Land Cover and Vegetation Coverage Changes in the Mining Area—A Case Study from Slovakia

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Abstract: Dealing with landscape changes in space and time is an important activity in terms of the process of future development of the selected area. In particular, it is necessary to focus on territories that are exposed to the effects of extraction activities. The main objective of the paper was the mapping of spatio-temporal changes in the landscape in connection with the extraction of minerals due to mining activities on the landscape using satellite images and data from the Corine land cover (CLC) database in the environment of geographic information systems. The selected study area is specific to the presence of four mineral deposits (three of which are under active mining). The Rohožník-Konopiská deposit was abandoned and the area was subsequently reclaimed. The study used Corine land cover (CLC) data and Landsat 5, 7, 8 satellite images for selected years in the period 1990–2021. The Normalized Difference Vegetation Index (NDVI) was calculated for vegetation cover analysis, which was further combined with the forest spatial division units (FSDU) layer. Areas in the immediate vicinity of the open-pit mine were selected for detailed analysis of vegetation changes. Using the FSDU data, an average NDVI index value was calculated using the Zonal statistics function for each plot. The results showed that over the selected period there have been changes indicating an improvement in the landscape condition by reclamation operations at two deposits, Rohožník-Konopiská (inactive) and Sološnica-Hrabník (active). The analyzed CLC data detected the change at the Rohožník-Konopiská deposit, but the active deposit Sološnica-Hrabník was not detected in these data. The loss of vegetation on the other two deposits is mainly due to pre-mining preparatory work, which causes the removal of soil and vegetation layers.

Keywords: open-pit mine; land reclamation; remote sensing; Corine land cover; NDVI

1. Introduction

In order to secure sufficient non-energy raw materials for construction and manufacturing activities in Europe, it is paramount that ongoing mining activities comply with the principles of EU policy legislation and directives [1,2]. Article 191 of the Treaty on the Functioning of the European Union [3] sets out the objective of preserving, protecting, and improving the quality of the environment, and the rational use of natural resources and also of mineral resources in the context of the principle of subsidiarity. EU environmental policy is primarily based on the principles of preventive action, remediation at the source, and the polluter-pays principle [4].

Mineral resources are an important and necessary condition for the smooth development of the state’s economy. The importance and need for the protection of mineral resources is emphasized in Article 4 of the Constitution of the Slovak Republic [5], where the state is established as the owner of mineral wealth. The role of the state is to create suitable conditions for mining companies and to enable the extraction of minerals. The
state fulfills the control function of rational and efficient use of mineral resources and sets mining restrictions in accordance with the goals of sustainable development.

Mining of minerals, mainly of a building and industrial nature, represents the largest sub-sector of non-energy raw materials extraction in the EU in terms of value and volume [6]. The extraction of raw materials, especially open-cast mining, has an impact on the landscape, soil, and topography [7]. The mining activity itself has an impact on agriculture [8,9], on human health [10,11], and may cause deforestation in the preparatory work [12]. The study by Duarte et al. [13] addressed the effects of noise pollution from mining activities on forest habitat. The effects of logging on the environment are in most cases borne by the residents. The mine and the processes involved in mineral extraction can become a popular attraction for tourism [14].

Aerial imagery and remote sensing data are used to capture ongoing changes in landscape structure [15,16]. Environmental monitoring using remote sensing is becoming an increasingly important tool in the study of various aspects of ecosystems at local, regional, and global scales [17]. In agricultural landscape monitoring, there is a growing demand for remotely sensed results that provide data collected in a short time and without physical presence [18]. Currently, GIS environments are used in combination with remote sensing data [19] to provide information for assessing and monitoring vegetation condition in harvested areas based on appropriately selected features [20]. Landsat imagery has been used in studies [21,22] to capture the extent of surface mining and its impact on the surrounding ecosystem.

Changes in vegetation are an important indicator for environmental-change studies [23,24]. The use of vegetation indices [25,26] represents procedures that allow the assessment of many factors that affect the environment at different levels.

