



Temporal Changes in Vegetation around Open Cast Quarries: Milas–Ören Lignite Coal Quarries [†]

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Abstract: Due to the rising coal demand for energy, open cast coal mines, as well as concerns about their environmental impact, have increased globally. Such mines, often situated in forested areas outside cities, raise apprehensions. This study evaluates the changes in vegetation around a Milas–Ören open cast lignite coal mining site, Türkiye, between 1984 and 2023, using Landsat images and Google Earth Engine. The results reveal a loss of around 1950 ha of forests, 570 ha of olive groves, and an expansion of mining areas by over 1700 ha. The study found that mining activities have environmental impacts outside as well as inside the mining area, and the study provides a long-term and systematic analysis of the current situation.

Keywords: open cast quarries; remote sensing; change detection; land use/land cover change; Milas–Ören lignite quarries; deforestation

1. Introduction

Future projections indicate an increase in energy consumption by 14% in OECD countries and by 84% in non-OECD countries by 2035 [1], while 5-fold growth is expected for Türkiye by 2050 compared to the early 2000s [2]. Currently, 51.8% of fossil fuel-based energy generation is sourced from natural gas and 48.2% from coal in the country, of which 60.2% of the latter is lignite coal [3,4].

Lignite coal is obtained by either underground or surface mining. Surface mining is a more economical method, requiring the removal of the vegetation and soil on the surface to extract the coal on the bedrock that is close to the land surface [5,6]. Such interventions, as well as the necessity to reserve large spaces for the expansion of the excavated areas and storage of excavation wastes, inevitably cause intense environmental damages such as disruption of the soil cover, land cover/land use, and habitats, an increased risk of soil erosion and floods, air and water pollution, and loss in agricultural productivity [7,8]. Amongst these, the impact of open pit mining areas on vegetation is critical and commonly researched in the literature using remote sensing (RS) and geographical information systems (GIS) capabilities and analyses. For example, NDVI is one of the most preferred techniques when focusing on the detection of vegetation [9–11]. PCT, maximum likelihood monitoring [9], simple ratio analysis [12], TVDI [13], and supervised classification [14] are also preferred for the determination of the impacts on vegetation.

Surface-mined lignite mines in Türkiye, such as in the Milas–Ören mining region, have been controversial due to the massive loss of forested areas, which has severe consequences for local communities and ecosystems nationally and globally. In this context, this study aims to examine the spatio-temporal changes in the Milas–Ören mining area between 1984 and 2023 and thus reveal the destruction of vegetation due to mining activities. In this



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regard, change detection analyses with 5-year intervals were performed using Landsat images with Google Earth Engine (GEE), and conversions from vegetated areas (forests and olive groves) to mining areas and bare lands were detected. The results contribute to assessing the current situation in the Milas–Ören mining district and developing strategies for conserving forests and biodiversity by promoting sustainable mining practices.

2. Materials and Methods

2.1. Study Area

The study area, covering 13,809.88 ha and located at coordinates 37.12 north and 27.9 east, comprises the open lignite quarries around Milas–Ören road in Muğla, Türkiye (Figure 1). A Mediterranean climate dominates the region, and the vegetation mainly consists of pine forests, maquis, and olive groves [15,16].

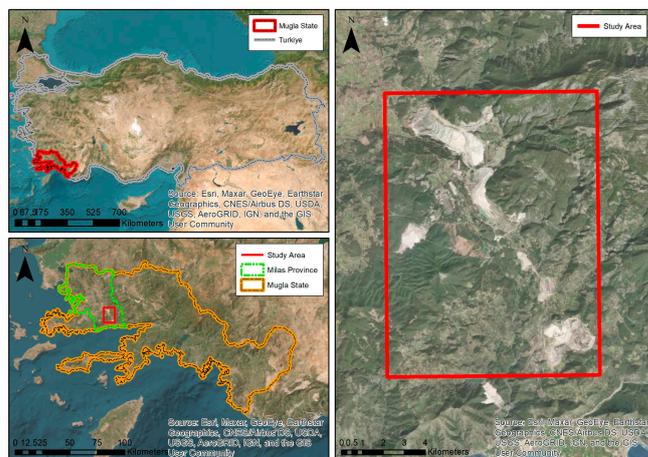


Figure 1. Location of the study area.

