GIS ANALYSIS OF LANDSCAPE TOPOGRAPHY TRANSFORMATION OF THE OPEN PIT "GRIVICE" (BOSNIA AND HERZEGOVINA)

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Abstract
GIS analysis of landscape topography transformation of the open pit "Grivice" (Bosnia and Herzegovina)
The authors analyze transformations of landscape topography of the open pit "Grivice" in Banovići basin (Northeastern Bosnia). This complex research is based on field screening and GIS analysis of Digital Elevation Models (DEMs) of researches terrain. Specifically, two DEMs of the Grivice area were prepared, a natural model based on a topographic map, scale 1:25000, issued in 1976 by the Military Geographical Institute (MGI) from Belgrade, while the Google satellite image from 2018 and the Digital Surface Model (DSM) were used for the anthropogenic model, issued in 2018 by the Japan Aerospace Exploration Agency (JAXA). Using methods and algorithms integrated in QGIS, raster and vector values of treated transformation parameters (hypsometry, slope and aspect, hydrographic network, etc.) were obtained, and their analytical-synthetic interpretation and geovisualization were also performed. Finally, ten thematic maps, which illustrate the anthropogenic transformation of the landscape topography of the researched area, were created.

Key words
GIS analysis, landscape topography, transformation, DEM, geo-visualizations, open pit "Grivice", Bosnia and Herzegovina

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1. Introduction

The Banović basin has a long tradition of mining. Since 1946, surface mining of coal has been carried out here at several localities, which are now closed, while currently two surface localities are being exploited: "Turija" and "Grivice" (Smajić et. al. 2018, 40; Smajić, Hadžimustafić 2017, 556). The research covers the locality "Grivice", where 483.18 ha of the territory of the Banovići basin has been affected by surface coal exploitation in the past 36 years. Concave and convex anthropogenic relief forms were formed by exploitation, which resulted, above all, in a significant transformation of the landscape topography of the Grivice area (hypsometry, slope and terrain aspect), disorganization of the surface hydrographic network, etc. In this regard, the characteristics of anthropogenic relief and development tendencies require a complex analysis of a set of issues relevant to this research, such as: classification and mapping of forms, quantitative forecast of transformations, definition of re-cultivation measures, etc. (Dinić 2007, 94; Smajić et al. 2018, 40).

Thematically similar, numerous studies around the world interpret the intense anthropogenic impact on the mining landscape, design themes, and comparative analysis of digital terrain models of mining areas, emphasizing the importance of 3D modeling and interactive visualization options (Jaskulski, Nowak 2019, 12; Wu et al. 2019, 18; Harnischmacher, Zepp 2014, 3; Harnischmacher 2007, 185; Dragićević et al. 2012, 3; Boengiu et al. 2016, 262; Pandey, Kumar 2014, 731; Brejcha et al. 2016, 151, etc.).

In general, the transformation of the landscape topography of the Grivica locality, at the temporal and spatial level, can be observed on the basis of a comparative GIS analysis of the pre-investment and recent relief. In order to achieve this, based on old topographic maps, a newer DSM and satellite image, and field observations, two DEMs of the Grivice area were prepared, whose interpretation and comparison provided data on the intensity and extent of transformation. Therefore, the research aims to identify and geovisualize the level of landscape topography transformation of the open pit "Grivice", using GIS, the method of comparison of terrain models and field work.

2. Materials and methods

The application of GIS in the analysis of recent transformations of landscape topography is a necessity, and digital projection models and satellite images have a special status. Their interpretation in combination with cartographic data provides the possibility of a complex GIS representation of the transformation of landscape topography of mining areas. In this regard, two DEMs of the Grivice area were prepared, pre-investment (natural) and recent (anthropogenic) (Fig. 2), whose with GIS comparison, along with field research, were identified, quantified and geovisualized transformations of the landscape topography of the treated locality. Two sheets of a topographic map with a scale of 1:25000, issued by the MGI from Belgrade in 1976, were used to prepare the natural DEM, while Google satellite imagery from 2018 and AW3D30 DSM were used for the anthropogenic DEM, issued in 2018 by the JAXA. These models of the Grivice terrain were compared using QGIS tools, while their interpretation is facilitated by a uniform pixel size (10 m).

In general, the research was realized in several stages: the cartographic basis was selected, the maps were scanned (in raster form with a resolution of 400 dpi), filtered, the rasters was adjusted, and the maps were georeferenced into a coordinate system of appropriate projection. After georeferencing, using QGIS tools, the vectorization of thematic contents from the topographic map (isohypses, watercourses, soils and vegetation) was performed, while using the Google Earth Pro application, the boundary of the surface mine and its parts was vectorized, relocated watercourses, canals, etc. The vectorized elements were used in the analysis of average and absolute terrain heights, hypsometry, terrain slope and aspect, disorganization of the hydrographic network, soil devastation and vegetation in the area of exploitation.

Using methods and algorithms integrated in QGIS, raster and vector values of treated transformation parameters were obtained, and their analytical-synthetic interpretation and geo-visualization were also performed. Finally, ten thematic maps, which illustrate the anthropogenic transformation of the landscape topography of the researched area, were created. In order to implement research, software solutions were used: QGIS Desktop (2.18.2 and 3.8.0) with GRASS (7.0.5 and 7.6.1), MS Excel 2007 and Adobe Photoshop 10.

3. Research area

The researched area is located in the Spreča paleodepression within the Inner Dinarides of Northern Bosnia. More specifically, the area is located in the Banovići basin, between 44° 25' 13'' and 44° 27' 06'' N and 18° 28' 59'' and 18° 31' 32'' E. The basin is gradually expanding from west to east, while is morphologically divided into northern and southern parts. The northern part of the basin, 14.5 km long and 2.4 km wide on average, is divided by the watershed between Draganja and Turija into the western part ("Banovići Selo" basin) and the eastern part ("Grivice-Omazići" basin) (Smajić 2012, 253; Smajić, Hadžimustafić 2017, 558). Topographically, the surface mine "Grivice" is located in the eastern part of the northern basin, between the pit "Omazići" and the mine "Turija", at a distance of 3 km north of Banovići.

The geological area covers an area of about 6 km^2. The deposit has the shape of an irregular broken rectangle elongated in the direction west-east, i.e. northwest-southeast, where the maximum length reaches 5.2 km and the width 0.60-1.75 km. The exploitation reserves of this mining potential amount to 61.84 million tons of brown coal and 786.81 million m^3 of overburden. The rural settlements of Grivice, Gaj, Mrdići, Gornji Bučik and others are located in the exploitation field and on the outskirts, whose several hamlets have disappeared due to the development of a surface mine (Smajić et al. 2009, 35).

