DASYMETRIC MODELLING OF POPULATION DYNAMICS IN URBAN AREAS

DASIMETRIČNO MODELIRANJE DINAMIKE PREBIVALSTVA NA URBANIH OBMOČJIH

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IZVLEČEK

Vprašanju razčlenjevanja javno dostopnih podatkov iz popisa so se posvečali že številni raziskovalci. Sodobni načini hranjenja ter predstavitve prostorskih in družbeno-ekonomskih podatkov v okolju GIS so prinesli pomemben napredek v metodologiji. Pri tem je pomembno tudi, da je javno dostopnih veliko pomožnih zbirk podatkov (satelitski posnetki, tematske plasti, ki se nanašajo na rabo zemljišč in pokrovnost tal, itd.), ki se vse hitreje dopolnjujejo. Zbirke podatkov o pozidanosti tal so eden od razredov pomožnih zbirk podatkov o zemljiščih, ki so zaradi antropogenih vplivov postala vodotesna, ter pričajo o stopnji prostorskega razvoja in prostorskih vsebinah, ki se povezujejo z razporeditvijo prebivalstva. Zbirka podatkov o pozidanosti tal je lahko v kombinaciji z dokumentacijo o načrtovanju mesta koristno orodje za dasimetrično kartiranje prebivalstva, ki opisuje rabo tal in višino stanovanjskih zgradb. Rezultati takšnega kartiranja so uporabni pri spremljanju prostorsko-časovne dinamike prebivalstva med dvema popisoma.

V študiji je predstavljena metodologija, pri kateri je zbirka podatkov o pozidanosti tal kombinirana s pomožnimi podatki na testnem območju iz glavnega načrta Mesta Beograd, s podatki iz popisa iz leta 2002 in rezultati iz leta 2011. Preverjanje veljavnosti modela kaže, da je predlagana metodologija uporabna na močno urbaniziranih območjih.

KLJUČNE BESEDE

dasimetrično modeliranje, pozidanost tal, podatki iz popisa, višina zgradb, urbanistično načrtovanje

ABSTRACT

Solving the problem of publicly available census data disaggregation has preoccupied numerous researchers intensively. A noteworthy advance in the methodology was made thanks to the contemporary storage and presentation of spatial and socio-economic data in the GIS environment. It is also important that a large number of auxiliary databases (satellite images, theme layers pertaining to land use and land cover, etc.) are publicly available and are periodically supplemented at increasingly shorter time intervals. Soil sealing databases are another class of auxiliary databases that pertain to land areas which have, due to anthropogenic influences, become a water-impermeable layer and indicate the level of spatial development and spatial contents that correlate to the population distribution. The soil sealing database can be a useful tool for dasymetric mapping of population when combined with town planning documentation that describes land use and height of residential buildings. The results of such mapping can help monitor the spatio-temporal dynamics of population trends in periods between two censuses.

This study presents a methodology in which a soil-sealing database is combined with auxiliary data in a test area covered by the Master Plan of the Belgrade City, with census data from the year 2002 and the results of the year 2011. The results of the model validation indicate application of the proposed methodology in highly urbanised areas.

KEY WORDS

dasymetric modelling, soil sealing, census data, building height, urban planning

1 INTRODUCTION

Achieving the most truthful presentation of a spatial population distribution preoccupies the minds of experts dealing with the mapping of demographic and socio-economic phenomena (Wright, 1936; Maantay et al., 2007; Mennis, 2009). Demographic data are usually collected in decennial censuses and are often presented as statistical surfaces (DeMers, 1999) that are graphically presented as choropleth maps. The census data used in these studies are aggregated on the level of spatial units intended for the presentation of such data. In the Republic of Serbia, census data are commonly presented on the level of census designation places (CDPs) (by aggregation of census and statistical districts data), which correspond to census blocks in the USA and enumeration districts in Great Britain.

A main drawback to presenting population density data in choropleth maps is that uninhabited areas become misrepresented since the aggregation of census data results in the construction of statistical surfaces for inhabited areas only. In order to generate a more realistic model of demographic data, census data should be integrated with spatial databases to include an accurate presentation of lot coverage and spatial contents.

