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Idrisi as a tool for slope stability analysis

Idrisi kot orodje za analizo stabilnosti pobočij

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Abstract

For the entire area of municipality of Krško the analysis of slope stability has been done. The analysis is based on publicly available geological data (MOP, Ministry of environment, ARSO – Slovenian Environment Agency etc.) and engineering – geological rock classification. Based on this a map of slope stability was produced. As a result the map is showing the maximum slope angles where the landslides start to appear.

Key words: municipality of Krško, GIS, slope stability analysis, stability map, stability classes, applied geology

Izvleček

Za območje občine Krško je bila s programom IDRISI izdelana analiza stabilnosti pobočij. Analiza je temeljila na osnovi javno dostopnih geoloških podatkov (MOP, Ministrstvo za okolje, ARSO – Agencija Republike Slovenije za okolje itd.) in inženirsko-geološke klasifikacije kamnin. Na osnovi te analize je bila izdelana karta stabilnosti pobočij, ki kot rezultat prikazuje mejne naklonske kote, pri katerih se začnejo pojavljati plazovi.

Ključne besede: občina Krško, stabilnostna analiza, GIS, stabilnostna analiza pobočij, karta stabilnosti, razredi stabilnosti, aplikativna geologija

Introduction

Long-term impact of exogenous factors such as surface weathering, river and stream erosion, and groundwater flow, cause changes on the surface of the terrain and weaken the rock strength. Such action can cause a kind of balance collapse between the gravity and the inner strength of rock. These two reasons are the main factors for development of the landslides. GIS – Geographical Information System is designed to work with databases or, for integration, observation, analyses, processing and plotting of spatially oriented data, as well [1].
Litostratigraphic geological units of the researched area are for this basic outline summarized in a condensed form after the Basic Geological Map (OGK) – sheet Zagreb [2] and sheet Novo Mesto [3, 4], with corresponding explanatory notes. The oldest rocks in this area belong to Middle Triassic – Anisian.

Triassic - T
Anisian T_2^1 – In the time of sedimentation in the Anisian stage a dolomite formed, with intercalations of bedded limestones. Dolomite is mostly of dim grey color, occasionally bedded and generally massive. Sometimes it is also brecciaed. There are no fossil remains in the dolomite. It lies concordantly on the Lower Triassic (Scythian) beds, and its age can be determined only by its stratigraphic position. It can be found north of Krško.

Ladinian T_2^2 – Above the Anisian dolomite in the Krško hills between the Sava valley and Bučka, and northwest of Krško, lies indurated massive, rarely thick-bedded dolomite with cherts. This dolomite is lightly grey, coarse-grained and changes into dolomitized limestone. As it is partly porous, it resembles the Cordevolian dolomite. In its upper part are present layers and lenses of black chert. In this dolomite one can also find lenses of green and violet tuff with interlayers of silicified tuff and cherts.

Late Triassic T_3 – Upper Triassic Dolomite can be found in the Gorjanci hills, south of Čatež. Lightly grey massive and sometimes thick-bedded dolomite prevails, with layers of dolomitized limestones. Upward it changes into bedded and lightly weakly bedded white and lightly grey coarse-grained dolomite with chert layers and lenses.

Cretaceous - K
Late Cretaceous K_2 – Upper Cretaceous beds lie mostly trangressively on Middle and Upper Triassic dolomites. On the surface they outcrop in the vicinity of Krško and Gorjanci hills, south of Krška vas and Boršt. Elsewhere they are mostly eroded or present as small erosional patches. Lithologically they are developed as a typical flysch, as an alternation of sandstones, marls, siltstones, calcarenites or marly limestones with layers of cherts and chaotical breccias.

Miocene - M
M_2^2 *(Tortonian)* – Middle Miocene Tortonian sediments appear south of Brežice and Čatež in the area of Mrzla vas in the Gorjanci hills. From a lithological point of view the sediments are very diverse. In the lower parts one can find breccias, loosely consolidated conglomerates, and above yellow and white marly limestone. Some beds of porous lithotamnian limestone also appear, which changes into a sandy and marly limestone and marl. The latter contains thin beds of sandstone.