In general, the exploitation of coal in the area of Grivice has formed positive and negative anthropogenic relief forms, which has resulted in significant landscape transformation of the area, especially emphasized in the transformation of hypsometric structure, slope and terrain aspect, surface hydrographic network, etc. By depositing the overburden in the landfills, the natural terrain was buried, and the formed flat surfaces were slightly technically and biologically recultivated. In general, the crater and surface mine deposits are still subject to spatial changes (Fig. 1 and 2).

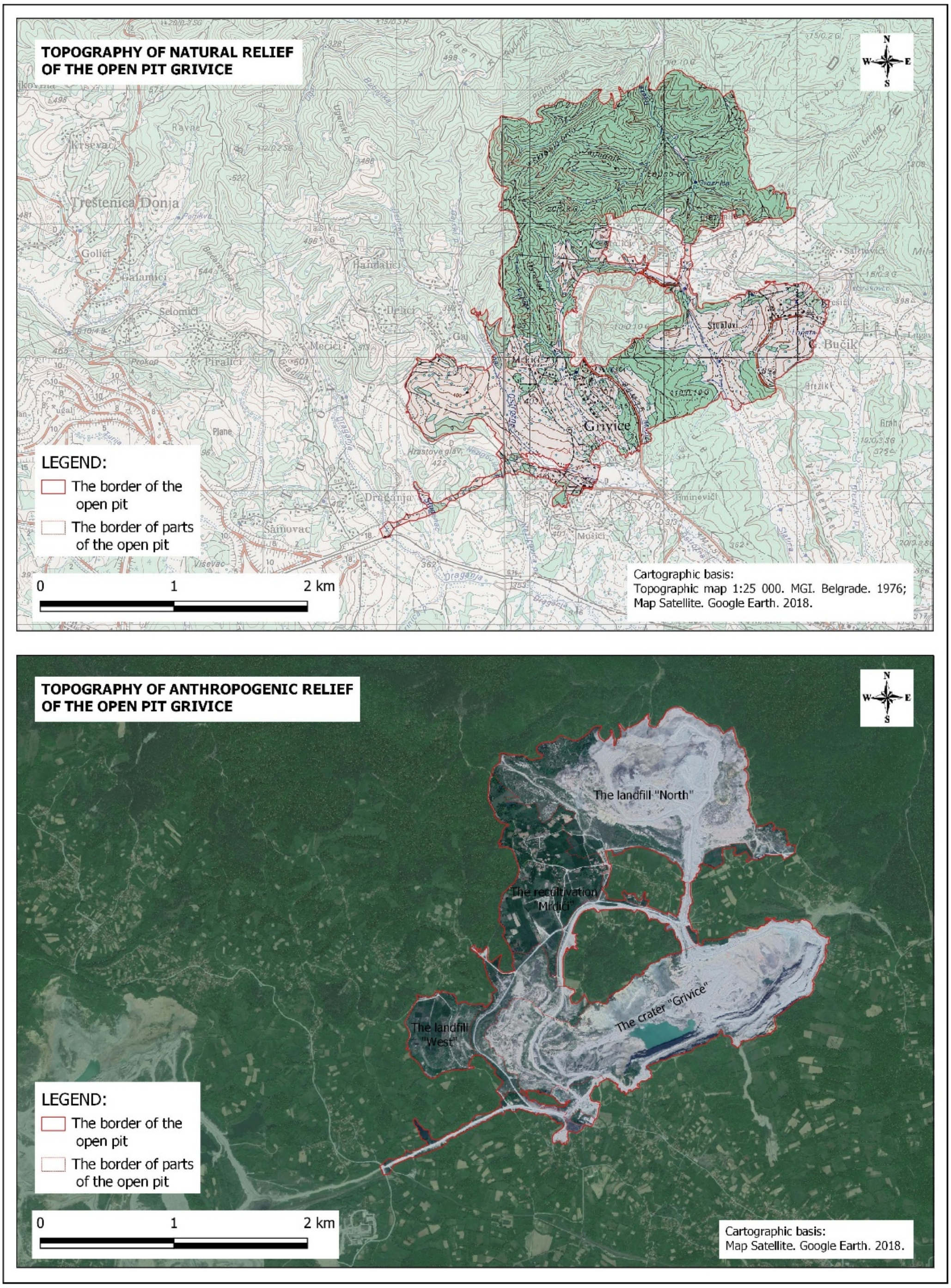


Fig. 1: Topography of natural (up) and anthropogenic (down) relief of the research area.

4. Results and discussion

The surface mine "Grivice" began its work on the overburden in 1984, and in 1985 the exploitation of coal began. In the past 36 years, 19.03 million tons of coal have been produced here, and 128.51 million m^3 of overburden has been excavated and disposed of in landfills. In this way, in the Grivice area, in addition to excavations, three landfills ("North", "West" and "Inner") were formed, in the composition of which the sediments of the roof of the coal seam dominate, i.e. clay marls of Oligocene age (Smajić 2012, 251). The exploitation caused a significant transformation of the landscape topography of the Grivice area, but also of the hydrographic, pedological and vegetation structure. This transformations are especially reflected in the disturbance of the natural terrain balance and the modelling processes, the evident increase in energy and instability of anthropogenic relief, the disturbance in the superficial of the hydrographic network and flow regime, etc. For comparison, in the Shengli mining area (Inner Mongolia) there is a pronounced influence of coal exploitation on environment, especially on landscape topography, in the form of landscape fragmentation, complexity and irregularity of shape, gradual decline of landscape stability, etc. (Wu et al. 2019, 18). Also, similar processes of antropogenic influence on the relief and the environment are documented in rumunian open pit Husnicioara (Boengiu et al. 2016, 262). Specifically, on "Grivice" locality, significant areas of natural soil (483.18 ha) were devastated by the formed concave and convex anthropogenic relief forms, dominantly brown shallow and medium deep soils on serpentines (64.65%), pelosols (30.02%), brown deep degraded soils on clays and loams (4.79%) and very poorly developed soils on serpentines (0.54%) (Pedological map 1972). Sessile and hornbeam forests are the most devastated among the other forest phytocenoses (74.62%), while agricultural areas, settlements, forest barren lands and others account for 25.38% (The map of vegetation 1980).

