environmental sciences proceedings

MDPI

Proceedings Paper

Temporal Changes of Vegetation Around Open Cast Quarries: Milas-Ören Lignite Coal Quarries†

Ceren Ozcan-Tatar [1,*], Bilge Bingul [2] and Saye Nihan Cabuk [3]

[1] Ph.D.c. Department of Remote Sensing and Geographical Information Systems, Eskisehir Technical University, Turkey; ceren_ozcan@ogr.eskisehir.edu.tr
[2] Ph.D.c. Department of Remote Sensing and Geographical Information Systems, Eskisehir Technical University, Turkey; bilgebingul@ogr.eskisehir.edu.tr
[3] Prof. Dr., Earth and Space Sciences Institute, Department of Geodesy and Geographical Information Technologies, Eskisehir Technical University, Turkey; sncabuk@eskisehir.edu.tr
* Correspondence: ceren_ozcan@ogr.eskisehir.edu.tr; Tel.: +90 554 525 68 98
† Presented at the title, place, and date.

Abstract: Due to 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 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 grove, and an expansion of mining areas by over 1,700 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]. 51.8% of the 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 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 soil cover, land cover/land use, and habitats, increased risk of soil erosion and floods, air and water pollution, 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 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 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 regard, change detection analyses with 5-year intervals were made using Landsat images with Google Earth Engine (GEE), and conversions from vegetated areas (forests and olive groves) to mining areas and barelands 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 (Fig. 1). The Mediterranean climate dominates the region, and the vegetation mainly consists of pine forests, maquis, and olive groves [15], [16].

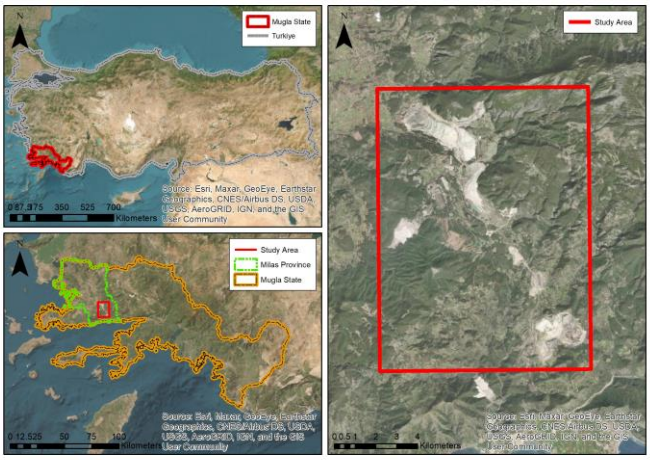


Figure 1. Location of the Study Area.

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 essential example of the massive environmental damage caused by open pit mining, 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 2014-2019 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 the supervised classification algorithm. Supervised classification was performed to determine land use/land cover (LULC) classes (forest, olive groves, mining areas, barelands, 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 barelands. CORINE Land Cover data were also used for validation of NDVI difference. And the validation overall accuracy of mage classification and the change detection is calculated by GEE automatically.

3. Results

3.1. LULC Change Detection Results

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

The results show that the conversion from forest to mining area was highest between 2004-2009 (126 ha), followed by 1984-1989 (115 ha), and 2009-2014 (111 ha). Besides, 1275 ha of forests in the study area were converted to barelands between 2019-2023, while this conversion was detected as 1138 ha between 1999-2004 and 869 ha between 2014-2019. The amount of forested areas converted to barelands was 32 times higher than those converted to mining areas between 1989 and 1994. Barelands were primarily observed in the periphery of the mining area (Fig. 2).

