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STATISTICAL APPROACH IN LAND-USE SUITABILITY ANALYSIS OF THE BELGRADE CITY SUBURBS

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1. INTRODUCTION

The need for smart sustainable urban solutions has never been greater than it is today. Master plan (MP) represents rather significant document for a city development and the City of Belgrade has a tradition and long history of development under MP framework (Djuric et al 2013). Current MP (Fig. 1), made by the Urban Planning Institute of Belgrade, has been adopted in 2003 and refers to the development period by the year of 2021 (http://www.urbel.com/default.aspx?ID=uzb_BG_planovi&LN=ENG).

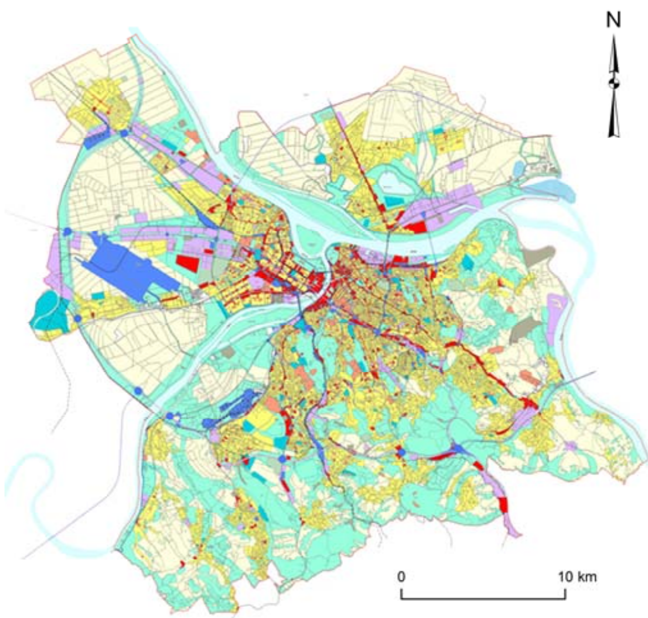

Figure 1.Current Master Plan of the city of Belgrade

On the other hand the City of Belgrade is facing a rapid urban sprawl so suburbanization problem is particularly pronounced. Since MP is following the current needs of the city, active subjects of economic development as well as urban municipalities, there is strong initiative to expand its current extents for the suburb areas.

Among other significant points of the MP, determination of the Land-Use Suitability (LUS) is considered to be one of the foremost planning references. LUS analysis is a tool used to define future land uses or their potential. Suitability techniques enable environmental managers, planners and engineers to analyze the interactions among various factors. Decision makers and developers can use the outputs to set policies and make decisions regarding the use of land. Contemporary environmental managers and planners are aware of the technological advancements in land-use allocation and suitability modelling. New methods of spatial analysis are now commonly used in the development of land-use plans, environmental impact reviews, and site selection studies for many different land uses and public and private facilities (Collins, 2001). The earliest applications of suitability analysis conducted by engineering geologists and civil engineers for Belgrade MP area, in form of hand-drawn sieve mapping overlays was done by Šutić *et al.* (1972). Later, numerous researchers performed similar suitability analysis for different purposes (urban planning, defining best/optimal road routes etc). First work involving suitability analysis in GIS environment has been done in 2009/2010 (Marjanović, 2009; Djurić, 2010), but none for Belgrade area.

This paper introduces a new approach and represents in fact, a pioneering work performed for the City of Belgrade. It represents how available thematic data, processed in GIS environment, can be and was used for LUS assessment. One of the statistical methods involving the Conditional Probability (CP) approach with the Weight of Evidence technique, has been used. Conventional methods on the other hand, are still needed to validate the outcomes and to calibrate these GIS-based methods, which are still to be developed and perfected.

There was a strong motif supporting this research, since in-charged City's government services have shown interest in extending the Master Plan (MP) to the Belgrade suburb areas.

2. CASE STUDY AREA

The study area includes the territory of Belgrade City, the capital of the Republic of Serbia. For the purpose of modelling, study area has been divided into the following splits: training and testing area (Fig. 2). The training area included the territory of Belgrade MP, while the remaining part of the Belgrade City territory (which is herein considered as suburban area) was adopted as the testing area (Tab. 1). Geographic extents of Case Study

Area are: 4994905N; 4902405S; 7419130E and 7488830W (ArcGIS predefined spatial reference system: MGI_Transverse_Mercator/Zone 7).