M_3^1 *(Sarmatian)* – In the area of Libna, Krška vas and Gazice Upper Miocene beds outcrop at the surface, consisting mostly of marl and clayey marl.

Pliocene - Pl
Pl_1^1 *(Early Pontian)* – Early Pliocene rocks outcrop at the terrace near Brežice. They are developed as a grey massive clayey marl and marlstone. Above it are continuously sedimented the Late Pontian (Pl_1^2) sand, sandy clay and sandy marl.

Plio-quarternary (Pl,Q)
A vast part of the studied area is build of Plio-Quaternary sediments (Pliocene/Pleistocene). In the lower part of these beds one can find grey and brown loam with quartz pebbles. On this base a 100 m thick sand and gravel terrace has been deposited. The terrace is covered by sandy clays, sand, silt and clayey gravel.

Quarternary (Q) – a, $a_{1, 2, 3}$

The complete basin is covered by fluvial gravel terrace of the Sava river. The thickness of this terrace is estimated to be 12 m in average (from 7 m to 20 m). It consists of sand and gravel of various granulation, and pebbles are mostly carbonate. After deposition, the river has incised fluvial terraces (a_1 to a_3) and drained oxbows. The latter are more abundant in the vicinity of villages Brege and Skopice. They are filled by organogenic clays and silts, and the environment is mostly marshy. Sandy and gravel terrace is sometimes covered by lentoid beds of silty and clayey sands. Their thickness varies from some decimeters to several meters.

Tectonics

The complete Krško basin is a young tectonic syncline depression, filled by Quaternary fluvial sediments. The subsidence of this area has started already in the Miocene and has intensely continued in Late Pliocene. The subsidence also took place in the Middle Pleistocene (neotectonics) and is active in the present time.

The syncline belongs to Zagorje Tertiary basin and forms its southeastern part. The syncline axis lies in the SW–NE direction. The northern boundary of the syncline is represented by the horst of Krško hills and the anticlyne of Bohor and Orlica, and the southern limb by the horst of Gorjanci hills. In the base of Krško syncline, below the Tertiary clastic sediments, the Middle and Upper Triassic limestones and dolomites appear. These rocks are intensely deformed and fractured.

Background and methods

For the purpose of stability analysis the rocks have been classified in the appropriate slope classes according to the Table 1. The results of classifications process, which was made on the basis of indication in Table 1, are presented in Table 2. As can be seen from Table 2 a strongly conservative approach has been selected. Decision on conservative approach is based on relatively small scale lithologic information [2–4] and in lack of information of rainfall impact on the rock stability [5–7]. As it is very well known, significant impact on rock and slope stability is attributed to rainfall [5, 6]. Unfortunately the impact is strongly depending on the type of rainfall duration, moisture content in soils and rocks, vegetation, seismic risk etc. Many of parameters mentioned before can't be directly included in topical analyses due to lack of knowledge on their impact on the rock formation [7], so to avoid them, only slope and lithological information with conservative transition approach to engineering geology information were selected.

The basic data for the rock slopes stability map were derived from geological data and DMR map – (Digital Terrain Model) with a cell size of 25 m × 25 m (Figure 1). Based on the DMR data the map of terrain slopes has been done (Figure 2). The creation of slopes map was completely made by Idrisi program using Slope function inside the Surface Analysis (Figure 3). The slopes map is only the first step in a way to the final rock slopes stability map.

Table 1: *Inclination angles depending on the rocks type* [8, 9]

Classification	Name	Inclination classes	Stable inclinations
rocks	igneous and metamorphic	rock	above 50°
	carbonates	rock	to 50°
	clastites	soil	
		rock	
soft rocks	tertiary sediments	soil	
		rock	
soil	gravely soils (*gravel fill*)		to 40°
	mixed soils (*clay and gravel fill*)	prevailing clay	
		prevailing gravel	
	lake, marsh and marine sediments		to 12°

