IDENTIFICATION AND GEOVISUALIZATION OF MORPHOLOGICAL-HYDROGRAPHIC CHANGES IN THE AREA OF THE OPEN PIT "TURIJA"

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Abstract

Identification and geovisualization of morphological-hydrographic changes in the area of the open pit "Turija"

In this paper morphological-hydrographic changes in the area of the coal open pit "Turija" in Banovići basin (north-eastern Bosnia and Herzegovina) are researched. The study was based on the field data and comparative analysis of topographic maps, satellite images, Digital Elevation Model and situational plans of the open pit area.

With conducted GIS analysis of natural and anthropogenic relief of open pit "Turija" the changes in the structure of hypsometric level, slope and aspect, and the changes in the surface hydrographical network etc. are determined. The general trend of ground levelling, decrease in altitude differences, gradual disappearance of physical micro relief, disappearance of geomorphologic boundaries on the surface, disorganization of hydrographical network, the development of positive and negative forms of relief, and greater presence of physical-anthropogenic processes and forms in relation to physical ones are determined. Reduction of territories with southerly, easterly and westerly aspects, and a significant increase in territories with northerly aspect is also determined.

Geospatial data obtained by GIS after their analytical and synthetic processing are geovisualized. Ten thematic maps were made and they provide insight into resulted changes in the researched geographical area. The explored indicators can serve as a significant factor in the future planning and selection of the type of re-cultivation of degraded areas in the area of research.

Keywords

Morphological-hydrological changes, relief, GIS analysis, geovisualizations, open pit "Turija"

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1. Introduction

The surface exploitation of coal in the Banović basin started in 1946, and since that time several surface excavations were done: "Dolovi", "Ravne", "Selo I", "Mušići", "Podgorje", "Selo II" "Čubrić" and others which are closed (Smajić, Hadžimustafić 2017, 556). Today, in the northern part of this basin there are two active open pit areas: "Turija" and "Grivice". This research deals with the consequences of the exploitation of coal in the surface area of "Turija", where, from the first exploitation (1975) untill now, about 770.87 ha of natural, mainly agricultural land have been affected.

This kind of exploitation of coal has caused significant physical-geographic changes in the relief of the researched area, which are most prominent in the change of natural landscape, due to the formation of anthropogenic relief forms of different dimensions. Particularly significant are the morphological-hydrographic changes that are reflected in the change of the structure of the hypsometric levels, slope and aspect, and surface hydrographic network. Similar but more intense direct and indirect anthropogenic impacts on relief have occurred for example, in the Ruhr District in the western Germany (Harnischmacher 2007, 185), the Kolubara basin in Serbia (Dragićević et al. 2012, 3), Husnicioara open pit in the central part of the Mehedinţi County in Romania (Boengiu et al. 2016, 262) etc. Identification of relief changes at the spatial and temporal level is possible by comparing the natural and anthropogenic relief on the basis of cartographic material. Therefore, the features of anthropogenic relief and the tendencies of its development imply the need to study a few key issues, such as: classification of forms, their mapping, quantitative forecast of anthropogenic relief changes, and determination of the necessary measures for its recultivation (Dinić 2007, 94; Smajić et al. 2014, 6). 3D modeling and interactive visualization options represent significant factors for landscape modeling of areas affected by mining (Brejcha, et al. 2016, 151). Thus, the aim of this paper is to determine the morphological-hydrographic changes in the open pit area "Turija", and to perform their geovisualization using GIS applications.

2. Material and methods

In this paper, a methodology of research has been applied to geospatial data obtained after their analytical-synthetic processing. The research process was carried out in several stages. For the purpose of identifying and analyzing the condition of the area prior to the surface exploitation of coal, the vectorization of the required contents from the topographic maps of VGI Belgrade, scale 1:25000 and 1:50000 (from 1956 and 1978) was performed, while the recent state was seen on the basis of maps: Google Earth Map (satellite images 2014) of the Federal Geodetic Administration of Bosnia and Herzegovina (orthophoto, 2013), USGS Earth Explorer (SRTM DEM 2014) and situational mine clearance plans, scale 1:2500 (from 2014).

After selecting the cartographic basis, scanning of maps in raster graphics of 400 dpi resolution, filtering and setting of raster for better visual appearance, more precise vectorization, as well as map georeferencing in a coordinate system of appropriate projection were performed (Gaus-Kriger's, global coordinate system long-lat and geodetic coordinate BiH system, zone 6). Based on the orthophoto snapshot, situational plans and field observations, the boundaries of the exploitation field, the boundaries of the workspace reached to the exploitation as well as the boundaries of the surface parts were vectorized. The vectorization of thematic contents (contour

lines, watercourses, etc.) was carried out, based on an average height analysis, the presence of hypsometric levels, inclination and slope exposures, as well as the disorganization of the river network in the field of surface exploitation were performed.

In order to fullfill the above mentioned procedures, various software solutions have been used: MapInfo Professional 10.0 with relevant tools (for georeferencing, vectorization, space analysis and data acquisition, mapping and stylization of maps, and getting finished thematic maps); Surfer 9 (for creating a digital elevation model); MS Excel 2013 (for mathematical and geostatistical data processing) and Adobe Photoshop 10 (for filtering and setting the raster).

3. Research area

The open pit area "Turija" is located in northeastern Bosnia, within the Inland Dinarides area. The area belongs to the macrogeomorphological region of the "Lowland, low mountains and foothills, and the basine of northern Bosnia" (Lepirica 2009, 12), while the regional geographic belongs to the macroregion "Peri-Pannonian Bosnia", where the southern part of the "Posavsko-sprečko-majevičko-donjodrinska Mesoregion" (Nurković, Mirić 2005, 85). The reservoir is located on the left bank of the river Spreča, in the river basin of Turija, in the northern part of Banovići basin, between 44° 24' 15'' and 44° 26' 02'' N and 18° 25' 17'' and 18° 29' 01'' E. It is separated from the open pit area "Čubrić", which is located in the southern part of the basin, by a prominent serpentine cliff with morphological elevations: Borovica, Miletina, Stražbenica, Osoje and Jelenak (Fig. 1).

The surface of exploration area is 770.87 ha, its length in the west-east direction is 4.93 km, the width in the north-south direction is 3.51 km. The area of the open pit area with the internal landfill has 209.65 ha, of which the excavation is 140.60 ha and the landfill 69.05 ha. The outer west landfill occupies an area of 165.34 ha or 21.45%, south landfill 120.69 ha or 15.66%, recultivated area of Banovići Selo 87.89 ha or 11.40%, routes and inter-routes areas 125.61 ha or 16.29%, while other areas occupy 61.75 ha or 8.01% of the explored territory.

"Turija" pit has the shape of an irregular ellipse whose longer side is stretched west-east. The length of the excavation with the internal landfill is 2.90 km, the maximum width is 1.47 km, the average width is 0.9 km, while the average height is 316.01 m. The working zone of this surface is at 248 m.a.s.l. The natural area of today's dredging with the internal dump spreaded in the range of 293-460 m.a.s.l., while the average height was 355.76 m. To the north of the surface site, the natural terrain is located at an altitude of more than 450 m, the western landfill is spread in the hypsometric range of 310-400 m and its average height is 362.88 m. The length of this landfill on the west-east is 2.23 km and a maximum width of 0.89 km. The natural area of today's landfill spreads in the range of 300-400 m.a.s.l. and the average altitude is 354.69 m. The area of Banovići Selo spreads in the hypsometric range of 390-440 m, while the average altitude is 415.51 m. The natural area spread in the range of 360-460 m.a.s.l, while the average height was 404.27 m. The southern landfill spreads in the hypsometric range of 370-440 m, while its average height is 405.59 m. The natural area of today's landfill spreads in the range of 350-460 m.a.s.l. and the average altitude is 385.35 m (Fig. 2).

