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Multi-Criteria Land Use Classification in GIS for Buildings Construction

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1 ABSTRACT

Preparation of spatial plan is response to the objectives, which are often in conflict. Planners decide to search for optimal solutions, where the optimum is usually a subjective assessment of meeting the set of goals and criteria. Given that the land is limited resource, it raises more the question of sustainability of life on Earth and the necessity of rational, scientifically-based land planning purposes. This study developed a methodology for multi-criteria land use classification based on a set of relevant factors and geographical parameters, using the AHP method (Analytical Hierarchy Process) for multi-criteria decisions and GIS tools for creation, storage, analysis and operations of the data.

The developed methodology is tested to solve the problem of evaluation and classification of land for the building construction, using data related to the area of Tuzla Municipality. The result of this research in a general sense is a methodology for multi-criteria land use analysis in GIS needed for spatial planning. In the specific sense a result of this research is the map of categorized land for building construction in the municipality of Tuzla, which clearly indicates the spatial potentials and constraints. Thematic maps, obtained as a result of applying the presented methodology allows planners make rational and strategically important decisions regarding the allocation of land purposes, and planning for sustainable development.

2 INTRODUCTION

As the land is very limited resource nowday, it is important to recognize its potential, and optimize its use. Due to the complex needs and a large number of criteria (environmental, economic, sociological, natural) decision-makers needs to use techniques of multi-objective planning and multi-criteria analysis in many social activities related to land, especially in the field of planning of spatial organization [4].

Because of the rapid urbanization process frequently arises the need for space planning purposes with emphasis on building high-rise buildings, and construction of urban infrastructure for housing, work and a variety of supporting activities of the population. Due to the large number of specific criteria (geotechnical, environmental, construction, urban and others), which need to be considered in this planning, the application of multi-criteria analysis methodology can have a significant impact on the quality, speed and cost of the planning. It will primary assist in valorization of land which serves as the ground for the planning. Efficient approach, which involves the application of tools for geospatial analysis (GIS) methods and techniques of multi-criteria system analysis, will enable spatial planners to solve easier and faster the problem related to land use planning for the construction of high-rise buildings and associated infrastructure [10]. This approach can be applied in the framework of special studies (evaluation of land use for the construction of high-rise buildings), which would give answers to many questions of importance for the spatial plan. Some of the issues which correlate with this research area are the following:

- identification of the land with natural and technological predispositions for building high-rise buildings,
- creation of the optimal model for the valorization of land which indicates cost effectiveness of investments and
- compliance with the measures and objectives of urban development according to international conventions.

3 APPLICATION OF MULTI-CRITERIA ANALYSIS TO URBAN LAND-USE PLANNING

3.1 A brief overview of the methodology

The methodology for the evaluation and classification of land for the construction of high-rise buildings consists the following 4 stages (Fig. 1):

- 1) Identification of multi-criteria decision making elements involves the identification of objective synthesis model. As the objective model in the study it is identified environmental synthesis model where weights are assigned considering environmental criteria.
- 2) Criteria weights definition means evaluation of weights assigned to criteria (factors) according to the target synthesis model.