Table 1. Some basic data about the study area (www.stat.gov.rs)

Case Study Area	Area (km^2)	Population (2011)
Training	776	1 373 000
Testing	2446	266 121

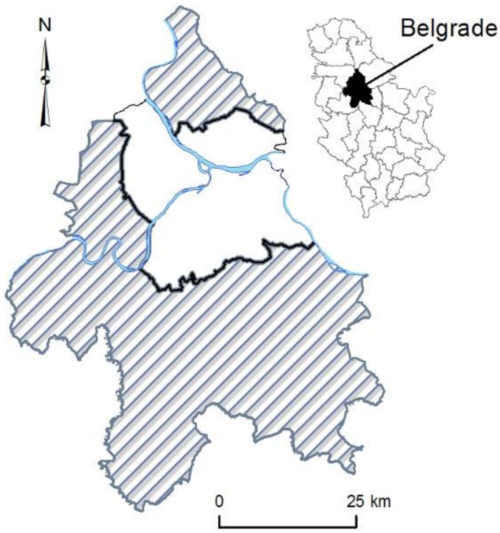

Figure 2. Geographic location of the study area (blank=training, hatched=testing area).

3. DATASET

The dataset has been assembled from different resources, and required different pre-processing manipulations, dependent on the model requirements. It has been established as a set of featured raster layers in a GIS environment.

COMPRESSIBILITY raster was made by reclassifying geological units. Basic Geological Maps at 1:100 000 scale (sheets: Belgrade, Pančevo, Obrenovac and Smederevo) were digitized and then reclassified by using ground compressibility as a criterion. Five categories were defined by the degree of ground compressibility (Jovanović et. al, 1977; F.G. Bell, 2007): Very high, High, Medium, Low and Very low. Very high degree of compressibility was considered as very unsuitable for urbanization, and vice-versa (Fig. 3-a). The reclassification was done because the original geological units were very diverse and complex for the analysis since they counted more than 50 classes.

The *LAND COVER* project is a part of the CORINE program (European Environment Agency, www.eea.europa.eu) and is intended to provide consistent localized geographical information on the land cover of all European countries. CORINE methodology implies visual interpretation of false color composites (4, 3, 2) of Landsat TM images (30 m resolution), which turned as a very convenient resource for this research. The CORINE land cover classes comprise of three levels, and herein, the third level has been used at 1:100 000 scale. New (intermediate) classification was formed, because the second level of CORINE classes was too simple and third was too complex (Fig. 3-b). Land cover classes were modified (reclassified) into five classes (Tab. 2).

Table 2. Land cover raster classification

Corine Classes (Level 3)	**Reclassification**
Continuous urban fabric	Class 1 (Built-up area)
Discontinuous urban fabric	
Industrial or commercial units	
Port areas	
Airports	
Construction sites	
Pastures	Class 2 (Suitable for the urbanization)
Natural grasslands	
Non-irrigated arable land	Class 3 (Conditionally suitable for the urbanization)
Complex cultivation patterns	
Land principally occupied by agriculture, with significant areas of natural vegetation	
Beaches, dunes, sands	
Green urban areas	Class 4 (Unsuitable for the urbanization)
Sport and leisure facilities	
Vineyards	
Fruit trees and berry plantations	
Broad-leaved forest	
Coniferous forest	
Mixed forest	
Transitional woodland-shrub	
Road and rail networks and associated land	Class 5 (Very unsuitable for the urbanization)
Mineral extraction sites	
Dump sites	
Inland marshes	
Water courses	
Water bodies	