One of the most widely used and studied vegetation indices is the Normalized Difference Vegetation Index (NDVI), which was developed in the early 1970s [27]. Even after several decades, this index has been included in the research methods of various studies [28–33], which offer the results of vegetation index analyses in different areas using the application of NDVI data over a selected period. Study [34] showed the possibility of using the NDVI index to monitor and analyze vegetation cover in areas of surface mineral extraction.

The mining life cycle [35] consists of the five stages of prospecting, exploration, development, exploitation, and reclamation, which are closely interrelated. The first stage includes the determination of the reserves of the deposit, which is the basis for economic evaluation. In the second stage, plans are drawn up to prepare for the opening-up and extraction of the deposit. Under Slovak legislation, it is subject to an environmental impact assessment (EIA) procedure. The third stage is the actual construction of the open-pit mine, roads, and other necessary facilities. The fourth stage is the actual extraction of the usable mineral.

The last stage of the mining life cycle [36] is post-mining land use, which is also related to the reclamation of the affected area. Addressing the importance of land and vegetation reclamation during mining activities [37] is of continuing interest to keep an eye on the future development of the landscape also from the perspective of ecological research [38–41].

The need to integrate the process of mine closure into all phases of the life cycle was highlighted in [42]. In the process of preparation for mining, the topsoil is removed with vegetation stored in a landfill. The re-use of the land is in the interest not only of the mining company, but above all of the landowners and the surrounding communities and municipalities [43].

The extractive industry alters and influences the character of the environment. For this reason, it is necessary to know the state of the landscape as well as the state of the vegetation in order to monitor and analyze possible impacts. The main objective of the paper was to assess the landscape change using remote sensing data. In the case study, the assessment concerned an area where mineral extraction has taken place and is currently taking place. The landscape changes were assessed by analyzing Corine land cover data.
and Landsat satellite images. Such analyses can provide a scientific basis for future land reclamation management and policy decisions of a given landscape.

2. Materials and Methods

The study area was selected in the Malacky district in the cadastral area of Rohožník and Sološnica in the western part of Slovakia (Figure 1). In the selected area there are four mineral deposits with a designated quarrying area. Three of them are currently being mined by surface mining.

![Study location](image)

In the designated mining area Rohožník III (Rohožník-Vajarská deposit), high-percentage limestone is mined (1948.1 kt for 2020) in the mining area Solosnica (Solosnica deposit), building stone—melaphry (655 kt for 2020), and Solosnica I (Solosnica-Hrabník deposit), calcareous slag (395.2 kt for 2020). In the Rohožník IV mining area, lime-slate mining was in progress and ceased in 1999.

The territory belongs to a warm climatic region, the T6 district, which is warm, slightly humid, and with mild winters [44]. The average annual air temperature is 9.2 °C and the average annual rainfall is approximately 600 mm.

The forest land consists mainly of deciduous forest stands, with a smaller representation of coniferous and deciduous forest stands, mainly pine forests. In the perimeter of both cadastral territories there are protected areas, White Mountains (SKUEV0267), Peterklin (SKUEV0907), and Rudava (SKUEV0163), which are classified as Special Areas of Conservation according to Natura 2000.

2.1. Input Data

In this study, data from multiple sources in different format types and coordinate systems were used. The data were processed and analyzed in ArcGIS Pro 2.8.

The digital orthophotographs (*.tiff) were provided by Geodesy, Cartography, and Cadastre Authority of Slovak Republic (GCCA SR). The orthophotomosaic imagery was collected in two cycles, namely, in 2017 (August 2017) and 2020 (August 2020). The images have a resolution of 25 cm/pixel (2017) and 20 cm/pixel (2020).

Landsat images were acquired for the years 1990, 2000, 2006, 2013, 2018, and 2021 using LandsatLook 2.0 [45] in GeoTiff format. The selected month was June. The spring months of March–May are characterized by higher rainfall with average temperatures and represent a period of vegetative growth. The months of July and August are considered to be the warmest months and vegetation changes may occur due to the increased temperature. Landsat images were downloaded from the Collection 2 Level 2. Due to the range of years, data from three programs, namely, Landsat 5, Landsat 7, and Landsat 8, were processed. A closer specification of the images is given in Table 1.
Table 1. Landsat data specification.