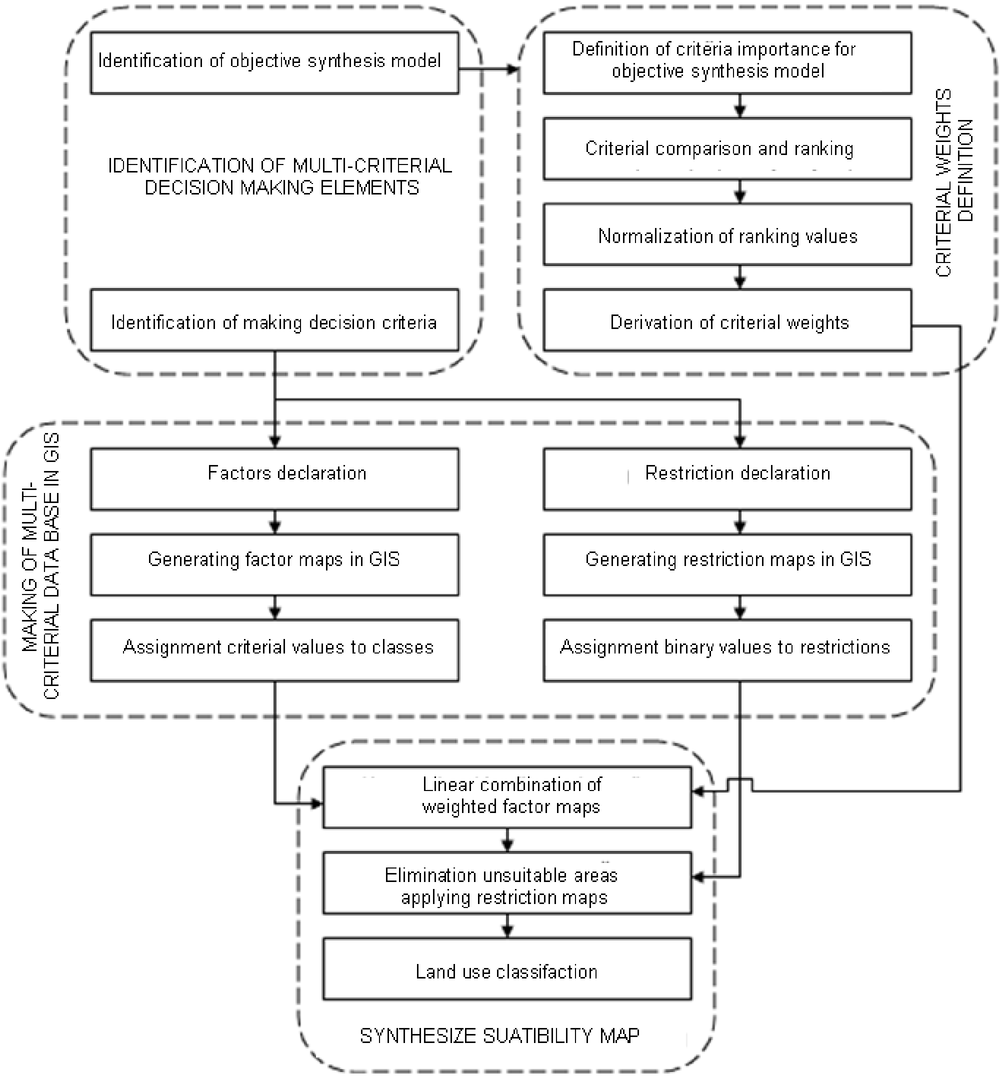

Fig. 1: Key stages in the procedure of land use classification for construction of high-rise buildings

- 3) Making of multi-criteria database in GIS is implemented generating factor maps and restriction maps, and assigning criterial and attribute values to each class of factor and restriction maps.
- 4.) Synthesize suitability map is realized through the analysis of linear combination weigthed factor maps, the elimination of unsuitable areas and land use classification. Overview of certain classes of land (with or without restrictions) is usually represented by area balances table.

3.2 Land suitability map

In the process of spatial planning a digital land suitability map is a graphical spatial representation of land use for certain use [5]. This map can be generated as thematic map in GIS, based on appropriate model of multi-criteria analyses [2]. Multi-criteria analysis includes different criteria that determines the geological, geomorphologic, environmental and other characteristics of land. Land suitability map for a particular purpose (e.g. the construction of high rise-buildings) contains the set of arranged and classified values (assigned to cells) by all established criteria. This map demonstrates the spatial distribution of classified abilities. The accuracy of geospatial analysis and performance of the used analytical algorithms depends very much on selected grid resolution [3]. The spatial framework with grid resolution (cell size) of 10x10 m is used in this study.

3.3 Criteria for evaluation of land suitability

Selection of the criteria is very sensitive task and it should take into account those aspects that significantly affect the selection of sites for construction facilities and that are relevant to the preservation of the environment (environmental syntheses model) [1]. As a result of the selection process within the framework of this study the following criteria and restrictions were identified [6]:

- 1. Technical and technological aspects:
  - 1.a. land accessibility,
  - 1.b. slope of the land surface
- 2. Security aspects:
  - 2.a. geotechnical suitability,
  - 2.b. influence of terrain sinking,
  - 2.c. restrictions related to the impact of landslides
- 3. Environmental aspects:
  - 3.a. restrictions in terms of already occupied areas (farmland, forest area, public transport area, water surface, surface and underground mines area)
- 4. Urban-ambiance aspects:
- 4.a. aspect of terrain.

3.4 Weights assignment procedure

In this study the AHP (analytic hierarchy process) method is used to weight and compare the criteria. It is based on creating a matrix of pairwise comparisons. In this technique, the weight can be defined using the basic eigen-vectors of a square reciprocal matrix of pairwise comparisons between the criteria. These comparisons are considering the relative importance of two criteria used to determine the suitability of a defined objective. Ratios are defined by continuous scale (Fig.2) of nine points (degrees).

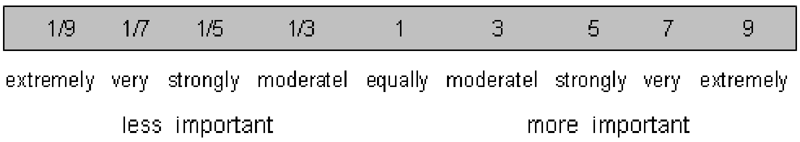

Fig. 2: The continuous rating scale used for the pair wise comparison of factors in the multi-criteria evaluation

Definition of weight includes comparison of every possible pair of criteria by entering scores (range) in a matrix of pairwise comparison (Table 1). As a good approximation for the calculation procedure of eigen-vectors can be used the sum of weights for each column and determination of the average value for each entry in all columns [8]. According to this procedure it is carried out criteria weighting in accordance to their importance as described in Table 1.

