UDK 622.271:519.6

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METHODOLOGY FOR PREPARATION OF THEMATIC GEOTECHNICAL MAPS FOR URBANIZATION PURPOSES USING POLYNOMIAL INTERPOLATION METHOD

ABSTRACT. This paper describes a methodology for definition of geotechnical conditions for urbanization suitability zoning, which is very popular and complex engineering field. The main goal is to present an approach for preparation of thematic geotechnical maps, which should serve as basis for planning activities. In order to prepare these maps, appropriate zoning methodology is proposed, where, the terrain suitability for urbanization depends on following basic factors: engineering-geological properties of the present materials, slope angle, groundwater level, seismicity and excavation conditions. According to the proposed methodology, ratings are assigned to the selected factors, depending on their importance for successful urbanization. Based on the assigned ratings, rating map for each factor is prepared, and then the final map is created, representing the sum of influences of each analyzed factor on the urbanization suitability. On all prepared maps, four terrain categories according the suitability for construction - urbanization, are separated. The proposed zonation methodology is practically applied for the territory of city of Skopje.

KEYWORDS: urbanization, zoning, suitability, maps, polynomial interpolation method.

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МЕТОДОЛОГІЯ ПІДГОТОВКИ ТЕМАТИЧНИХ ГЕОТЕХНІЧНИХ МАП ДЛЯ ПЛАНУВАННЯ МІСТ З ВИКОРИСТАННЯМ ПОЛІНОМІАЛЬНОГО МЕТОДУ ІНТЕРПОЛЯЦІЇ

АНОТАЦІЯ. У статті дано опис методології визначення геотехнічних умов, що є важливими для просторового планування міст - поширеного і складного інженерного питання. Основна

мета – представити підхід для підготовки тематичних геотехнічних мап, які слугуватимуть основою для планування. Для підготовки цих мап запропоновано відповідну методологію, якою визначено, що придатність території для просторового планування міст залежить від таких основних показників: інженерно-геологічних властивостей сучасних матеріалів, кута схилу, рівня підземних вод, умов сейсмічності і виймання ґрунту. Відповідно до запропонованої методології призначені рейтинги для вибраних показників залежно від їх важливості для просторового планування міст. Базуючись на цих рейтингах, підготовлено мапи для кожного показника, а потім створена кінцева мапа, яка підсумовує впливи кожного проаналізованого показника щодо придатності до просторового планування міст. На усіх підготовлених мапах виділено чотири категорії територій відповідно до придатності до будівництва – просторового планування міст. Запропонована методологія зонування практично впроваджена для території міста Скоп'є.

КЛЮЧОВІ СЛОВА: просторове планування міст, придатність, мапи, поліноміальний інтерполяційний метод.

INTRODUCTION

With the long development of civil engineering, it became obvious that for rational and successful urban planning, design and construction of structures, an excellent understanding of the ground conditions is essential. Different factors govern the behavior of the natural rock masses during the construction and exploitation phase and these should be all well understood in order to have successful projects.

Depending on the location of each particular structure, the influence of these factors can have different meaning. As most important in most cases we can consider the morphological, geological, seismic, hydrological, hydrogeological and geotechnical factors. Complete understanding of these factors, will enable definition and allocation of the different geo-hazards. In many instances, the combination of the geo-hazards and the engineering activities has been reason for enormous socio-economic damages, and unfortunately even human losses [2, 6]. In order to prevent and avoid these socio-economic losses, worldwide practice and trend is the preparation of appropriate thematic maps that serve as basis for urbanization purposes.

The preparation of these maps is according appropriate methodologies, based on detailed analysis of available literature, specific principles for site zoning, and right selection of various qualitative and quantitative parameters.

Terrain zoning on these maps is presented, from which urbanization suitability categories can be recognized. The use of such maps before the start of the processes of planning and construction, helps engineers to avoid terrains with natural unfavorable geological – geotechnical conditions, leading to more efficient construction and safer structures [5].

Methodology for preparation of geotechnical maps as bases for urbanization purposes is presented in this paper, applied for the territory of Skopje, the capital city of R. Macedonia. The maps are prepared with GIS technology, more exactly using the software ArcGIS.

In the present state of art, using GIS is the most suitable approach for preparation of such technical documentation [3].

2. METHODOLOGY FOR URBANIZATION SUITABILITY ZONING

The process of defining a methodology for urbanization suitability zoning requires an understanding of all factors affecting the urbanization of a given area. The first step is selection of factors. Then, for each factor a rating system is being defined, so that each factor has several classes. The analyzed factors are related to the corresponding ratings using polynomial interpolation method. The main idea in developing this method is to find a way to establish analytical correlations between any value of factor and its rating.