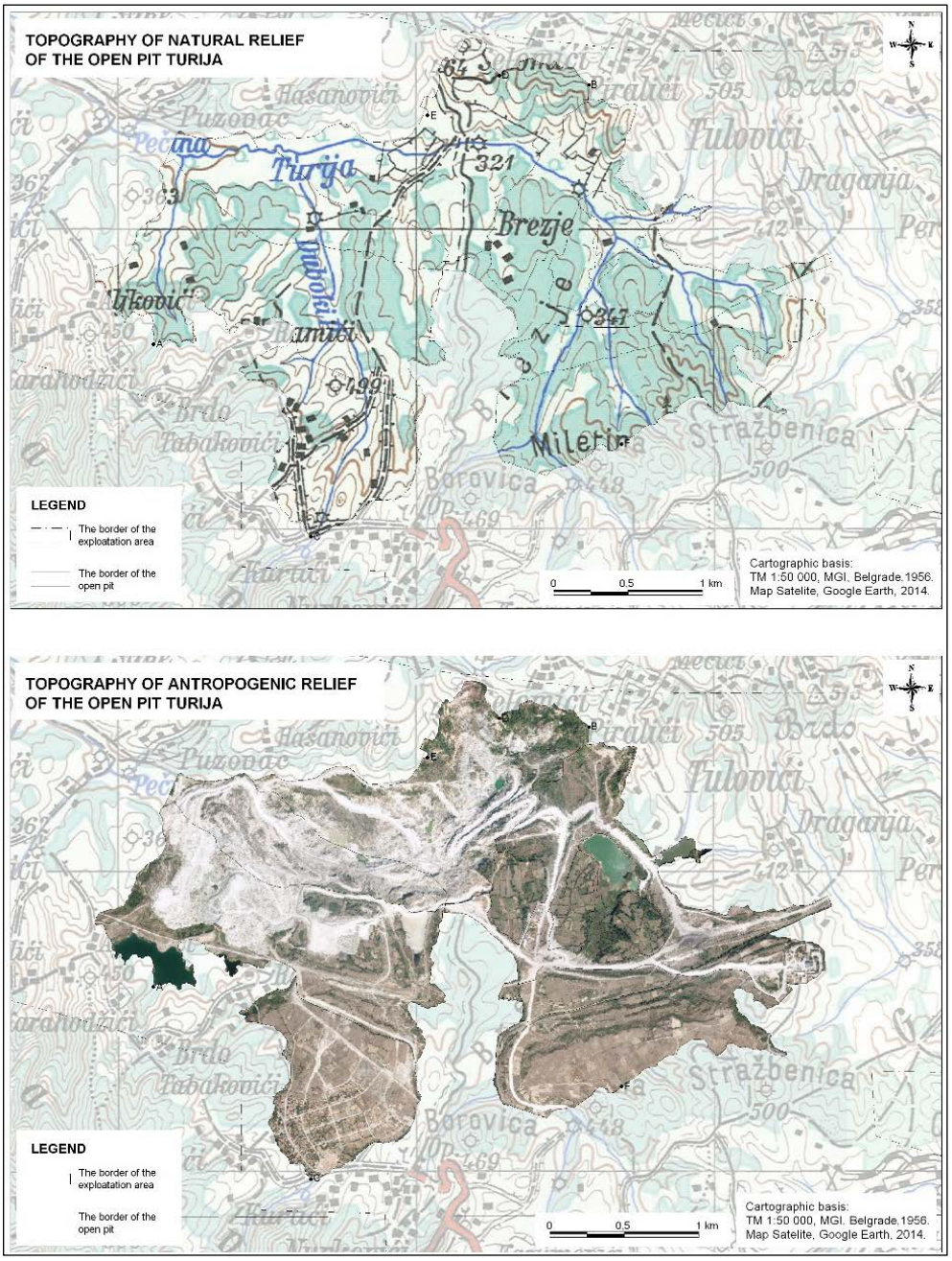

Fig. 1: Topography of the open pit "Turija"

Exploitation reserves of this mining potential at the end of 2017 were about 50 million tons of brown coal, while the total amount of discovery was estimated at around 611.52 million cubic meters. On the periphery of the pit there are several rural

settlements, such as Borovac, Donja Treštenica, Tulovići, Draganja, Brezje, Banovići Selo and others (Smajić et al. 2009, 35).

4. Results and discussion

In 1974, the "Turija" open pit area began to work on overburden, and in 1975 the coal exploitation began. In the period from 1992-1995 the work on the surface was temporarily suspended, and the coal exploitation started again in 2005. From the first exploitation operations by the end of 2017, about 19.50 million tons of brown coal was produced on the surface of "Turija", and around 134.94 million m^3 was excavated and disposed of at landfills. In this way, numerous landfills have been formed here, the composition where sedimentation of the coal layer is mainly dominated, i.e. clay marl from oligocene period. Therefore, the process of surface exploitation of coal has generated great morphological changes in this area. The surface affected by this kind of exploitation is degraded and disturbed by mining, so the terrain morphology is a combination of natural relief and artificially formed floors, craters, surface dumpsites, excavations etc. The example is in Dombas where there are more than 1300 crater elevations whose sides have angle of inclination 30-45°. Concentrated in large numbers, these forms of anthropogenic relief vary considerably not only the relief morphology but also the overall appearance of the geographic landscape (Kotlov 1978, taken from Dinić 2007, 94). In the basin of Suvodol coal, east of Bitola, more than 140 million cubic meters of coal, in the territory of 10 km^2 have been excavated since 1982, causing a 3-mile diameter depression and a depth of 50-100 m, while the landfill near becomes a typical anthropogenic hill (Dragićević, Milevski 2010, 300). In this way, in "Turija" locality, significant areas of natural land have been degraded, thus completely damaging natural pedogenic processes here. A total of 770.87 ha of natural land has been degraded, and the phytocenosis of the natural habitat is completely destroyed. The most degraded are podzol-pseudoglay terraced and sloped soils (509.05 ha or 67.36%), alluvial noncarbonated soils (74.75 ha or 9.89%), brown carbonate soil on the marl (50.78 ha or 6.72%), brown acid medium deep and shallow soil at amphiboles (44.53 ha or 5.89%), and 76.57 ha or 10.14% of other soils. The most degraded forest phytocenoses are beech forests (266.74 ha or 35.30%) and sessile oak and common hornbeam (206.37 ha or 27.31%), while agricultural areas, settlements, forests and other waste 282.51 ha or 37.39%.

According to the 3D model, the surface of the anthropogenic relief is smaller than the surface of the natural relief for 4.42 ha (Smajić 2012, 279). Differences in the area of the territory of this area are the consequence of the more pronounced vertical relief dissection of the earlier natural compared to the present anthropogenic relief (Fig. 2, 3, 4, 5 and 8). According to the "Turija" surface development program until 2031, it is planned that the exploitation will cover new 115 hectares, which will result in additional land expropriation. In this connection, the digging field would expand to the area of the Brigići, Podovi and Brezje countryside, and the landfill on the Borovac countryside.

