ASSESSING SIMILARITIES BETWEEN PLANNED AND OBSERVED LAND USE MAPS: THE BELGRADE'S MUNICIPALITIES CASE STUDY

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Abstract

Techniques for evaluating similarities between categorical maps obtained by different spatial modeling techniques or representing similar space in different time instances are still developing. This paper reviews a current approach for assessing the similarity in land use maps that are used in city planning processes. The performance of recently designed *kappa location* and *kappa histo* measures as well as *fuzzy* set map comparison approach were tested on a case study area that comprises three cities of Belgrade's municipalities with different urban characteristics. By assessing similarities between the land use map of the Master plan designed for the year 2021 and the map representing the currently observed land use conditions, the level of realized planned activities as well as the level of discrepancy from the Master plan could be evaluated.

Keywords: Kappa statistics, land use map, fuzzy, urban planning

INTRODUCTION

Categorical thematic maps are produced for different purposes: land cover, land use, forest inventory, soil types or properties, etc. The development of high-resolution spatial modeling techniques, geographical information systems and more accessible remote sensing data has increased the need for map-comparison methods. There are several motivations for developing proper map-comparison methods and measures (Visser and de Nijs, 2006) that include: 1) detection of temporal/spatial changes or hot-spots; 2) the comparison of different spatial/temporal models, methodologies or scenarios; 3) the calibration and validation of land use models, 4) the model uncertainty and sensitivity analysis, and 5) the evaluation of map accuracy.

The objective of this paper is to provide insight into the appropriate analysis techniques and the discussion of the factors that must be considered when performing any similarity assessment. In addition, a detailed description of proposed comparison techniques is given in order to fully realize the importance of similarity assessment discussed in this paper.

METHODS

The *kappa* statistic measures the differences between the observed agreement among two maps and the agreement that might be achieved solely by chance due to the alignment of those two maps (Aronoff, 2005). It is quite convenient for the map comparison if an equal number of classes are applied (Bonham-Carter, 1994).

The *kappa* index that was introduced by Cohen (1960) presents a measure of agreement adjusted for chance and it is calculated as:

$$\kappa = \frac{P(O) - P(E)}{1 - P(E)} \quad (1)$$

where *P(O)* presents observed agreement and and *P(E)* is the proportion of agreement that may be expected to arise by chance.

$$P(O) = \sum_{i=1}^{n} p_{ii}; \quad P(E) = \sum_{i=1}^{n} p_{iT} \cdot p_{Ti}; \quad P(\max) = \sum_{i=1}^{n} \min(p_{iT}, P_{Ti}) \quad (2)$$

The calculation of the *kappa* index is based on the main diagonal of the contingency table (table 1) together with its row and column marginals. Each element p_{ij} in contogency table is the fraction of cells in category *i* in Map A and in categoty *j* in Map B.

Table 1. Generic form of a contingency table.

		Map B categories				
		1	2	…	n	total map A
Map A categories	1	p_{11}	p_{12}	…	p_{1n}	p_{1T}
	2	p_{21}	p_{22}	…	p_{2n}	p_{2T}
	…	…	…	…	…	…
	n	p_{n1}	p_{n2}	…	p_{nn}	p_{nT}
	total map B	p_{T1}	p_{T2}	…	p_{Tn}	1

The *kappa* index values falling in the ranges of 0.41-0.60 are categorized as moderate, values between 0.61-0.81 are substantial and values higher than 0.81 are consider as almost perfect as was outlined in similar studies (Landis and Koch, 1977).

The standard *kappa* index has been used in different fields, from medical applications and biostatistics (Lantz, 1997) to a great variety of geoscientific applications. In the field of geosciences, the *kappa* index was subsequently adopted by the remote sensing community as a useful measure of classification accuracy (Congalton, 1991). There is also a wide number of applications that are related to the validation of machine learning techniques in spatial modeling (Kovačević et al, 2009; Foody, 2004).