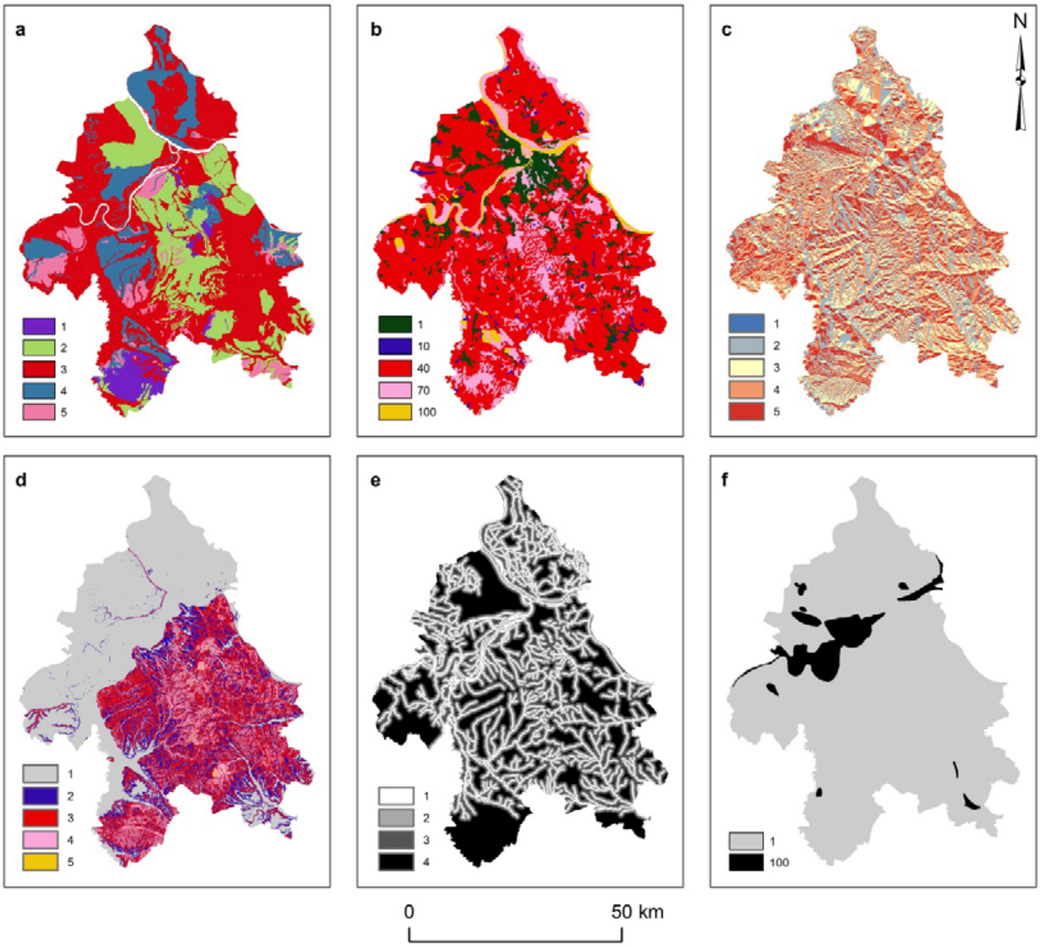

Figure 3. Dataset: a) Ground compressibility (1=Very Low, 2=Low, 3=Medium, 4=High, 5=Very High); b) Land Cover (1=Built-up area, 10=Suitable for the urbanization, 40=Conditionally suitable for the urbanization, 70=Unsuitable for the urbanization, 100=Very unsuitable for the urbanization); c) Aspect (1=Flat, 2=South, 3=West, 4=East, 5=North); d) Slope (1=Very Low, 2=Low, 3=Medium, 4=High, 5=Very High)e) Distance from stream (1=<100, 2=100-400, 3=400-800, 4=>800)
f) Protected areas (1=Non-protected, 100=Protected)

When analyzing an area for urban development relief characteristics in generally play a major role (Tošković, 2006). Therefore, initial computations considered generating 50 m resolution *DIGITAL ELEVATION MODEL* (DEM) (Hutchinson, 1996), by digitized 2.5 m equidistance contours, using *Topo to raster* interpolation method (Hutchinson, 1988, 1999, 2000) of the *Spatial Analyst* extension in the ArcGIS 10. DEM has been further used to generate *SLOPE* and *ASPECT* rasters (Burrough, 1998).

Urban planners consider *ASPECT* to be a significant attribute when projecting urban development (Tošković, 2006), since it is necessary to calculate the solar illumination for each location/cell/pixel (Daniels, 1997). Criteria used for this model is that the most suitable for building are the flat and westward exposed terrains. Vice-versa, the least suitable is a terrain exposed to the north (Fig. 3-c).

SLOPE raster is found significant for the model since all of the landslides on the territory of the City of Belgrade are formed on slopes greater than 7° (Djurić, 2011). Therefore, lower slope values as well as flat terrain were considered to be more suitable for building and vice versa (Fig. 3-d).

*DISTANCE FROM STREAM*raster was made by buffering (*Euclidian distance* module in ArcGIS 10) digitized intermittent and permanent stream flows, (Fig. 3-e). Streams were digitalized from Topographic maps of Belgrade (scale 1:100 000).