Table 2: *Inclination angles derived from geology map*

Rock description	Age	Slope (°)
Alluvial deposits	al	15
Alluvial deposits: mostly sand to clay	al	10
Alluvial deposits: gravel to clay	a	15
Limestone, breccia	K2	50
Limestone and dolomite, breccia and conglomerate	Ol2	50
Limestone, limestone breccia, silicified limestone, chert with parts of dolomite	J1+2	50
Limestone, silicified limestone, chert	J3	50
Limestone and dolomite with chert, marl, shale and tuff	T22	40
Limestone marls, sandstone, sand and conglomerate	2M31, 2	35
Limestone and sandstone	1, M31	35
White limestone	M22	50
Breccia, conglomerate, shell, claystone, marl, limestone and chert	K2	40
Dolomite with layers of mica mudstone, sandstone, shale and shaley limestone	T1	44
Dolomite, marly limestone, mica shale and sandstone	T1	40
Dolomite, limestone, shale, chert and tuff	T2	35
Clay	j	10
Clay and loam with pieces of chert	Pl, Q	10
Clay and clay with gravels	Pl, Q	10
Clay, gravel	sg	15
Shale, calcarenite and limestone breccia	K14, 5	35
Clay and sandy marl with inlays of sand and sandstone	M32	35
Shale, limestone with chert, calcarenite and tuffs	T22	35
Shale, limestone with chert, marl and limestone breccia	K1, 2	35
Terra rossa	ts	10
Quartz sand	Pl 3	35
Marl, marly limestone, limestone and sandy marl	M22	35
Marl, marly limestone, limestone and sandy marl	M31	35
Marl, marly clay, send, conglomerates	Pl11	10
Sea clay	Ol2	10
Limestone	M22	50
Massive limestone, partially dolomite	T31	50
Massive limestone and dolomite marl	T21	50
Massive granulated dolomite	T31	50
Massive granulated dolomite	T32+3	50
Soft clayey marl	M32	20

Rock description	Age	Slope (°)
Shale, quartz sandstone and conglomerate	C, P	40
The lowest terrace: gravel, sand, clay	a1	15
Organic and bioclastic limestone, sandstones, lime and clayey marl	2, M22	40
Sand	M, Pl	30
Sand and gravel with a few inserts of clay and sandy marl	Pl1	30
Sand, sandstone, sandy clay, sandy marl and shale with coal	Ol, M	20
Sand, sandy marl and clay	Pl12	15
Composite limestone	T32+3	50
Limestone, marly limestone with chert	J, K	50
Dolomite with chert	T32+3	50
Slope debris	s	35
Massive dolomite	T21	50
Gravel, sand and clay	Pl, Q	15
Red and greenish sandstone, siltstone, and conglomerate, claystone	P22	40
River sediments in gravel terraces and erosion remnants - mostly felsic gravel	Pl, Q	35
Brown and green marl, sandy marl, marly limestone and grey or red limestone with inserts of breccia	K2	35
Weathered brown clay	Pl, Q	10
Mine works	10	
Grey to black partially stratified limestone	K11	50
Grey marl	M32	40
Grey marl and sandy marl	M31	40
Grey marl, white and brown sandy marl, sandstone and quartz sand	M22	40
Grey stratified and white grained dolomite	T2+3	50
Grey stratified dolomite, tuff, limestone, dolomite breccia and conglomerate	T22	40
Grey clay	g	10
Grey and brown clay	Pl, Q	10
Stratified limestone with chert	T31	50
Well rounded conglomerate	pr	35
Diabase and tuff	bb	25
Below micritic limestone and hard marl, up clayey marl	M31	40
Gravel and sand of middle river terrace	a2	35
Light grey densely stratified limestone	J1,2	50
Light grey massive dolomite and dolomite with chert	T2,3	50
Light grey stratified limestone	J1+2	50
Light grey stratified and massive dolomite with limestone inclusions	T21	50
Conglomerate of first river terrace	t	50