A more precise presentation of population distribution and its dynamics in urban planning is important for several reasons including: 1) understanding the directions and intensity of population redistribution to determine the strategic trends of urban area development, and 2) to provide an accurate depiction of population density for the purposes of urban planning and restructuring. The population density of the classical choropleth method can provide an underestimate of population density whereas dasymetric modelling usually results in a more accurate representation with typical higher population densities and concentration (Krunić et al., 2011). Urban planners need to be in tune with such data so that the quality of life can be updated and maintained in towns undergoing significantly altered conditions of space load. An accurate representation of space load will justify the planning of higher quality infrastructures, increased availability of public services with upgraded capacity, ensured safety in case of industrial accidents and defence against natural disasters or terrorist attacks, etc. Also, the generation of an enhanced statistical surface provides inputs for further socio-economic analyses of urban population at the level of neighbourhoods and phenomena and processes in its development. Statistical data should not be underestimated or overestimated, since they are necessary in planning, and since a reliable and updated spatial database represents a good basis for spatial policy and spatial development (Kranjčević, 2007).

The dasymetric mapping method can help create a more realistic depiction of population density because it divides modelled space into zones that share higher degrees of homogeneity. Such spatial divisions provide a more truthful reflection of the variations in a statistical layer with the support of additional variables and their correlations.

Mennis (2003) defines dasymetric mapping as a kind of areal interpolation that uses additional/auxiliary data to aid in the areal interpolation process in order to produce a finer distribution of population or other spatial phenomena. A dasymetric map depicts a statistical surface, most commonly population density, as a set of simply connected smaller spatial units such that variation within each unit is minimized and the unit boundaries approximate the steepest escarpments of the surface (Mennis, 2009). This approach enables simple population redistribution in different spatial units, which are suitable for the subsequent spatio-temporal modelling (Kocabas and Dragicevic, 2013). The detailed fine overviews of these methods are presented in several studies (Maantay et al., 2007; Mennis, 2009; Li et al., 2007). These methodologies include the binary dasymetric, the three-class dasymetric model, the regression model, and the locally fitted regression model. Each of these aforementioned models provide different solutions for explaining spatially heterogeneous density when population data is spatially disaggregated.

The development of new methods for spatial population distribution modelling was given high importance by the growing application of GIS tools (Reibel, 2007). Undoubtedly, the development of new dasymetric methods was influenced by the growing number of satellite images available at the geo-market (Wu and Murray, 2007). Although satellite remote sensing data cannot reveal population density directly, it could be a starting point in describing the urban morphology of built-up and non-developed areas (Mennis, 2003). Even so, a big obstacle hindering the wider application of this kind of data is the technical know-how and accessibility of software to perform image-processing of these images (Langford 2007).

A key spatial database that is commonly used in dasymetric applications in the territory of Europe is the COoRdinate INformation on the Environment (CORINE) land cover (CLC) database (Gallego, 2010). However, a major drawback to the use of the CLC data set is its limited spatial resolution, which leads to over-/underestimation of sparsely populated areas depending on the applied method (Steinnocher et al., 2010). Researchers including Linard et al. (2011) have started to test other publicly available spatial databases (AVHRR, MODIS, GLC 2000, GlobCover) in order to enhance the accuracy of population density models. Their test results indicated that the best model performances are achieved by the GlobCover base, whose advantages are due to finer resolution and the fact that it contains a larger number of present classes with regards to the other databases.

Other innovative strategies include using nighttime lights as a commendable source to characterize population distribution (Sutton et al., 2001, 2003). As such, nighttime lighting imagery from Google Earth was used for mapping of the rural population distribution in China (Yang et al., 2012)

Lately, the impervious surface fraction or index has been used as an unavoidable auxiliary piece of data in dasymetric modelling. Imperviousness correlates strongly with population density and also does not require extensive calibration. In addition, the performance of imperviousness as a source of ancillary data is very similar to that of land cover (Zandbergen, 2011). The impervious surface fraction appears to be slightly but consistently better than the land-use classification database when comparing the performance of indicators (Wu and Murray, 2005).

The impervious index in combination with land use data has already been used for the requirements of dasymetric population dynamics modelling (Morton and Yuan, 2009). However, their study focused more on using regression coefficients to define the correlative dependence between the population density and the impervious index.

