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Sensing Coal legacies: A comparative analysis of the Jiu Valley and Boone-Raleigh County mining regions using satellite images

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In Appalachia and South Carpathia, a long tradition of coal exploitation has left deep traces in the environment and the socio-economic profile of (former) mining towns. The present study set out from the question of how coal legacies are reflected in satellite images of the Jiu Valley, and the Boone and Raleigh counties in West Virginia. To this end, we used remote sensing techniques to analyze the urban and environmental developments in these regions on the basis of two snapshots taken in 1986 and 2019. Our results suggest that, even if the coal mining techniques used, the national political regimes, and the topography of the land differ to a great extent, in the studied regions there exist similar patterns of socio-economic decline and environmental transformation, which are discussed in the paper.

Key-words: *coal mining, remote sensing, mountaintop removal, land cover classification.*

1. Introduction

In Appalachia and South Carpathia, a long tradition of coal exploitation has left its mark in the environmental and socio-economic profile of (former) mining towns. Whereas over the past 40 years, the US and Romania experienced very different political developments, mining communities in both countries seem to be confronted with similar challenges; notably, underdevelopment, environmental destruction, and oblivion. Motivated by a growing interest in comparative studies of the Appalachian and East Carpathian regions (Davis 2016; Davis et al. 2016; Kideckel 2018), this paper takes a look from the sky at Appalachia and South

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Carpathia and asks: *How are the legacies of coal mining reflected in satellite images of the two regions?*

Using remote sensing techniques, we analyzed the urban and environmental developments in the Boone-Raleigh counties in West Virginia and the Jiu Valley in Romania. Whereas the study area in the Appalachians exhibits patterns of intensive surface mining, the Jiu Valley is shows marks of post-communist deindustrialization, such as decommissioning of mining facilities, demographic decline, and renaturation. For the analysis we chose two satellite snapshots from May 1986 and May/July 2019 of the two regions. This choice was motivated by the fact that, in 1989, the long-standing Romanian communist regime was removed from power, which led to a massive deindustrialization of the country. The choice of the months of May and July was determined by the cloud coverage situation.

Between 1986 and 2019 the Jiu Valley transitioned from Communism to Post-Communism. For the region, this entailed the gradual closing of the mines, starting with 1996 until today. Besides the socio-economic impact and political implications of the closure of these mines, the legacies of the mining industry, in the form of surface constructions and installations, had to be repurposed or removed, as required by European Law. Owing to the mono-industrial character of the region, the latter solution prevailed, leaving the landscape in the proximity of the urban settlements visibly transformed when looked at both from the ground and from the sky.

Between 1986 and 2019, the Boone-Raleigh counties experienced a gradual increase in mountain top removal operations, which is clearly visible in satellite images. But, as opposed to the Jiu Valley, where most of the transformations are also visible from the ground, in the Boone-Raleigh counties, the passerby is left with a rather compelling impression of nature's beauty, as long as one stays on the state highways and does not venture deeper into the forest.[3]

The different *envirotechnical* (Prichard 2012) transformations of the two regions are backed by similar socioeconomic transformations, which resulted in the demographic decline of both regions. These developments speak of what might be referred to as a specific kind of "mono-industrial determinism," as the two region exhibit similar patterns of socioeconomic decline, albeit from different reasons and with different envirotechnical consequences. The analysis of multispectral satellite images using an interdisciplinary approach might thus contribute to a better understanding of the relation between the visible effects of different coal mining techniques and the critical moments in the history of the two regions.

[3] This is based on what Dr. David A. Kideckel told us during one of the conference breaks.