Factors	Land Accessibility	Terrain Slope	Geotechnical Usability	Terrain Sinking	Terrain Aspect
Land Accessibility	1	1/5	3	5	1/7
Terrain Slope	5	1	5	7	1/3
Geotechnical Usability	1/3	1/5	1	3	1/7
Terrain Sinking	1/5	1/7	1/3	1	1/9
Terrain Aspect	7	3	7	9	1
Sum of weights	**13.53**	**4.54**	**16.33**	**20**	**1.72**

Table 1: Sum of weights calculation

The total value of the sum weights for all columns is 56.12. Dividing this value with the sums for each criteria we got a weight of individual criteria (Table 2).

Factors	Normalized weights
Land Accessibility	0.24
Terrain Slope	0.08
Geotechnical Usability	0.29
Terrain Sinking	0.36
Terrain Aspect	0.03
Σ	**1.00**

Table 2: Calculation of average (normalized) weights

3.5 Creation of factor maps

Multi-criteria evaluation is realized using cartographic algebra on factor (criteria) maps in the GIS [11]. The following discussion describes the steps in the procedure of multi-criteria evaluation of land use for planning high-rise buildings in the municipality of Tuzla. The classification of terrain hights, and creating maps for the exposure factor (terrain aspect) and land slopes uses digital terrain model, which is obtained by inverse distance weighting interpolation of a set of elevation points (Fig. 3) [9]. On the basis of determined parameters (rank of horizontal and vertical angles) for each class of orientation and inclination in GIS, the factor (criteria) maps are created (Fig. 4). Assignment of criteria values of classes is automatic process that realizes by grid query (for the selection of class and entering the same attributes for all cells of the same class).

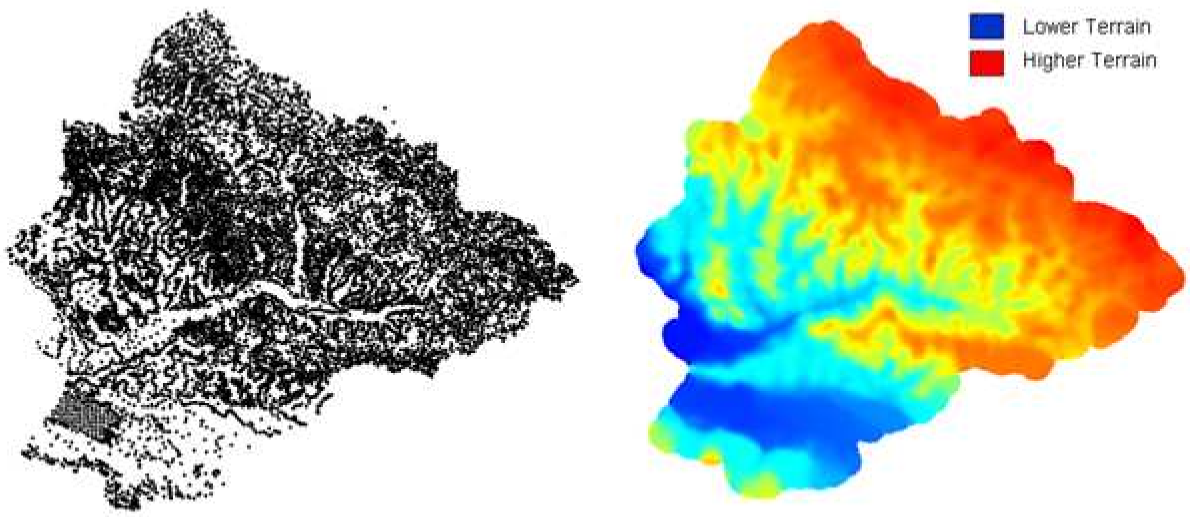

Fig. 3: Creating a DTM of Tuzla municipality (right) from a set of vertical points (left)