<table>
<thead>
<tr>
<th>Mission and Sensor</th>
<th>Date Acquired</th>
<th>Cloud Cover (%)</th>
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<tbody>
<tr>
<td>Landsat 8 OLI TIRS</td>
<td>17 June 2021</td>
<td>8.51</td>
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<tr>
<td>Landsat 8 OLI TIRS</td>
<td>16 June 2018</td>
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</tr>
<tr>
<td>Landsat 8 OLI TIRS</td>
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<tr>
<td>Landsat 5 TM</td>
<td>15 June 2006</td>
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<tr>
<td>Landsat 7 ETM+</td>
<td>22 June 2000</td>
<td>4.0</td>
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<tr>
<td>Landsat 5 TM</td>
<td>19 June 1990</td>
<td>16.0</td>
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</table>

The images were selected with minimal cloud cover. The spatial resolution of the images was 30 m. The exception to the cloud cover was 2018, where imagery was available with higher cloud cover, but located in a different area. The time interval of the imagery was chosen to correspond with the Corine Land Cover program data. No suitable imagery was available for the selected area in 2012, so 2013 data was used.

2.2. Methodology

In order to determine the changes that have taken place in the landscape, it was necessary to draw maps of the landscape over the chosen period. The progress of the work is presented through a flowchart (Figure 2).

Copernicus CORINE Land Cover vector data for 1990, 2000, 2006, 2012, and 2018 were used for the analysis of land cover change in both cadastral units. The latest available versions made available on the Copernicus Land Monitoring Service website [46] were used in the data analysis. According to [47], the thematic accuracy is higher than the specified minimum of 85%. The files were transformed to the Unified Trigonometrical Cadastral Network (EPSG:5513) coordinate system and using the Clip function of ArcGIS Pro 2.8, and they were clipped to cadastral units. Areas were calculated for each element and class, which were then compared.

Landsat data are available within Collection 2 in two levels of processing, Level-1 and Level-2. Level-1 data are in the form of Digital Numbers ready for preprocessing in connection with the conversion to Top of Atmosphere (TOA) reflectance or radiance [48]. Level 2 processing provides data corrected for atmospheric effects [49]. The Landsat satellite imagery used in this study was downloaded from Collection 2 Level-2 already with surface reflectance values and no further atmospheric correction is required. The Level-2 images are directly usable for the NDVI calculation [50].
Another problem in image preprocessing is cloud cover. The selection concentrated on images with minimal cloud cover. In the case of one image, a cloud cover of 34.95% was accepted as it was the lowest in the period. Landsat Collection 2 Level 2 data provides a Quality Assurance (QA) band that contains cloud and shadow information. The images were processed using tools in the ArcGIS Pro 2.8 environment.

NDVI is calculated as the difference between the near-infrared (NIR) and red (Red) reflectance divided by their sum (1):

\[
\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}},
\]

where NDVI is normalized difference vegetation index.

For the calculation of NDVI within the Landsat data, the respective bands 4 and 5 for Landsat 8 and bands 3 and 4 for Landsat 7 and 5 were applied [51].

The resulting analyses in the form of rasters were divided into basic intervals – 1 to 0.1—no vegetation, 0.1–0.2 open soil, 0.2–0.4 Sparse vegetation, 0.4–0.6 Moderate vegetation, 0.6–1 Dense vegetation. On the basis of these intervals, the whole territory of both cadastral units of Rohožník and Sološnica was evaluated.

Another input to the analysis process was data from the register of forest spatial distribution units [52]. The forest spatial distribution unit is the basic unit that is also used for forest condition surveys [53]. These spatial data contain attributes about forest units and their basic characteristics. The original file contained 940 polygons. From the file, 158 polygons were removed, representing forest roads and dumps, power lines, and buildings on forest land.

For the purpose of the analysis, areas in the immediate vicinity of ongoing mineral extraction were selected. The zonal statistics function was then applied to calculate the basic statistical parameters for each area. The input data consisted of NDVI maps and the zone was represented by vector data of forest spatial distribution units.

### 3. Results and Discussion

The proposed methodology was used to capture changes in the landscape and to analyze vegetation cover around surface quarries. For mapping landscape disturbance by mining, Lechner et al. [54] proposed and developed a more detailed classification scheme integratable with the Corine scheme.