The lignite quarries in the area, dating back to 1979, were commissioned by the state for the thermal power plants in Yeniköy, Kemerköy, and Yatağan. The Milas–Ören mines were privatized in 2014, and 23,000 ha were granted a lignite mining license. Unused licensed areas cover 11,200 ha, including forests, agriculture, pastures, and residential areas [15]. The study area is an important example of the massive environmental damage caused by open pit mining, as it is one of the largest lignite deposits in Türkiye.

2.2. Materials

The Milas–Ören lignite quarries and their adjacent environments were systematically analyzed using satellite images at 5-year intervals from 1984 to 2023. Images from the 1984–2009 period were sourced from Landsat 5, those from 2014 to 2019 were acquired from Landsat 8, and the 2023 image was captured by Landsat 9.

2.3. Methods

This research applied the Normalized Difference Vegetation Index (NDVI) and supervised classification techniques at 5-year intervals in the study area between 1984 and 2023. The findings from each interval were subsequently compared to facilitate an efficient change detection process, with all computational tasks performed using the GEE. NDVI analysis is the ratio of the difference and sum of the NIR and Red Bands of the image. The GEE uses the maximum likelihood method as its supervised classification algorithm. Supervised classification was performed to determine land use/land cover (LULC) classes (forest, olive groves, mining areas, bare lands, settlements, agricultural areas), while NDVI analysis was performed to detect the vegetation status in areas without land change. Also, CORINE Land Cover database was utilized for classification verification. Change maps were created using image differencing technique, showing the conversions from forests and

olive groves to mining areas and bare lands. CORINE Land Cover data were also used for validation of NDVI difference. And the validation overall accuracy of mage classification and the change detection was calculated by GEE automatically.

3. Results

3.1. LULC Change Detection Results

The overall validation accuracy of the supervised classification is minimum 74%, maximum 84%, and on average 80%. The Kappa value is minimum 0.64, maximum 0.77, and on average 0.72. The validation of the accuracy of the change detection for the post-classification image is minimum 59%, maximum 69%, and on average 63%.

The results show that the conversion from forest to mining area was highest between 2004 and 2009 (126 ha), followed by 1984–1989 (115 ha) and 2009–2014 (111 ha). In addition, 1275 ha of forest area in the study area was converted to bare lands between 2019 and 2023, while this conversion was detected to be 1138 ha between 1999 and 2004 and 869 ha between 2014 and 2019. The area of forests that was converted to bare lands was 32 times larger than that converted to mining areas between 1989 and 1994. Bare lands were primarily observed in the periphery of the mining area (Figure 2).

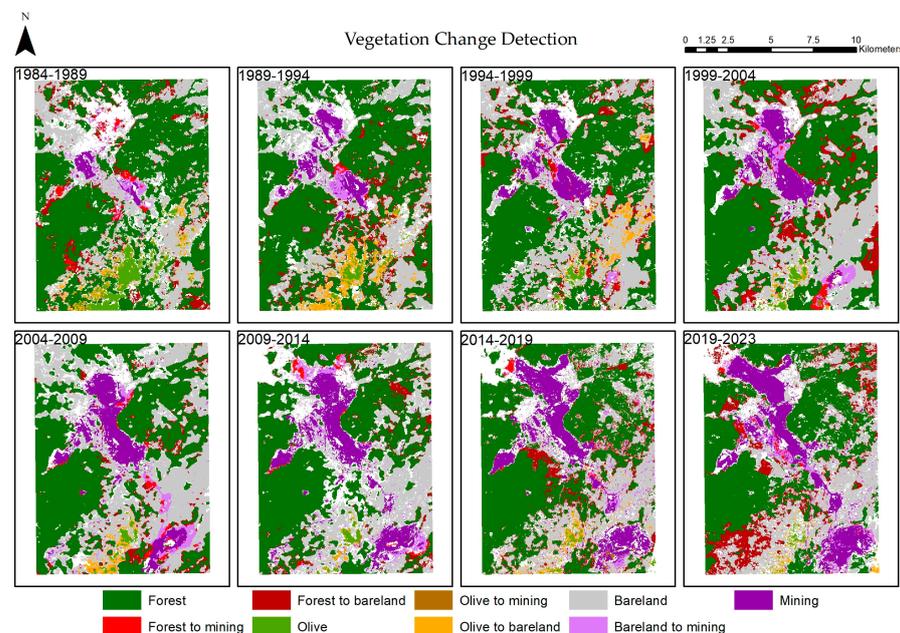


Figure 2. Five-year interval vegetation change detection analysis.