2. Sensing coal legacies: A comparative, interdisciplinary approach

We regard coal mining as being an *envirotechnical* system, composed of an entire complex of institutions, communities, and (auxiliary) technologies embedded in a natural environment. Drawing on Thomas Hughes' notion of "open" technological systems (Hughes 1987), Prichard notes that "the concept of envirotechnical system encapsulates and specifically foregrounds [the] dynamic imbrication of natural and technological systems" (Pritchard 2012, 223). Being part of the even larger technical system of energy production, the strategic importance of coal mining is contingent on the other elements of that larger system as well as on the environmental politics of the day. Determinant factors include, for example, national and global coal prices as well as political stances towards climate change and other environmental issues. While the problem of mountain top removal is relatively well-studied in the United States, embedding coal mining into a larger socio-techno-environmental context arguably justifies the use of more sophisticated technologies of elicitation. In this sense, comparing the two mining regions in West Virginia and Romania on the basis of multispectral satellite images at different moments in history can provide researchers with means for embedding field observations into a larger picture obtained through remote sensing techniques. While more detailed and in-depth impressions might be obtained through archival research or lengthy periods of immersion into the field, satellite images arguably provide a fresh perspective on relatively well-studied problems. The two perspectives should therefore be understood as being complementary, with benefits for both social scientists and remote sensing specialists interested in various aspects of the regions of interests.

While being generally reserved for military and agricultural purposes before the popularization of the Internet (Edwards, 2010), today multispectral images captured by various civil satellites (e.g., from the LANDSAT and SENTINEL missions) are available for free in different online databases. In this context, our purpose in this paper was twofold. First, we followed our own curiosity as to how the two mining regions looked like "from the sky" at different moment in their recent history in order to better understand the ongoing debates in the Appalachian-Carpathian studies community. Second, we sought to inspire other scholars to employ remote sensing methods for monitoring and understanding the visible envirotechnical legacies of mining operations. Given the experimental character of the approach and the limited resources we were able to invest in this project, in this study we only used two snapshots, lying 37 years apart. A more systematic approach might reveal other significant patterns over shorter periods of time. In the following we provide some technical details about the way in which the analysis was conducted before turning to a discussion of the results of this analysis.

3. Study area

3.1. Jiu Valley, Hunedoara, Romania

Jiu Valley is a depression area corresponding to the upper Jiu river basin, situated in South Carpathia, as shown in Figure 1. It is also called Petrosani Depression, after the city with the highest number of inhabitants in the area. The depression is located between the slopes of the Retezat Mountains (V-NW), Şureanu (N-NE), Parâng (E-SE) and Vâlcan (S-SW), having an average altitude of about 620 meters and peaks of over 2,500 meters above sea-level. The climate of the depression is submontane, cool with an average annual temperature of 6°C, abundant rainfall and frequent temperature inversions (Burlacu et al. 2019).

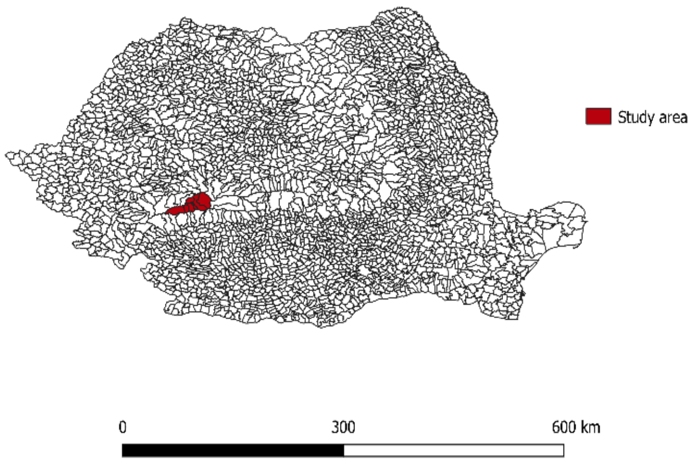

Figure 1: Study Area – Jiu Valley, location within Romania.

The economy of the Jiu Valley is dominated by mining and pastoral activities. The economic development of the area is linked to the underground exploitation of coal, which started in the mid 19th century. Mining reached its peak in Romania in 1989 (with ca. 278 mines) and continued to be an important industry component beyond 1990. The decline of coalmining started after 1996, as a result of restructuring measures at the national level. By 2000, almost half of the jobs related to coalmining disappeared (Burlacu et al. 2019).