4.1. Morphological changes

The natural geomorphological environment of the exploration area is characterized by hilly reliefs with rounded peaks at an altitude of 293-480 m. The northern and southern parts of the area were characterized by the highest hypsometric levels (over 460 m), while the significantly lower hypsometric levels represented the area of today's surface where the altitude rarely exceeded 340 m. Therefore, this site is entirely located in the foreland hypsometric area (Tab. 1; Fig. 2).

In a broader sens, the area belongs to the northern slopes of Mount Konjuh (1327 m). Several oblique morphological hights are at its edge: Borovac (406 m) in the northwest, then Brezova glava (496 m) in the north, Bečarevića brdo (544 m) and Gradina (501 m) in northeastern, Stražbenica (506 m) Miletina (457 m) in the south-east, Borovica (481 m) and Viševac (734 m) in the south, Vis (806 m) in the south-western part and the other (Topographic map 1978).

The process of surface exploitation of coal has made significant changes in the relief of the surface "Turija" which are most prominent in the change of natural landscape due to the formation of anthropogenic relief forms of different dimensions (digging, dumps etc.). Outer landfills have flooded the natural terrain, and large-scale flooded areas have been formed, with a smaller or greater degree of technical and biological recultivation. Crater and open pit landfills are still subject to spatial changes.

4.1.1. Hypsometric characteristics

Hypsometry is the basic indicator of the relief morphometric structure. It represents the percentage of areas with a certain elevation, or with different hypsometric belts. Knowing the hypsometric structure of the mine area "Turija" is of utmost importance since the elevation represents a significant microclimatic modifier and thus most directly affects the direction of biological recultivation of degraded surfaces.

By analyzing the hypsometric characteristics of the natural relief, it was found that the lowest hypsometric belt (up to 300 m.a.s.l.) in the area of today's "Turija" open pit area has reached 7.74 ha or 1.0% of the researched area. Hypsometric belt 300-400m occupied 667.79 ha or 86.63% of the total area, while the highest area within this belt was 330-370 m above sea level (406.19 ha or 52.69%). Hypsometric belt 400-480m occupied 95.34 ha or 12.37% of open pit area. Most of the territory within this belt had an altitude of 400-440 m (83.41 ha or 10.82%) (Tab. 1). It was also found that the absolute altitude difference of the natural terrain is 167 m, while the average altitude is 370.45 m.

Tab. 1: Categories and spatial dimensions of elevation.

Natural relief			Anthropogenic relief			Index A/N
Elevation (m)	Area (ha)	Portion (%)	Elevation (m)	Area (ha)	Portion (%)	
-	-	-	240-260	20,03	2,60	-
-	-	-	260-280	42,20	5,48	-
280-300	7,74	1,00	280-300	38,55	5,00	498,27
300-320	48,35	6,27	300-320	57,45	7,46	118,82
320-340	148,39	19,25	320-340	81,85	10,62	55,16
340-360	203,22	26,36	340-360	138,41	17,96	68,11
360-380	183,97	23,86	360-380	123,31	16,00	67,03
380-400	83,86	10,88	380-400	109,29	14,18	130,32
400-420	51,38	6,66	400-420	82,46	10,70	160,51
420-440	32,03	4,15	420-440	76,01	9,86	237,32
440-460	10,52	1,37	440-460	1,12	0,14	10,61
460-480	1,42	0,18	-	-	-	-
Total	770,87	100,00	Total	770,68	100,00	

Source: Data obtained by GIS analysis. Cartographic basis: Topographic map 1:50000. MGI. Belgrade. 1956; Map Satellite. Google Earth. 2014; SRTM DEM. USGS Earth Explorer. 2014.

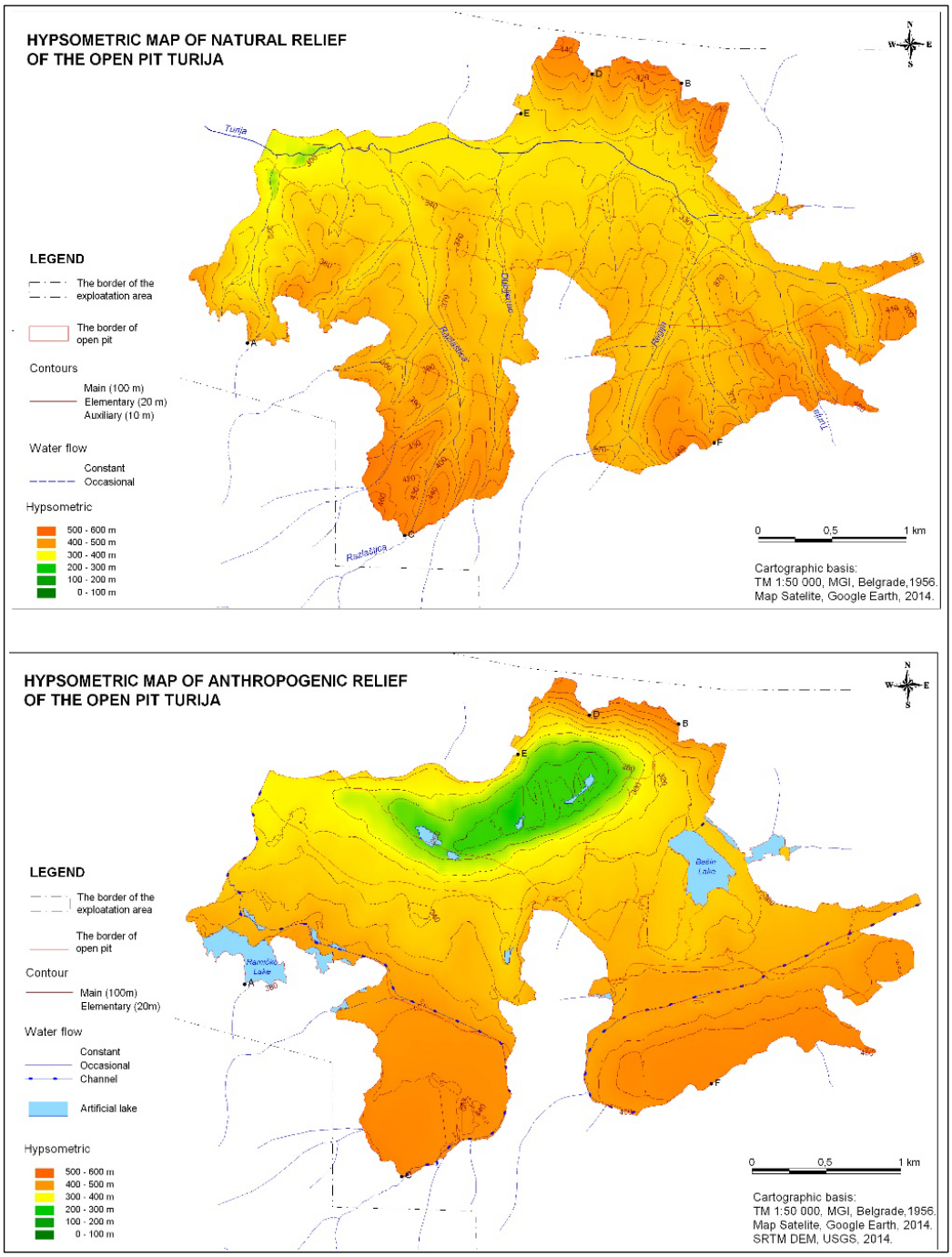

Fig. 2: Hypsometric map of the open pit "Turija"

