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Two Centuries of Land Use Changes Influenced by Intensive Mining and Smelting Activities (Middle Spis, Slovakia)

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ABSTRACT

Aims Mining activities and mining-related industries in the Middle Spis area (Slovakia) contributed significantly to the irreversible changes of landscape structure. The aim of this study is to analyze and detect the landscape changes in four former mining villages during four-time horizons. Total landscape structure changed - for over 200 years was detected using landscape matrix.

Materials & Methods Four land indices/coefficients (Shannon diversity index, the coefficient of ecological stability, the coefficient of anthropogenic pressure, and the coefficient of landscape originality) were used to evaluate the landscape state for each research period landscape matrix expressed the course of transition changes. Evaluation of land structure in different time horizons and land use/land cover changes between different time horizons were performed using QGIS.

Findings The most significant land use changes were identified between 1785 and 1986 when mining activity was the most extensive. The forest area decreased about 363 km2. On the contrary, the area of technical units increased about 82.9 km2, and residential areas tripled their area. After 1986 processing plants were closed and mining activities reduced, but landscape stayed disrupted by mining bodies. Nevertheless, a slight increase in the forest area (almost 50 km2) was determined. The values of indices and coefficient did not show the positive trends even after the end of activities.

Conclusion Mining activities and mining-related industries significantly disrupt the landscape that negatively affects the quality of the environment and the quality of life. After the end of mining activities, the situation became better, but the actual state of the landscape could be changed only by demanding reclamation.

Keywords Former Mining Area; Geographical Information System; Historical Maps; Land Use Indices; Landscape Matrix

CITATION LINKS

[1] Acid mine drainage from abandoned mine sites: Problematic and ... [2] Contamination of wild-grow ediblemushrooms by heavy metals in a former ... [3] Fractionation of heavy metals and evaluation of the environmental risk for the alkaline soils of the Thiassio plain: A residential, agricultural, and industrial area... [4] Land use history (1840-2005) and physiography as determinants of southern ... [5] Land use change prediction using a hybrid ... [6] Accumulation and environmental risk assessment of heavy metals in soil and plants of four different ecosystems in a former polymetallic ores mining and ... [7] Specialized aspects of GIS and spatial ... [8] Comparison of land use/land cover change and landscape patterns in Honghe National Nature Reserve and the surrounding ... [9] Satellite remote sensing of ecosystem functions: Opportunities, challenges ... [10] Development of a geospatial model to quantify, describe and ... [11] Geographical modelling of spatial interaction between human activity and forest connectivity in an urban landscape ... [12] Monitoring land changes in an urban area using satellite imagery, GIS and ... [13] Landscape of Nitra city and ... [14] How does landscape context contribute to effects of habitat fragmentation on diversity and population ... [15] Land Use Changes within the Slovak Biosphere ... [16] Opposite Trends in Response for Shannon and Simpson Indices ... [17] Land-Use Development of Cultural Landscape of Slovak Enclave Sari in Hungary ... [18] The mining landscape of the Ostrava-Karviná coalfield: Processes of landscape change from the 1830s to the ... [19] Anthropocene landscape changes and the legacy of nineteenth and twentieth-century mining in the .... [20] GonzÍez-Gutiérrez RB, Álvarez-Martínez J. Changes in land use due to mining in the north-western mountains of Spain during the ... [21] Land cover changes in Slovakia 1900-2006 related to the distance from industrial areas and economic development [22] Degradation of grasslands vegetation next to [23] Anthropogenic transformation of geosystems [24] Environmental Contamination by Heavy Metals ... [25] Land use changes relation to georelief and distance ...

Introduction

Mining activities represent the important progress of human civilization, but on the other hand, cause a lot of environmental problems. Open ore mining is one of the fastest growing human modifications of the earth's surface, and transformations of landscapes and ecological functioning.[1] Pollution of the environment leads to the crop toxicity and health problems.[2, 3] The biggest extension of mining activities in Slovakia started in the 19th century when the extraction of surface ores was cost-effective, and the ores contained a high proportion of heavy metals.

Middle Spis area is well known for being one of the biggest Cu and Hg ore deposits in Middle Europe. Long-term mining activities caused irreversible changes of the landscape structure. The abandoned mines, tailing ponds, and waste rock dumps which are localized within agricultural lands and located close to the residential areas still pose a serious threat to human health and health of ecosystems by releasing toxic elements into the environment.[2] Area is based the environmental regionalization considered environmentally loaded and hazardous for human health. Nowadays, the ore production is reduced to the minimum in Krompachy village, completely stopped in Rudňany village and Poráč village, seasonal baryte mining is still ongoing.