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

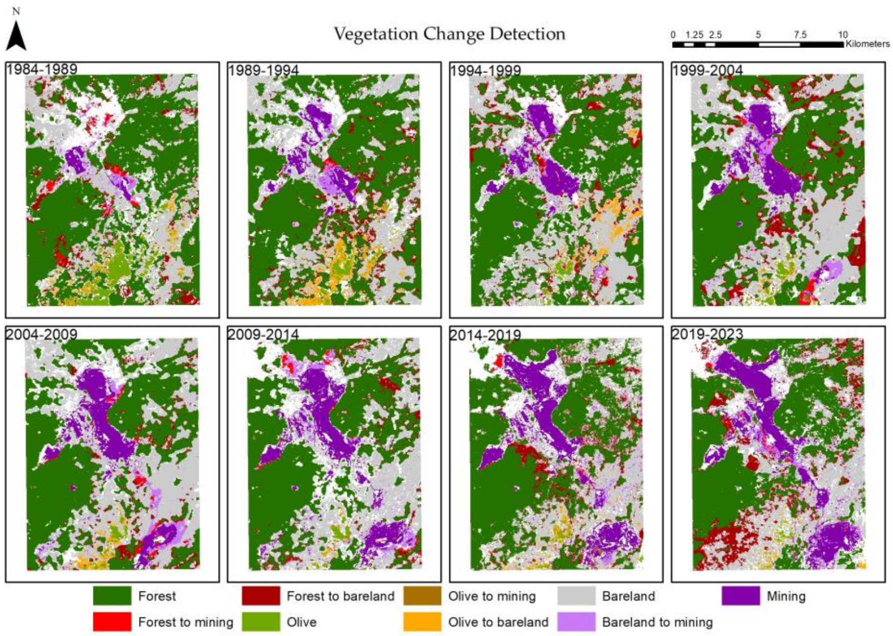
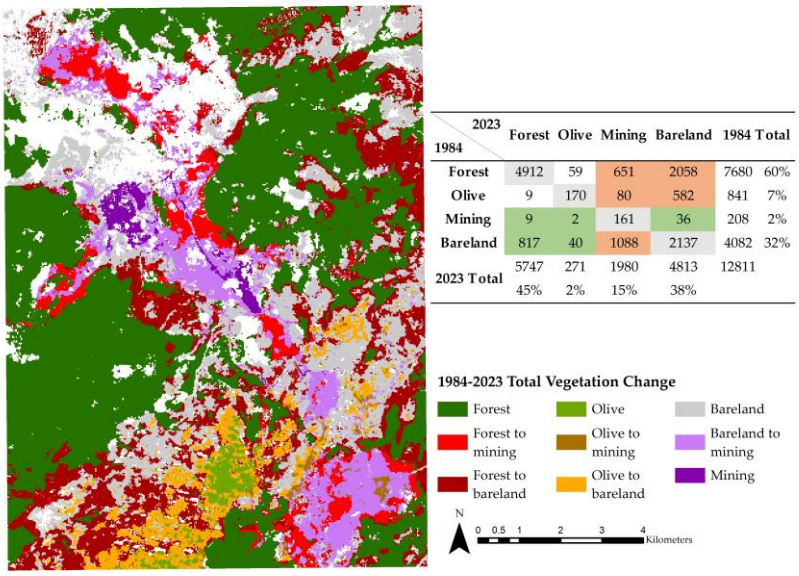


Figure 2. 5-year interval vegetation change detection analysis.

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



1984 \ 2023	Forest	Olive	Mining	Bareland	1984 Total	
Forest	4912	59	651	2058	7680	60%
Olive	9	170	80	582	841	7%
Mining	9	2	161	36	208	2%
Bareland	817	40	1088	2137	4082	32%
2023 Total	5747	271	1980	4813	12811	
	45%	2%	15%	38%		

Figure 3. 1984-2023 vegetation change detection map.

3.2. NDVI Results

Figures 4 gives 5-year NDVI change maps for the Milas-Ören Lignite Mines and its surroundings. The boundaries of the mining areas, initially marked in blue for 1984, have been determined to expand to the red boundaries by 2023. During this expansion, decreases in NDVI have been detected within and outside the active mining site.