By analyzing the CORINE Land Cover data of the Copernicus programme for the selected period, changes in the spatial distribution of individual land cover classes were detected. These changes are detailed in Table 2. In order to assess the changes across the selected site, the two cadastral areas were merged into a single area with a total area of 6520.10 ha.

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<tr>
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<td>3.33</td>
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<tr>
<td>324</td>
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<td>0.66</td>
<td>43.19</td>
<td>0.66</td>
<td>0.48</td>
<td>0.01</td>
<td>1.45</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Table 2. Representation of CLC classes for the study period 1990–2018.
When comparing 1990 and 2018 (Figure 3), there was an increase in the area of non-contiguous development (112). Significant changes were particularly visible in the village of Rohožník, where new single-family houses have been built in accordance with the changes in the municipality’s zoning plan. An area of meadow and pasture (231) was also identified in 2018, which has not been captured in other years. A significant increase of 86.16 hectares was identified for an area defined as predominantly agricultural landscape with a significant presence of natural vegetation (243). A surprising finding was the shrinking of the area coded 312 coniferous forests, where there has been a 47% reduction in area, and a similar pattern for the area of transitional woodland (324).

**Figure 3.** Displaying Corine land cover data for selected years: (a) 1990; (b) 2018.

In 1990 (Figure 3a), two sites were identified where mineral extraction took place, namely the Rohožník-Vajarská and Rohožník-Konopiská deposits. Data from 2018 (Figure 3b) showed mineral extraction only at two deposits, Rohožník-Vajarská and Sološnica. Mining at the third deposit, Sološnica-Hrabník, was not captured in the Corine land cover data. The dimensions of the defined mining area of this deposit are approximately 490 × 1300 m. According to the current orthophotos, the extraction area is approximately 675 × 250 m. The deposit was opened in 1986. The mining process allows the mined area to be technically and biologically reclaimed at the same time [55].

Mining at the Rohožník-Konopiská deposit was terminated in 1998 and the site was subsequently reclaimed. This can be seen in Figure 3b where the original use of site 131 is already identified as 311. The reclaimed area of Rohožník-Konopiská has thus become a site that has contributed to the improvement of the environment as well as the quality of life of the inhabitants of the nearby village. The village’s intramural area has been extended by a built-up area of mainly family houses in the vicinity of the former mining pit, which is currently characterized as a private nature conservation area. The change in the landscape can also be seen in Figure 4, where the resulting area complemented the existing recreational use opportunities in connection with the cottage area and the Vývrat water reservoir in the neighboring cadastral area of Kuchyňa.

Methods of soil restoration after mining activities in the form of ecological reclamation are described in studies [56,57]. Liu et al. [58] compared land restoration after mining activities in two sites artificial and natural restoration, where the artificial restoration site performed better.

The Rohožník-Konopiská site was reclaimed in 2000–2002. In the first step, the area was cleared of mining waste and the slopes began to be strengthened. In 2003, facilities were built to ensure a stable water level. This also included the construction of artificial islands. The area is now a nature reserve with a wetland habitat with a high level of species diversity.
The study [67] showed a decrease in NDVI values in summer and early autumn, especially in the area of this area. The area is approximately 0.09 hectares, which in percentage terms is 0.0014% of the total area.

Unit Register [52] were used as zonal areas. In 2018, an area with a value in the interval 0.6–1, dense vegetation was identified. From 1990 to 2000, and over the other years its values were relatively stable with an increase than in the other years. The interval 0.4–0.6, medium dense vegetation, showed an increase in soil quality indices and establishment of a layer of annual and perennial herbaceous plants in eight years.

To capture the possible impact of anthropogenic activities on the landscape, spatial variations in Landsat satellite imagery data were analyzed over the selected area. The images were input for the calculation of the vegetation index NDVI. Similarly, study [62] used the NDVI index to assess the landscape condition in a coal mining area. In the study by Labant et al. [63], they dealt with the open-pit mine as a heat island in addition to the NDVI index.