It has been found that land use and/or land cover (LULC) changes inevitably affect the structure and function of ecosystems, influenced regional climate, hydrology, vegetation, biogeochemical cycles, and biodiversity,[4] cause significant decrease in rainfall, increase the surface temperature, and have adverse effects on the adjacent areas.[5] The middle Spis area is well known as a historical mining area with enormous mercury and copper ore deposits.[6] The most extensive mining activity, followed by a significant increase of industrial areas, in the 19th century was recorded. Geographical Information System (GIS) widely contributed to the advancement of studies that evaluate the evolution of the ecological and social structure of landscape.[7] In addition, GIS represents useful and flexible environment for displaying, storing, and analyzing digital data necessary for change detection.[8] Satellite remote sensing (RS) provides multi-spectral and multi-temporal data that can be used to quantify the type, amount, and location of LULC changes.[9, 10] The combination of RS, GIS, and Global Positioning System has been found as a very effective tool for the LULC change detection.[11] A lot of authors dealt with the determination of LULC changes in the different regions. Wan *et al.*[8] used RS and GIS for the detection of land changes in National Nature Reserve and its surrounding. Landscape metrics were used for LULC change detection in an urban area in China to design landscape planning and resource management.[12] In this study, LULC structure was analyzed in former mining middle spis area, specifically in four rural villages, in four different time horizons using indices and coefficients. Because the most extensive mining (industrial) development was recorded in the 19th century, changes between 1785 and 1986 were the most serious. At the beginning of the 20th century, the situation became better, because more attention has been paid to environmental protection and declination of the mining activity in the Middle Spis region.

The aim of the study was to evaluate the changes of the landscape structure in the former mining area during past 200 years. Four times horizons (1785, 1822, 1986, and 2016) selected, based on significant historical events related to the mining activities in this region, were chosen to point out the gradual changes in landscape structure. Because industrial development, connected with building or spreading of industrial areas, the same as rapid urban development was the most significant at the beginning of the 19th century, we suppose the most significant changes between 1822 and 1986. The subsequent decline in the industrial production, at the beginning of the 20th century, could be reflected in the improvement of the landscape structure.

Materials and Methods

Middle spis area is well known for being one of the biggest Cu and Hg ore deposits in Middle Europe. Long-term mining activities caused irreversible changes to the landscape structure. The abandoned mines, tailing ponds, and waste rock dumps which are localized within agricultural lands and located close to the residential areas still pose a serious threat to human health and health of ecosystems by releasing toxic elements into the environment.[2] Area is based the environmental regionalization considered environmentally loaded and hazardous for human health. Nowadays, the ore production is reduced to a minimum in Krompachy village, completely stopped in Rudňany village and Poráč village seasonal baryte mining is still ongoing.

Four villages (Krompachy [48°54'741'' N; 20°52'420'' E], Slovinky [48°52'304'' N; 20°50'918'' E], Rudňany [48°53'727'' N; 20°40'511'' E], and Poráč [48°52'713'' N; 20°43'580'' E]) as the part of former mining Middle Spis area were selected for research purposes (Figure 1). The maps of I. Military mapping from 1785 (1:28 000), II. Military mapping from 1822 (1:28 000), maps from 1986 (1:10 000) and the digital model of the real word (reachable at WMS server) were used. Paper maps (1785, 1822, and 1986) were digitized, georeferenced and transferred to coordinate system S-JTSK. Because the actual map (2010) was already georeferenced, it was used as the basis. The georeferentiation process is based on reference points- elements which did not change their position overtimes (churches, crossroads, and river confluences).

In the QGIS environment, individual environmental elements (forest, grassland, etc.) were manually selected from digital maps and assigned to the categories. The LULC classification scheme was used according to Hreško.[13]. Eight LULC categories were classified: (1) Forest, (2) grassland, (3) arable field, (4) subsoil and substrate, (5) watercourses and water surface, (6) residential and recreation areas, (7) technical units (including mining bodies and processing plant areas), and (8) transport units. Evaluation of the land structure in the different time horizons and LULC changes between the different time horizons were performed using QGIS.

Four land indices/coefficients Shannon diversity index (SH),[14] coefficient of ecological stability (ES),[15] coefficient of anthropogenic pressure (AP),[16] and the coefficient of landscape originality (LO)[17] were calculated using EXCEL software.