Olive groves were found to be transformed into mining areas and barrens. The olive groves in the south were converted into bare lands between 1984 and 1989 (245 ha), 1989 and 1994 (465 ha), and 1994 and 1999 (304 ha), and then, a mining area was opened in the eastern part (Figure 2).

Figure 3 presents the total changes between 1984 and 2023. According to the analysis, 2048 ha of forest area was converted into bare lands, and 615 ha was converted into mining areas (Figure 3). The total area of forest and olive grove that was turned into mining area was 731 ha, while the total area that became bare land was 2640 ha. On the other hand, 1088 ha of bare lands from 1984, which could have been reforested and restored to vegetation, was converted into a mining area in 2023.

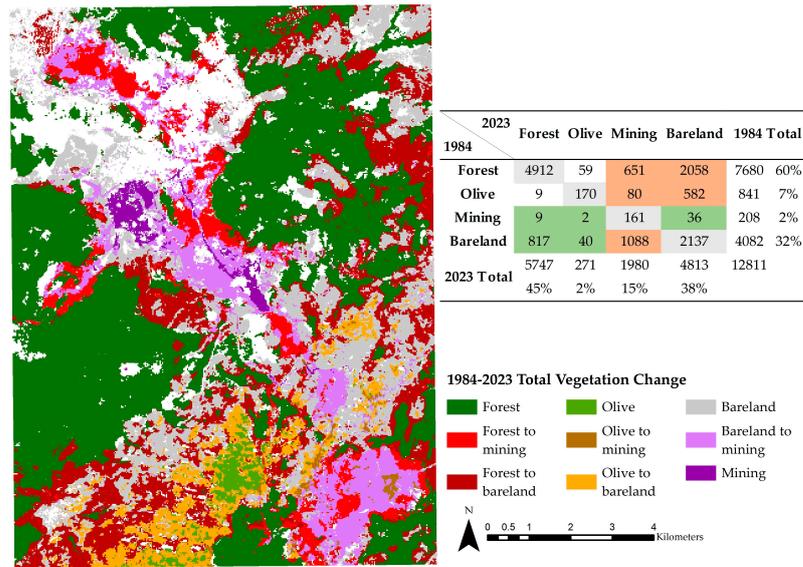


Figure 3. A 1984–2023 vegetation change detection map.

3.2. NDVI Results

Figure 4 presents 5-year NDVI change maps for the Milas–Ören lignite mines and their surroundings. The boundaries of the mining areas, initially marked in blue for 1984, have been determined to have expanded to the red boundaries by 2023. During this expansion, decreases in the NDVI have been detected within and outside the active mining site.