PROTECTED AREAS is an attribute raster resulting from compiling two maps: Zones of Sanitary Protection of Fresh Water Sources and Swamp Habitat, both on the administrative territory of the City of Belgrade. Extents of registered features are digitized from existing maps. According to the current legislation and Rule Book for defining and maintaining zones of sanitary protection of sources for water supplying, "zone of sanitary protection is an area around water supplying object, where building and activities of built objects as well as the conducting of any other activity is being surveyed". Swamp habitat is considered to be an area either protected by the decree of Institute of Nature Conservation of Serbia in order to protect biodiversity or simply not suitable for building because of its geotechnical characteristics. Therefore, marked territories from both maps were considered as areas where building is forbidden, hence evaluated as not suitable (Fig. 3-f).

LUS1 has been generated from the original MP as a raster image with 10 m cell resolution, containing the following classes: SUITABLE, CONDITIONALLY SUITABLE, UNSUITABLE and VERY UNSUITABLE. It has been used as a modeling and evaluation reference.

LUS2 is actually a stability map, i.e. a simplified LUS map based on some preliminary mapping results. It has the same 10 m resolution and involves two classes: STABLE (SUITABLE + CONDITIONALLY SUITABLE) and UNSTABLE (UNSUITABLE + VERY UNSUITABLE). It has been used only as an evaluation reference.

4. METHODS

For the generation of the model a Conditional Probability (CP) approach has been used. The primary goal of any CP-based technique is to increase the probability of predicting some variable, by having other variables at disposal to correlate against, and to append this new dependency (posterior probability) to the original probability of the variable (prior probability). For the purpose of this research, the dependent variables were *LUS1* classes and the thematic variables (lithological, morphometric, environmental etc) which are cross-correlated with *LUS1* classes are the independent variables. There are numerous mechanisms for developing CP and they all involve different weighting measures. Herein, the Weights of Evidence has been used (Bonham-Carter 1994, Hagen, 2003).

Weights of Evidence is a log-linear Bayes-rule-based technique. It enables the prediction of a posterior probability by using weights, i.e. by generating correlative positive W^+ and negative W^- weights of independent variables. Positive weights are differences between posterior logits of a variable's class, given the presence of *LUS1* classes. Negative weights are also posterior logits differences, given the absence of *LUS1* classes, i.e. given the presence of *LUS1* class negatives ("non-*LUS1* class"). Weighting can be easily done in a GIS environment, by simple raster cross-tabulation, having the *LUS1* reference on one side, and a reclassified variable on the other. Assuming that *C* represents the target *LUS1* class pixels, and *F* class pixels of an independent variable, the contingency portions of $C \cap F$ (overlap of a given *LUS1* class and a given variable's class), $\neg C \cap F$ (overlap of a non-*LUS1* class and a given variable's class) and the other respective overlaps ($C \cap \neg F$ as *LUS1* class outside the given variable's class, and $\neg C \cap \neg F$ as non-*LUS1* outside the variable's class) are easily extracted, and fed into equations (Eq. 1,2).

$$W^+ = \ln \frac{\#\{C \cap F_i\}}{\#\{\neg C \cap F_i\}} \quad (1)$$

$$W^- = \ln \frac{\#\{C \cap \neg F_i\}}{\#\{\neg C \cap \neg F_i\}} \quad (2)$$

Thus, each class in each variable is provided with a pair of weights, which describe the intensity and character (±) of its engagement with the *LUS1* class pattern. By assuming the conditional independence of all *n* variables, the latter can be expressed as prior probability of *LUS1* class corrected by the sum of positive/negative weights of all variables' classes, depending on the presence or absence of a particular *LUS1* class (Eq. 3).

$$\mathrm{logit}\left(P(C,F)\right) = \mathrm{logit}(C) + \sum_{i=1}^{n} \sum_{j=1}^{m_i} W_{i,j}^{\pm} \quad (3)$$

It is further feasible to calculate the certainty of every class of every factor, and mask all data instances which are too uncertain or missing, by extracting it from the standard deviation of posterior probabilities as $W^{\pm}/\sigma(W^{\pm})$ (Bonham-Carter 1994).

Finally, the weights could be adopted not only for the observed area (training area), but also for some adjacent areas for which the *LUS1* class reference turns unavailable. In this fashion, the *LUS1* classes are being spatially predicted, not just analyzed and assessed.

Advantages of the technique certainly lies in objective, data-driven assessment, capability to operate with multiple inputs and multiple classes, ease of handling of missing or irrelevant data (by assigning zero or close-to-zero weights), to accompany the result with the certainty estimate and to make according exclusions where needed.