Until the beginning of the 19th century, when mining operations began, the number of inhabitants living in the Jiu Valley area was very small, with agriculture being the main occupation in the area. Over the course of almost two centuries, the mining centers attracted a high number of new inhabitants. According to the

Hunedoara County Statistics Department, the maximum population registered was recorded by the 1997 census, counting 169 911 inhabitants. As a result of the local and national socio-economic developments, by 2015, the population decreased to 139 718 (Burlacu et al. 2019).

3.2. Boone and Raleigh Counties, West Virginia, USA

The Boone and Raleigh counties are situated in the southern part of West Virginia, in the Appalachians, as shown in Figure 2. Below the densely forested slopes of the Appalachian Mountains in southern West Virginia is a layer cake of thin coal seams. To uncover this coal profitably, mining companies are building large surface mines (World of Change, 2019). One of the surface mining techniques used throughout West Virginia is mountain top removal, which is also characteristic of the Boone and Raleigh counties. This technique has negative consequences for the environment and the humans residing in the proximity of mines. Before mining operations may start, all topsoil and vegetation must be removed. Then, explosives are used to blow up the mountain tops. Coal and debris are then removed using enormous earth-moving machines. Environmental reclamation efforts are required by federal laws, but coal companies often receive waivers from state agencies, following the rationale that economic development will occur on the newly flattened land (End Mountaintop Removal, 2019).

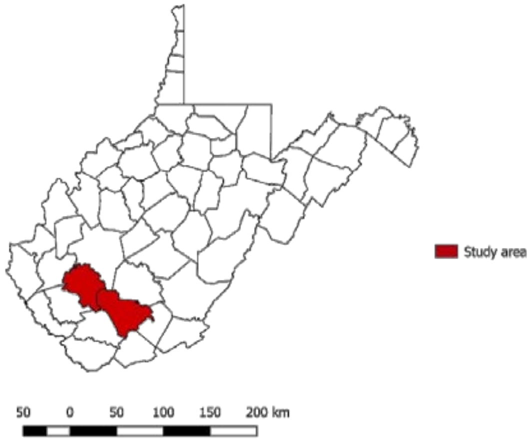

Figure 2: Study area – Boone and Raleigh Counties – location within West Virginia. Boone County – upper left, Raleigh County – lower right.

According to a study conducted by researchers from the Duke University (Ross et al. 2016), forty years of mountaintop removal have made parts of Central Appalachia 40 percent flatter than they were before excavation.

In 1970, a number of 2,714 residents from Boone County made their living through coal mining. The county saw a steady rise in those numbers throughout the 1970s and into the early 1980s before seeing a gradual decrease that would continue throughout the 1980s. In 2003, total employment for the county was 7,682 jobs, and coal represented 42.3 percent of the total employment. Boone County ranked number one in direct coal employment for West Virginia (Bowen et al. 2018). Then, between 2008 and 2016 Boone County experienced an 80% decline in coal mine output and employment. This decline had severe socio-economic consequences, considering that coal employment accounted for more than half of total employment in the county in 2008 (Bowen et al. 2018). This development can be correlated with a global trend in exploring alternative, less polluting energy sources.

4. Materials and methods

4.1. Random forest

In the course of this research we conducted a land cover classification, aimed at identifying 5 main classes (or types) of land coverage: forest, bare soil, settlement or artificial surfaces, grassland, and water. To this end, we used an ensemble machine learning algorithm called Random Forest, which is based on decision trees. The input data is classified by each decision tree, after which a majority vote between trees decides the class (Rodríguez-Galiano et al. 2011). The reference data used in training the random forest model has been created manually by drawing polygons for each class using a geo-information-systems application called QGIS. This has been achieved using red-green-blue (RGB) composites of the satellite images in the background. For each study area and data, a separate reference data set has been created in order to account for the variability of vegetation and land surface. Therefore, each random forest model uses its own reference data set. Satellite images from the Landsat and Sentinel Missions have been used as input data to the trained models. The pixel values corresponding to each of the polygons used as reference data represented the features used by the random forest models to differentiate between classes. For each study area and date, a separate random forest model has been created.