2.1. Selection of factors the urbanization suitability

Urbanization suitability of a given area may depend on many factors, related to the morphological, geological, hydrogeological and geotechnical properties of the terrain. Here as most important ones are considered: the Lithological type (LT), Slope Angle (SA), Ground Water Level (GWL), Seismic Intensity (SI) and Excavation Conditions (EC) [5].

For each of these factors, a maximal rating has been assigned, depending on their influence on urbanization suitability (Table 1). In the proposed methodology for zonation, all of the factors have same value for the maximal rating, i.e. the author considers that all factors included are equally important when determining the urbanization suitability of the terrain.

Table 1. Maximal values of the ratings for the factors

Classification parameter	Maximal rating
LT	2
SA	2
GWL	2
SI	2
EC	2
Total (TUSR)	10

The details for ratings for each factor are given in Tables 2 to 6. For each of these factors four groups of possible values are defined, related to four terrain categories:

1. Optimally favourable terrain
2. Favourable terrain

Table 2. Range of values and ratings for Slope Angle (SA-R)

Slope angle (°)	Rating
1 – 5	0
< 1 and 5 – 10	0.3
10 – 20	1
> 20	2

Table 3. Range of values and ratings for Ground Water Level (GWL-R)

GWL (m)	Rating
> 12	0
5 – 12	0.5
1.5 – 5	1.5
< 1.5	2

Table 4. Range of values and ratings for maximal Seismic Intensity (SI-R)

Seismic intensity (°)	Rating
< 5	0.3
5 – 6	0.9
7 – 8	1.4
> 9	2

Table 5. Range of values and ratings for Excavation Conditions (EC-R)

ERMR (excavation method)	Rating
4 – 25 (easy excavator digging)	0.3
26 – 40 (hard excavator digging)	0.8
41 – 60 (ripping)	1.4
61 – 100 (blasting)	2

Table 6. Range of values and ratings for Excavation Conditions (EC-R)

Lithological composition defined with Lithological Type	Rating
1	0
2	0.4
3	1
4	2

3. Conditionally favourable terrain
4. Unfavourable terrain

Analyzing the data from Table 6, it can be seen that Lithological composition of the bedrock is defined with adequate Lithological Type (LT). Having in mind that a good part of the rock masses are characterized with similar physical-mechanical properties although their lithological composition and age are different, engineering geological grouping of the rock masses is done. Arbitrary values were used from 1 to 4 as a basis for correlation with ratings for Lithological Types. So, the following types are differentiated:

1. Group of hard magmatic, metamorphic or sedimentary rocks as granites, marbles, massive limestone and others, with range of values for internal friction angle φ>45° and cohesion c > 100 kPa. In this group also belong the consolidated rocks: soft to semi hard rocks (sandstones, calcareous marls, schist with favorable dip of foliation, with range of values for internal friction angle φ =36–45° and cohesion c=50–100 kPa [5].
2. Group of rocks with a relatively low degree of lithification: marly clays, poorly cemented sandstones, marls, argillaceous shale, weathered schists, with range of values for internal friction angle φ =26–35° and cohesion c=30–50 kPa [5].
3. Group of rocks with a low degree of lithification; soft rocks to hard soils as hard clays, compacted sands, claylike gravels, with range of values for internal friction angle φ =21–25° and cohesion c=15–30 kPa [5].
4. Loose rocks with low shear strength and high deformability, and loose detrital rocks or rocks with a reduced degree of lithification (clays and silts, sandy clays, sandy silts), with range of values for angle of friction φ =10–20° and cohesion c=0–15 kPa [5].

Groundwater level is considered as zonation factor because of the possible water flows in the construction pits, the aggressiveness of the groundwater, conditions for suffusion development, bearing capacity reduction etc. So, the most unfavorable case is when the aquifer zone is shallow below the terrain surface and then serious problems occur with dewatering of the construction pit, capillary effects on the footings and the construction, liquefaction development and so on [2]. The dip of the terrain is dictated by its morphology, which is important because the dimensions of the excavation and the stability of the terrain depend on the dip and height of the slope. That means that, terrains with 1 – 5% dip require small volume of earth works i.e. low cuttings, cut and fillings and embankments. That dip is suitable for easy dewatering of the atmosphere water and sewage systems construction as well. Furthermore, dewatering of the terrains with dip lower than 1% is quite difficult. On the other hand the excavation is problematic when the dip of the terrain is steep and also that terrain is susceptible to instabilities [2]. The degree of the maximal seismic intensity is very crucial factor considering that our country is seismically active area [2]. Before the Skopje earthquake in 1963, poor attention has been paid for aseismic design. The earthquake pointed out that consideration of the expected seismic intensity is of great importance in designing and construction of structures in seismically active areas as Skopje [5]. Terrain categorization according to the factor Excavation Conditions is expressed through the excavation categories defined in the ERMR system (ERMR - Excavation Rock Mass Rating by M. Jovanovski 2001). This factor is important in planning and designing of structures, considering that the cost of the excavation per m^3 depends on the applied excavation method (digging, ripping and blasting) [2]. All factors can be mapped, calculated, measured or assumed using different direct or indirect investigation methods.