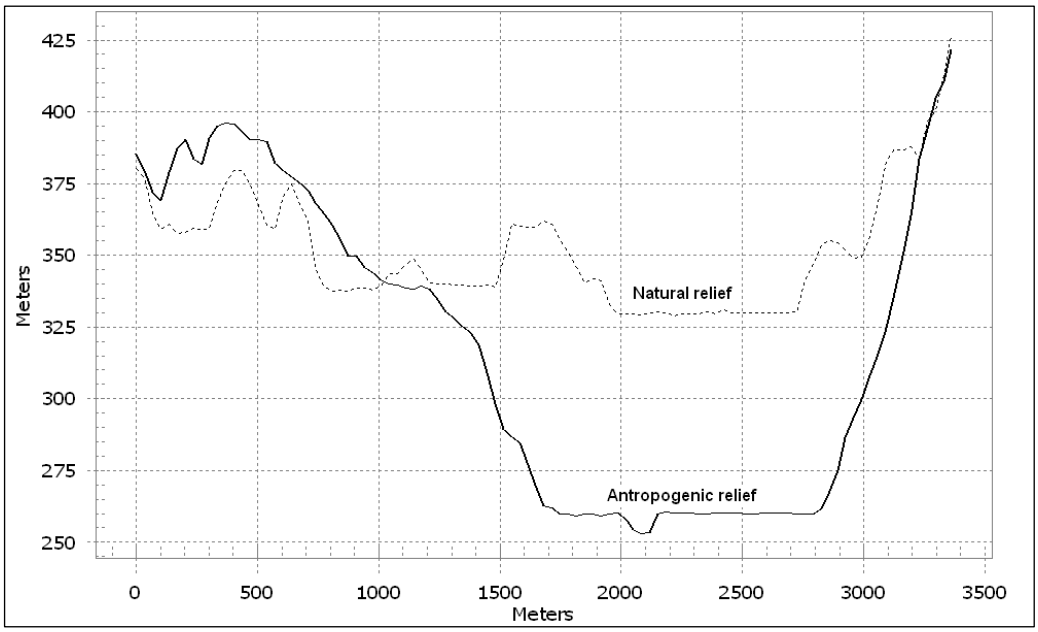

Fig. 3: Cross-profile (A-B) in a section of hypsometric map.

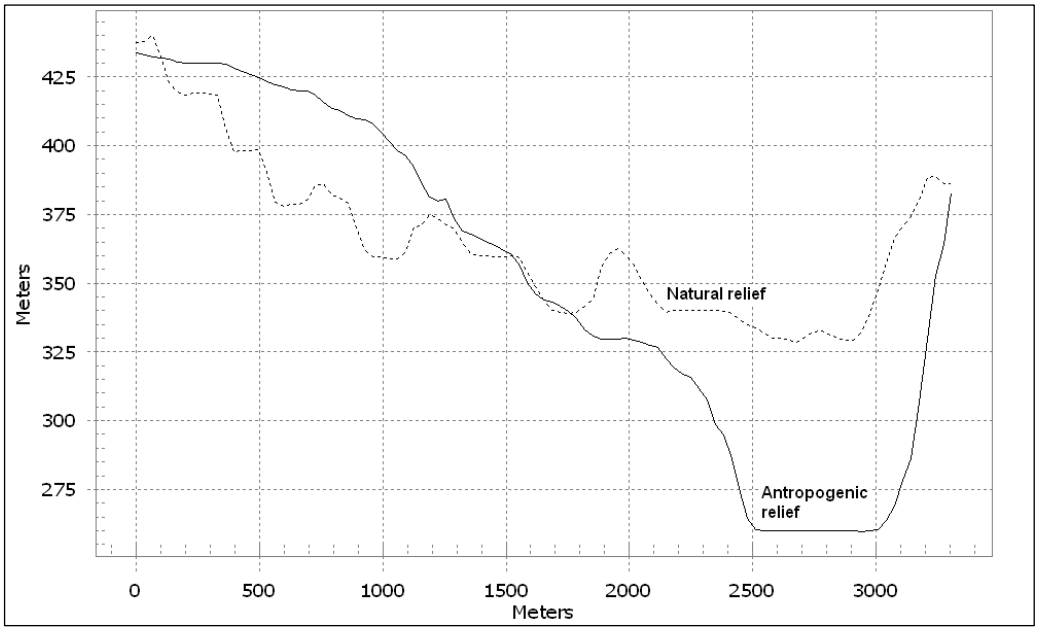

Fig. 4: Cross-profile (C–D) in a section of hypsometric map.

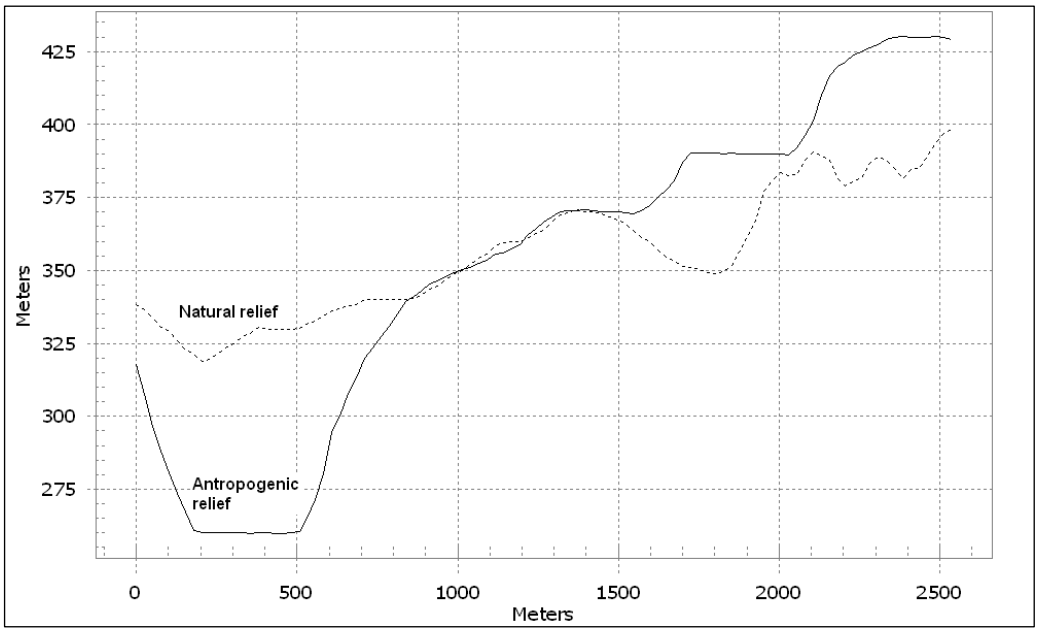

Fig. 5: Cross-profile (E-F) in a section of hypsometric map.

By analyzing the hypsometric characteristics of anthropogenic relief, it was found that the lowest hypsometric belt (up to 300 m.a.s.l.) occupies 100.78 ha or 13.08% of the researched area. Hypsometric belt 300-400 m is 510.31 ha or 66.22% of the total area, while the highest area within this belt is 340-390 m above sea level (323.58 ha or 41.99%). Hypsometric belt 400-460 m covers 159.59 ha or 20.71% of total surface area. Most of the territory within this belt has an altitude of 400-430 m (142.40 ha or 18.48%). It was also found that the absolute altitude difference of anthropogenic terrain is 192 m, while its average altitude is 350.28 m.