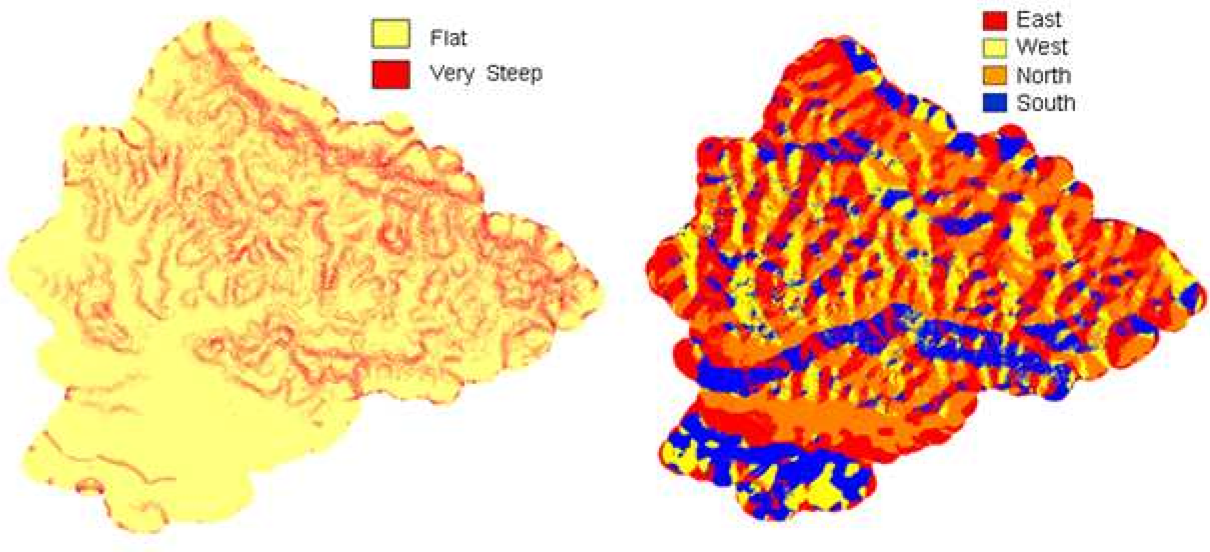

Fig. 4: Creating a land slope (left) and terrain aspect factor maps (right)

Assignment (scoring) of criterial values for certain classes of terrain slope and aspect criteria is described in Table 3. Entering chronometrical values over XYT file leads to the factor maps of land accessability (Fig. 5).

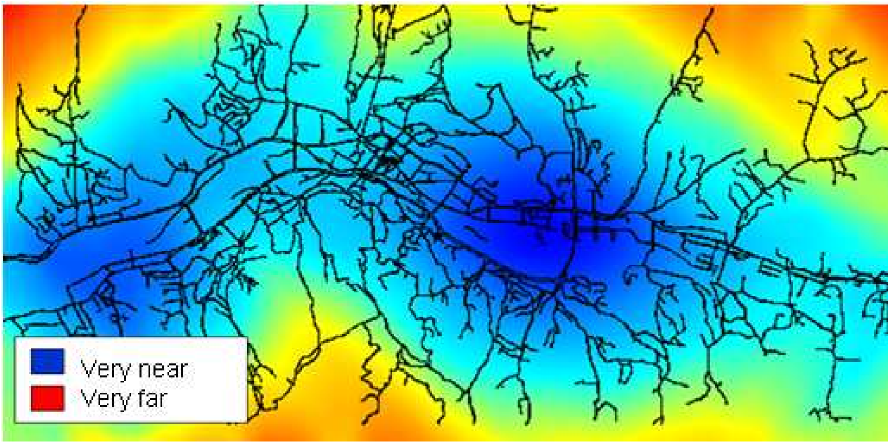

Fig. 5: Factor map of land accessibility

Assignment (scoring) of criterial values for certain classes of land accessabilty criteria is described in Table 3. Fig. 6 shows factor map of geotechnical zones created by existing digital geotechnical map of Tuzla urban area.

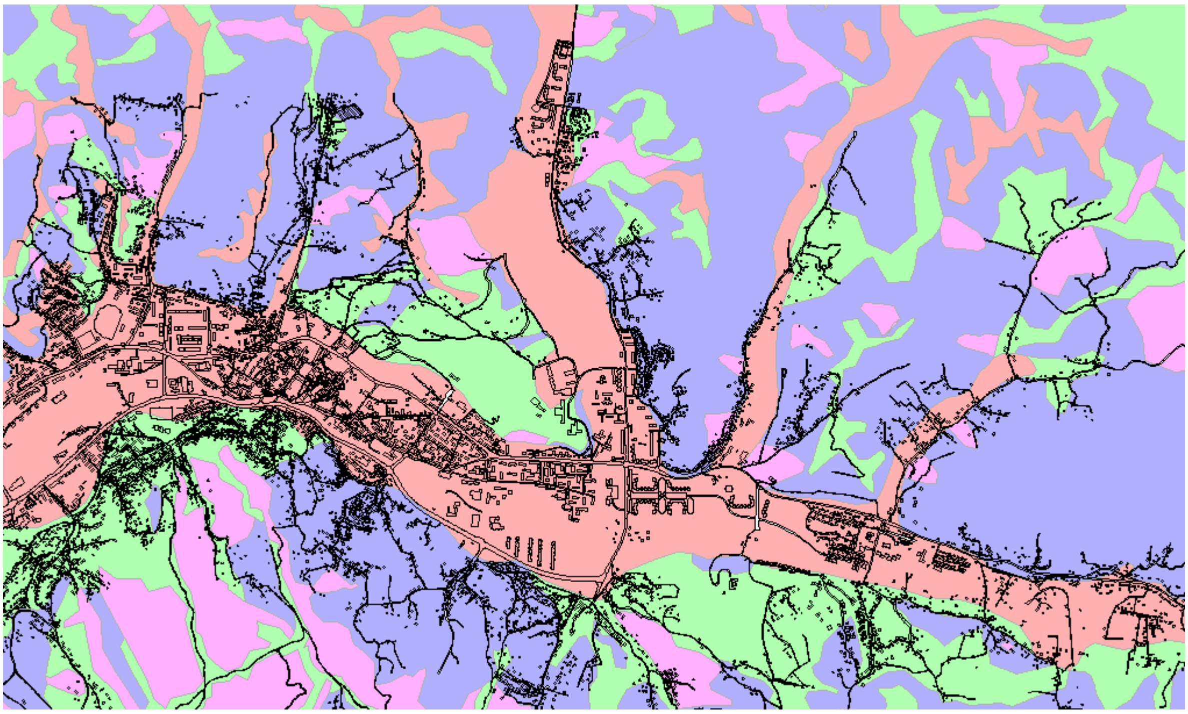

Fig. 6: Factor map of geotechnical zones: zone 1 (red color), zone 3 (green color), zone 3 (blue color), and zone 4 (purple color)