The changes of the landscape structure were evaluated by the "superposition method" using landscape matrix. The landscape matrix expresses all changes of the landscape in the compact form. It is a network of the point on the map, which in the different maps (different time horizons of the same area) were transformed to another element or stay unchanged. After overlaying all time layers, we got six combinations of changes: 1785/1822; 1785/1986; 1785/2010; 1822/1986; 1822/2010; and 1986/2010. Because the changes between 1785 and 1986 were the most significant, we focused on their more detailed analysis (Table 1).

Table 1: LULC changes between 1785 and 1986 in the Middle Spis area expressed by the transformation matrix

		LULC categories in 1785								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Sum**
LULC categories in 1986	**1**	**5166**	1219	49.1	17.9	116	7.3	0	114	6691
	2	1466	**703**	82.0	12.4	43.5	13.3	0	60.4	2381
	3	155	139	**19.9**	0	9.61	4.3	0	8.9	338
	4	27	23.2	0.34	**1.25**	0.72	0.15	0	1.82	54.9
	5	62.3	58.2	7.57	0	**4.25**	1.60	0	3.3	137
	6	41.7	72.9	26.6	0	6.93	**13.7**	0	7.12	169
	7	34.2	33.7	6.37	0	4.08	0.48	**0**	3.48	82.4
	8	150	85.2	22.5	0.56	7.95	6.17	0	**8.03**	280
	Sum	7103	2335	214	32.2	193	46.9	0	207	**10134**

LULC: Land use and/or land cover

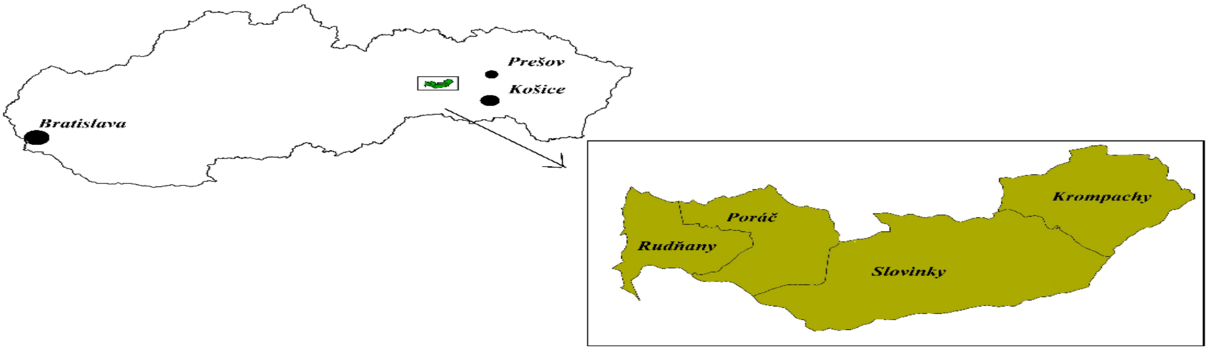

Figure 1: The position of the research area within the Slovakia

Findings

LULC structure in the different time horizons was evaluated by selected indicators and coefficients. The positive trend of SH between 1785 and 1986 indicated the increasing diversity of the mining area (Figure 2). ES index represents the ratio of stable (forest and grassland) and unstable land (residential areas and industrial areas) land cover categories. In our study, the increasing area of unstable land categories resulted in ES decreasing. During the study period, the LO index decreased about 33%, and AP increased during all research period.

LULC categories for each time horizon are listed in Table 2. All evaluated time horizons of the Middle Spis area are characterized by the large areas of forest. In 1785, the forest occupied 7103 km^2 (68.9%) of the study area. In 1986, the area of forest decreased by 6% compared to 1785. Grasslands area increased from 2335 km^2 in 1785 to 2448 km^2 in 2010. Technical units appeared for the first time on the map in 1986. More than two-time increase of residential areas was reported between 1822 and 1986. Until 2010 it decreased again.

LULC changes between 1785 and 1986 are listed in Table 1 and Figure 3. The area of 10134 km^2 stayed during this period unchanged. A significant decrease of the forest area caused by intensive mining and smelting activities were reflected in technical and residential area expansion. In 1986 residential areas covered 41.7 km^2 of the original forest area and more than 70 km^2 of the original grassland area. Grasslands have grown at the expense of 1466 km^2 of the forest area. Large area of original arable fields was changed to grasslands or occupied by residential areas. LULC cover changes between 1785 and 2010 have shown that area of 6573 km^2 stayed during research period unchanged. The forest area was reduced significantly because of grassland expansion, which, in 2010, occupied 1241 km^2 of the original forest area. Technical units were created at the original forest or grasslands area the same as residential unit areas.