Pontius (2000) was one of the first, who criticized the use of simple *kappa* statistics in comparison to digital raster maps. He introduced two new statistics indices in order to examine separately the similarity of location κ_{loc} and quantity κ_{quant}. The *kappa location* corresponds to the measurement of similarities in the spatial allocation of categories in the two compared maps. Unlike *kappa quantity* statistics that have been proved as unstable and incomprehensible (Sousa et al., 2002), *kappa location* statistics are sustained as a comprehensive measure because it gives the similarity scaled as the maximum similarity that can be reached with the given quantities:

$$\kappa_{loc} = \frac{P(O) - P(E)}{P(\max) - P(E)} \tag{3}$$

In order to overcome the drawbacks of the *kappa quantity* statistics, Hagen (2002) introduced a new statistical index called *kappa histogram* κ_{histo}:

$$\kappa_{histo} = \frac{P(\max) - P(E)}{1 - P(E)} \tag{4}$$

Both statistics κ_{loc} and κ_{histo} are sensitive to particular differences in locations and in the histogram shapes for all the categories (Visser and de Nijs, 2006).

The mutual relation between κ_{loc} , κ_{histo} and standard κ could be expressed as:

$$\kappa = \kappa_{histo} \cdot \kappa_{loc} \tag{5}$$

The latest approach in assessing similarities of raster maps is based on fuzzy set theory (Zadeh, 1965). Geoscientists and GIS professionals adopted this theory (Burrough, 1996; Burrough and McDonnell, 1998) with the purpose of characterizing inexactly defined spatial classes or entities that deal with ambiguity, vagueness and ambivalence in mathematical or conceptual models of spatial phenomena. Based on fuzzy set theory, Hagen (2003) proposed the new approach in assessing spatial similarities and changes between raster maps. The fuzzy-based map-comparison method was primarily developed for the calibration and validation of the cellular automata models for land-use dynamics.

Considering two sources of fuzziness; *a*) locational based on the concept that the fuzzy representation of a raster cell depends on the cell itself and, to a lesser extent, also the cells in its neighbourhood, and *b*) categorical which originate from vague distinctions between categories.

The extent of the neighbouring cells or locational fuzziness could be expressed by a distance decay function. The categorical fuzziness can be introduced by setting off-diagonal elements in the Category Similarity Matrix to a number between 0 and 1 that corresponds to membership values of different categories. Since there are no straightforward rules for assigning membership values, choosing values in the matrix is subjective, and it could be selected on the basis of a priori experience.

The *kappa fuzzy* index is similar to the traditional *kappa* statistic in that the expected percentage of agreement between two maps is corrected for the fraction of agreement statistically expected from randomly relocating all cells in compared maps.

We used a freely available Map Comparison Kit[1] software tool in the research presented here for the comparison of raster maps based on standard cell by cell map comparisons (the standard and variants on *kappa statistics*) and fuzzy-set calculation rules.

CASE STUDY AREA

The study area includes part of the territory of city of Belgrade, which is the capital of Serbia. Three neighboring out of a total of seventeen Belgrade municipalities were tested including: Zemun, Novi Beograd and Surčin that represent the different urban types of municipalities (Fig.1).

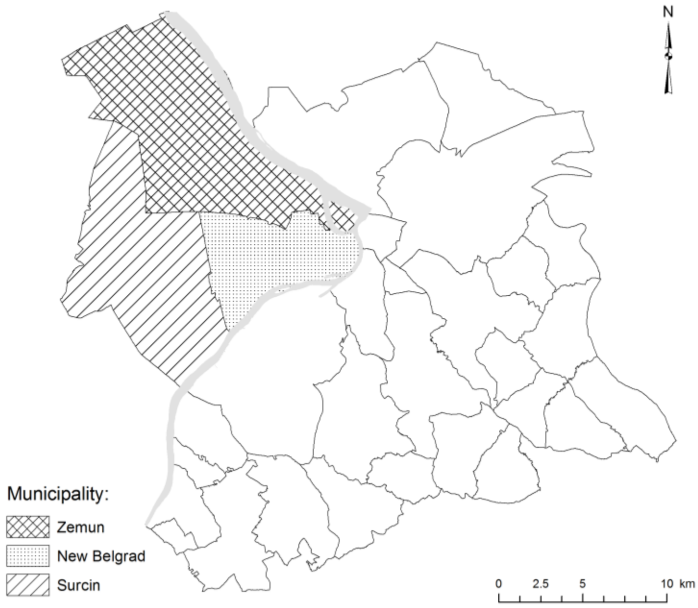


Fig. 1. Case study area within the city of Belgrade.