4.2. Satellite data

Landsat is a mission of the USNLIP (US National Land Imaging Program), which provides continuous monitoring since 1972. Landsat provides optical images with a spatial resolution of 30 m and a temporal resolution of 16 days. Landsat-5 was launched in 1984 and has been the most prolific optical satellite, delivering high quality global data of Earth's surfaces for 28 years and 10 months, until it was decommissioned in 2013. The Thematic Mapper sensor onboard Landsat-5 captured images in 7 spectral bands: 3 in the visible spectrum of the light, 2 in near-infrared, 1 thermal and 1 in mid-infrared (Landsat-5, 2019). In the present study, the satellite images have been chosen based on the conditions that they have been captured in spring or summer (to be able to observe the vegetation) and that they are cloud-free. In accordance with these conditions, for both study areas, images from May 1986 have been chosen. In the random forest algorithm, all 7 spectral bands have been used. Additionally, a vegetation index has been calculated and used in the analysis, namely the normalized difference vegetation index (NDVI), which provided the 8th feature in the random forest models for 1986. Figures 3 and 4 show red-green-blue (RGB) composites for Jiu Valley and Boone and Raleigh counties respectively.

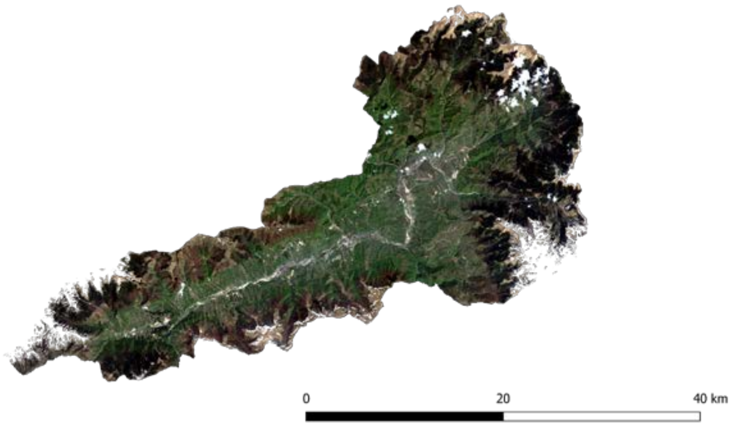

Figure 3: Landsat-5 RGB composite of the Jiu Valley. The image has been captured in May 1986.

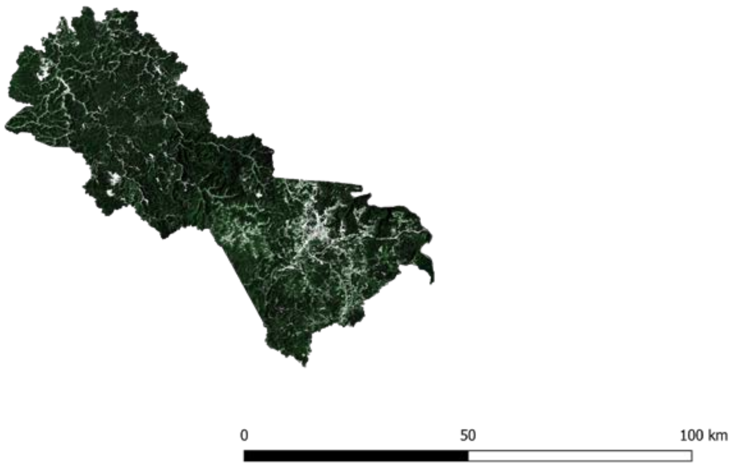

Figure 4: Landsat-5 RGB composite of the Boone and Raleigh counties. The image has been captured in May 1986.

Sentinel is an Earth observation mission from the EU Copernicus Program of the ESA. The Copernicus Sentinel-2 mission comprises a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit. The satellites have been launched in June 2015 and March 2017 respectively. The aim of the mission is to monitor variability in land surface conditions. Sentinel-2 provides optical images, which have a spatial resolution of 10 m and a temporal resolution of 5 days. The Multi-Spectral Instrument (MSI) sensor provides 13 spectral bands which range from the visible spectrum to shortwave infrared (Sentinel-2, 2019). In the course of this research, 10 spectral bands and the NDVI have been used as features in the random forest models for 2019. Images from May 2019 and June 2019 have been used for Jiu Valley and Boone and Raleigh counties. The images have been chosen based on the same conditions used for Landsat-5. Figures 5 and 6 show RGB composites for Jiu Valley and Boone and Raleigh counties respectively.