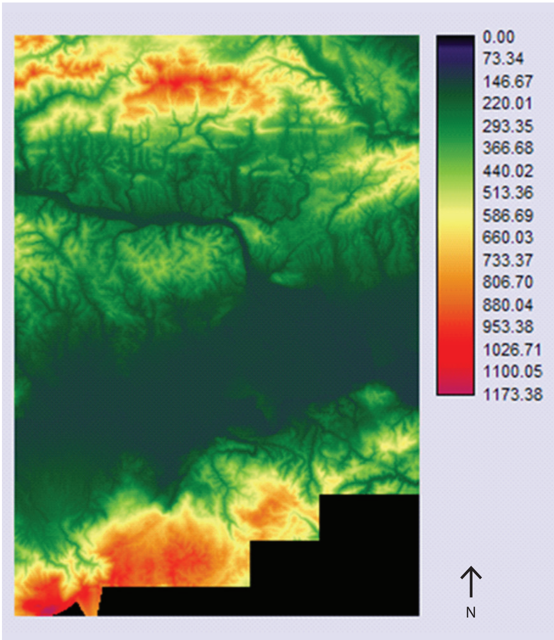

Figure 1: *Map of digital elevation model municipality of Krško Unit: [m. o. s. l.].*

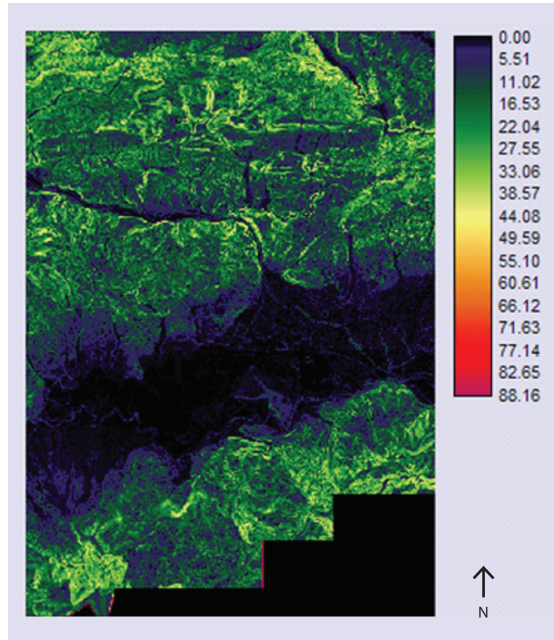

Figure 2: *Map of slopes.*

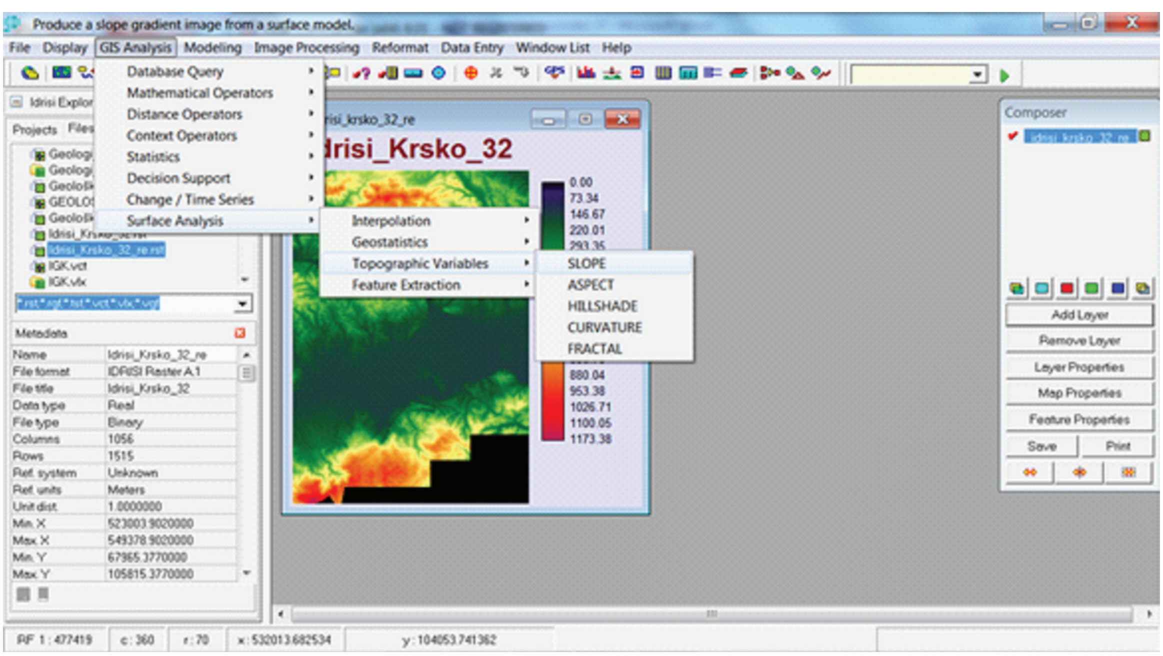

Figure 3: *Demonstration of the operation Idrisi – Taiga.*

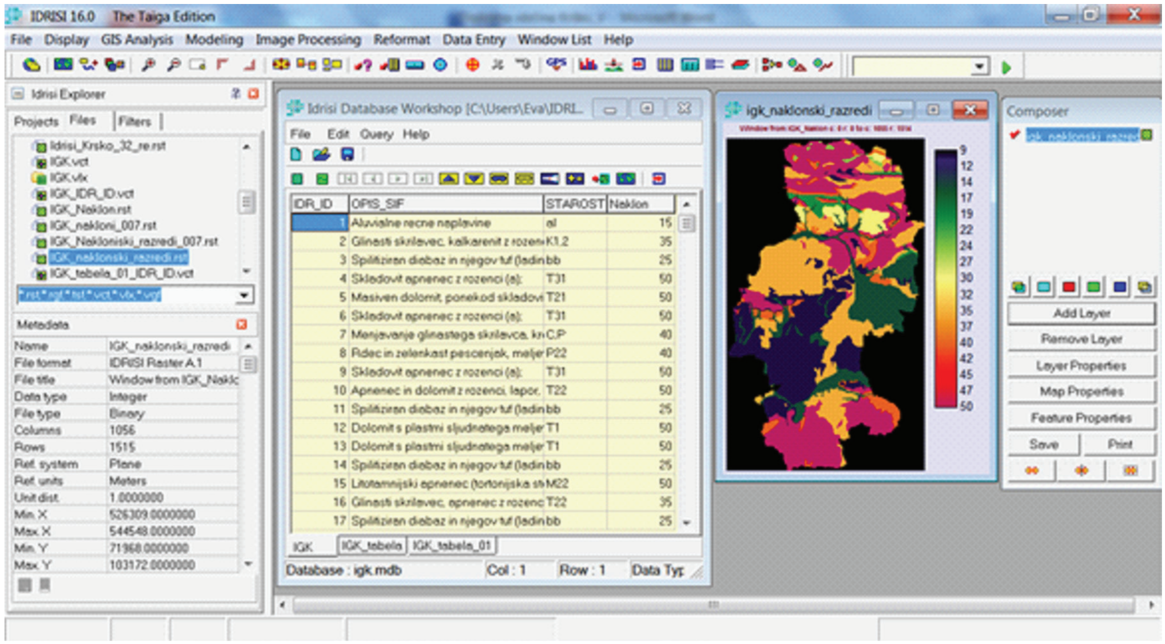

Figure 4: *Transformation of geological information into the rocks' maximum allowable inclinations.*