Assignment (scoring) of criterial values for certain classes of geotechnical sutability criteria is described in Table 3. As a criteria that affects the suitability of land for the construction of buildings in terms of terrain sinking it is used map with zones (Fig. 7) based on the geodetic observation intensity of surface deformation phenomena (caused by salt underground exploitation).

Assignment (scoring) of criterial values for certain classes of terrain sinking criteria is described in Table 3. Method of evaluation for each class is based on risk degree of surfice deformation in the period of terrain consolidation [13].

Based on the obtained criteria values (Table 3) and corresponding critera weight (Table 2), the GIS generated thematic map of land suitability for the specific purpose (the construction of high rise-buildings).

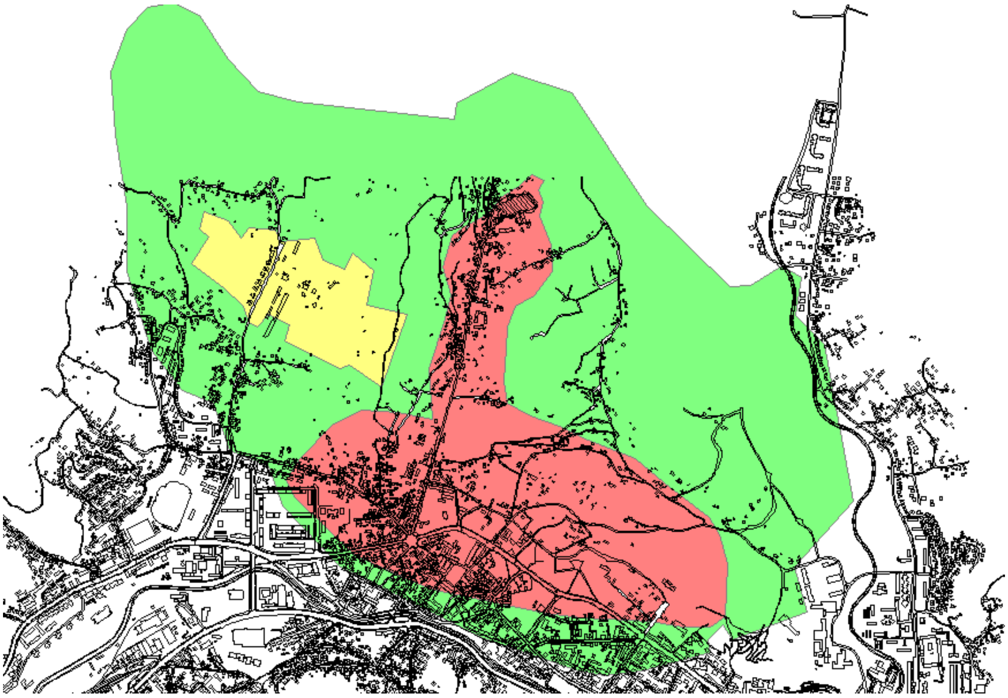

Fig. 7: Factor map of terrain sinking in Tuzla urban area: 1st zone (red color) , 2nd zone (yellow color), and 3rd zone (green color)

Terrain Slope Classes	Terrain Slope Description	Terrain Aspect Classes	Terrain Aspect Description	Land Accessibility Classes	Land Accessibility Description	Geotechnical Usability Classes	Geotechnical Usability Description	Sinking Terrain Classes	Sinking Terrain Description	SCORES (1-5)
flat	0-5%	South	135-225°	very near	0-5min	1st zone	very usable	4th zone	no risk	5
small inclination.	5-10%	-	-	near	5-10min	-	-	-	-	4
inclined	10-20%	East/ West	45-135°/ 225-315°	accessible far	10-15min	2nd zone	moderate usable	3rd zone	low risk	3
steep	20-30%	-	-	far	15-20min	-	-	2nd zone	moderate risk	2
very steep	30-45%	North	315-45°	very far	20-30min	3rd zone	less usable	1st zone	high risk	1

Table 3: Criteria values assignment (scoring)

3.6 Land classification for the planning of buildings

To get the final results of multi-criteria analysis it is necessary to perform aggregation of the weighted critera values by factor (criteria) maps and ranking (classification) of the land for a particular purpose. The total value of land for each grid cell is calculated on the basis of the following expression [12]:

$$\upsilon_z = (w_1 f_1 + w_2 f_2 + w_3 f_3 + w_4 f_4 + w_5 f_5 - \upsilon_{\min})/(\upsilon_{\max} - \upsilon_{\min}) \qquad (1)$$

- w_i presents weights for particular criteria (factors) i = 1 .. 5,
- f_i are assigned values (points) per class for the appropriate criteria, and
- $\upsilon_{\max}$ i $\upsilon_{\min}$ are the maximum and minimum value of the land critera value.