The possible combinations of the factors' ratings define the suitability for urbanization of a given area.

2.2. Application of polynomial interpolation method

The polynomial interpolation method, used for solving many problems in geotechnics, here is applied for Urbanization Suitability Zonation.

The method is applied using the data from Table 2 to Table 5. For all evaluation factors, corelative curves are defined, with main goal to have possibility to assign an adequate rating for all parameters. The established correlations between values for evaluation factors and ratings are presented with the following equations:

$$SA\text{-}R=0.0017SA^2+0.0145SA-0.005$$
$$GWL\text{-}R=0.0101GWL^2-0.3073GWL+2.3114$$
$$SI\text{-}R=0.0131SI^2+0.0701SI+0.0077$$
$$EC\text{-}R=-9E\text{-}5ERMR^2+0.0286ERMR+0.0117$$

where: SA-R, GWL-R, SI-R и EC-R are adequate calculated ratings for any value of individual factors.

Graphical presentation of the defined polynoms in a form of interpolation charts is given in Figure 1.

In the presented equation the determination coefficient for all cases has very high values ($R^2=0.9995$ to $R^2=0.9998$) which refers to very strong connection between analyzed parameters.

2.3. Definition of terrain's categories according to urbanization suitability

In order to obtain the final map, so called urbanization suitability map, a sum of the ratings from each factor is required. The sum of the ratings represents total rating, TUSR (Total Urbanization Suitability Rating), based on which the zonation is conducted.

In the next step, 4 (four) terrain's categories, according to the suitability for urbanization – construction were defined, presented in Table 7 together with the appropriate total ratings.

The defined interpolation chart and correlation for analytical connection between the Urbanization Suitability Category (USC) and the Total Urbanization Suitability Rating (TUSR) are presented in Figure 2.

Table 7. Terrain's suitability categories with appropriate TUSR

Suitability Category	TUSR
Optimally favourable terrain	0 – 3
Favourable terrain	3 – 5
Conditionally favourable terrain	5 – 7
Unfavourable terrain	7 – 10

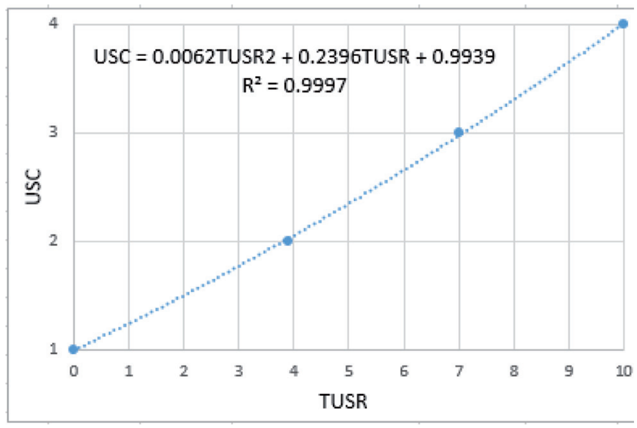

Fig. 2. Correlation between USC and TUSR.

The correlative equation is: USC=0.0062TUSR2+0.2396TUSR+0.9939.

3. PRACTICAL APPLICATION OF THE PROPOSED METHODOLOGY FOR THE TERRITORY OF CITY OF SKOPJE

3.1. Basic information for City of Skopje

Skopje is located in the north of the Republic of Macedonia, in the center of the Balkan Peninsula (Figure 3). The city is built in Skopje valley, which is oriented on a west-east axis, along the course of Vardar River which flows into Aegean Sea in Greece.

The valley of Skopje represents a depression surrounded by mountainous and hilly formations, built of rocks of different age, starting from Precambrian up to Paleogene, while the valley itself is filled with Neogene-Quaternary and recent sediments (alluvium, proluvium, soil debris, Pliocene sediments).

From tectonic point of view, Skopje valley is a mosaic of differently uplifted and down-thrown blocks, separated by faults. This kind of tectonic setting of the valley exerts its high seismicity in the central area as well as in the peripheral zones [1].