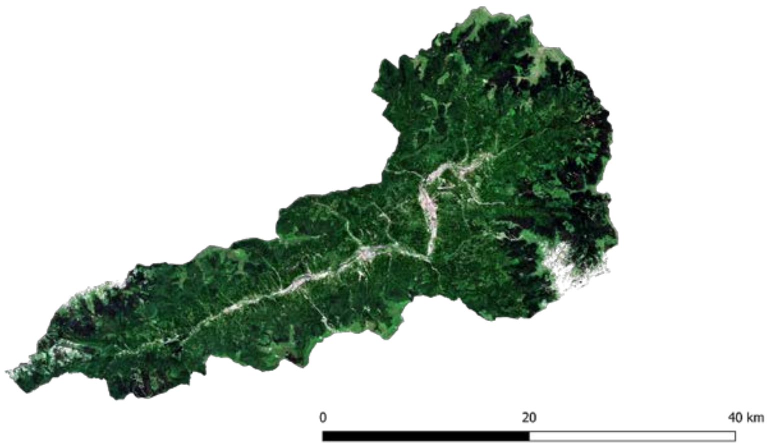

Figure 5: Sentinel-2 RGB composite of the Jiu Valley. The image has been captured in May 2019.

Figure 6: Sentinel-2 RGB composite of Boone and Raleigh counties. The image has been captured in July 2019.

5. Results

5.1. Land cover classification - Jiu Valley

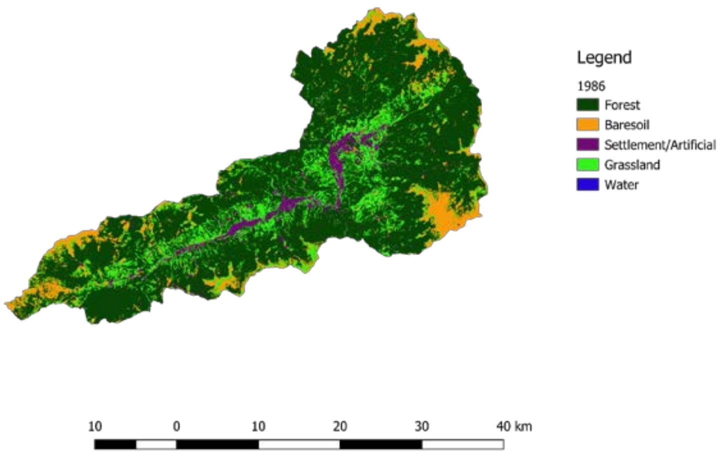

Figure 7: Land cover classification of the Jiu Valley for May 1986.

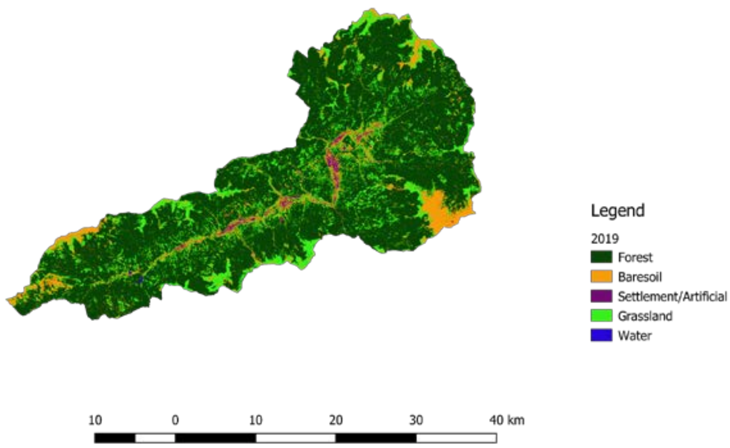

Figure 8: Land cover classification of the Jiu Valley for May 2019.