Table 4. ranks the values according to which land classification is made for the purpose of building construction.

Category of Area	Description	Rank
extraordinary suitable	area suitable for high buildings (multi-stores with 5 and more stores)	0.75 - 1.00
very suitable	area suitable for smaller buildings (multi-stores up to 5 stores)	0.50 - 0.75
suitable	area suitable for smaller individual buildings (up to 2 stores)	0.25 - 0.50
unsuitable	unsuitable area for buildings	0.00 - 0.25

Table 4: Land use classification for construction of multi-stores buildings

Based on the rank of values it is realized thematization and classification of the total land values in GIS generating map of land sutibility for construction of buildings (Fig. 8). To get the final land use maps it is necessary to apply restrictions which reduces the area with land unsuitable for building. The further discussion describes the approach to the introduction of restrictions in multi-criteria model.

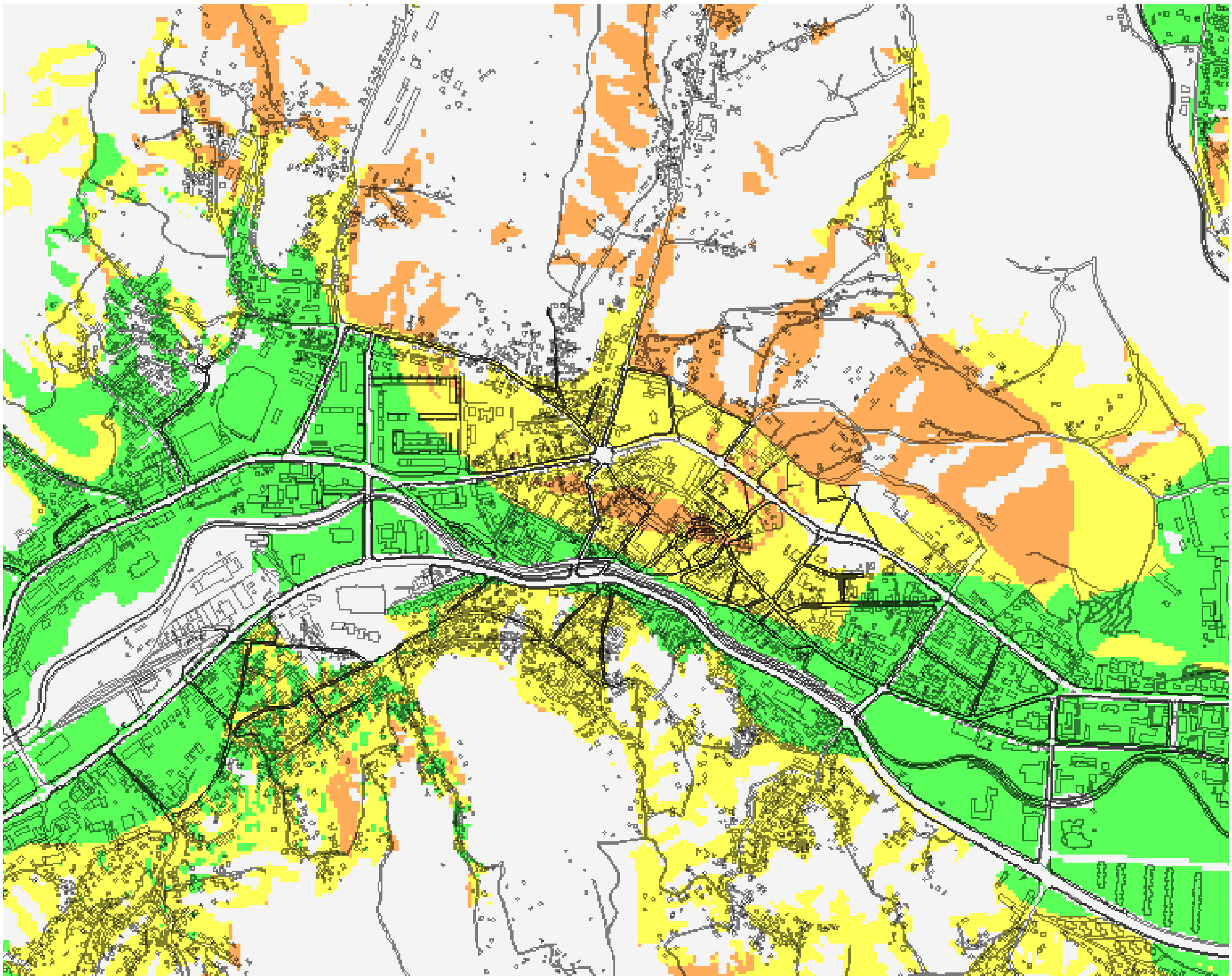

Fig. 8: Multi-criteria land use classification for buildings construction in Tuzla urban area (green – extraordinary suitable, yellow – very suitable, orange – suitable and gray – unsuitable area)