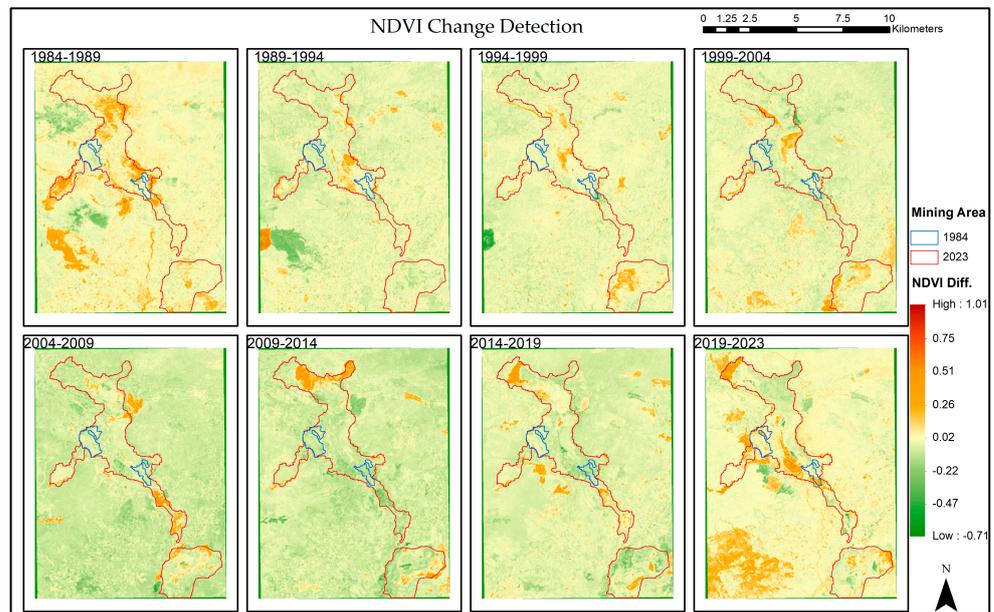


Figure 4. Five-year NDVI change detection maps.

In the following, NDVI changes for 5-year intervals are summarized:

- 1989–1994: No significant NDVI changes were recorded within the blue boundaries in 1984, and decreases in vegetation became more prominent in areas outside these boundaries.
- 1994–1999: A recovery/improvement in vegetation was seen in the west.
- 1999–2004: Significant NDVI decreases emerged in the mine site’s eastern, northeastern, and southeastern regions, suggesting a broader decline in vegetation.
- 2004–2009: Increases in NDVI values were detected in the north and east.

- 2009–2014: A noticeable recovery in the eastern and northeastern regions and decreased vegetation in the west were detected.
- 2014–2019: Increases in the north and northwest were observed.
- 2019–2023: Increases in vegetation were encountered in the east and northeast, while a decline in vegetation in the northwest was detected.

The NDVI change detection analysis between 1984 and 2023 revealed significant declines in vegetation, coinciding with the expansion of the mining area (Figure 5). Especially in the western, northern, and southern regions of the mine, these declines were more intensive. This analysis indicates that the impact of mining activities is not limited to the immediate boundaries of the mine. Rather, it has adverse effects on vegetation over a broader area.

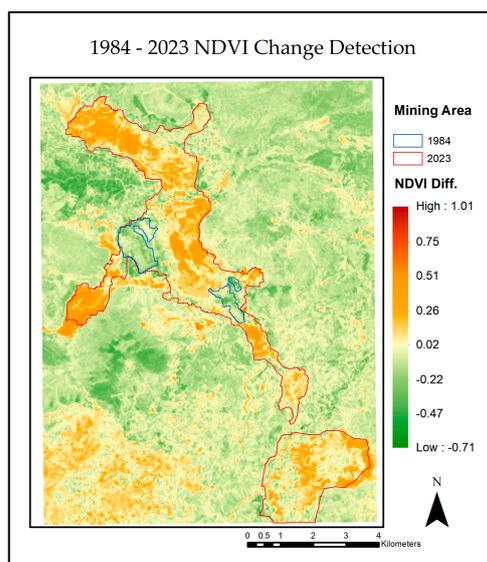


Figure 5. A 1984–2023 NDVI change detection map.

4. Discussion and Conclusions

In this study, LULC and NDVI analyses were carried out in Milas–Ören mines to examine the impact of open cast mines on the vegetation between 1984 and 2023 using Landsat images. In total, 731 ha of vegetated areas has been converted to mining, while 2640 ha has been indirectly affected and damaged by mining. Our LULC change detection analysis showed that forested areas were often transformed into bare lands before being transformed into mining areas. Therefore, the area that changed from forest to mining may be perceived as smaller than the area that changed to bare lands in 5-year comparisons.

The NDVI change maps between 1984 and 2023 indicate that mining activities have had pronounced negative effects on the vegetation. With the expansion of the mining area, decreases in vegetation were observed within and outside the boundaries of the mining site. These changes demonstrate that the environmental impact of mining activities is not limited solely to the direct operational area; these activities also affect the surrounding ecosystem.

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