The municipality of Zemun has three suburban settlements: Zemun Polje, Batajnica and Ugrinovci, and one urban, Zemun, the old town. Zemun dates back to the Neolithic period and has developed as a separate town until 1934 when it merged with Belgrade. The Old town of Zemun was declared as the regional, cultural and historical site of great significance for the Republic of Serbia. The Master Plan of Belgrade includes all settlements except Ugrinovci, which makes a total area of 9,942 ha with a population of about 15000.

Novi Beograd (New Belgrade) is the municipality with the highest population density. The municipality covers an area of 4,096 ha, with a population of about 220 000 inhabitants. Its construction was planned and begun after World War II. The municipality of New Belgrade is divided into large residential blocks of a nearly rectangular shape that are separated by wide boulevards. New Belgrade has recently become the commercial center of Belgrade.

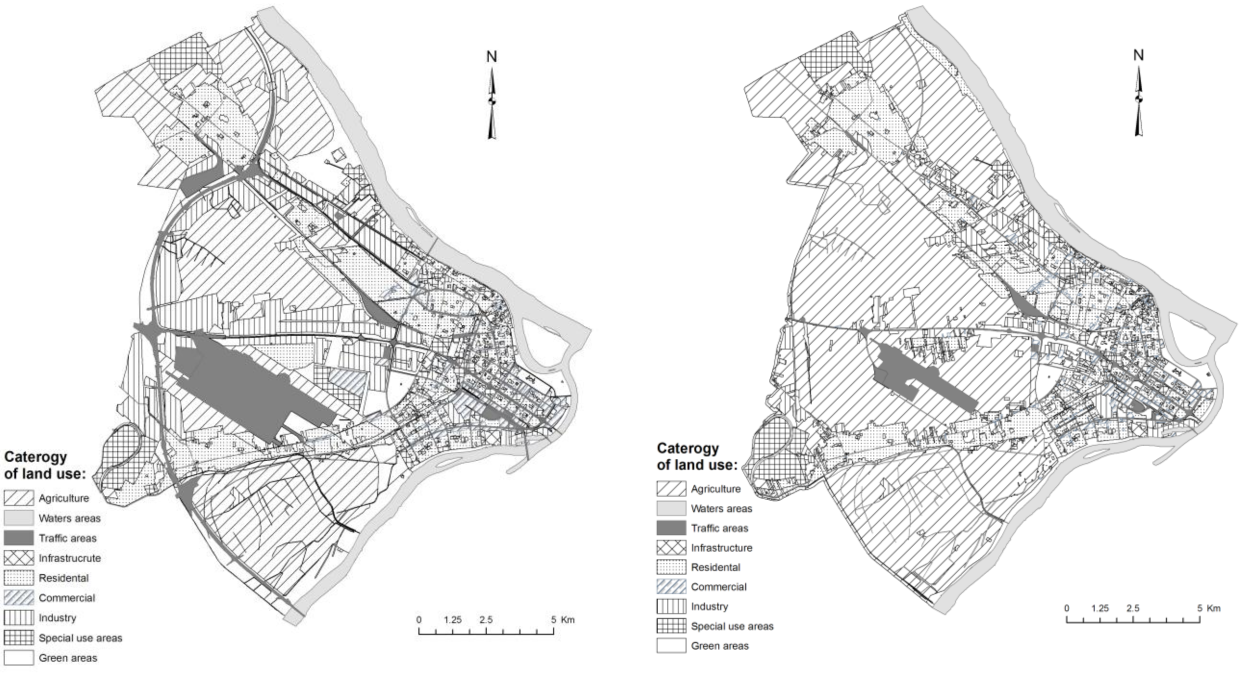
[1] http://www.riks.nl/mck/

The municipality of Surčin was formed in 2004 from part of the municipality of Zemun. The Municipality consists of seven settlements, and some of them are situated within the boundary of the Master Plan. The airport complex "Nikola Tesla" is situated in the north-eastern part of the municipality and has a significant influence on its spatial development.