The resulting index values were in the range (−1, 1). Negative values are likely to indicate water and a value close to 1 indicates dense foliage. The NDVI is a way of monitoring the health of vegetation. Figure 5 shows the result of the index calculation for the selected period 1990 to 2021.

In Figure 5a–f, the Rohožník-Vajarská deposit and the Solosnica deposit are clearly visible. The Solosnica-Hrabník deposit is more difficult to identify, which may be due to the chosen mining method in relation to the reclamation of the mined out area.

The NDVI index is a simple indicator used to assess the health status of vegetation [64]. It is used to examine changes in vegetation cover over different time periods [65]. Knowing the health status of vegetation around an open pit mine can be a key element in its reclamation [66].

Table 3 provides an expression of the change in the value of the NDVI index for each interval within the selected years. More pronounced changes were seen in the interval 0.2–0.4, where the area identified for 1990 was approximately double that of the other years examined. Similarly, the values in the interval 0.1–0.2 for 2000 were considerably higher than in the other years. The interval 0.4–0.6, medium dense vegetation, showed an increase from 1990 to 2000, and over the other years its values were relatively stable with an increase in 2021. In 2018, an area with a value in the interval 0.6–1, dense vegetation was identified. The area of this area is approximately 0.09 hectares, which in percentage terms is 0.0014% of the total area.

There is no dense forest cover in the selected site, but rather sparse, woody vegetation. The study [67] showed a decrease in NDVI values in summer and early autumn, especially for coniferous forests. As mentioned above, pine forests occur in the study area.

To examine vegetation change in more detail, data from the Forest Spatial Distribution Unit Register [52] were used as zonal areas.
In the vicinity of the Sološnica-Hrabaník deposit, three areas were selected, designated 369, 689, and 704 (Figure 6a). All three areas are located in the immediate vicinity of ongoing mining. For each of the plots, the average NDVI value was calculated for each year under study. As can be seen in Figure 6b, areas labeled 369 and 704 showed an increase in the NDVI index value, which was also visible in the orthophotos from 2018 (Figure 6a). Plot 689, on the other hand, showed a decrease in the NDVI index value. The variation in the pattern of index values over the selected period is due to the choice of mining method at this site. After the extraction of the raw material, the area in question started to be reclaimed. Landscape restoration after the end of mining at a given site can be linked to the ongoing mining activity [68].
In the case of the Rohožník-Vajarská and Sološnica deposits, the reclamation of the extraction area depends on the completion of the extraction of the deposit. In the first case, two areas were selected, designated 722 and 343, and in the second case, areas 667 and 307 (Figure 7a). All areas showed variability in the value of the NDVI index. In the case of plot 722, the decrease in value in 2013 is interesting (Figure 7b). According to the orthophotos taken in 2012 [69], the removal of vegetation cover was observed. Area 343 showed an improvement in vegetation cover. For area 307, there was a significant decrease in 2018 (Figure 7b). In 2006, there was a decrease in the NDVI index value in the northern part of the open-pit mine—area 667. According to the evaluation of the orthophotos, the Solosnica deposit may have extended the mining area to this area as well.

Other areas in the vicinity of ongoing mining have shown relatively stable values. One of the main factors influencing the changes in vegetation cover can be considered to be the initial phase of opening and preparation of the extraction. In this phase, the vegetation cover is removed and the scrub forest land is cleared. The removed soil is deposited and subsequently used for reclamation after the end of harvesting.

Given the widespread use of the NDVI index, the study by Huang et al. [50] focused on the risks associated with end-users and the need to educate them in this area. The need for mapping the area where surface mineral extraction has taken place due to potential impacts on the hydrology of the catchment was also highlighted in the study by Townsend et al. [39].

Slovakia has long ensured a high level of environmental protection by integrating environmental aspects into the preparation and approval of strategic documents with a view to promoting sustainable development. Evidence of this is the government-approved document “Environmental Strategy 2030” [70], in which the minimization of the environmental impacts of mining activities is also a subject of concern, with a warning about the insufficient monitoring of hazardous areas, which have historically been neglected and unreclaimed for a long period of time.

With the adoption of the European Commission’s plan in the form of the European Green Deal, EU countries will be tasked by 2030 to make resource management and use more efficient, focusing on biodiversity restoration [71] in an effort to improve environmental quality. Citizens and their health and quality of life for future generations are the main focus.