By analyzing and comparing the relevant indicators, the average altitude of the anthropogenic relief, compared to the natural relief, was reduced by 20.17 m. An increase of the area with the hypsometric belt to 300 m (91.67 ha or 12.13%) and over 400 m (74.64 ha or 9.88%) was determined, and a decrease of 300-400 m (for 166.31 ha or 22.01%). This structure of hypsometric belts in the researched area is the consequence of landscaping and excavation of the terrain on the exploitation field due to which the relief has continually lowered, and the disposal of marls, tailings and other material on the formed landfill, causing the terrain permanently to ascend (Fig. 3, 4 and 5). Thus, due to the surface exploitation of coal, several mountain slopes (360-460 m.a.s.l.) disappeared completely extending the open pit area.

With the discovery of the marl on the outer landfill, several valleys of mountain streams (Regija, Dubljenac, Razlaštica and others) have been excavated in this area, and large areas with a smaller or greater degree of technical and biological recultivation have been formed. Today, in the northern part of the explorated area is the open pit "Turija", whose altitude ranges is from 248-440 m, while the average altitude is 316.01 m. In addition, several anthropogenic lakes are of different morphometric characteristics.

4.1.2. Slope

In the geomorphological interpretation of the terrain, it is particularly important to analyze the slope relief from the aspect of inclination and spatial orientation of slopes (Smajić, Hadžimustafić 2016, 14). The spatial distribution and coverage of individual slope categories is a significant indicator of the extent and intensity of morphostructural and exogeomorphological processes affecting the morphogenesis of slopes during the paleogeorphological period, but also as an indicator of the future impacts of these processes on the characteristics and interrelationships of rising and falling or denudation and accumulation (Radoš et al. 2012, 187). In this respect, the slope and aspect models for terrain area "Turija" were created. For the ground slope model, a 10-meter digital model area was used and ten gradient classes were separated (Tab. 2).

Tab. 2: Categories and spatial dimensions of slopes

Inclination (°)	Natural relief		Anthropogenic relief		Indeks A/N
	Area (ha)	Portion (%)	Area (ha)	Portion (%)	
0-1°	101,61	13,18	87,63	11,37	86,25
1-3°	116,11	15,06	163,57	21,22	140,87
3-5°	106,19	13,78	165,57	21,48	155,92
5-8°	113,55	14,73	143,63	18,64	126,49
8-12°	113,50	14,72	98,69	12,80	86,95
12-16°	87,28	11,32	54,32	7,05	62,24
16-20°	59,48	7,72	26,63	3,46	44,78
20-30°	65,97	8,56	27,51	3,57	41,70
30-40°	7,17	0,93	3,13	0,41	43,64
>40°	0,02	0,00	-	-	-
Total	770,87	100,00	770,68	100,00	100,00

Source: Data obtained by GIS analysis. Cartographic basis: Topographic map 1:50000. MGI. Belgrade. 1956; Map Satellite. Google Earth. 2014; SRTM DEM. USGS Earth Explorer. 2014.

By analyzing the gradient values of the natural relief of the researched area, it has been found that the gradients up to 5° were widespread at 321.91 ha or 42.02% of the territory, gradients 5-12° to 227.05 ha or 29.45%, while gradients 12-20° to 146.76 ha or 19.04% of total area. It is noticeable that there are only 73.16 ha or 9.49% of surface area on a gradient higher than 20°. Due to such slopes of the terrain, this part of the area was subjected to very intense slope processes that conditioned the local emergence of the rocks on the surface.

By analyzing the anthropogenic relief of the surface, it has been found that slopes up to 5° are widespread on 416.77 ha or 54.07% of the territory, sloping 5-12° to 242.32 ha or 31.44%, while slopes 12-20° to 80.95 ha or 10.51% of total area. It is also noticeable that there are only 30.64 ha or 3.98% of the researched area on the gradient of more than 20°. Due to such slopes of terrain formed by man or technology, this part of the exploration area is distinguished by a very strong erosion, reinforced constriction and material conveyance.

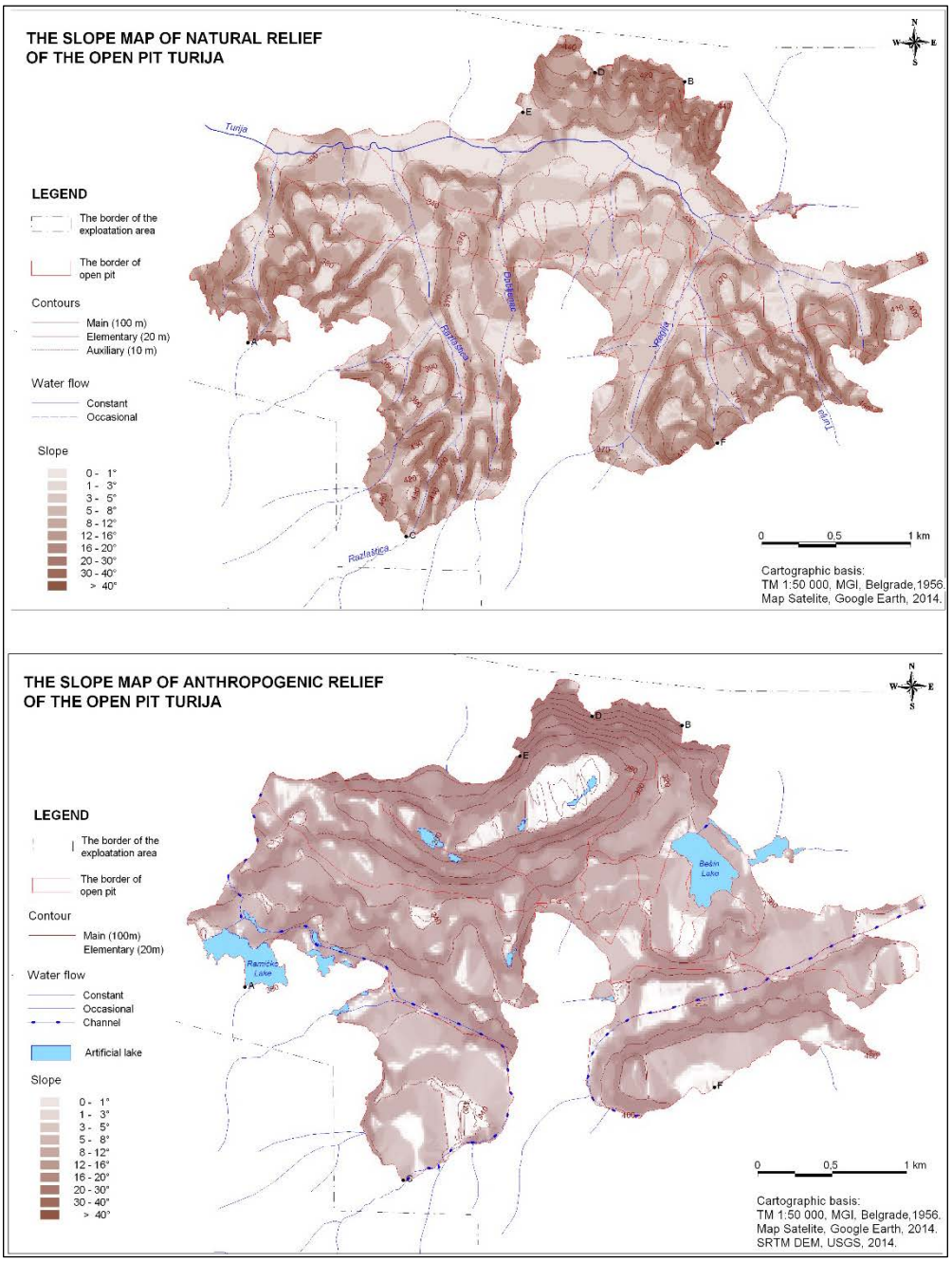

Fig. 6: The slope map of the open pit "Turija".