Shortcomings on the other hand, are not too numerous. These mostly regard the conditional independency assumption, which disables the interrelation among the factors, and the contribution it might bring to the model. Further, it does not work with nominal conditioning factors, but requires quantification and normalization prior to the analysis, while another perspective, but time-consuming and computationally-intensive alternative is to segregate such data into binary cases. Also, the numeric variables with ordinal and dichotomous scales cannot keep continual values, but have to be reclassified and ranged by arbitrary intervals, which is commonly optimized by a trial-and-error variations of number of classes and values of cut-offs, which turns very demanding with large number of inputs, and it introduces some subjectivity in the procedure. Finally, the drawback is also a high dependency on the pattern data size, in this case, the number of *LUS1* vs. non- *LUS1* class pixels, since too few instances lead to an unreliable model.

5. RESULTS

The modeling process has been carried out in two sub-stages. The first required defining the class weights in the training area, developing a (continual) LUS model, and aligning the modeled LUS classes with the original ones (*LUS1*), by seeking for the best fit (reclassifying arbitrarily). It resulted in the MODEL1. In the second part the weights obtained in the first stage were reused for developing the (continual) LUS model for the testing area. After reclassifying it, the MODEL2 has been obtained. An important difference between these two LUS models is that the classes of MODEL2 have had to be aggregated in the following fashion: SUITABLE and CONDITIONALLY SUITABLE classes have fallen into STABLE, whereas remaining UNSUITABLE and VERY UNSUITABLE to UNSTABLE class. The reason was that the referent map for the testing area *LUS2* has been fashioned likewise, so that the model evaluation could have taken place.

The weights generated for the MODEL1 (Table 3) have been checked for certainty, and those failing to top the relative certainty threshold of 10% have been annulated (in order to ease the processing effort).

Table 3. Weights of independent variable classes

Attribute	Class	Total Weight
Ground Compressibility (derived from geological setting and engineering geological classification)	- very low	–2.8404
	- low	–5.7758
	- medium	–0.6207
	- high	–0.7582
	- very high	+0.7249
Land Cover (reclassified CORINE land cover)	- built-up area	–0.8323
	- suitable for urbanization	–0.6382
	- conditionally suitable for urbanization	+0.2120
	- unsuitable for urbanization	–0.0990
	- very unsuitable for urbanization	+0.4895
Aspect (reclassified, DEM-based)	- flat	–1.3353
	- south	–0.0023
	- west	+0.0337
	- east	–2.0415
	- north	+0.3136
Slope (reclassified, DEM-based)	- very low (<5°)	–0.0972
	- low (5–10°)	–0.0126
	- medium (10–25°)	–0.5943
	- high (25–45°)	–0.0675
	- very high (>45°)	+0.3257
Distance From Stream (reclassified, DEM-based)	- <100 m	–0.9112
	- 100–400 m	–0.0134
	- 400–800 m	–0.4137
	- >800 m	+0.1102
Protected Areas	- protected	–5.2227
	- non-protected	+19.4370
Elevation (reclassified, DEM-based)	- <100 m	–1.2197
	- 100–150 m	+0.7353
	- 150–200 m	+0.7880
	- 200–250 m	–0.3354
	- >250 m	–3.3455

The results of the MODEL1 (evaluated against the existing LUS map) turned less convincing than expected (Table 4). It is apparent that some classes are much better depicted, particularly class UNSUITABLE, while the biggest problems occur for SUITABLE and CONDITIONALLY SUITABLE class (Figure 4a). Very high False Negative (FN) rate indicates that too many instances have been misclassified in the most inconvenient and the most costly fashion (claiming that the area is suitable for construction whereas it is actually the opposite). This leads to disapproving of the model for a direct LUS classes mapping. However, the potential of mapping particular classes remain.

In this context, the MODEL2 has proven that the plausible prediction is achieved for the UNSUITABLE + SUITABLE classes (Figure 4b). Conveniently these are exactly the classes that have been intended for further modeling outside the training area. Overall accuracy of MODEL2 is significantly high (nearly 80%) while the FN rate drops significantly, so the model does not make FN type of error as much MODEL1 did.

