choropleth map of population density and, in parallel, the spatial distribution of settlements, i.e. urbanized areas. Figures 2 and 3 show differences between the population density interpreted by choroplet and dasymetric maps of the citiy of Novi Sad and municipality of Kikinda. Attention is drawn to differences in modelling the population density between city/municipal centres and surrounding settlements, as well as to the differences occurring within the city/municipal centre itself (between industrial and sport-recreation surfaces, and other city tissues).

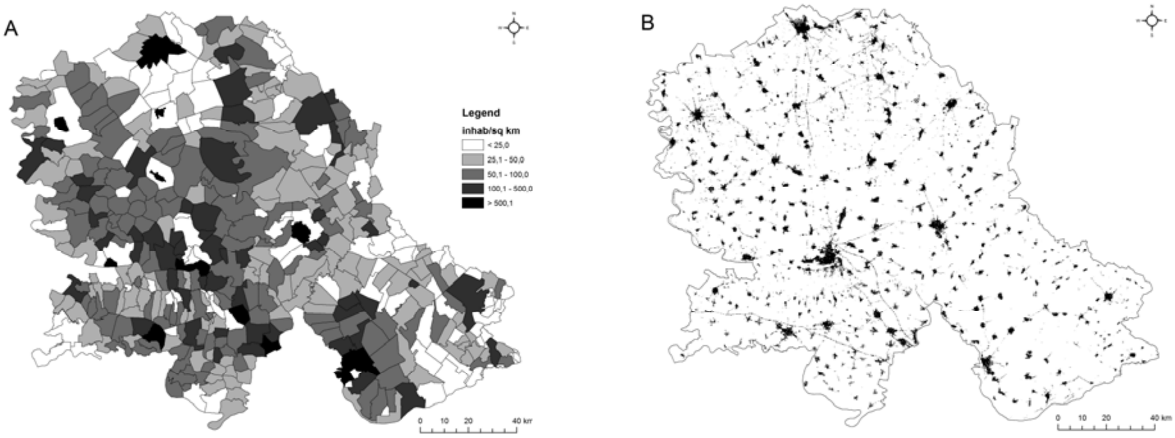

Figure 1. Example of the choropleth map (A) of the population density of Vojvodina (2002) and spatial distribution of urbanized areas (B) (CORINE, 2010)

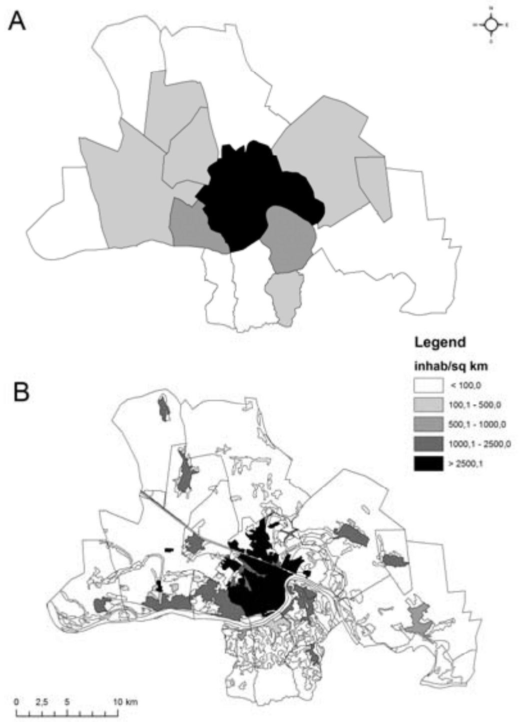

Figure 2. Choroplet (A) and dasymetric map (B) of population density of the city of Novi Sad

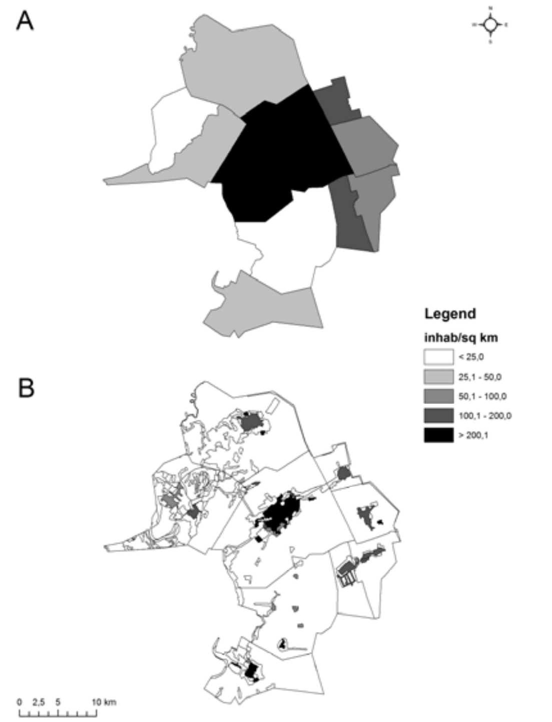

Figure 3. Choroplet (A) and dasymetric map (B) of population density of the Kikinda Municipality

CONCLUSIVE CONSIDERATIONS

Rapid development of computer technology, advanced GIS software tools, availability of satellite images, and other data obtained by remote sensing in the last twenty years, have increased scientist's and researcher's interest in dasymetric mapping method. In this paper, the advantages of this method compared to traditional choropleth method were indicated.

Dasymetric modelling was developed through two general approaches. The first approach was used for population distribution using statistical data on bigger territorial units (from the level of settlements and municipalities) which were then distributed by specific local phenomena of population density, the so-called downscaling. This analytical approach is more suitable for modelling the (sub)regional and higher-level territories. The second approach of conditionally deductive character was used for modelling the population number/density based on assessed (or empirically determined) values in the smallest considered spatial units (e.g. block in the settlement), followed by „aggregation of" such phenomena thus producing the total population number, the so-called upscaling. This approach is more suitable for local analysis in densely - populated urban settings.

Common feature for both approaches is the use of predictors, which make analytical process become more complex, but substantially influencing its precision and quality. However, while using predictors, the detail quality and degree of spatial generalization, particularly of grid data, must be taken in account, as well as conditional time-agreement of data. This means that grid predictors of rough resolution are not used for local analysis, and that older satellite images are not to be used for modelling the new statistical data, etc.

There are wide and significant possibilities for using the dasymetric modelling of spatial distribution of population, i.e. population density, primarily for analyses and projections in spatial and urban planning, assessment of vulnerability in emergency situations, environmental protection, socio-economic disciplines, etc.

The example shown in this paper represents an initial analysis, as well as illustration of possibilities offered by dasymetric modelling at the regional level and in strategic planning. The advantages were proven, but also the drawbacks of the method, primarily reflected in subjectivity of analysts while selecting predictors and assessing the percentage representation. In this context, the previous empirical investigations would be of importance. In addition to further engagement in improving the dasymetric modelling, we expect an increasing interest of other researchers in this method, whereby the detail quality would be improved, while the method itself would be used in other scientific disciplines and practice, particularly in socio-economic research.

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