The assessment on Master plan realization is usually carried out for these three municipalities separately, but since these municipalities form one entity as well, the assessment is carried out for all three municipalities together. The total research area covers 22.236 ha, or about 30% of the total area of Master Plan.

The Master plan of Belgrade designed to 2021 was made by the Institute of Urbanism of Belgrade in the year 2003. The map of the Master Plan was used as the reference map with a raster size of 20x20 m and 908x1278 cells (Fig. 2a). Actual land use is defined based on ortophoto maps taken in 2010. The vector map, (polygons of land use) was rasterized at 20 m spatial resolution, with same dimensions as the primary map (Fig. 2b). The Master Plan of Belgrade for year 2021 was done in 2003, so based upon actual land use situation in 2010 we can do analysis of plan implementation over the past seven years. The aim is to determine whether the urban growth differ from planned in the period 2003-2010 and to evaluate the extent to which it was implemented. Based upon used statistics we can analyze implementation of Master Plan according to land use categories, based weather on location or quantity. *Kappa location* value can offer us information whether the certain land use category is developing on location that is planned for that category. Whilst *kappa histo* value can offer us information about the extent to which this category development is implemented.

Land use classification is carried out in nine categories on both maps: agriculture, wetlands, traffic areas, commercial, industry, residential, infrastructure, green areas and special use areas (sport, public services ...).



A) B)

Fig. 2. a) Land use map of Master plan 2021, b) Observed land use map for 2010.

RESULTS AND DISCUSSION

All *kappa* indices were calculated for the total case study area as well as for each municipality separately in order to examine similarities between planned and observed land use maps

The fig. 3 below shows the spatial distribution of agreement, since *kappa* statistics are based on a straightforward cell-by-cell map comparison (Fig. 3).

Fig. 3. Cell by cell comparison

Table 1. *Kappa* statistic indexes

	Total area	Zemun	New Belgrade	Surčin
$\kappa appa$	0.569	0.627	0.596	0.429
κ_{loc}	0.855	0.863	0.800	0.914
κ_{histo}	0.662	0.727	0.746	0.469

In all areas, except in Zemun (Table 1), the *kappa* index has a value between 0.41-0.60 which indicates moderate Strength of Agreement (Landis and Koch, 1977). Zemun has value of 0.63, which indicates that Strength of Agreement is substantial. However, the absolute value of *kappa* has no intrinsic meaning in assessment of results of land use change models, since the amount of land use change is not considered (van Vliet, 2009). Inconsistency of the two maps can be explained by analyzing the values of *kappa location*, *kappa histo*. The values of *kappa location* are high, which indicates that spatial distributions of different categories of land use over the maps are almost the same. Differences between planning and real states (conditions) of land use are more reflected in quantitative dissimilarities. The almost perfect matching in location depicts that the urban development is going as planned, i.e. land use persistence.

In order to get better insight in each category behavior, the *kappa* statistics per category can be calculated as an option. For a categorical *kappa* statistic, the two maps are transformed to a map consisting of only two categories, i.e. the considered category as first one and the second category as the combination of all other categories (one versus all).

Table 2. Total area *Kappa* statistic per category.

	Agricult.	Wetlands	Traffic areas	Infrastruct.	Resident.	Commerc.	Industry	Special use	Green areas
$\kappa appa$	0.474	0.996	0.522	0.586	0.826	0.520	0.362	0.785	0.361
κ_{loc}	0.911	1.000	0.964	0.761	0.861	0.708	0.777	0.855	0.619
κ_{histo}	0.520	0.996	0.542	0.769	0.959	0.734	0.466	0.918	0.583

Looking at the *kappa* values per categories (Table 2), for total area, we can see that the largest dissimilarities are occurring in industrial and green areas.