3.2. Thematic maps and final urbanization suitability map

According to the previously defined methodology for zonation of the terrain from an aspect of urbanization suitability, five thematic maps, for each factor, were

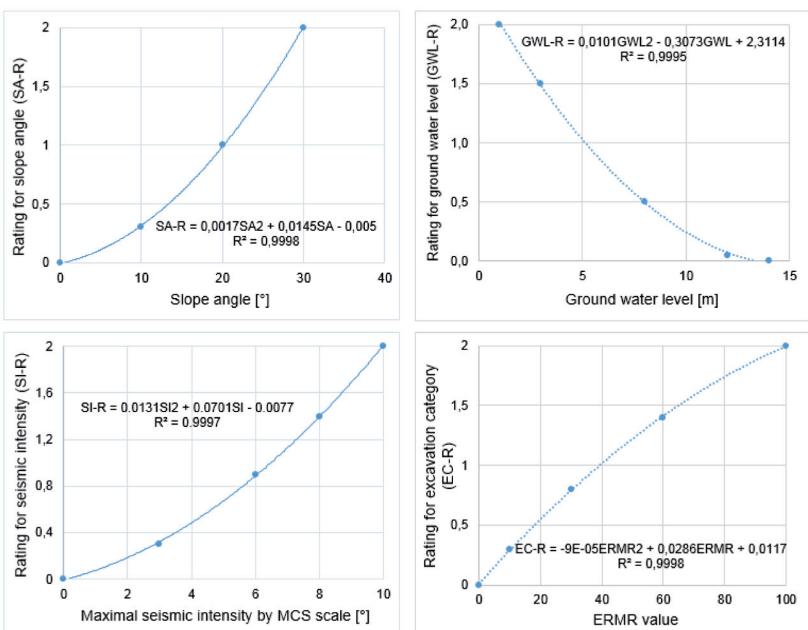

Fig. 1. Correlation between ratings for Slope Angle, Ground Water Level, Seismic Intensity and Excavation Conditions with factor values using polynomial interpolation.

prepared. All of these maps were prepared with GIS technique, which means ArcGIS software was used.

The results obtained in the thematic maps for each analyzed factor are presented in Table 8, as a statistical output.

Table 8. Statistic data from the thematic maps for each factor

Factor	Suitability categories in percent per each factor in the analyzed area (%)				Total (%)
	Optimally favourable terrain	**Favourable terrain**	**Conditionally favourable terrain**	**Unfavourable terrain**	
Lithological type	11.66	17.66	45.27	25.42	100
Slope angle	24.36	56.27	11.79	7.58	100
Ground water level	35.10	56.43	8.47	0.00	100
Seismic intensity	0.00	0.00	4.31	55.69	100
Excuvation conditions	57.24	31.55	7.55	3.66	100

Fig. 3. Geographical position of the analyzed area: Skopje, Republic of Macedonia (after MapQuest maps).

With intersection of these thematic maps in ArcGIS, the final map was obtained for urbanization suitability of Skopje [4].

In Table 9 a statistical overview of the data obtained in the map is given. Exactly, the presence of each suitability category in percentage is shown.

Furthermore, in Figure 4 the obtained urbanization suitability map for the territory of Skopje is presented.

Table 9. Statistic data from the thematic maps for each factor

Suitability category	**Percent (%)**
Optimally favourable terrain	10.24
Favourable terrain	86.34
Conditionally favourable terrain	3.39
Unfavourable terrain	0.03
Total:	**100**

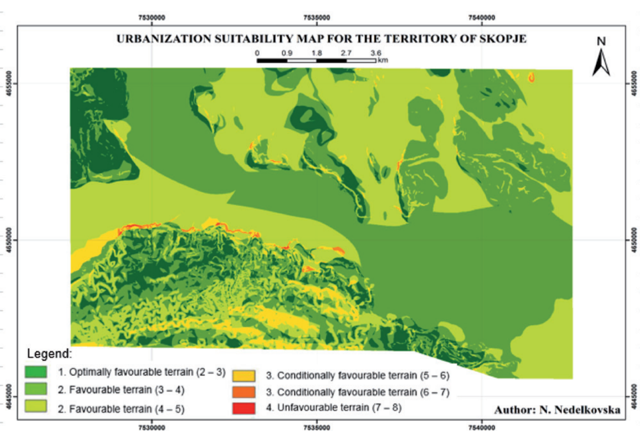

Fig. 4. Urbanization suitability map for the territory of Skopje.

4. CONCLUSIONS

Morphological, geological and geotechnical factors throughout an area-region proposed for new development of further urbanization of existing cities have great impact on the civil engineering. It is important to understand their nature in all phases, starting from the design, construction, and exploitation of the structures. Furthermore, their unfavourable combination can make some terrains very susceptible to some type of geohazard, which means that the safety of structures in such zones can become questionable over time. Therefore, with the presented approach and its further development, some type of standardized method for urbanization purposes can be established. If applied in fight time, such method can present strong tool, contributing not only for the improvement of civil engineering, but the society in general.

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