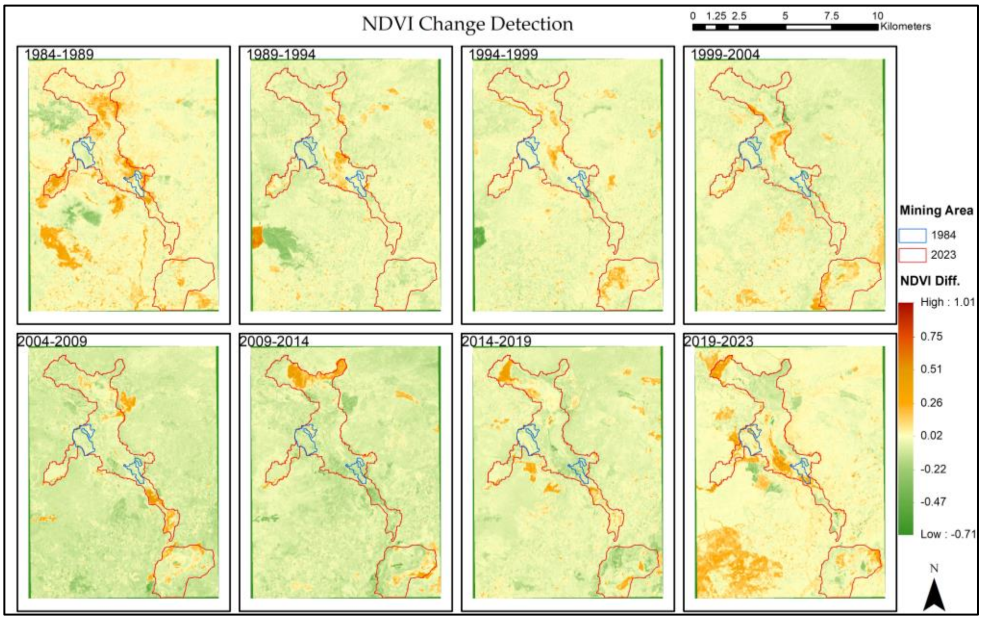


Figure 4. 5-year NDVI change detection maps

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 east, northeast, and southeast 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 (Fig. 5). Especially in the west, north, and south 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. Still, it has adverse effects on vegetation over a broader area.

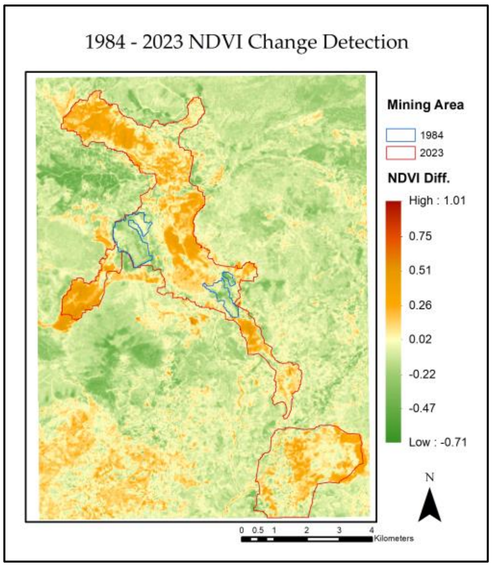


Figure 5. 1984-2023 NDVI change detection map.

4. Discussion and Conclusion

In this study, LULC and NDVI analyses were carried out in Milas-Ören Mines to examine the impact of open-cast mines on vegetation between 1984-2023 using Landsat images. 731 ha of vegetated areas have been converted to mining, while 2640 ha have been indirectly affected and damaged by mining. LULC change detection analysis showed that forested areas were often transformed into barelands before transforming into mining areas. Therefore, the area changed from forest to mining may be perceived as less than barelands 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 but also the surrounding ecosystem.

Author Contributions: Conceptualization, C.O.T. and S.N.C.; methodology, C.O.T. and B.B.; software, C.O.T. and B.B.; resources, C.O.T.; data curation, C.O.T. and B.B.; writing—original draft preparation, C.O.T. and B.B., writing—review and editing, S.N.C.; visualization, C.O.T. and B.B.; supervision, S.N.C. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by The Scientific and Technological Research Council of Türkiye (TUBITAK) 2244 program under project number 119C200.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: We encourage all authors of articles published in MDPI journals to share their research data. In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Where no new data were created, or where data is unavailable due to privacy or ethical restrictions, a statement is still required. Suggested Data Availability Statements are available in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics.