Figures 7 and 8 show the results of the random forest land cover classification in the Jiu Valley for 1986 and 2019 respectively. Figure 9 compares the percentages obtained for each class.

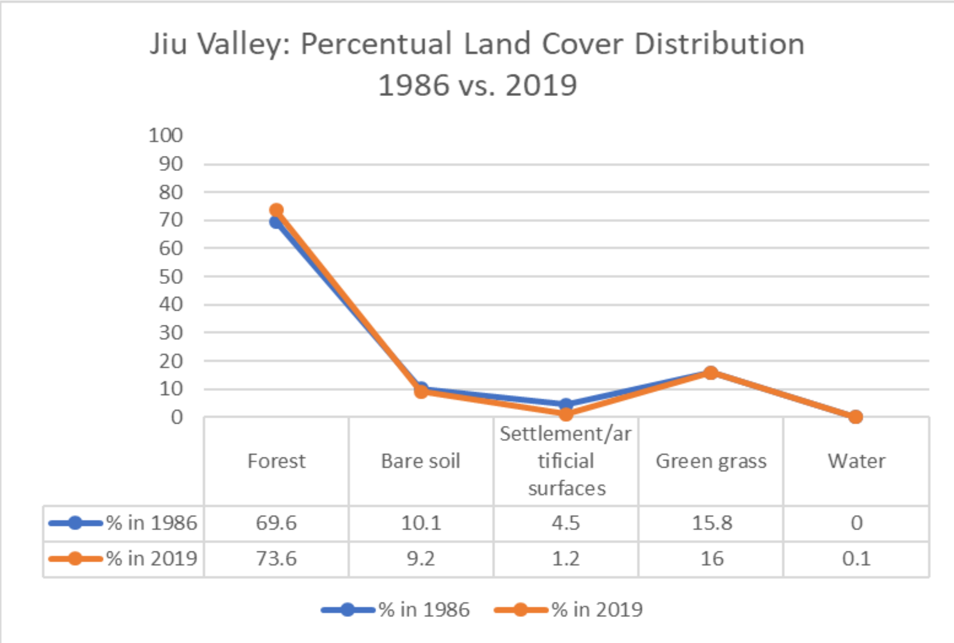

Figure 9: Percentual land cover distribution for 1986 (blue line) and 2019 (orange line) in the Jiu Valley.

As these diagrams show, one of the most evident changes in land cover is the increase of forest by 2019 from 69.3% to 73.6%. This change could be explained by the decrease of coaling activities. Coaling reached its peak in the area in 1989 and remained relatively steady until 1996 when measures of restructuring the industry were taking by the first government of post-communist Romania committed to economic reforms. As a result, by 2000 half of the coal mining-related jobs were lost. Since, large quantities of wood were necessary for mining processes and structures, a decrease in coaling also brought a decrease in forestry activities (Burlacu et al. 2019).

More grassland can be observed around settlements in 1986. Grassland in this case represents pastures and meadows, which are used in agricultural activities. The decrease of these pastures by 2019 could be related to the decrease in the number of inhabitants (partly) determined by the closing of the mines.

A decrease in settlement by 2019 can be observed, from 4.5% to 1.2%. This phenomenon could be linked with the decrease of the number of inhabitants and thus of the population density. Also, by 2019 a lot of coal mining facilities were demolished (Radoi 2016).

5.2. Land cover classification Boone and Raleigh Counties

Figures 10 and 11 show the results of the land cover classification for the Boone and Raleigh counties for 1986 and 2019, respectively. Figure 11 compares the percentages obtained for each class. One of the changes that can be observed is the decrease in forest between 1986 and 2019. Deforestation can be attributed to the increase of the number and size of surface coal mines, created using the mountaintop removal technique.

Another change related to mountain top removal is the increase in grassland from 4.4% to 13.3%. This change could be explained by restoration measures after coal exploitation. Although the law requires coal operators to restore the land to its approximate original shape, the rock debris generally cannot be securely piled as high or graded as steeply as the original mountain top. To meet federal reclamation requirements, the mining sites are often sprayed with non-native grasses (End Mountaintop Removal, 2019).