GIS analysis of the Grivice anthropogenic terrain showed that the surface mine crater covers 33.99%, landfills 44.61%, the reclaimed area "Mrdići" 12.88%, while other parts account for 8.52% of the territory. The crater of the open pit has the shape of an irregular ellipse whose longer axis extends approximately in the southwest-northeast direction. The maximum length of the crater reaches 3.37 km, while the width is variable (0.36-1.38 km) (Fig. 1). Disposal of overburden, from the western part of the surface mine, was previously carried out to the internal "Western" and external "Northern" landfill. The "Western" landfill is located on the south side of the Gaj settlement in the former "Grivice" crater (western part). The height of the landfill in the northwestern part is 450 m, in the southeastern part 380 m, while the fall of the landfill in the north-south direction is 2%. It is bordered on the west and south by road communication that connects the settlements of Grivice and Gaj, on the east by a local road that connects the settlements of Grivice and Mrdiće, while on the north side it leans on the northern end slope of the mine. Overburden from the upper floors of the surface mine (360-324 m) was deposited at this landfill, while material from the lower floors is currently disposed of at the external landfill "North". After the currently available disposal space in the western part of the "North" landfill is filled, the disposal of the overburden will be redirected in the eastern direction. Therefore, it is necessary to connect the newly formed landfill floors with a route, through the settlement of Bučik, with the working zones on the overburden in the crater, which requires additional expropriation of land (7.5 ha). The highest altitude of the landfill is in the northwestern and western part (440-450 m), it is slightly lower in the central, southern and eastern part (390-400 m), while it is the lowest in the northern part (310-320 m) (Fig. 2 and 3). Part of the landfill "West" was recultivated and formed as agricultural land, while a part of the residential settlement Mrdići with the collective center of the same name was built on the recultivated area of the landfill "North". In the period until 2031, it is planned that the exploitation will cover a new 266 ha (Spatial Plan of the Municipality of Banovići 2017, 95), which would ultimately result in a significant increase in the devastated areas of Grivice locality.

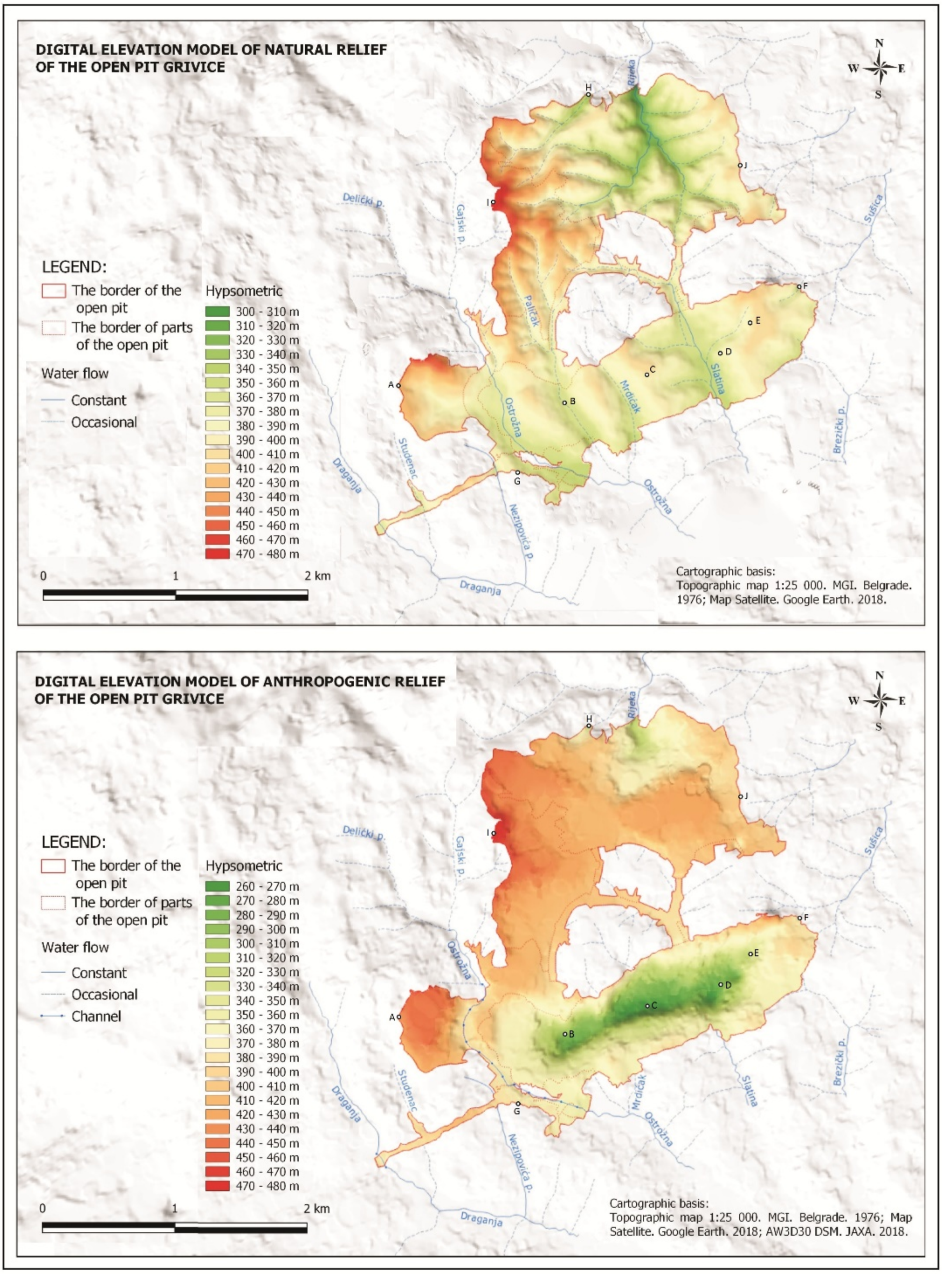


Fig. 2: Digital Elevation Model of natural (up) and anthropogenic (down) relief of the research area.

4.1. Transformation of landscape topography

The transformation analysis of the landscape topography of the Grivice area was carried out on the basis of the prepared 10-meter digital terrain models. The results of GIS analysis of DEM natural and anthropogenic terrain show that the Grivica locality is entirely located in the foothill hypsometric belt, and that the most significant transformations have affected areas of large topographic forms of the anthropogenic origin (Tab. 1; Fig. 2 and 3).