By analyzing and comparing the obtained data, a reduction in the surface area of up to 1° (13.98 ha or 1.81%) was noted, and the increase of the landfall was 1-8° (136.92 ha or 17.77%), especially in the category of slopes 3-5° (for 59.38 ha or 7.70%). This area is characterized by weaker drain and smaller gullies as well as a

significant increase in drain power and erosive processes, resulting in linear erosion leading to an increase in horizontal diversity. On the other hand, the proportion of the explored area decreased by more than 8° (by 123.14 ha or 15.96%), and the territories with slope of 12-16° has decreased the most (38.46 ha or 4.99%). Thus, in the area of the "Turija" open pit area there is a clear general trend of levelling the terrain and decreasing the height differences, increasing the area of inclination 1-8°, and decreasing the area of inclination up to 1° and over 8° (Tab. 2; Fig. 6).

4.1.3. Aspect

To analogously determined slopes, it is necessary to determine their spatial orientation. As a basic factor for the spatial orientation of the slopes, according to the earlier natural relief, the prevailing direction of providing hilly-like relief forms and valley streams has been taken, which is why the area is dominated by the eastern, western and northwest aspects, while in today's anthropogenic relief most of the northern, north-eastern and northwest aspect (Tab. 3; Fig. 7). In general, the influence of area aspect on geomorphological processes is very significant because differently exposed slopes receive a different amount of short-wave radiation, which influences the characteristics of climatic elements as exogenous-geomorphologic agents (Radoš et al. 2012, 193).

Tab. 3: Aspect categories and their spatial coverage

Slope aspect	Natural relief		Anthropogenic relief		Indeks
	Area (ha)	Portion (%)	Area (ha)	Portion (%)	A/N
N	79,62	10,33	201,65	26,16	253,27
NE	106,53	13,82	128,58	16,68	120,70
E	121,70	15,79	60,22	7,81	49,48
SE	80,71	10,47	50,32	6,53	62,35
S	68,42	8,88	97,27	12,62	142,17
SW	82,49	10,70	56,79	7,37	68,85
W	119,90	15,55	56,89	7,38	47,45
NW	111,51	14,46	118,96	15,44	106,68
Total	770,87	100,00	770,68	100,00	100

Source: Data obtained by GIS analysis. Cartographic basis: Topographic map 1:50000. MGI. Belgrade. 1956; Map Satellite. Google Earth. 2014; SRTM DEM. USGS Earth Explorer. 2014.

By analyzing the aspect of the slope of the natural relief, it was found that the shady aspect (297.66 ha or 38.61%) covers the most of exploration area (N-NE-NW), were the sunny aspect covers (S-SE-SW) 231.62 ha or 30.05% of total area. It was also found that the eastern (121.70 ha or 15.79%) and western a (119.90 ha or 15.55%) were almost equally represented in the relief of the exploration area.

By analyzing the exposition of the anthropogenic relief slopes, more than half of the territory has the shady aspect (N-NE-NW) (449.19 ha or 58.28%) while the sunny aspect (S-SE-SW) area has 38 ha or 26.52% of total area. It was also found that the eastern aspect (60.22 ha or 7.81%) in the relief of the exploration area was slightly more represented than the western (56.89 ha or 7.38%).

By analyzing and comparing the presented indicators it was determined that the surface of the area occupied by the shady aspect increased by 151.53 ha or 19.67%, while the area under the sunny aspect decreased by 27.24 ha or 3.53%. When talking about the shady slopes the northern aspect increased the most (122.03 ha or 15.83%), while in sunny slopes only the area with the southern aspect increased (28.85 ha or 3.74%). The surface area of eastern aspect decreased by 61.48 ha or

7.98%, while the western aspect area decreased by 63.01 ha or 8.17% (Tab. 3; Fig. 7).

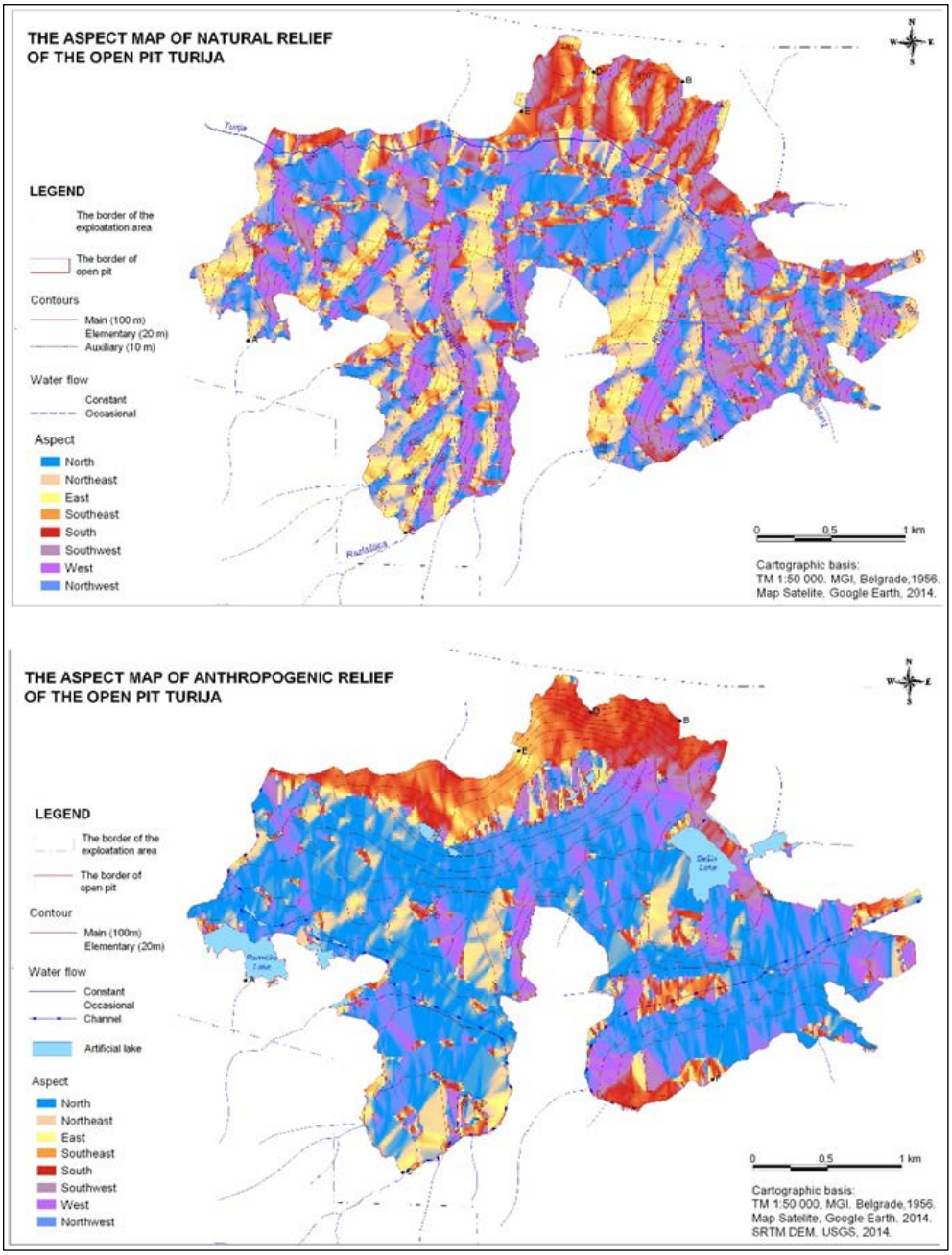

Fig. 7: The aspect map of the open pit "Turija".