Wu and Murray (2005) used impervious surface fraction derived from Thematic Mapper (TM) imagery as an auxiliary variable to interpolate population density via cokriging geostatistical modelling. Their study used the population mean centre of census designation places to transform areal units of population density in order to point out features that should be considered as a primary variable since the reported census statistics are not based on a sampling point. This variable was also used for the spatial prediction of a demographic indicator of population change index by means of geographically weighted regression (Fotheringham et al., 2002) in the region of eastern Serbia (Bajat et al., 2011).

The objective of this study is to propose a methodology for spatial and temporal modelling of population dynamics (modelling population changes between census years) for the requirements of urban planning. The developed method use primarily publicly available national statistics data as well as standard data related to land use that is already in the planners' possession. The results depict a realistic population distribution in urban areas and the obtained model would reveal details about spatial aspects including directions and intensity of population dynamics. The models produce higher-quality input data for further analysis of population preferences such as 1) dwelling space density, 2) distribution of social and professional affiliations of the population, 3) daily oscillations in the population distribution due to commuting or daily migrations and 4) the development of gentrification process, etc.

This study presents how soil imperviousness data can be scaled by a spatial database of building height typology to developed dasymetric model used for analyzing a population distribution in an urban area. The urbanized area and the inner part of the city of Belgrade including the 11 urban municipalities with 32 settlements (census designated places, CDPs) are taken into consideration in this study.

1.1 World-wide Dasymetric Databases

Research projects that evaluate mapping techniques for spatial population distributions are currently being conducted at a global level. One of such examples is the LandScan Global Population Database (LSGPD), 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 a global level (Dobson et al., 2000). The LandScan database is a dasymetric model of population distribution in a grid format and is based on census data that is available for each country that provides a 24-hour ambient population estimate at a resolution of 30 arc seconds by 30 arc seconds (grid size 1×1 km). This database was calculated using parameters such as intended purpose of land use, terrain slope, vicinity of communications, night light, etc. The ongoing project of ORNL is developing very high resolution 3 arc seconds (~90m) population distribution data for the USA (LandScan USA) that comprise nighttime residential as well as daytime (ambient) population data sets for the purpose of estimating diurnal population dynamics (Bhaduri et al., 2007).

The Special Report on Emission Scenarios (SRES) is a similar project showing the assessment and projection of the spatial population distribution for the period of 1990-2100 (Bengtsson et al., 2006). This map is a long-term projection of world population dynamics for the purpose of assessing climate change and water resource management. A database of similar purpose is the The Gridded Population of the World: Future Estimates 2015 (GPW2015) with a resolution of 2.5 minutes by geographic coordinates (e.g. latitude-longitude) and is based on the projection of population for 2015 (Balk and Yetman, 2004). Population estimates were projected until the year 2015 using the same simple extrapolation methods as the Gridded Population of the World version 3 (GPWv3) and prior GPW databases. The GPWv3 was produced under the Global Rural-Urban Mapping Project (GRUMP) and it is represented by a 30 arc-second grid depicting the population density around the globe.

2 DATA AND METHODS

2.1 Soil Sealing Database

A Soil Sealing (or imperviousness) high-resolution raster layer was produced during 2006-2008 as part of the Global Monitoring for Environment and Security (GMES) programme with the aim to complement the CORINE land cover data. The need for production of five high-resolution (HR) land cover layers emerged on behalf of the European Environment Agency (EEA): imperviousness, forest, grassland, wetland and water. The European HR Soil Sealing layer has been produced based on semi-automatic processing of IMAGE2006 data based on SPOT 4/5 and IRS-P6 fine spatial resolution optical satellite imagery (de Lima et al., 2007). The Soil Sealing layer represents a new type of information layer in the European environmental assessment, being the first example of the planned series of high-resolution Land Monitoring layers with European coverage. The raster layers reveal 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. Its main use is the characterization of the human impact on the environment. Multi-sensor and bi-temporal orthorectified satellite imagery of the IMAGE2006 project was used to derive soil sealing data covering 38 European countries (32 EEA Member States and 6 West-Balkan countries) (Maucha et al., 2011). The database is available in two spatial resolutions of 20 m and 100 m, respectively (European Environmental Agency, 2010). For the purpose of this study, the 20m-resolution database has been used. This database has been already used for downscaling of population in Europe. Steinnocher et al. (2010) used the soil sealing base to estimate the building density as an intermediate layer with the aim to produce a 500m-resolution disaggregate population grid for a north-south transect of Europe.