Tab. 1: Categories and spatial dimensions of elevation

Elevation (m)	Natural relief		Anthropogenic relief		Index A/N
	Area (ha)	Portion (%)	Area (ha)	Portion (%)	
250-260	-	-	1,51	0,31	-
260-270	-	-	4,44	0,92	-
270-280	-	-	8,16	1,69	-
280-290	-	-	8,97	1,86	-
290-300	0,02	0,00	7,35	1,52	35194,28
300-310	0,51	0,10	7,87	1,63	1555,88
310-320	2,24	0,46	9,52	1,97	424,91
320-330	4,71	0,98	10,47	2,17	222,13
330-340	8,04	1,66	13,08	2,71	162,66
340-350	18,04	3,73	18,23	3,77	101,06
350-360	45,01	9,32	35,09	7,26	77,96
360-370	66,67	13,80	41,06	8,50	61,58
370-380	81,46	16,86	43,37	8,98	53,24
380-390	86,20	17,84	41,66	8,62	48,34
390-400	69,64	14,41	40,62	8,41	58,33
400-410	41,83	8,66	57,25	11,85	136,85
410-420	23,39	4,84	54,32	11,24	232,18
420-430	14,82	3,07	38,89	8,05	262,38
430-440	10,18	2,11	25,38	5,25	249,22
440-450	5,95	1,23	12,90	2,67	216,91
450-460	3,26	0,67	1,95	0,40	59,66
460-470	0,70	0,14	0,81	0,17	115,75
470-480	0,50	0,10	0,27	0,06	54,68
Total	483,18	100,00	483,18	100,00	100,00

Source: Data obtained by GIS analysis. Cartographic basis: Topographic map 1:25000. MGI. Belgrade. 1976; Map Satellite. Google Earth. 2018; AW3D30 DSM. JAXA. 2018.

The natural morphological environment of the Grivica area was characterized by hilly relief (300-480 m). The northwestern, western and southwestern part of the area was characterized by the highest levels (440-480 m above sea level), while the lower and southern parts of the terrain were characterized by significantly lower levels, where the height rarely exceeded 400 m. Currently, the lowest hypsometric levels characterize the surface mining area.

With GIS analysis of DEM natural terrain, the average height of the area of 382.89 m was determined, while the absolute height difference was 170 m. The lowest belt (up to 300 m) covered a small area (0.004%), while the 300-400 m belt covered 79.17%, and the highest territory had a height of 370-400 m (62.03%). The hypsometric belt over 400 m covered 20.83% territory, while the most common levels were 400-430 m (79.54%) (Tab. 1). In the northwestern area, the morphological elevation Skravno hill (472 m) stood out, in the northern Jagodnik (400 m) and Lojino hill (390 m), in the western Osredak (440 m) and others (Fig. 1). The GIS analysis of DEM anthropogenic terrain showed its average height of 381.63 m, while the absolute height difference reaches 210 m. The lowest belt (up to 300 m above sea level) covers 6.30% of the territory, and the most common levels are 270-290 m (56.32%), while the 300-400 m belt covers 54.01%, and the highest territory has a height of 360-400 m (63.88%). The hypsometric belt over 400 m covers 39.69% territory, and the most common levels are 400-430 m (78.46%) (Tab. 1).

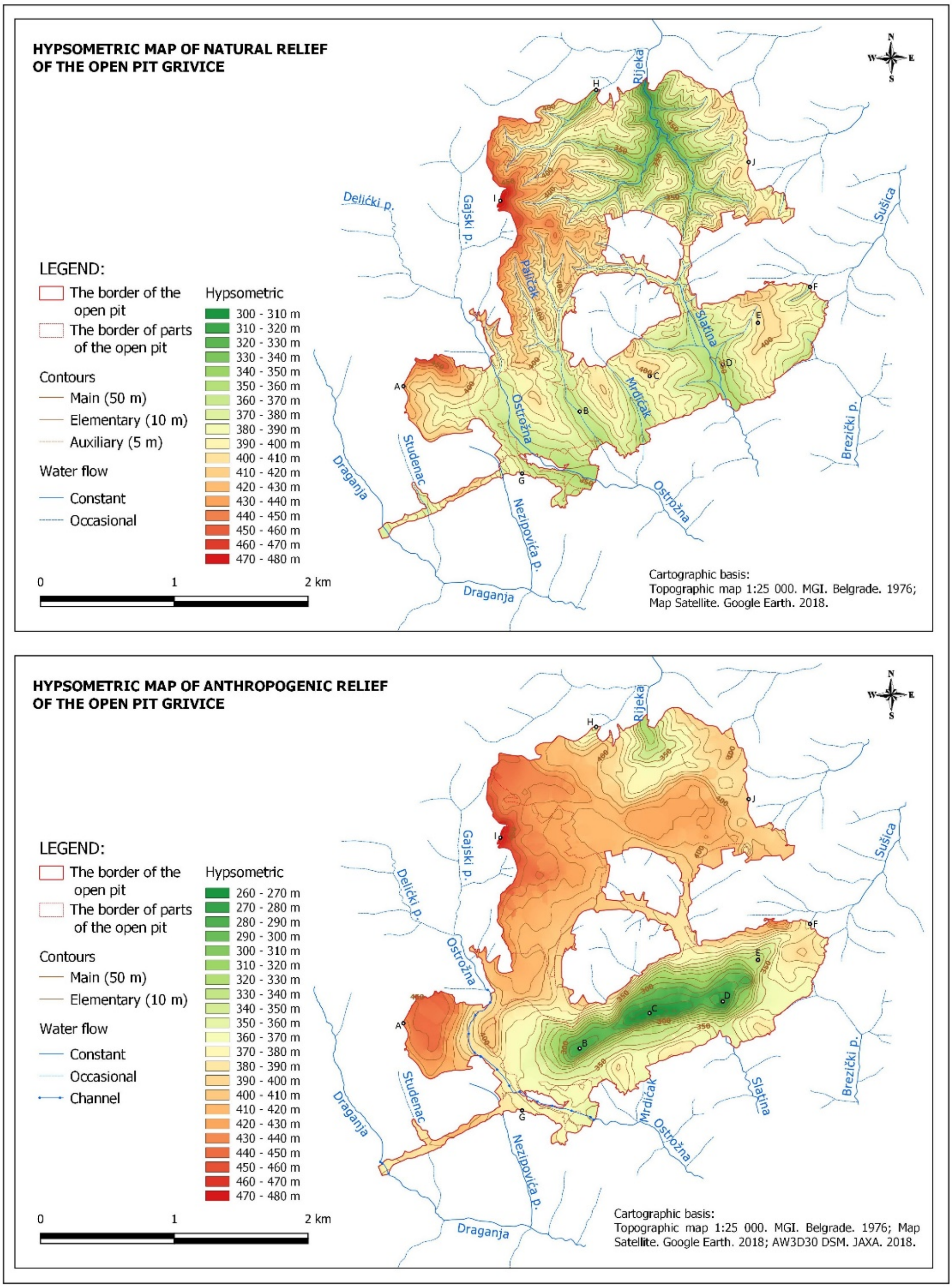


Fig. 3: Hypsometric map of natural (up) and anthropogenic (down) relief of the research area.