Evaluating spatial data in the context of mining operations that may affect the environment near populated areas is a topical issue. The priority of mining companies should be to safeguard and improve the quality of life of the inhabitants.

Slovakia as an EU Member State is also obliged to harmonize Slovak law with EU directives, which it transposes into generally binding legislation (Figure 8). The general binding legislation on environmental impact assessment influences the regulation of mining activities in accordance with the principles of EIA and SEA in the amendments to the provisions of mining laws.
Calculated zonal statistics. (a) Selected feature zone data; (b) Zonal statistics—mean Vajarská-Rohožník; (c) Zonal statistics—mean Sološnica.

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Extraction of mineral resources, especially opencast mining, is characterized by soil disturbance and in the associated disturbance of vegetation. This study focused on the analysis of Corine land cover data and Landsat multispectral imagery. The results showed the potential of using remote-sensing data for capturing changes and assessing the condition of landscapes affected by mining activities. Mining activities can adversely affect the surrounding area and lead to the disturbance or loss of valuable habitats. There are many examples of the open-pit mine that have already benefited biodiversity throughout their life cycle. These are also the cases addressed in this study. The Rohožník-Konopiská site was reclaimed after the end of mining and today it is a sought-after nature reserve. At the...
4. Conclusions

Extraction of mineral resources, especially open-cast mining, is characterized by soil disturbance and in the associated disturbance of vegetation. This study focused on the analysis of Corine land cover data and Landsat multispectral imagery. The results showed the potential of using remote-sensing data for capturing changes and assessing the condition of landscapes affected by mining activities. Mining activities can adversely affect the surrounding area and lead to the disturbance or loss of valuable habitats. There are many examples of the open-pit mine that have already benefited biodiversity throughout their life cycle. These are also the cases addressed in this study. The Rohožník-Konopiská site was reclaimed after the end of mining and today it is a sought-after nature reserve. At the Sološnica-Hrabník deposit, a mining process with continuous reclamation was chosen. The appropriateness of the choice of the work procedure was also demonstrated by the results of the NDVI analysis for the individual separate areas located in the vicinity of the open-pit mine.

In the case of the assessment of impacts on vegetation through vegetation indices, the need to divide the area into smaller areas (in our case FSDUs), which within the unit are characterized by similar structure and forest composition, becomes apparent. Monitoring vegetation changes in these areas can provide more detailed information on the potential impacts of mining activities.

Conclusions from the analyses confirm the minimizing impact of mining on the surrounding area in the villages of Rohožník and Sološnica. At the same time, the effectiveness of the implemented reclamation measures was confirmed in the form of extension of the recreation zone for local inhabitants and increase of the attractiveness of the micro-region for tourism. As the results showed, if environmental factors are taken into account during extraction, negative impacts on the surrounding environment can be minimized.

Further research is open in terms of extending the methodological procedures to monitor in more detail the manifestations of mining activity even after mining has ceased. High-quality and accurate data from analyses of landscape changes from different periods contribute to explaining certain key aspects in the context of the permitting process for non-energy mining activities. The results of the analyses based on the chosen methodology could be implemented in the monitoring of applied measures subject to the EU inspection procedure.


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References


29. Galle, N.J.; Brinton, W.; Vos, R.; Basu, B.; Duarte, C.; Collier, M.; Ratti, C.; Pilla, F. Correlation of WorldView-3 spectral vegetation indices and soil health indicators of individual urban trees with exceptions to topsoil disturbance. *City Environ. Interact.* 2021, 11, 100686. [CrossRef]


56. Řehounková, K.; Řehounek, J.; Prach, K. *Near-Natural Restoration vs. Technical Reclamation of Mining Sites in the Czech Republic*; Faculty of Science USB: České Budějovice, Czech Republic, 2011; p. 211.

58. Liu, Y.; Lei, S.; Gong, C. Comparison of plant and microbial communities between an artificial restoration and a natural restoration topsoil in coal mining subsidence area. *Environ. Earth Sci.* 2019, 78, 204. [CrossRef]