2.2 Residential Building Blocks Layer

The other sort of input data concerns residential blocks. They are an integral part of planning documents which were made previously for the Belgrade Master Plan in the year 2000 and are in digital form using the GIS environment such that they are presented in vector format (shp. files) (Figure 1 on the right). Obviously, a building block is designated as a residential area clearly delimited by roads. Only residential blocks are considered in this case study whereas mixed blocks were not used in the experiment. An attribute associated to each block is its building height typology (BHT). The typology defines 4 classes in compliance with national regulations (Table 1).

No. of storeys	Building Height Typology (BHT)	Weights	No. of blocks in 2002	No. of blocks in 2011
up to 3 (ground floor [GF]+1+ garret[G])	1	1	5293	6117
4-5 (GF+3+G)	2	3	522	560
6-8 (GF+6+G)	3	5	274	284
above 9 (GF+6+G)	4	7	27	29
Total number		6136	6990	

Table 1: Building height typology of residential blocks

The building blocks grew by approximately 14 % in the period between two censuses and indicate a period of intensive construction development for the conditions in Serbia. The highest number of constructions is attributed to class 1 which is dominant in suburban areas. Each of the classes is attributed a weight coefficient that is derived from the statistical data for Belgrade. Further to official statistics, one household has the average of three members. The obtained weight coefficients correspond to the mean number of inhabitants who would reside in a vertical line of a building on a 20 m^2 area based on the average number of square meters and structure of housing units which correspond to each class (having in mind the gross area inclusive of staircases and hallways in buildings).

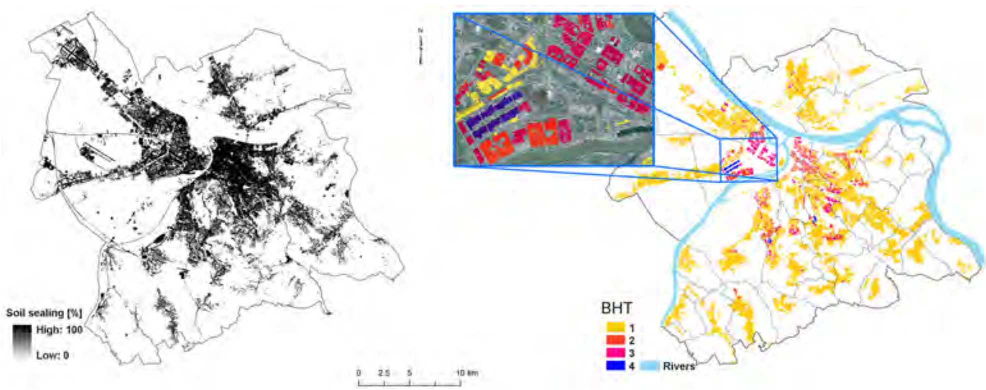

Figure 1: Soil sealing data layer (left), residential building blocks layer of the year 2002.

2.3 The case study of city of Belgrade

Belgrade, the capital of the Republic of Serbia, is situated at the confluence of the Sava and Danube rivers (N=44° 49' E= 20° 27'). The administrative area covers 3,223 km^2 and the city has around 1.6 million inhabitants. Its territory is divided into 17 municipalities that comprise 157 settlements. According to official census data records, the area of interest includes 1,264,585 inhabitants and 457,333 households in the year 2002 (Statistical Office of the Republic of Serbia, 2003), and 1,303,125 inhabitants and 565,044 households according to the recently performed census (Statistical Office of the Republic of Serbia, 2011). In the period 2002-2011 the Region of City of Belgrade had an increase of population (approx. 4 %) while in other Regions population decreased from 5 % in the Western and Northern to 11 % in the Southern and Eastern Serbia (Petrić et al., 2012).

The development of Belgrade and its agglomeration has several stages in spatio-morphological, economic and demographic development (Vojković et al., 2010). At the beginning of the 20th century, the central Belgrade area covered only about 12 km^2 with about 70,000 inhabitants (in the year 1900), while the administrative territory of the then Belgrade district spread over the area of 2,025 km^2 with about 126,000 inhabitants. Due to accelerated industrialization and abrupt urbanization, the Belgrade area permanently grew in the second half of the 20th century and changed its spatio-functional structure. From the end of World War II to the last 2002 census, Belgrade multiplied the number of its inhabitants by 2.5 times. Intensive demographic growth was a result of migration flows and territorial expansion whereby new settlements were included in the administrative town area and immigrant streams were intensive. Powerful and disorganized migration, not only from the territory of Serbia but also the other republics of former Yugoslavia, proves the significance of Belgrade in broader surroundings.