The results of the comparison of DEMs of the Grivice terrain show a slight decrease in the average height of the anthropogenic relief (by 1.26 m), with more pronounced increase in height difference (by 40 m), an increase in territory up to 300 m (by 6.29%) and over 400 m (by 18.86%), and a reduction of the territory of 300-400 m (by 25.15%). The identified hypsometry is a consequence of cutting and excavating the terrain in the excavation area, which reduced the relief, and depositing the overburden on the formed landfills, as a result of which the elevation of the terrain is emphasized. A similar process was recorded in the area of the neighboring mine "Turija" where the decrease in the average height is 20.17 ha, and the increase in the height difference is 25 m (Smajić et al. 2018, 47). For example, comparison of the DEMs also recorded the height difference of the natural (80 m) and anthropogenic terrain (482 m) of the "Bełchatów" coal open mine in central Poland (Jaskulski, Nowak 2019, 10). The average height of the excavation "Grivice", in the southern part, is 336.88 m, maximum 440 m, while the maximum depth reaches 260 m. The landfills, in the western and northern part, covered parts of the Ostrožna and Rijeka watercourses (spring catchment area), as a result of which flat areas were formed. The average height of the landfill "West" is 407.66 m, maximum 453.64 m and minimum 363.61 m, while the average height of the landfill "North" is 399.12 m, maximum 452.41 m and minimum 316.14 m (Fig. 3, 4, 5 and 6).

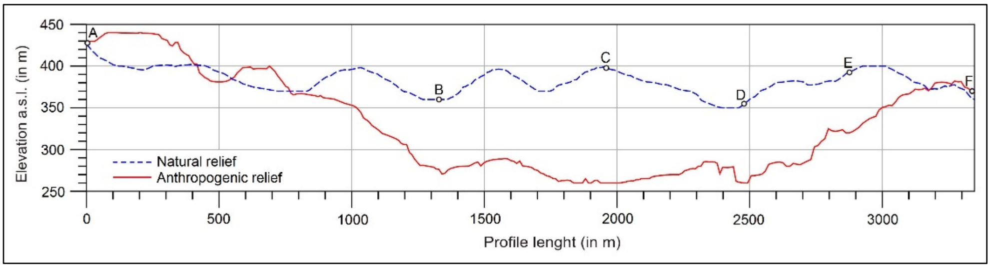


Fig. 4: Cross-profile (A-B-C-D-E-F) in a section of hypsometric map

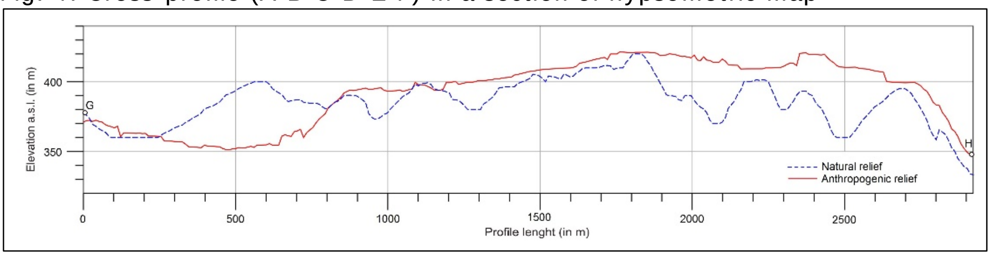


Fig. 5: Cross-profile (G-H) in a section of hypsometric map

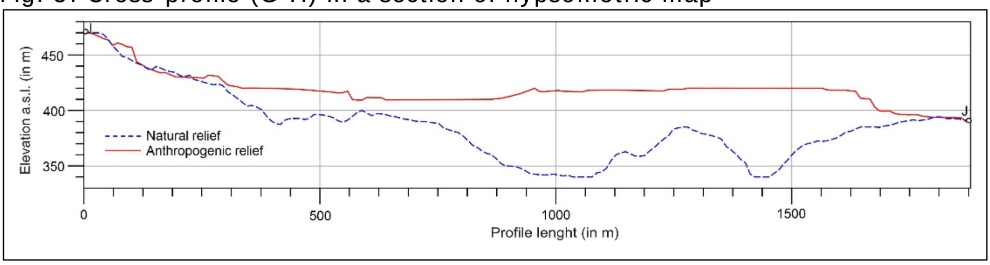


Fig. 6: Cross-profile (I-J) in a section of hypsometric map

Based on a 10-meter model of the area, models of slope and aspect of both areas of the surface mine were also prepared. Slope values were obtained using methods and algorithms integrated in QGIS, and ten slope classes were singled out (Tab. 2).

Tab. 2: Categories and spatial dimensions of slopes.

Inclination (°)	Natural relief		Anthropogenic relief		Index A/N
	Area (ha)	Portion (%)	Area (ha)	Portion (%)	
0-1°	41,47	8,58	47,04	9,74	113,43
1-3°	24,47	5,06	72,49	15,00	296,23
3-5°	28,95	5,99	65,24	13,50	225,40
5-8°	61,86	12,80	74,92	15,51	121,10
8-12°	102,79	21,27	66,69	13,80	64,88
12-16°	83,46	17,27	47,48	9,83	56,89
16-20°	59,49	12,31	31,11	6,44	52,30
20-30°	72,28	14,96	49,01	10,14	67,80
30-40°	8,40	1,74	22,15	4,58	263,76
> 40°	0,02	0,00	7,04	1,46	35221,34
Total	483,18	100,00	483,18	100,00	100,00