Since the green and agriculture areas are unbuilt categories, they are the categories with the most discrepancies. Those discrepancies are caused by illegal construction of residential housing in planned green areas and by planning industrial category on agricultural areas.

Almost perfect location similarities in the category of traffic areas indicates that the existing traffic areas were constructed according to the plan, but only 50 precent have been realazed at the moment. It is planned to build new roads and to expand the airports mainly in locations that are currently in agricultural areas.

Table 3. Zemun *Kappa* statistic per category.

	Agricult.	Wetlands	Traffic areas	Infrastruc.	Resident.	Commerc.	Industry	Special use	Green areas
$\kappa appa$	0.553	0.998	0.597	0.162	0.827	0.421	0.424	0.813	0.398
κ_{loc}	0.862	1.000	0.947	0.262	0.905	0.422	0.750	0.847	0.847
κ_{histo}	0.641	0.998	0.631	0.618	0.914	0.999	0.566	0.960	0.471

Spatial distribution of almost all categories is substantial, except infrastructure and commercial areas. Values of *kappa* indicate that the built infrastructure is in great disagreement with the planned (Table 3). This disagreement is mainly in the location and area of suburban settlements. Disagreement between commercial areas can be justified for several reasons: some of the existing industrial and residential areas had shifted to commercial land use and planned commercial areas were not built.

Table 4. New Belgrade *Kappa* statistic per category.

	Agricult.	Wetlands	Traffic areas	Infrastruc.	Resident.	Commerc.	Industry	Special use	Green areas
$\kappa appa$	0.347	0.995	0.832	0.785	0.833	0.530	0.422	0.585	0.448
κ_{loc}	0.930	1.000	0.954	0.949	0.881	0.835	0.707	0.936	0.488
κ_{histo}	0.373	0.995	0.872	0.827	0.945	0.635	0.597	0.625	0.918

All unbuilt areas in the observed land use map are defined as green areas; on the other hand, part of the areas which are used as agriculture areas were planned as green space (Table 4). That is the main reason why *kappa location* for green area is small, while *kappa histo* is high. But, in the category of agriculture, the value of *kappa location* and *kappa histo*, is opposite, for the same reasons. It is planned for New Belgrade to become a commercial center of Belgrade, but it is not yet realized to the end.

Table 5. Surčin *Kappa* statistic per category.

	Agricult.	Wetlands	Traffic areas	Infrastruc.	Resident.	Commerc.	Industry	Special use	Green areas
$\kappa appa$	0.350	0.989	0.396	0.750	0.800	0.055	0.248	0.877	0.154
κ_{loc}	0.964	1.000	0.979	0.960	0.859	0.073	0.927	0.923	0.471
κ_{histo}	0.363	0.989	0.405	0.781	0.931	0.754	0.268	0.950	0.328

Surčin is the municipality with the lowest *kappa* statistic within the studied area (Table 1). Discrepancies are mostly occurring in the commercial area. Spatial distributions of this category indicate that only 7 percent of cells are located on the planed space. Since a new ring road is planned to be built through the territory of the Surčin municipality and the airport is also placed there, the measure of the quantitative similarity of traffic is low (Table 5).

The total area planned for commercial use is about one percent of the whole area of the municipality, and it doesn't affect the value of the total *kappa* statistics. Lower values of *kappa histo* indicate the quantitative dissimilarities, which is logical since planned urban areas in the municipality account for 30 percent of the total area while in 2010 the urban area extends to 17 percent.

Besides the *kappa* indexes calculation, the fuzzy set map comparison was also performed. There is some degree of similarity in land use considering the overlaping of the categories. Categories of green and agriculture areas are similar since they both belong to the unbuilt category whereas residential and commercial categories are often combined facilities.

The similarity between adjacent categories was realized with the following Category Similarity Matrix (Table 6):

Table 6. Category Similarity Matrix.