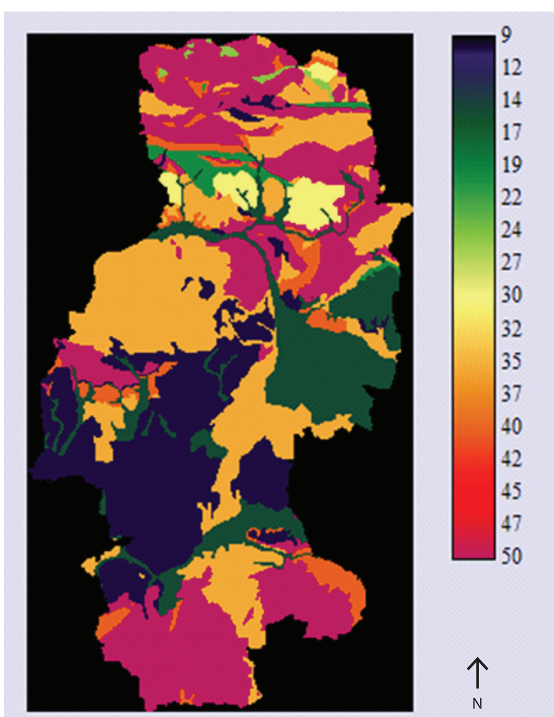

Figure 5: *Map of Maximum rock slope stability.*
Unit: [Degrees]

The second step was based on the geological data described before. In this step the geological information was transformed to the rocks maximum allowable inclinations. As a result of this transformation (Figure 4) a Map of maximum rock slope stability was made (Figure 5).