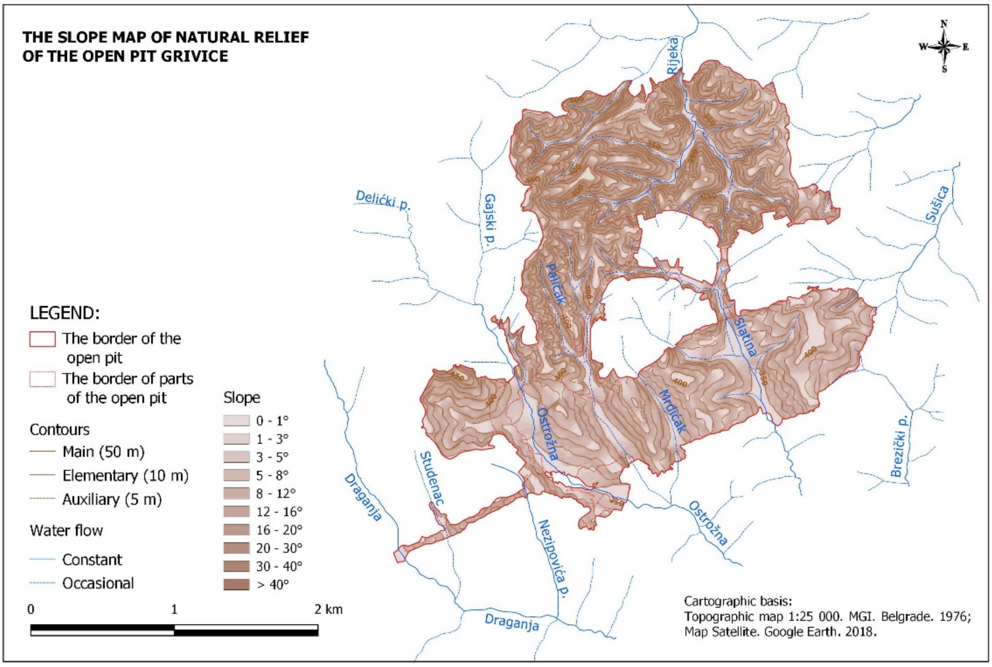
Source: Data obtained by GIS analysis. Cartographic basis: Topographic map 1:25000. MGI. Belgrade. 1976; Map Satellite. Google Earth. 2018; AW3D30 DSM. JAXA. 2018.

The analysis of the slope model of natural relief showed that slopes up to 1° were spread on 8.58% of the territory, 1-5° on 11.06%, 5-12° on 34.08%, and on slopes 12-20° on 29.58% of the territory. Morphologically, the area was dominated quite inclined, steep and very steep slope morphogenetically shaped by slope processes of flooding, dredging, crawling and sliding, and inclined plains. On a slope over 20°, 16.70% of the territory was affected by intensive slope processes and medium steep and steep slopes dominated mostly.

The analysis of the anthropogenic relief shows that the slopes up to 1° are spread on 9.74% of the territory, 1-5° on 28.51%, 5-12° on 29.31%, while the slopes of 12-20° are on 16, 27% of the territory. Morphologically, the area is dominated by the average, quite inclined and steep slope and steep plains. On a slope over 20°, there is 16.19% of the territory affected by intensive slope processes, with a significant share of moderately steep and very steep slopes (Tab. 2).

The results of the comparison of the slope model of the hilly area show a significant increase of the slope territory up to 8° (by 21.31%), especially in the category 1-3° (by 9.94%) and 3-5° (by 7.51%), and over 30° (by 4.30%), and the reduction of the slope territory by 8-30° (by 25.61%), especially in the category of 12-16° (by 7.45%) and 16-20° (by 5.87%). Thus, a slight trend of terrain leveling is emphasized at this locality (Fig. 7).

The research also includes the analysis of the spatial orientation of the slopes of the Grivice area. Aspect values, expressed in azimuths (0-360°), were also obtained using methods and algorithms integrated in QGIS, and eight aspect intervals were separated (Tab. 3).



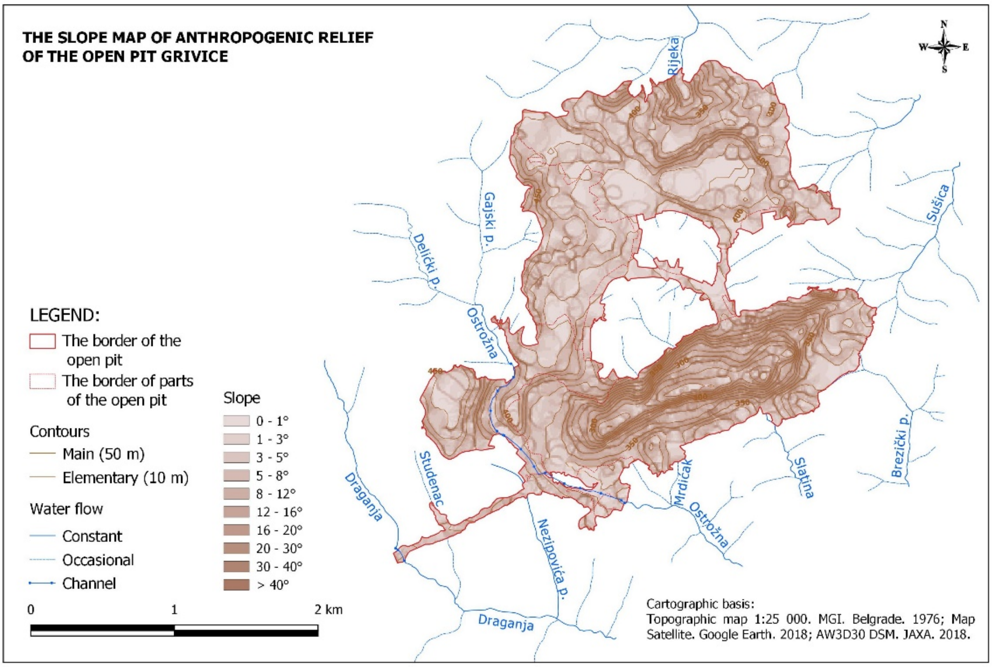


Fig. 7: The slope map of natural (up) and anthropogenic (down) relief of the research area.

Tab. 3: Aspect categories and their spatial coverage.

Aspect	Natural relief		Anthropogenic relief		Index A/N
	Area (ha)	Portion (%)	Area (ha)	Portion (%)	
N (337,5-22,5°)	66,37	13,74	66,78	13,82	100,62
NE (22,5-67,5°)	65,74	13,60	56,25	11,64	85,57
E (67,5-112,5°)	71,46	14,79	74,61	15,44	104,41
SE (112,5-157,5°)	69,14	14,31	87,76	18,16	126,92
S (157,5-202,5°)	65,94	13,65	76,12	15,75	115,43
SW (202,5-247,5°)	72,69	15,04	42,99	8,90	59,14
W (247,5-292,5°)	38,93	8,06	35,25	7,29	90,53
NW (292,5-337,5°)	32.91	6,81	43,44	8,99	131,97
Total	483,18	100,00	483,18	100,00	100,00

Source: Data obtained by GIS analysis. Cartographic basis: Topographic map 1:25000. MGI. Belgrade. 1976; Map Satellite. Google Earth. 2018; AW3D30 DSM. JAXA. 2018.