3.7 Application restrictions in multi-criteria model

Restrictions in multi-criteria model are applied as Boolean restrictions [8]. The procedure is reduced to multiplication land suitabilities (total land criteria values calculated by expression 1) and the restrictions according to the following expression:

$$\upsilon_{zo} = \upsilon_z * \Pi o_j \,, \qquad (2)$$

where oj is assigned a binary value for the j-th restriction (0 for elimination areas and 1 for other areas), and Π is the product of considered restrictions. There are the following restrictions applied in the study:

- landslides (active, passive and potential) (Fig. 9) [13],
- forest and agricultural areas (Fig. 10) and
- transportation infrastructure and water areas.

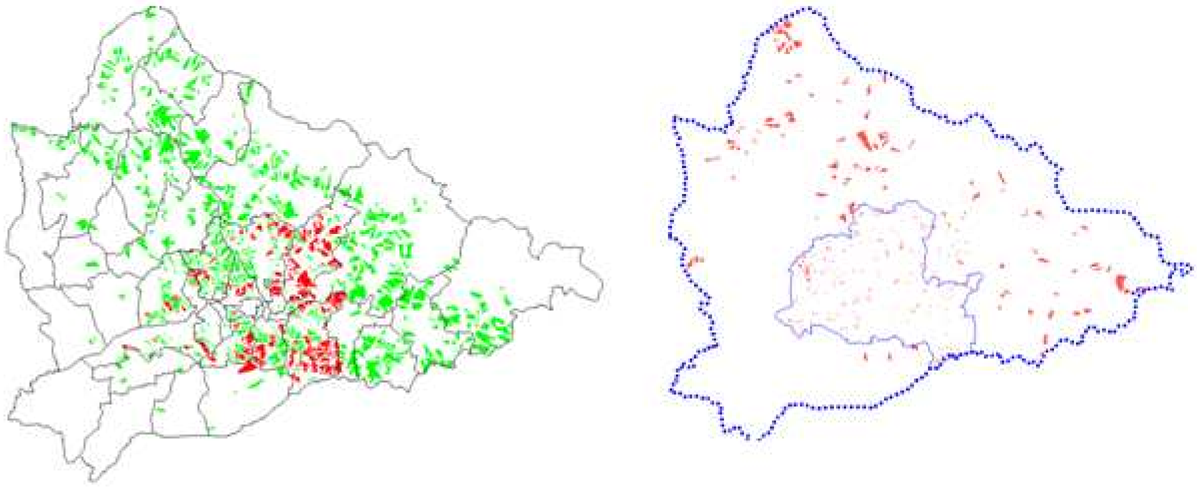

Fig. 9: Left: active (red color) and passive (green color) land slide areas; Right: potential (red color) land slide areas with administrative boundaries of Tuzla municipality

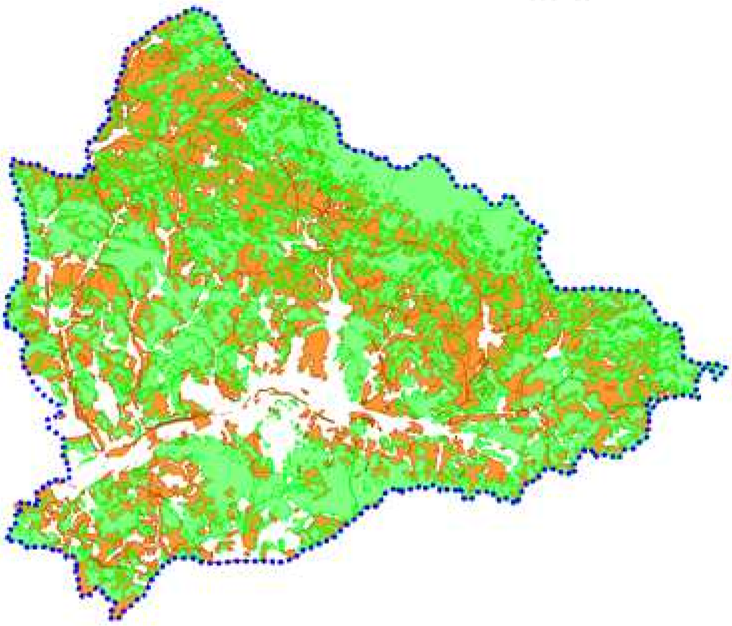

Fig. 10: Farmland (brown color) and forest areas (green color) with Tuzla municipality boundaries

By this way land use map of multi-criteria classification for buildings construction in Tuzla municipality is generated in GIS (Fig. 8).