A dramatic decrease in settlement by 2019 from 12.2% to 4.8% can also be observed. Although the number of inhabitants also decreased, which would explain some decline in settlement, such a dramatic drop seems rather unlikely and could be attributed to a pixel size effect caused by the difference in spatial resolution between Landsat and Sentinel-2 images. Small gardens and green spaces, which could not be sensed in 1986 with 30 m pixel size, are fairly visible in the 2019 Sentinel-2 images with a pixel size of 10 m.

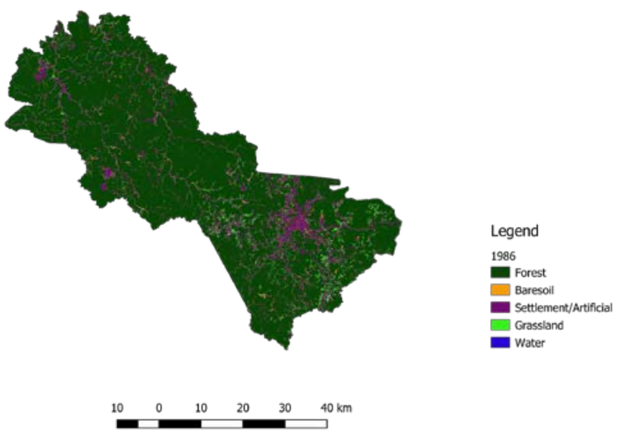

Figure 10: Land cover classification of the Boone and Raleigh counties for May 1986.

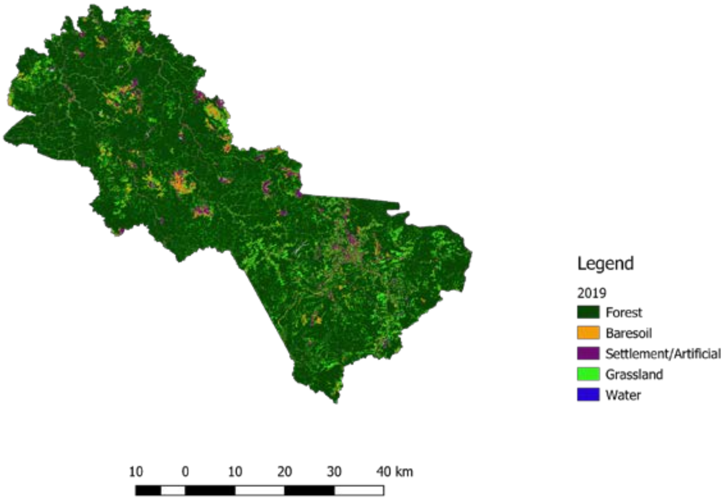

Figure 11: Land cover classification for Boone and Raleigh counties for July 2019.