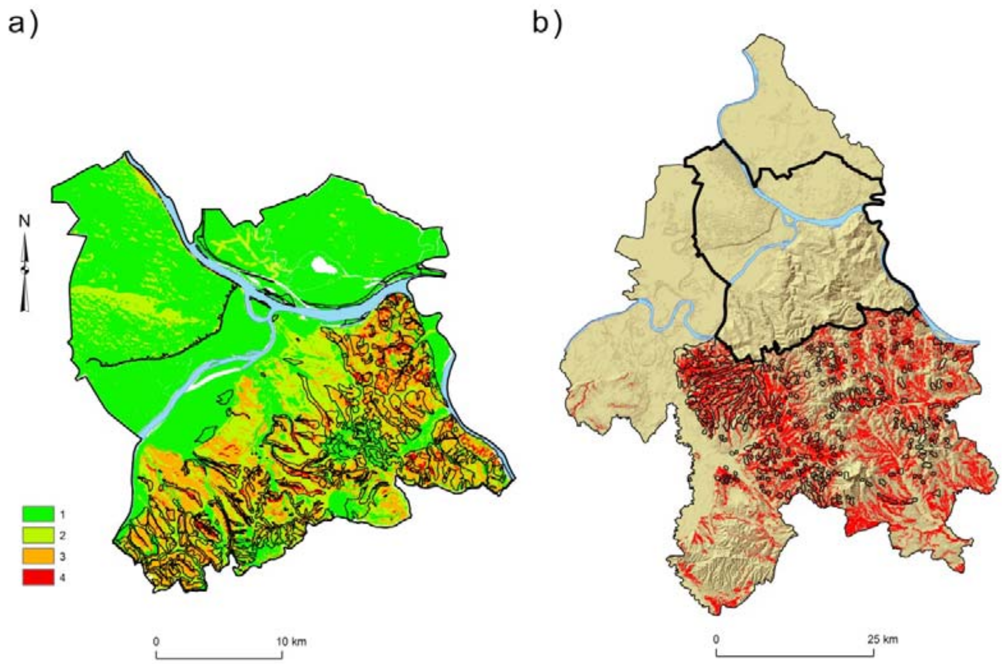

Figure 4. a) MODEL1: 1=Suitable, 2=Conditionally Suitable, 3=Unsuitable, 4=Very Unsuitable. LUS1 classes UNSTABLE+VERY UNSTABLE shown in black contours;

b) MODEL2: LUS class UNSTABLE (UNSUITABLE+VERY UNSUITABLE) is shown red. LUS2 class UNSTABLE shown in black contours. Training area (MP area) is contoured bold black

One possible solution for handling of the lower LUS classes and improving of MODEL1 could be a combination of heuristic (expert-based) and CP technique, which would amortize the effect of CP weights on the lower classes by the expert judgment, while the rest of the classes remain affected as usual.

Table 4. Model evaluation

Model	Overall Accuracy [%]	FN rate for classes UNSUITABLE + SUITABLE
MODEL1	27	0.70
MODEL2	79	0.17

6. CONCLUSION

The study has shown a great potential of using statistical models for supporting development of MP for the suburban areas. The accuracy is particularly high in UNSTABLE+VERY UNSTABLE classes. For further notice, the model could be additionally fitted by involving some expert-based methods (for instance AHP method). The method turned less time and resource-demanding than conventional approach. However it should not be regarded as a replacement of conventional approach, but rather as a preliminary prognosis, which can aid the process of generating MP and related maps.

7. AKNOWLEDGMENTS

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SUMMARY

The paper addresses the problem of suburb development potential in the City of Belgrade. Suburbanization problem is particularly pronounced due to the rapid spreading of the city, and there is a strong initiative for extending the existing Master Plan for these suburb areas. One of the important points in that context is determination of the Land-Use suitability, as one of the foremost planning references. Herein, a statistical model is proposed for modeling of the Land-Use suitability relying on the available thematic data, including the following sources: Land-Cover, Geological, Topographic and Protected areas maps and some synthetic maps derived from these sources in a GIS environment. For the modeling purposes, the Conditional Probability approach has been implemented, using Weight of Evidence technique, in particular. Two modeling schemes have been involved: (i) model is being built and correlated in the extents of the known Land-Use suitability

(training area) (ii) model is being extrapolated to the areas with partly known Land-Use suitability (by having only two particular suitability classes at disposal). Such strategy enabled optimization of classification scale, crucial for the actual comparison of the actual state and the final model, as a combination of (i) and (ii). The results were convincing and by reaching more nearly 80% of accuracy, they parallel the results of the earlier work based on different methodology. Finally, a practical applicability of the model has been also discussed.

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