Until the 1970's, the strict urban area encompassed the majority (90 %) of Belgrade's total population growth. In that first period of urban development, right after the World War II, the highest population growth rates were found in the central Belgrade municipalities. As the old central town core had already been urbanized and densely inhabited higher growth rates were also established in the broader zone of the Belgrade urban area during the inter-census period from 1953-1961. Numerous settlements from the immediate hinterlands and suburban municipalities of the time were losing their population as they kept moving to Belgrade. The central Belgrade area (parts of 10 town municipalities, Master Plan area) is characterized by specific demographic development and polarization of demographic trends: a) depopulation of the oldest urban core of the town (municipalities Stari Grad, Vračar and Savski Venac); b) dynamic population growth in the municipalities of Voždovac, Zvezdara, Zemun and Palilula; c) intensive concentration of population in the municipalities of New Belgrade, Čukarica and Rakovica. In the economic structure of Belgrade, the predominant activities are those of the tertiary-quaternary sector, with slow modernization of industry.

2.4 Population Change Index

The population change index provides a standardized measure for comparing population changes over time and across geographic regions and it represents one of the initial indicators in urban planning. The index depicts the intensity and a rate of population change and represents the ratio of change in the number of inhabitants at certain location over an observed period, often between two censuses:

$$PCI = \frac{P_2}{P_1} \cdot 100\% \quad (1)$$

PCI - 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*, wherein 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.

2.5 Proposed Methodology

The proposed methodology for dasymetric mapping is a modified formula for the estimate of population in buildings as defined by Lwin and Murayama (2009). They proposed two methods, the fist being areametric and the second being volumetric. Each of these methods is based on footprint layer for each building in the considered area. The proposed formula for the volumetric method reads:

$$\mathrm{BP}_i = \left(\frac{CP}{\sum_{k=1}^{n} BA_k \cdot BF_k} \right) \cdot BA_i \cdot BF_i \quad (2)$$

BP_i - population of the building *i*,

CP –census tract population,

BA_i - footprint area of the building *i*,

BF_i - number of floors in the building *i*.

A modified formula (hereinafter referred to as M1 model) which would substitute the footprint and number of floors by soil-sealing and height typology would read:

$$\mathrm{Bs}_p = \left(\frac{CP}{I_n} \right) \cdot \mathrm{Ss}_p \cdot \mathrm{Ts}_b, \quad I_n = \sum \left(\mathrm{Ss}_p \cdot \mathrm{Ts}_b \right) \quad (3)$$

Bs_p - number of inhabitants per target grid cell,

Ss_p - soil sealing value per grid cell,

Ts_b - building block height typology weights (Table 1)

CP - total number of inhabitants within census designation place,

I_n - census designation place index that corresponds to total sum of multiplication of soil sealing values and building typology

In this way, the population data are directly disaggregated to the pixel, i.e. grid cell level. The proposed formula ensures that the total number of people within CDP area remains the same. This is referred to as the pycnophylactic property of dasymetric maps (Tobler, 1979).

2.6 Performance Measures of the Model

The mean average percentage error (MAPE) was used to appraise the performance of the proposed model and the defined basic unit for evaluation is a building block.

$$MAPE = \frac{100\%}{n} \cdot \sum_{t=1}^{n} \left| \frac{A_t - F_t}{A_t} \right| \tag{4}$$

A_t - actual value of population within a building block,

F_t - forecast value of population within a building block.

Percentage errors have the advantage of being scale-independent and are frequently used to compare forecast performance in cases where data are considerably different in size or across series if they are scale-dependent. However, measurements based on percentage errors have the disadvantage of being infinite or undefined if there are zero values in a series, as is frequent for intermittent data (Hyndman, 2006). The coefficient of determination R^2 was used also as a quantitative measure to evaluate the performance of the model.

3 RESULTS AND DISCUSSION

Figure 2 (left) shows a conventional choropleth map of population density based on the 2002 tract of the Belgrade urban area. The depicted polygons stand for the CDPs boundaries. The higher population densities in the city tend to occur in the central city part. The dasymetric map (Figure 2 right) depicts the population density using the grid cell as the basic unit (see the close-up detail). Grey coloured areas on the map mark the soil-sealing layer which does not overlap with residential blocks.