Acknowledgments: In this section, you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).

Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

[1] C. Wolfram, O. Shelef, and P. Gertler, "How Will Energy Demand Develop in the Developing World?," *Journal of Economic Perspectives*, vol. 26, no. 1, pp. 119–138, 2012.

[2] Z. Yumurtaci and E. Asmaz, "Electric Energy Demand of Turkey for the Year 2050," *Energy Sources*, vol. 26, pp. 1157–1164, 2004, doi: 10.1080/00908310490441520.

[3] T.C. Enerji ve Tabii Kaynaklar Bakanlığı, "Elektrik." 2022.

[4] T.C. Enerji ve Tabii Kaynaklar Bakanlığı, "Kömür." 2022. Accessed: Jun. 20, 2022. [Online]. Available: https://enerji.gov.tr/bilgimerkezi-tabiikaynaklar-komur

[5] Türkiye Kömür İşletmeleri Kurumu, "Açık Ocak Madenciliği." 2021. Accessed: Jul. 23, 2022. [Online]. Available: https://www.tki.gov.tr/acik-ocak-madenciligi

[6] S. Üçışık Erbilen and G. Şahin, "ENERJİ COĞRAFYASI KAPSAMINDA TÜRKİYE'DE LİNYİT," *Doğu Coğrafya Dergisi*, vol. 20, no. 33, p. 135, Jan. 2015, doi: 10.17295/dcd.07598.

[7] A. Karadağ, "LİNYİT İŞLETMELERİ VE TERMİK SANTRALİN ARDINDAN SOMA'DA DEĞİŞEN ÇEVRE, KENT VE KİMLİK," *Ege Coğrafya Dergisi*, vol. 15, no. 2006, pp. 31–50, 2007.

[8] F. Çeçen, "Kömür Madenciliğinin Çevresel Etkileri," p. 17, 2015.

[9] H. Schmidt and C. Glaesser, "Multitemporal analysis of satellite data and their use in the monitoring of the environmental impacts of open cast lignite mining areas in Eastern Germany," *International Journal of Remote Sensing*, vol. 19, no. 12, pp. 2245–2260, Jan. 1998, doi: 10.1080/014311698214695.

[10] G. Sarp, "Determination of Vegetation Change Using Thematic Mapper Imagery in Afşin-Elbistan Lignite Basin; SE Turkey," *Procedia Technology*, vol. 1, pp. 407–411, 2012, doi: 10.1016/j.protcy.2012.02.092.

[11] M. Gül, K. Zorlu, and M. Gül, "Assessment of mining impacts on environment in Muğla-Aydın (SW Turkey) using Landsat and Google Earth imagery," *Environ Monit Assess*, vol. 191, no. 11, p. 655, Nov. 2019, doi: 10.1007/s10661-019-7807-3.

[12] A. Erener, "Remote sensing of vegetation health for reclaimed areas of Seyitömer open cast coal mine," *International Journal of Coal Geology*, vol. 86, no. 1, pp. 20–26, Apr. 2011, doi: 10.1016/j.coal.2010.12.009.

[13] K. Przeździecki, J. Zawadzki, and Z. Miatkowski, "Use of the temperature–vegetation dryness index for remote sensing grassland moisture conditions in the vicinity of a lignite open-cast mine," *Environ Earth Sci*, vol. 77, no. 17, p. 623, Sep. 2018, doi: 10.1007/s12665-018-7815-6.

[14] A. O. Akanwa, F. I. Okeke, V. C. Nnodu, and E. T. Iortyom, "Quarrying and its effect on vegetation cover for a sustainable development using high-resolution satellite image and GIS," *Environ Earth Sci*, vol. 76, no. 14, p. 505, Jul. 2017, doi: 10.1007/s12665-017-6844-x.

[15] D. Gümüşel and E. Gündüzyeli, "Kömürün gerçek bedeli: Muğla," CAN Europe, 2019.

[16] Muğla İl Kültür ve Turizm İl Müdürlüğü, "Coğrafya (Konum-İklim-Ulaşım)." http://mugla.ktb.gov.tr (accessed Dec. 15, 2022).