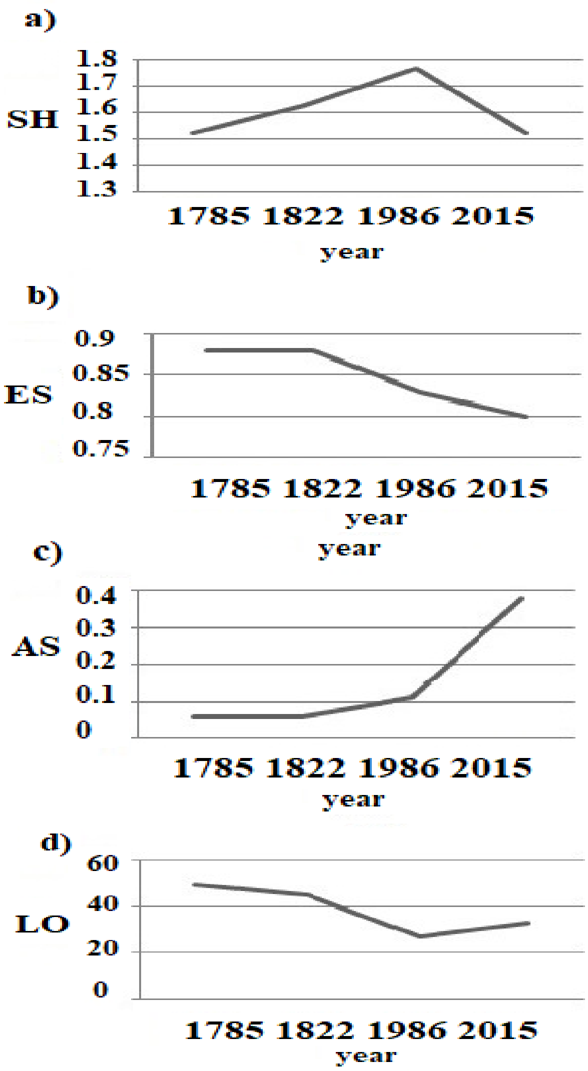

Figure 2: The values of Shannon diversity index -SH (a), coefficient of ecological stability -ES (b), coefficient of anthropogenic pressure - AP (c), and coefficient of the landscape originality (LO) in the research area

Table 2: The area and percentage of LULC categories of the mining area in different time horizons

LULC categories	Area in 1785		Area in 1822		Area in 1986		Area in 2010	
	(km²)	(%)	(km²)	(%)	(km²)	(%)	(km²)	(%)
1. Forest	7103	68.9	7078	69.9	6691	62.6	6740	62.6
2. Grasslands	2335	23.5	2431	23.4	2380	26.4	2448	25.7
3. Arable fields	214	2.68	238	2.34	338	3.55	407	5.02
4. Subsoils and substrate	20.9	0.18	17.6	0.22	54.9	0.53	24.9	0.34
5. Water courses and water surface	193	2.35	165	1.55	137	0.98	70.7	0.81
6. Residential and recreation areas	45.9	0.44	56.7	0.54	168	1.93	133	1.49
7. Technical units	0	0	0	0	82.4	0.84	85.9	1.19
8. Transport units	207	1.92	165	2.01	280	3.15	234	2.85