The observed changes were generated by anthropogenic activity that formed anthropogenic relief forms of significantly different slope aspect compared to the

natural ones. The formed anthropogenic relief is characterized by homogeneous aspect when compared to the natural relief due to the different degree of ground dissection. Therefore, the orientation of the slopes of the researched locality is a significant factor in planning and selecting the type of recultivation of degraded surfaces since the success of biological recultivation on the slopes of landfills depends on their inclination and aspect.

As the impact of the slope aspect is considerably higher in areas with higher insolation, the landfill should be shaped so that there are fewer finishing slopes with the south and more with the northern aspect. In this regard, the quality of slopes in landfills could be presented in this order: north, northeast, northwest, east, west, southeast, southwest and south (Knežiček, et al. 2006, 147). However, if due to the mass balance of marl and fitting of the landfill to the existing terrain the last four aspects cannot be avoided, the slopes should provide a smaller slope due to the reduction of the adverse consequences of insolation.

4.2. Hydrographical changes

The river network of the exploration area, prior to the start of surface exploitation, consisted of several continual and occasional watercourses flowing into the river Turija, whose water source is located in the area of Miletina (457 m.a.s.l.) and the Stražbenice (506 m.a.s.l.) and the estuary of Modračko lake to 206 m.a.s.l. By analyzing the topographic maps, scale 1:25000 and 1:50000, it was found that the eastern part of the area previously provided the watershed that were partitioned between the Turija and the Litva basin, to the western small and eastern part from the village Garići to Tulovići, mainly north-south. In the east of the watershed were the lowest terrains with mild slopes that tune to the northeast, while in the western part the slopes merged to the northwest.

The upper part of the Turija basin includes the western part of the Banovići basin with numerous valleys of north-south direction (Trešnjeva, Očauša, Klopotovac, Vranar, Duboki stream etc.). Although the area generally belongs to the northern slopes of the Konjuh mountain, the continuity with it has been interrupted by a hilly ridge and an orographic water distribution of the northwest-southeast direction. Because of this, the western part of the basin does not touch the surface watercourses from the Konjuh area, while the watercourses from the southwest of the watercourse belong to the Krivaja basin. Thus, the main recipient of this area is the Turija River, which generally runs east-to-west along the Seona River, when it changes the course on the south-northwest. The total length of its flow is about 22 km.

The length of the watercourse in the open pit area "Turija", according to the earlier natural relief, was 23.08 km, and the density of the river network in this area of 7.71 km^2 was 2.99 km/km^2. The length of watercourses with constant water supply was 15.50 km or 2.01 km/km^2, while the total length of occasional watercourses was 7.58 km or only 0.98 km/km^2. Thus, the river Turija receives water from confluents that are mostly disturbed by mining works, and a smaller number of undisturbed confluents flowing from the western part of the basin (Pribitkovič stream, Očauša etc.). The other watercourses are partially disturbed and flow into the peripheral surface drainage channel that drains the waters into the river Turija (Fig. 8). The river Turija is formed from the streams Turija and Klopotovac which are disorganized due to surface exploitation of coal. Their water partially enters into the Turija open pit area stream. So, the river Turija is disorganized in its stream, and the stream is turned to the southern sides of the river, which receives the Vranar stream, Duboki Potok,

and later receives the stream Trešnjev and Očauš in its original course. The flow of the Turija river, measured in October during the water level between middle and medium, was about 0.13 m^3/s, while water flow into the pit was 5 m^3/min.

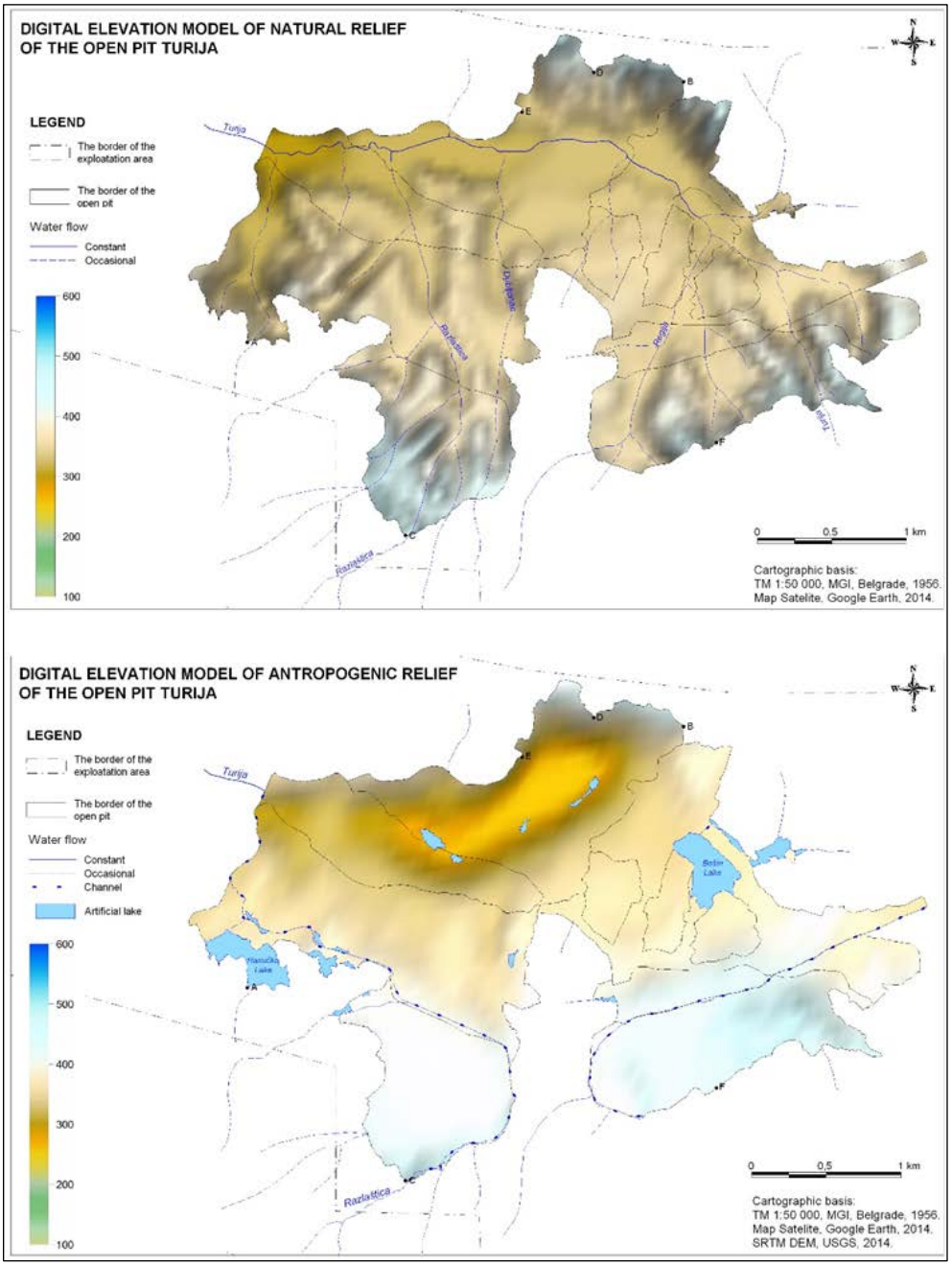

Fig. 8: Digital Elevation Model of the open pit "Turija".