	Agricult.	Wetlands	Traffic areas	Infrastruct.	Resident.	Commerc.	Industry	Special use	Green areas
Agricult.	1	0	0	0	0	0	0	0	0.6
Wetlands	0	1	0	0	0	0	0	0	0
Traffic areas	0	0	1	0	0	0	0	0	0
Infrastruct.	0	0	0	1	0	0	0	0	0
Resident.	0	0	0	0	1	0.4	0	0	0
Commerc	0	0	0	0	0.4	1	0.2	0	0
Industry	0	0	0	0	0	0.2	1	0	0
Special use	0	0	0	0	0	0	0	1	0
Green areas	0.6	0	0	0	0	0	0	0	1

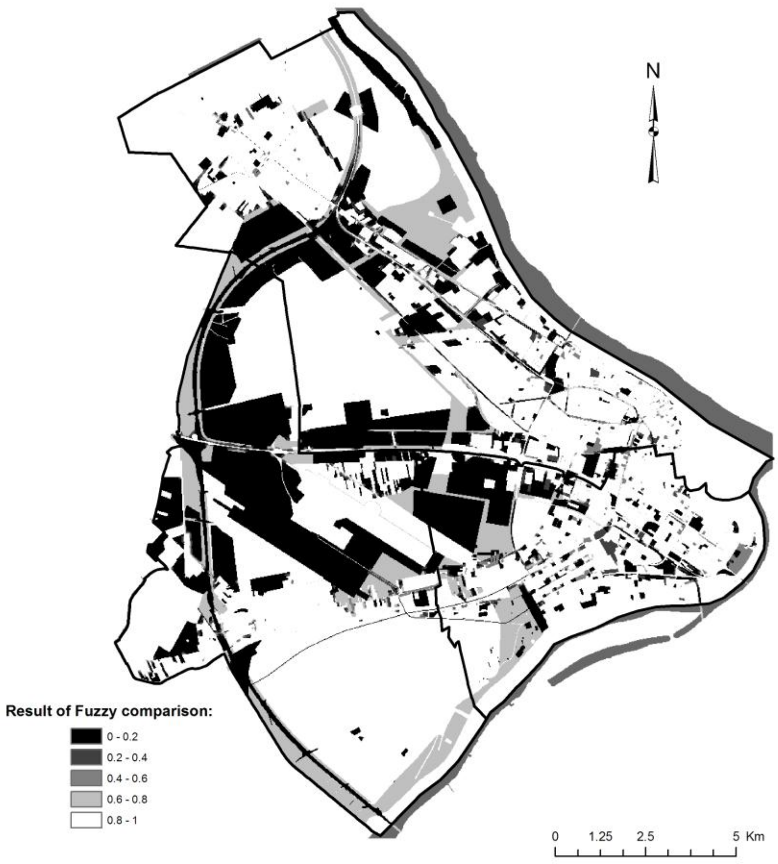


Fig. 4. Spatial assessment of similarity in the fuzzy set approach.

In Fig.4 each cell has a value between 1 (for identical cells) and 0 (for total disagreement). The darker areas indicate the more intensive disagreement. Unlike Fig.3 it is possible to obtain a gradual analysis of the similarity of two maps, by distinguishing total agreement (white areas), medium similarity and low similarity (the shades of gray) and total disagreement (black areas).

CONCLUSION

In this work the advantages of using the *kappa* statistics and its new variants to compare maps were demonstrated. It is interpretable, allows different results to be compared, and suggests a set of diagnostics in cases where the reliability results are not good enough for the decision making purposes. Moreover, map comparison methods are very useful to assess the similarity of a set of land use maps on a grid size level. In our case study area, we can conclude that in the period from year 2003 to 2010 urban growths has been carried out according to plan, with minor exceptions.

We suggest that this measure be adopted more widely within urban planning community. Further investigations should be conducted in order to come up with some standards that should used as a benchmarks in the land-use change assessment. Also, recently introduced metrics like *kappa simulation* (van Vliet, 2009; van Vliet et.al., 2011) have to be considered in the future work.

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