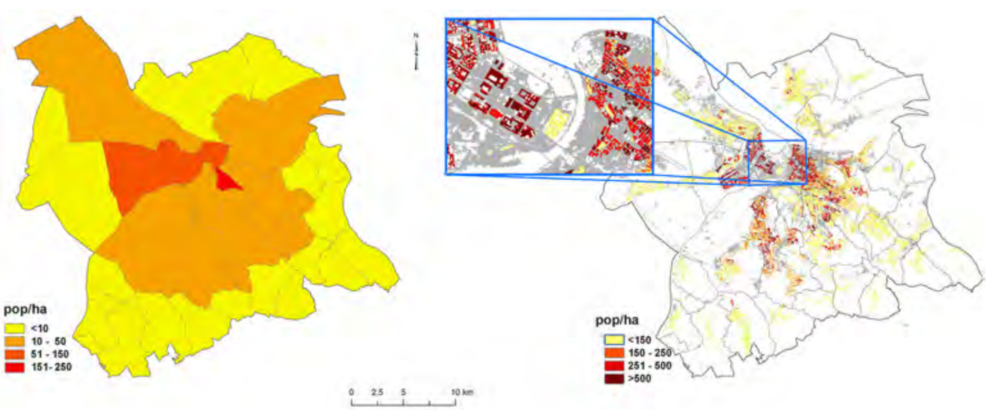

Figure 2: Choroplet map (left) and dasymetric map (right) depicting population density for the year 2002

Figure 3 (left) shows a choropleth map of population density based on the latest 2011 census. Significant changes in the number of inhabitants are noted in one CDP only when the two choropleth maps are compared.

The proposed method (M1) was evaluated using actual building population data acquired from the City Administration Office for study purposes. On that occasion, the validation was made using 60 residential blocks and the data pertaining to 2011. In order to evaluate the performance of the proposed method (M1), the results were compared with results obtained by the three-class dasymetric model (hereinafter referred to as M2 model) (Maantay et al., 2007) based on CORINE 2006 data as an ancillary predictor while using constant density fractions for land use classes (90 % for urban land, 8 % for agriculture and 2 % for forest areas).

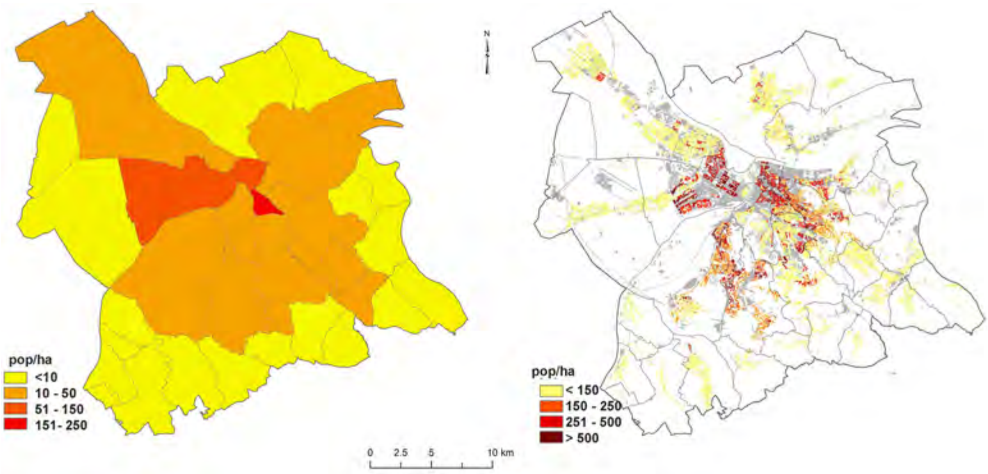

Figure 3: Choroplet map (left) and dasymetric map (right) depicting population density for the year 2011

The MAPE values are presented in Table 2. For the entire validation set, the obtained MAPE value for the proposed method (M1) is 14.87 % in contrast to 61.65 % for the three-class dasymetric model (M2).