All watercourses or their parts located within the working surface area or in its immediate environment (Turija, Regija, Dubljenac, Razlaštica etc.) are destroyed or disorganized by surface exploitation. In this way, a total of 23.08 km of watercourses was destroyed, while 14.67 km of watercourses were disorganized right next to the primary area of exploitation. This completely damaged the natural shore function of watercourses in the wider exploration area. There are several artificial canals which are 7.69 km long, due to the surface exploitation of coal. For comparison, about 11.97 km of watercourses were devastated and destroyed in the open pit "Dubrave" (Kreka basin), and 12.74 km of artificial defects and canals were created (Smajić et al. 2014, 20). Large anthropogenic influences on river change also occurred in the Kolubara basin, on the territory of Serbia, when the river Kolubara was redirected to Peštan (Dragićević et al. 2012, 7). In this way Kolubara adjusted the Peštan basin to its kinetic energy, resulting in the coast degradation of the first category of 5.15 km (46.3%), the other 4.22 km (37.9%) and the third 1.76 km (15.8%) (Dragićević, Milevski 2010, 299).

Several anthropogenic lakes with a total area of about 27 ha were formed in the open pit area "Turija" due to some residue depressions (Fig. 8). The largest lake by surface area is "Bešin" (11.35 ha), slightly smaller is Ramićko lake (10.02 ha), and the lowest is Tulovićko lake (2.44 ha). The average depth of the Bešin lake is 6 m and it is about 412 thousand m^3 of water, while the average depth of the lake is 3 m and it is about 110 thousand m^3 of water. The length of the Bešin lake is 1736 m, its length in the north-south direction is 530 m, while the east-west direction is 355 m. The water reflection of this lake is 350 m.a.s.l. Lakes within this surface have existed for many years and have formed their own water regime. The largest anthropogenic lake, according to the amount of water, in this area is Ramićko lake. This anthropogenic lake was created due to the marl disposal of on the outer landfill of the "Turija" open pit area near the village Ramići. The lake is located on an autochthonous substrate while on the north side it is polluted by the mentioned landfill. The volume of Ramićko lake is 0.47 km^3. The water mirror of this lake is located at 379 m and it involves water from the nearby basin of about 50 ha.

The average depth of Ramićko lake is 18 m and there are about 1.6 million m^3 of water in it. The length of the coast of this lake is 2.13 km, its length in the northwest-southeast direction is 652 m, while the width in the north-southwest direction is 325 m. Considering that the lake is characterized by good accessibility and clean water it is suitable for the development of bathing tourism and fishing.

5. Conclusion

Anthropogenic activity on the open pit area "Turija" produced about 19.5 million tons of brown coal, and about 134.94 million m^3 of marl was deposited at the landfill site. In this way, 770.87 ha of natural land was degraded, causing significant morphological-hydrographic changes that are most prominent in the change of natural landscape, due to the formation of anthropogenic relief forms of different dimensions. Field research and GIS analysis of the natural and anthropogenic relief of the open pit area, the general trend of levelling the terrain and reducing the height differences of the treated site was found. According to the 3D model, the surface of the vertically separated natural relief is larger than the surface of the anthropogenic relief for 4.42 ha, that the average altitude of the anthropogenic relief is lower than the average height of the natural relief by 20.17 m, and that territories with a hypsometric belt up to 300 m and over 400 m increased, while areas of 300-400 m.a.s.l. decreased.

Significant increase of the terrain with inclines ranging from 1 to 8° happened, and reduction of the area with inclines up to 1° and over 8°. In addition, anthropogenic relief is characterized by homogeneous aspects in relation to natural relief. The territories with the shady aspects increased, while the territories with sunny, eastern and western aspects decreased.

The river network, whose density was 2.99 km/km^2 was entirely disorganized and it completely damaged the natural depletion function of the watercourse of this area; 15.50 km of permanent and 7.58 km of occasional watercourses were completely destroyed, several watercourses or parts of them were removed, some artificial canals of 7.69 km, and several anthropogenic lakes with a total area of 17 ha were created. Since the formation of anthropogenic relief forms is one of the more extreme forms of degradation of the natural environment, it is necessary to perform recultivation of the surface area during the post-exploitation period. In the planned period recultivation should include the western landfill of the "Turija" open pit area, while in its post-exploitation period its crater should served as the outer landfill of the open pit area "Grivice". In this way his filling would have acquired the prerequisites for quality recultivation of this locality. Since the mining is obliged to respect the legal regulations and take appropriate measures in terms of recultivation of degraded areas and the protection and preservation of the environment, the presented morphologic-hydrographic indicators can serve as a significant factor for future planning and selection of recultivation type of degraded surfaces.

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IDENTIFICATION AND GEOVISUALIZATION OF MORPHOLOGICAL-HYDROGRAPHIC CHANGES IN THE AREA OF THE OPEN PIT "TURIJA"

Summary

In this paper morphological-hydrographic changes in the area of the coal open pit "Turija" in Banovići basin (northeastern Bosnia and Herzegovina) are researched. The study was based on the field data and comparative analysis of topographic maps, satellite images, Digital Elevation Model and situational plans of the area.

Anthropogenic activity on the open pit area "Turija" produced about 19.5 million tons of brown coal, and about 134.94 million m^3 of marl was deposited at the landfill site. The surface affected by this kind of exploitation is degraded and disturbed by mining, so the terrain morphology is a combination of natural relief and artificially formed floors, craters, surface dumpsites, excavations etc.

In this way, 770.87 ha of natural land was degraded, causing significant physical-geographic changes that are most prominent in the change of natural landscape, due to the formation of anthropogenic relief forms of different dimensions. Particularly significant are the morphological-hydrographic changes that are reflected in the change of the structure of the hypsometric levels, slope and aspect, and surface hydrographic network.

Field research and GIS analysis of the natural and anthropogenic relief of the open pit area, the general trend of levelling the terrain and reducing the height differences of the treated site was found. According to the 3D model, the surface of the anthropogenic relief is smaller than the surface of the natural relief for 4.42 ha, the average altitude of the anthropogenic relief is lower than the average height of the natural relief by 20.17 m, and that territories with a hypsometric belt up to 300 m (91.67 ha or 12.13%) and over 400 m (74.64 ha or 9.88%) increased, while areas of 300-400 m.a.s.l. decreased (for 166.31 ha or 22.01%).

Significant increase in the terrain with inclines ranging from 1 to 8° happened (136.92 ha or 17.77%), and reduction of the area with inclines up to 1° (13.98 ha or 1.81%) and over 8° (by 123.14 ha or 15.96%). In addition, anthropogenic relief is characterized by homogeneous exposures in relation to natural relief. Reduction of territories with southerly (27.24 ha or 3.53%), easterly (61.48 ha or 7.98%) and westerly aspects (63.01 ha or 8.17%), and a significant increase in territories with northerly aspect (by 151.53 ha or 19.67%) is also determined.

The river network, whose density was 2.99 km/km^2 was entirely disorganized and it completely damaged the natural depletion function of the watercourse of this area; 23.08 km of watercourses were completely destroyed, some artificial canals of 7.69 km, several anthropogenic lakes with a total area of 17 ha were created etc.

Since the formation of anthropogenic relief forms is one of the more extreme forms of degradation of the natural environment, it is necessary to perform recultivation of the surface area during the post-exploitation period. Therefore, the explored indicators can serve as a significant factor in the future planning and selection of the type of re-cultivation of degraded areas in the area of research.