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). Specifically, analysis of the aspect model of natural relief shows that sunny aspects (southeast, south and southwest) characterized the highest areas of surface mining (43.00%), shady (northwest, north and northeast) 34.15% of the territory, while eastern aspects (14,79%) were more represented than western ones (8.06%). In the case of anthropogenic relief, sunny aspects characterize 42.81% of the territory, shady 34.45%, while eastern aspects (15.44%) which are significantly more represented than western ones (7.29%).

The results of the comparison of the aspect models of the Grivice area show that the territory with shady aspects increased by 0.30%, and with sunny aspects decreased by 0.19%. In general, the territory with the northwest, south-eastern and southern aspects increased the most, and decreased with the southwest and north-eastern aspects. Also, the territory with eastern aspect increased by 0.65%, while the territory with western aspect decreased by 0.76% (Tab. 3; Fig. 8).

The observed transformations were generated by anthropogenic activity that formed anthropogenic relief of significantly different slope aspect compared to the natural ones. Bearing in mind the success of biological reclamation on landfill slopes depends on their slope and aspect, the landfills should be designed with a larger number of final slopes with northern aspects, and less with southern. Also, the slopes should be provide with a smaller slope due to the reduction of the adverse consequences of insolation (Smajić et al. 2018, 52; Knežiček et al. 2006, 147).

4.2. Hydrographical transformation

The river network of the Grivice area consists of the Draganja watercourse with the tributaries Ostrožna and Slatina, the Rijeka watercourse which drains the northern area flowing into Modračko Lake, and four occasional watercourses of Sušica, the left tributary of the Spreča (Fig. 8). The total length of watercourses in the area of surface mining was 19.94 km, and the density of the river network was 4.13 km/km^2 (0.86 km/km^2 of permanent and 3.27 km/km^2 of occasional watercourses).

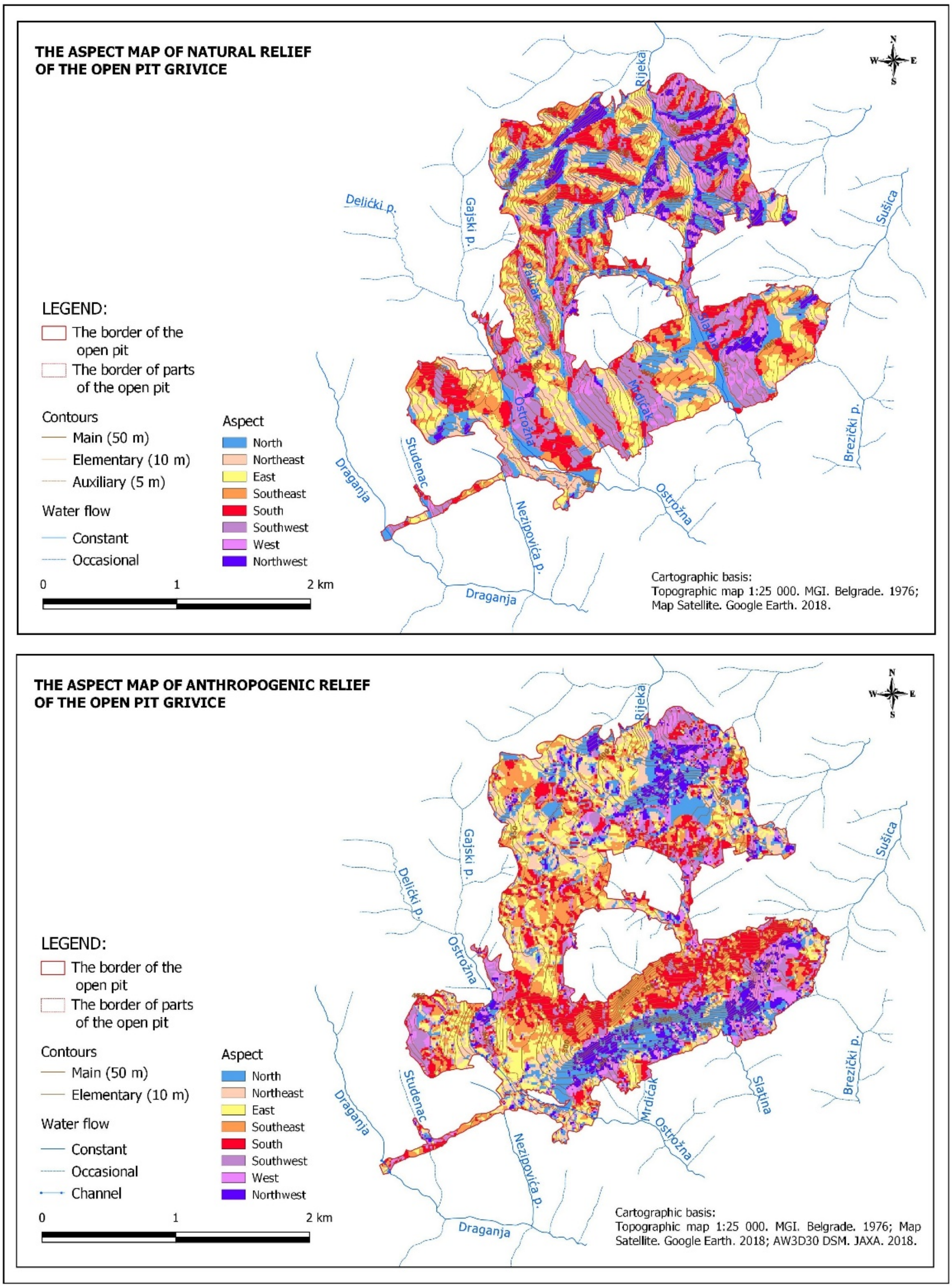


Fig. 8: The aspect map of natural (up) and anthropogenic (down) relief of the research area.

Draganja is a left tributary of Litva, flowing in a northwest-southeast direction. The surface of the Draganja river basin is 10.00 km^2, and the length of the stream is 7.50 km. This watercourse flows along the southwestern edge of the researched area in the length of 0.15 km. The confluence of the rivers Ostrožna (3.60 km^2) and Slatina (2.30 km^2) into the river Draganja is located in an urban area of Banovići, southeast of the surface mine.

The river Ostrožna was the longest permanent watercourse that flowed through the researched area in the length of 1.68 km. The tributaries of the Ostrožna in this area consisted of occasional watercourses in the length of 4.67 km, mainly from the left catchment area (Mrdićak, Palićak, etc.).