LULC: Land use and/or land cover

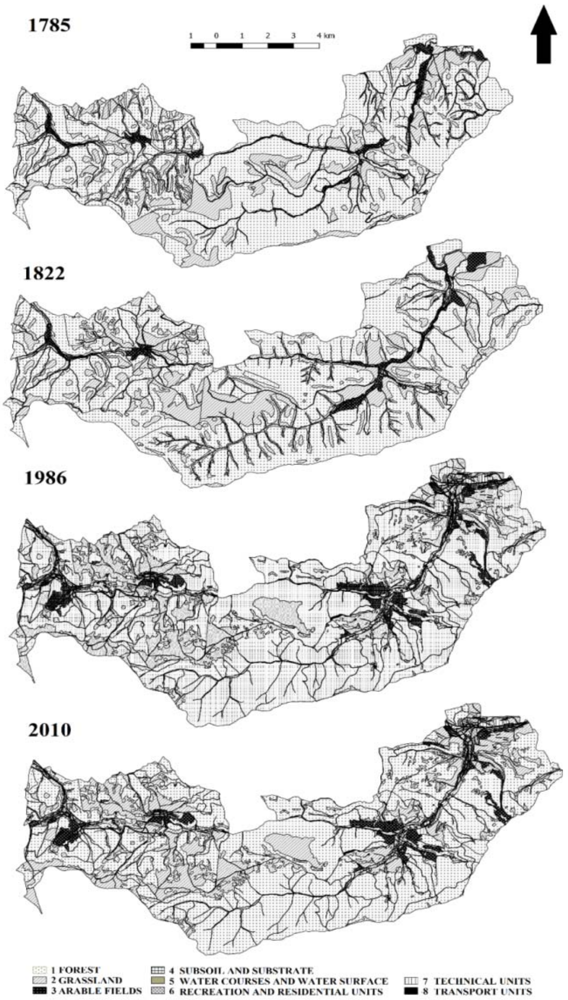

Figure 3: Land use and/or land cover structure of villages in Middle Spis area in 1785 and 1986

Discussion

Several authors have analyzed the mining activities and mining-related industries as the main factor of the landscape changes.[18-20] Consistently with our results, they confirmed, that mining activities and associated industrial activities have a huge negative and irreversible impact on the landscape structure. Indices and coefficients that have been used to evaluate the current state of the environment for each of the time horizons are in line with the mining activities development in the study area. In accordance with Liga *et al.*,[21] our results confirmed increasing tendency of the SH with increasing industrial activity. The greatest boom of mining activities and related processing activities was recorded from the mid-19th to the mid-20th century. Ironwork, in 1841, in the cadastre of Slovinky village, copper processing plant in Krompachy in 1951 and the iron ore and mercury processing plant in 1945 in Rudňany were built.[22] This research period (1785–1986) is characterized by a sharp decrease of the ES and LO, what is the result of a subsequent decrease of the positive landscape elements. On the contrary, the area of technical elements, residential areas, and transport units had an increasing tendency.

Landscape development is reflected by decreasing the area of one element at the expense of the other. Between years 1785 and 1986, the residential areas, technical units, and transport units expanded at the areas originally belonged to the forests and grasslands, in a lesser extent, they have replaced arable soils (Table 1). Consistently with our results, Liu and Yang,[12] who monitored landscape changes in connection with urban areas expansion have found, that residential and industrial areas were created predominantly at the original forest areas.

At the end of 20th century and the beginning of the 21st century, the mining activities were limited or stopped because the ore production was not as profitable as before.[12] Deficiency of the working opportunities caused the population migration to the biggest cities.[23] A slight decrease of the transport units and residential unit's area reflected this. The area of the forest and the meadows also increased slightly. It has been found that ground subsidence caused by underground mining activity led to the demolition of structures and made it impossible to use the land for agricultural purposes.[18] After the end of mining activities, it was possible to reuse the land again. In our study, an increase of the arable fields between 1986 and 2010 was determined. In addition, the lack of job opportunities in the industry has been reflected in the increased interest in agriculture.[24].

Despite the enormous environmental problems, the area of the positive elements (forest and grassland) in Middle Spis, the area did not decrease significantly. In addition, after the end of mining activities, the increase of positive landscape elements was determined. In accordance with our results, Olah *et al*.[25] and Midriak and Zauškova[24] also reported the gradual increase of forest area after reducing AP on the landscape.

Conclusion

In the former mining Middle Spis area, the most serious changes were detected between 1785 and 1986 when mining was profitable and reached the largest dimensions. It brought expansion of settlements and technical elements in the area. The values of SH index reached in 1986 the highest value and the LO was the lowest. After 1986 situation became more positive, more attention has been paid to the environmental protection, and because mining in this area was not as profitable as before, activities were stopped or limited. New situation has been positively reflected in the change of the landscape structure. The area of the forest and the grasslands increased, and the area of negative fields such as residential units decreased.

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Ethical Permissions

Not reported.

Conflicts of Interest

There are no conflicts of interest with respect to the University of Prešov.

Authors' Contributions

The first author, Dr. Demková, worked on the second part of the research, what included map selection, their georeferencing, and processing in the QGIS programme. The second author, Dr. Bobuľská worked on the second part of the research, what included mathematical operations included coefficients and indices calculation and transition matrix calculation.

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