BHT	No.of blocks	MAPE [%]	
		M1	M2
1	26	17.14	37.56
2	12	12.84	80.40
3	21	13.65	79.78
4	1	6.17	82.22

Table 2: MAPE values for each BHT

Figure 4 shows a scattergram of modelled vs. actual population within building blocks. The value for the coefficient of determination of $R^2 = 0.968$ indicates high performance of the proposed model while the coefficient $R^2 = 0.534$ of the three-class dasymetric model (M2) indicates that the M2 model is not appropriate for resolving spatial heterogeneity of population density in urban centres.

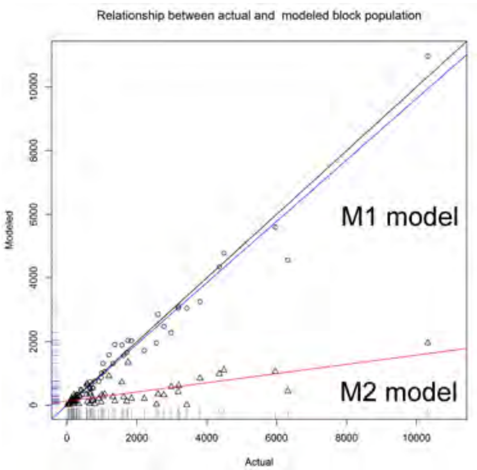

Figure 4: Scattergrams with superimposed regression lines of proposed dasymetric model (M1) and three-class dasymetric model (M2)

During selection of residential blocks for validation purposes, care was taken to make sure that samples were evenly distributed within the city including zones with different building typologies. This contributed to identification of more error sources by analysis of differences in the actual and modelled number of residents within a block.

During classification of the number of floors (as already explained), all polygons with mean number of floors up to three (ground floor + first floor + garret) were classified in the first class. However, this group, which is the most represented one in the Master Plan area, includes family housing up to four housing units. This type of housing is quite variable in terms of the number of residents and largely influences the obtained results. Errors caused by this method of classification are not unambiguous typically because residential blocks intended for family housing with one housing unit often contain extended-family residents that results in higher occupancy than intended whereas residential blocks containing a higher density of housing units usually have a smaller number of residents. To achieve better results, the first class should be divided into two sub-classes which are attributed different "weights", thus insuring a better apportionment of residents in the first class.

Besides the difference in the number of housing units, the first class is largely influenced by the average number of residents per m^2 in a residential block. In fact, residential blocks inhabited by population with higher income can lead to false estimations of population density since the housing area corresponding to one resident is much higher than the average and can result in a 20 % overestimate of residents (Figure 5 left).

Averaging of the number of floors on a residential block level implies an error manifested in cases where residential structures of different classes are homogenized in one residential block. The number of such blocks is small and they are characterized by two cases. In the first case, those are residential blocks which are specific for their structure, because buildings with different numbers of floors are built next to each other and thus constitute a unit, while in the second case, those are blocks which embrace illegally constructed buildings with a different number of floors than the already existent residential buildings. Absolute differences in such blocks range from 10% to 30 %, depending on deviations of particular residential buildings from the mean number of floors within the block. The effect of this error would be mitigated by redefinition of a residential block into individual blocks with particular number of floors.

Maximum error appears in multi-family residential blocks that contain both type one and type two residential structures. In these cases, the error is positive, because the actual number of inhabitants is much higher than the obtained one (Figure 5 middle). These extreme deviations (up to 50 %) are a consequence of the above explained errors altogether.

Figure 5: Identified error sources of differences in the actual and modelled number of residents within a block

According to the documentation of the Master Plan of the year 2021, the total area intended for housing grew by 500 ha within the period from 2002 to 2011. The growth was accounted by 20 ha in the inner central urban zone, 170 ha in the outer zone and 310 ha in the peripheral zone. The inner central zone contained a high level of development with construction mostly targeted towards upgrading the capacity of existing structures or the construction of new buildings in the place of deteriorated residential buildings. As the Soil Sealing from 2006 was also used for population distribution from the 2011 census, there are residential blocks within the outer central zone that contain pixels of very low, or zero values. Those residential blocks are mostly pre-existing with upgraded levels of development in the period of 2006-2011. As a result, the values of the soil sealing pixels do not match the actual ones for that region. The lack of pixels results in a smaller number of inhabitants within a polygon and causes a positive error difference with a maximum of 24 % (Figure 5 right, bordered with circles).