Discussion and results

The first two maps were needed for the further rock stability analysis. The combination of data derived from Map of slopes (Figure 2) and Map of maximum rock slope stability (Figure 5) using Idrisi image calculator was made (Figure 6). The process can be described with the equation (1):

$$RS = \frac{Slopes}{Max.\ rock\ stability} \qquad (1)$$

To do the final map of stability (Figure 7) it was necessary to obtain the so called normalized values of relative slopes (Equation 2).

$$norm.\ value = 1 - \frac{Slopes}{Max.\ rock\ stability} \qquad (2)$$

And finally using a Reclass command (Figure 8) 4 classes of stability were defined. The first: very stable (1–0.8), second: stable (0.8–0.5), third: conditionally stable (0.5–0) and the fourth: unstable with the values below 0.

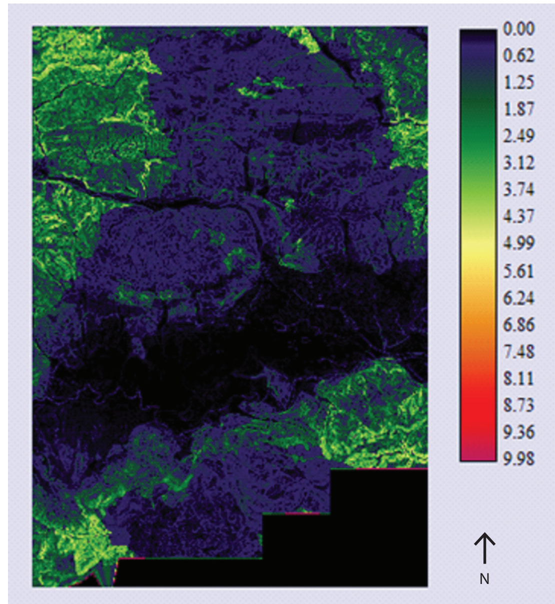

Figure 6: *Map of the relative slopes.*

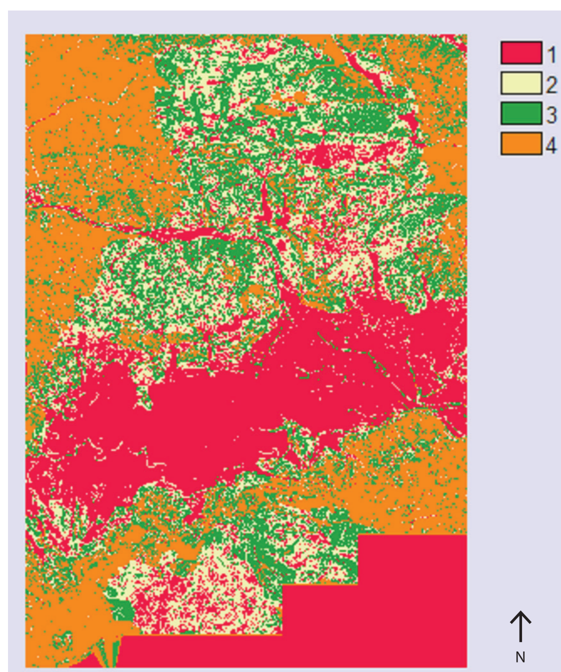

Figure 7: *Final stability map.*

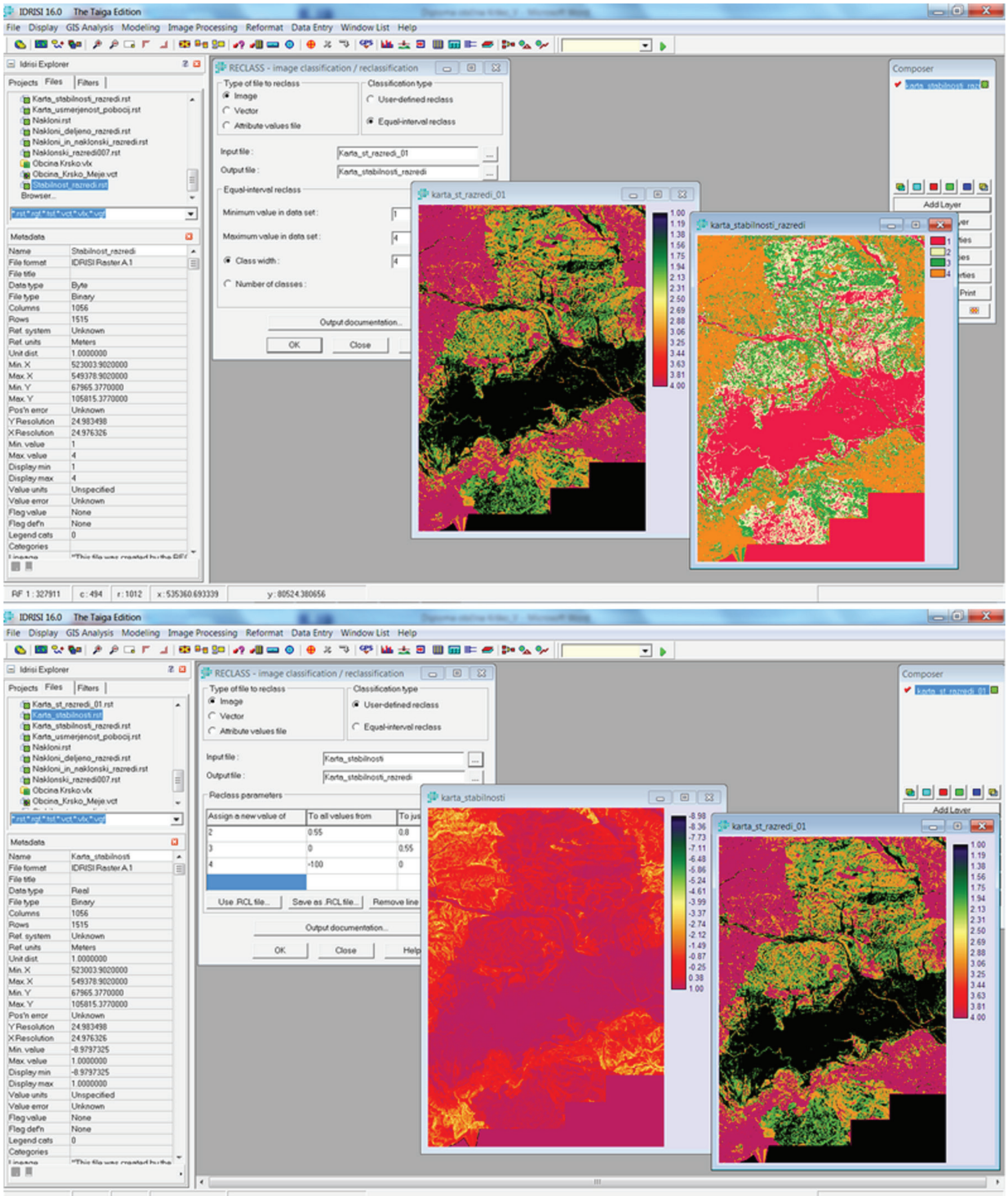

Figure 8: *View works by Idrisi- eat (making maps stability, maps stability classes and final maps stability with four classes).*

Conclusion

For the entire area of municipality of Krško an analysis of stability has been done using Idrisi GIS. Generally available public geological and topographical data were used for analyzing and processing described maps. It needs to be emphasized that during the process the data on intensity of rainfall were not included due to their absence on a smaller scale.

Because of the fact, that rainfall precipitations were not included in the process of slope stability analysis, the demands of stability were placed higher as they would be. Considering these facts the classes of stability were made on the more conservative approach than they would be in case the data on intensity of rainfall precipitations were available.

Analyses and maps like these presented are generally helpful especially for urbanists for creation of urban plans. At the same time they are very helpful for prediction of landslide occurrence especially in the populated areas in the period of heavy rainfall.

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