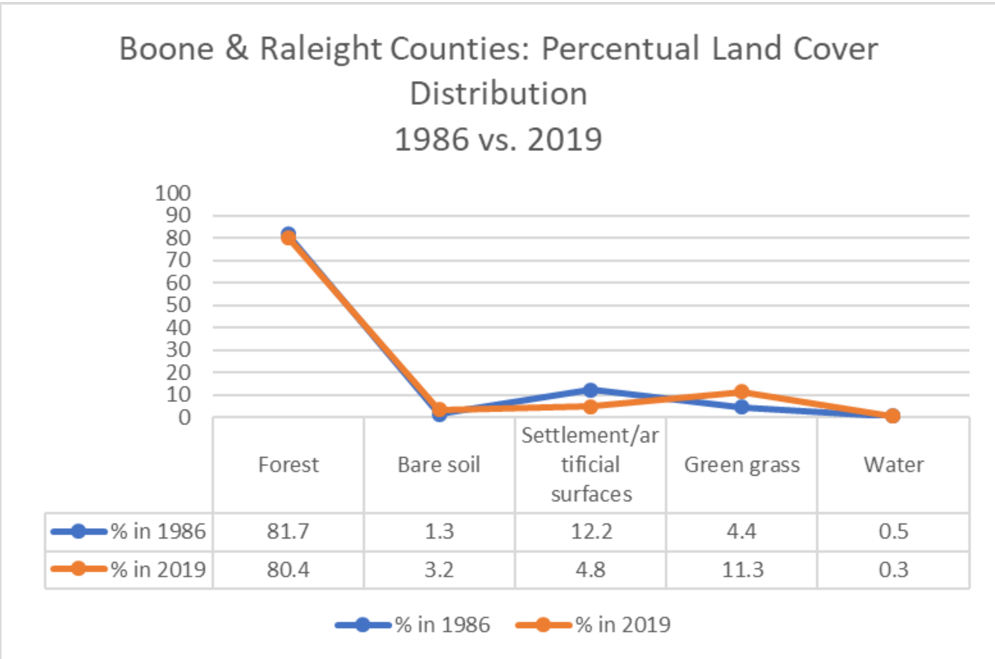

Figure 12: Percentual land cover distribution for 1986 (blue line) and 2019 (orange line) for Boone and Raleigh counties.

6. Discussion

In the 95,219 ha large study area of the Jiu Valley, there are evident signs of socio-economic decline, with a 3.3% reduction in settlement/artificial land coverage due to the decommissioning of mining installations and population decline, amounting to a decrease of 3,176.3 ha in 2019 compared to 1986. At the same time, our results suggest that, due to the greening of the decommissioned mining sites and the slow-down of economic activity, an increase of 4% (3,768.8 ha) in forest can be observed between 1986 and 2019. This result is counter-intuitive considering the steady increase in illegal logging activities in post-communist Romania. This result can also be traced back to the poor quality of the image from 1986 compared to those taking in 2019 and a series of technical simplifications that were necessary to facilitate the comparison. Also, even if areas in higher regions (including near peak regions) became more accessible thanks to advanced forestry equipment and therefore have also been affected by illegal deforestation, they may still be classified as forest by the algorithms we have used. To compensate for this bias, it is necessary to collect so-called ground samples from key regions, which can better inform the classification process. The conflict potential in the region seems high because of unsolved political issues reflected by the decline in settlement. This potential was and still is alleviated by migration to other regions in Romania and elsewhere, as well as by financial compensations from the Romanian state. Also, the choice between decommissioning old mines and repurposing them – for example, as museums – also bears a certain conflict potential, which is made evident by the high number of industrial facilities which vanished between 1986 and 2019.

The 286,061 ha large Boone-Raleigh region experienced rather dramatic environmental disruption between 1986 and 2019, with a 1.3% loss (3,602.5 ha) in forest and a 1.9% (5,424 ha) increase in bear soil, owing to mountain top removal mining and settlement decline. This created the premises for conflicts between the local population and environmental activists on one side, and mine operators on the other one, which are well documented in the United States. The scale of the disaster is reflected rather compellingly in the satellite images. These images reveal that, even if some mining sites have been decommissioned and ecologically restored, more fresh sites have emerged, creating a unique and disconcerting landscape in the region.

7. Conclusion

This study set out from the question of how coal legacies are reflected in satellite images of the Jiu Valley and Boone-Raleigh regions. What we have referred to as "sensing coal legacies" amounted to tracing environmental disruption, socio-economic decline, and conflict potential in mining regions across historical periods and political regimes. With today's unprecedented availability and accessibility of multi-spectral satellite images, facilitated by high-speed Internet and the growing number of civil satellites, it is now possible to scrutinize land use and transformation in a systematic way with relatively little efforts. This preliminary study sought to inspire more work in this direction, by the example of the legacies of coal mining. As it was suggested by participants at the conference, in order to improve the approach, a finer grained selection of moments in the evolution of mining regions may yield even more insights, which could be more reliably related to field observations and different critical moments in the history of these regions. For example, for the Jiu Valley the two decades after 1996 are of special interest because most mines were closed during that time. A year-by-year snapshot-based study of that period might thus shed more light upon, perhaps, the most difficult period in the Romanian coal mining history.

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