3.1 Population Dynamics Modelling

Dynamic modelling of population fluctuations in urban areas is mostly focused on the estimate of ambient and nocturnal population (Bhaduri et al., 2007, Sutton et al., 2003, Krunić et al., 2011). This study focuses on estimating the spatial distribution changes of population between two censuses.

Changes in spatial population distribution between two censuses are depicted in two ways. Figure 6 (on the left-hand side) shows absolute change in the intercensus period (subtraction of the

2011 dasymetric map grid cell value from the 2002 map value), while Figure 6 (on the right-hand side) shows the relative change of the population by the Population Change Index (PCI). The PCI map is generated by incorporating map algebra, i.e. the two grids division operation (Figure 6 right). In classic studies, PCI is usually represented on the level of administrative units such as in the case of census data. The described methodology obtains data on the grid cell level which enables subsequent aggregation of the data to the level of a spatial unit suitable for specific application.

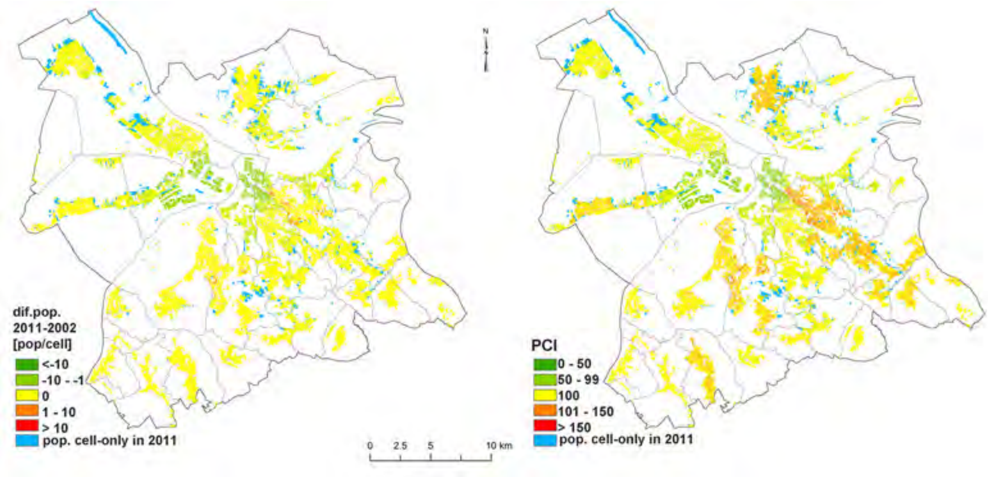

Figure 6: Population dynamics modelling between two censuses by map of differences (left) and PCI map (right)

The spatial pattern of population dynamics for the City of Belgrade confirms theoretical model of phases of urbanization (Klaasen et al., 1981; Berg, 1982) and it is in accordance with the current level of socio-economical development (Tošić, 2012). Absolute growth and an increased intensity of the population development was achieved in the periphery of the Belgrade agglomeration during the analyzed intercensus period as apposed to development in the central core. Causes of such spatial dynamics are numerous and complex and the most important among them are the following factors: a) the periphery is settled by a young fertile population that contributes to the positive natural growth b) the periphery is more attractive for migrants than the urban core, c) values of the available land and real estates are (still) lower in the periphery, d) there is more space which is available for development, e) transport accessibility is higher and f) urban planning regulations are more loose, etc.

4 CONCLUSIONS

The proposed methodology is feasible for a large number of applications including: regional and urban planning, traffic and infrastructure planning, hazard mapping, population health monitoring, etc. The great potential of this methodology is based on public availability and regular updating of used data. Soil sealing data constitute the basis which shall be permanently updated for the requirements of the CORINE project and most probably shall be publicly available in the future. The next similar project related to the year 2012 shall be available in 2014 (European

Environmental Agency, 2012). Permanent updating of this layer for the requirements of future CORINE issues enables us to use it for spatial modelling of dynamic population changes in certain time intervals.

A wide spectrum of users can use soil sealing for the requirements of modelling spatial population distributions since it is a ready-to-use product that does not require possession of any specific software or any knowledge necessary for remote sensing data processing. The high spatial resolution of this base enables high-resolution urban population distribution modelling.

Although the obtained results have shown satisfactory model performance, the next interesting step in the research might be for it to represent a comparison between these results and the results obtained by use of calibrated weight coefficients that would correspond to soil-sealing values.

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