3.8 Area balances

Table 5 shows area balances (in %) of land use classification. Area balances are commonly used as numerical quantifiers for comparative analysis of specific areas. Table 5 descriptions area distribution by individual classes (I to IV), and the impact of certain restrictions on the availability of land for construction high-rise buildings.

<table>
<tr><th colspan="2">Land Classes/
Restriction</th><th>I
Extraordinary suitable for building in %</th><th>II
Very suitable for building in %</th><th>III
Suitable for building in %</th><th>IV
Unsuitable for building in %</th><th>Total in %</th></tr>
<tr><td colspan="2">Without restriction</td><td>1.76</td><td>5.25</td><td>44.61</td><td>48.38</td><td>100</td></tr>
<tr><td rowspan="4">With restriction applied</td><td>Excluded active land slides</td><td>1.75</td><td>4.82</td><td>43.87</td><td>49.57</td><td>100</td></tr>
<tr><td>Excluded active and passive land slides</td><td>1.71</td><td>4.28</td><td>39.65</td><td>54.37</td><td>100</td></tr>
<tr><td>Excluded active, passive an potential land slides</td><td>1.69</td><td>4.19</td><td>38.70</td><td>55.42</td><td>100</td></tr>
<tr><td>Excluded all kinds of land slides, forest and agricultural land, transportation and water areas</td><td>0.93</td><td>1.32</td><td>4.72</td><td>93.04</td><td>100</td></tr>
<tr><td colspan="2">Area differences with and without restriction applied</td><td>- 0.83</td><td>- 3.93</td><td>- 39.89</td><td>44.66</td><td>0.00</td></tr>
</table>

Table 5: Area balances (with and without restrictions)

4 CONCLUSION

Despite the large number of approaches and methods of land use planning, as well as significant progress in terms of application of information technologies, many issues related to the theory and practice of land organization are still open. The need for new methods and tools in spatial planning becomes particularly pronounced because of the problems caused by the trends of the time in which we live. These trends are related to the increasing shortage of land resources, demographic growth of the population, digital and information revolution, the development of traffic and transport, the growth of cities, the impact of humans on the environment and other phenomena. In other words, this is a period of very rapid changes, requiring fast reactions and responses. Pressure on land is not only evident through the needs of existing purpose, but also through increasing the number of activities and functions related to its use. To respond all challenges, urban planners needs new methods and techniques for analyzing and finding acceptable solutions.

As land is still very limited resource, it is important to maximize its potential, and optimize its use. Due to the complex needs and a large number of criteria (environmental, economic, sociological and natural) multi-criteria planning and analysis supports decision-makers in the many social activities related to environment, especially in the area of spatial planning. The methodology presented in the study for multi-criteria land use classification in GIS for building high-rise buildings based on the use of geospatial analysis tools and multi-criteria decision making methods, is used to solve the problem of evaluation and classification of land for the construction of high-rise buildings in Tuzla urban area. The results of the analysis clearly indicates the potential and restriction of areas for construction this kind facilities.

5 REFERENCES

[1] BOGUNOVIC, Dusko: Razvoj sistema naselja u Bosni i Hercegovini i njegova optimizacija sa funkcionalno-regionalnog aspekta i aspekta prirodnih uslova-istraživački projekat, Institut za arhitekturu, urbanizam i prostorno planiranje, Sarajevo, 1986

[2] BATTY, M and LONGLEY P.A: Advanced Spatial Analysis, ESRI Press 2003

[3] LONGLEY P., GOODCHILD M., MAGUIRE D., RHIND D.: Geographic Information Systems and Science, John Wiley&Sons, Ltd. England 2002

[4] COHON, Jared L.: Multiobjective Programming and Planning, Dover Publications Inc., Mineola, New York 2004

[5] BUBLIN Mehmed: Prostorno planiranje, Univerzitetska knjiga, Sarajevo, 2000

[6] MARINOVIC-UZELAC, Ante: Prostorno planiranje, Dom i svijet, Zagreb 2001

[7] PETRIC, Jovan: Operaciona istraživanja, IP nauka, Beograd, 1997

[8] EASTMAN, J. Ronald: Raster Procedures for Multi-Criteria/Multi-Objective Decisions, The Clarc Labs for Cartographic Technology and Geographic Analysis, Clark University MA, USA, 1995

[9] HAINING, Robert: Spatial Data Analysis: Theory and Practice, Cambridge University Press 2003BUTHOR, Author: Title of the source. Vienna, 2009

[10] BIRKIN M., CLARKE G., CLARKE M., WILSON A.: Intelligent GIS, Location decisions and strategic planning, GeoInformation International, Pearson Professional Ltd. Cambridge 1996

[11] WORBOYS M. and DUCKHAM M.: GIS - A Computing Perspective, CRC Press, USA

[12] PONJAVIC, Mirza: Primjena GIS-a u implementaciji prostornog plana, IV konferencija urbanista u BiH, Tuzla, 2002

[13] MULAC, Miralem: Klasifikacija i kategorizacija savremenih egzogenodinamičkih procesa i pojava na području općine Tuzla, doktorska disertacija, RGGF, Univerzitet u Tuzli, 2008