The Slatina watercourse drained the eastern and most of the central area in the length of 4.15 km. Due to surface exploitation, this watercourse was destroyed, and all occasional watercourses and springs in the length of 2.31 km, upstream from the excavation, were indirectly disorganized, because they remained without a natural sub-pathological function.

Waters from the northern part of the surface mine are drained by the Rijeka watercourse. The river was formed by several occasional watercourses and permanent springs, and the most abundant source was "Groznica" which was located east of Lojino hill at 340 m. The length of permanent watercourses was 1.45 km, while the length of occasional ones was significantly longer (5.75 km). The source of the river Rijeka is covered with material from the "North" landfill, which is a kind of hydro-ecological problem. In fact, it is an area from which drinking water is supplied to settlements located downstream in the Rijeka river basin. In the extreme northeastern area, there were four occasional watercourses of Sušica, whose length in the exploitation field was 0.40 km.

In general, surface exploitation at the Grivica site destroyed 19.94 km of watercourses, while 8.04 km were disorganized, next to the working area. Several artificial culverts and canals were formed, 1.44 km long, whose main function is to divert watercourses, accept and prevent the penetration of surface waters and atmospheric precipitation into the crater (Fig. 8). Therefore, the regulation of the Šehića spring watercourse was carried out and the northern peripheral canal was built. In this way, the natural potamological function of watercourses in the wider area of the surface mine is disturbed.

Two water reservoirs were formed in the crater of the mine, in the western and eastern districts. Drainage of water reservoirs is done by pumping into sedimentation basins outside the crater, from where the purified water is discharged into natural recipients, streams Slatina and Ostrožna, i.e. the river Litva (Fig. 1).

5. Conclusion

The application of GIS in the analysis of recent transformations of landscape topography is a necessity, and digital projection models and satellite images have a special status. By interpreting and comparing the terrain models and thematic maps prepared on this basis, data on the intensity and scope of transformation of landscape topography, hydrography, soil and vegetation of the Grivice area were obtained.

The results of GIS analysis of DEMs show that the most significant transformations affected areas of large topographic forms of anthropogenic origin. A slight trend of leveling of the Grivica terrain was determined, accompanied by a slight decrease in the average height of anthropogenic relief (by 1.26 m) and a more pronounced increase in altitude difference (by 40 m), increase in territory up to 300 m and over 400 m, and decrease in territory 300-400 m. The slope area was significantly increased to 8° and over 30°, and decreased by 8-30°. The territory with shady and eastern aspect was also increased, and decreased with sunny and western aspect. The territory with the NW, SE and S aspect increased the most, and decreased with the SW and NE aspect.

The river network, with a density of 4.13 km/km^2, is completely disorganized, and the natural potamological function of the Grivice area (19.94 km) is completely disrupted. Significant areas of natural soil and vegetation were also devastated (483.18 ha); predominantly brown shallow and medium-deep soils on serpentines (64.65%) and pelosols (30.02%), and of forest phytocenoses predominantly sessile and hornbeam forests (74.62%).

In the period until 2031, it is planned to expand the excavation field to the area of the settlements Gornji Bučik, Mrdići and Grivice, and landfills to the area of the hamlet Šehića potok and the eastern part of landfill "North", which will result in a significant increase in devastated areas and volume transformations of landscape topography and hydrography of Grivice locality. Bearing in mind that the interpretation of DEMs and satellite images in combination with cartographic data provides the possibility of establishing a complex GIS representation of landscape transformation of the Grivice area, especially topographic, the identified indicators have applicative significance in planning the revitalization of the post-exploitation landscape of the research area.

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GIS ANALYSIS OF LANDSCAPE TOPOGRAPHY TRANSFORMATION OF THE OPEN PIT "GRIVICE" (BOSNIA AND HERZEGOVINA)

Summary

In this paper transformations of landscape topography of the surface mine "Grivice" in Banovići basin (Northeastern Bosnia) are researched. Interpretation of this transformations, at the temporal and spatial level, can be observed on the basis of a comparative GIS analysis of DEMs of the pre-investment and recent terrain. In order to achieve this, two DEMs of the Grivice area were prepared, pre-investment (natural) and recent (anthropogenic), with GIS comparison of these models, along with field research, transformations of the landscape topography of the researched locality were identified, quantified and geovisualized. Two sheets of a topographic map with a scale of 1:25000, issued by the MGI from Belgrade in 1976, were used to prepare the natural DEM, while the Google satellite image from 2018 and the AW3D30 DSM were used for the anthropogenic DEM, issued in 2018 by the JAXA. These models of the Grivice terrain were compared using QGIS tools, while their interpretation is facilitated by a uniform pixel size (10 m).

Using methods and algorithms integrated in QGIS, raster and vector values of treated transformation parameters (hypsometry, slope and aspect, hydrographic network, etc.) were obtained, and their analytical-synthetic interpretation and geovisualization were also performed. Finally, ten thematic maps, which illustrate the anthropogenic transformation of the landscape topography of the researched area, were created.

Specifically, the results of GIS analysis of DEMs showed that the most significant transformations affected areas of large topographic forms of anthropogenic origin. A slight trend of leveling of the Grivica terrain was determined, accompanied by a slight decrease in the average height of anthropogenic relief (by 1.26 m) and a more pronounced increase in altitude difference (by 40 m), increase in territory up to 300 m (by 6.29%) and over 400 m (by 18,86%), and decrease in territory 300-400 m (by 25.15%).

The slope area was significantly increased to 8° (by 21.31%), especially in the category 1-3° (by 9.94%) and over 30° (by 7.51%), and decreased by 8-30° (by 25.61%), especially in the category 12-16° (by 7.45%) and 16-20° (by 5.87%). The territory with shady (by 0.30%) and eastern aspect (by 0.65%) also increased, and decreased with sunny (by 0.19%) and western aspect (by 0.76%). The territory with the NW, SE and S aspect increased the most, and decreased with the SW and NE aspect.

The river network, with a density of 4.13 km/km^2, is completely disorganized, and the natural potamological function of the Grivice area (19.94 km) is completely disrupted. Significant areas of natural soil and vegetation were also devastated (483.18 ha); predominantly brown shallow and medium-deep soils on serpentines (64.65%) and pelosols (30.02%), and of forest phytocenoses predominantly sessile and hornbeam forests (74.62%).

Since the interpretation of DEMs and satellite images in combination with cartographic data provides the possibility of establishing a complex GIS representation of landscape transformation of the Grivice area, especially topographic, the identified indicators have applicative significance in planning the revitalization of the post-exploitation landscape of the research area.