



# Examination of the Change in the Vegetation Around the Kirka Boron Mine Site by Using Remote Sensing Techniques

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**Abstract** Within the scope of the study, the change occurring in the vegetation cover was examined in different temporal and spatial scales for in the example of Kirka boron mining site. Two different satellite images, namely Landsat and Sentinel, were utilized while the competence of these two satellite images were analyzed. Unsupervised classification and vegetation indexes have been used from remote sensing techniques. It was observed that the mining area boundary could not be determined using vegetation indexes, whereas unsupervised classification techniques showed that the mining site occupies 1144.5 ha area. NDVI and NDRé analyses were conducted to determine the vegetation change outside the

mining area. It has been determined that the analyses performed with the NDVI (normalized difference vegetation index) and NDRé (normalized difference red edge index) indexes show different results on water surfaces, while they show similar results in rest of the areas. In NDVI analysis, it has been determined that the two satellite images gave similar results in NDVI analyses, while having higher spatial resolution, sentinel satellite images were able to capture more details.

**Keywords** Mine site · NDVI · NDRé · Remote sensing · Unsupervised classification

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## 1 Introduction

Mining activities cause environmental, social, and economic impacts both during and after the mines' operations. Mining activities may have associated with negative impacts on ecosystems and environments such as degradation of lands (Haryani et al., 2018; Qian et al., 2014; Werner et al., 2019), contamination of soil or water, deforestation, erosion and alteration of soil profiles, climate change, and loss of ecosystem services. They may also result in land-use and land cover change that can be analyzed spatially with the aid of remote sensing (RS) and geographical information systems (GIS) (Crowley & Cardille, 2020). RS refers to the use of aerial or satellite imagery to study features on Earth's surface, and GIS is essentially a computer-based system by which geographical data are managed, analyzed, and manipulated, usually to produce 2-D or 3-D visualizations, including maps (Werner et al., 2019). RS and GIS could be used for examining landscape structure and function, and historical changes, as well as simulating future changes in landscape (Crowley & Cardille, 2020). To assess and reduce the negative changes, locations and spatial structure of vegetation caused by mining activity should be examined at the landscape scale (Ma et al., 2018).

Mining activities cause vast amount of vegetation destruction through land clearing, topsoil removal, or exploitation itself. Mining activities take place on large-scale areas and their negative impacts on the environment, on vegetation cover, and health continues after the operations are complete (Latifovic et al., 2005). Destruction in vegetation tends to bring about changes in biodiversity, in climate, and in ecosystem services. Latifovic et al. (2005) examined land cover change in Athabasca oil sands region in Canada. LANDSAT5 and LANDSAT7 data were used to compare vegetation cover between 1992 and 2001. The results showed that more than 700 ha of vegetation cover was degraded in the first phase of the study. In the second phase, NDVI data provided by NOAA-AVHRR satellites was used to calculate Key Resources Indicator (KRI), then temperature and global radiation were all taken into consideration to detect changes for the time period between 1990 and 2002. It was presented that there was a light decrease in greenness of the vegetation and increase in the air temperature in close proximity to the mining area.

Waring et al. (2011) used MODIS Global Disturbance Index (MGDI) to detect disturbances in woody

ecosystems and it was found quite efficient in terms of monitoring large-scale ecosystem disturbances. However, it was not suitable for annual herbaceous ecosystems in arid and semiarid areas. Because plants in these ecosystems have shallow roots responding precipitation fluctuations immediately and making it difficult to analyze the cause of disturbance, either precipitation anomalies or mining activities (Gitelson & Merzlyak, 1994; Ma et al., 2018). Ma et al. (2018) suggested a vegetation disturbance index (VDI) to distinguish disturbance by combining precipitation data and MODIS Enhanced Vegetation Index (EVI) and used VID on the Mongolian Plateau for the time period of 2000–2015.

Monitoring of mining sites through the years helps to detect changes in vegetation cover. Even after the mining activities cease and restoration process begins, assessments of environmental changes would still give insights into pattern of the degradation (Karan et al., 2016; Li et al., 2016). This study aims to examine vegetation cover in different temporal and spatial scales around Kirka Boron Mine Site. In addition, the adequacy of the satellite images obtained from different satellites within the scope of the study was tried to be determined. Though traditional methods for monitoring such as site visits, collecting samples from the field, and testing in laboratories could be quite costly, time-consuming, and need more labor work, they could still be used especially while analyzing large volume of geographic data, on various scales. To clarify the effects of mining activities on vegetation cover, site visits for collecting samples and site visits could be conducted when needed.

Within the scope of the study, the change occurring in the vegetation cover in the example of Kirka Boron Mine Site was examined in different temporal and spatial scales. In addition, the adequacy of the satellite images obtained from different satellites within the scope of the study was tried to be determined. In this context, analyses were made for 10 years and 1-year periods by using remote sensing technologies. Two different satellite images, Landsat and Sentinel, with 30- and 10-m spatial resolutions, were used.

## 2 Material and Method

### 2.1 Study Area

The study area, boron works minins site, named as Eti Mine Kirka Boron Management, is located

4.5 km west of Kırka town of Seyitgazi Plain of Eskişehir province. The area is located on the Western part of the Central Anatolia Region, Turkey (Fig. 1). Turkey, indeed, is the biggest exporter in the world by possessing 72.3% of all boron reserves (Yenmez, 2009).

Eti Mine Kırka Boron Management is an enterprise that possesses world's biggest borax deposit and constitutes an important part of Kırka-Sarıkaya borax deposit reserves. Thus, it is a high value economic asset not only for the region but also for the whole country.

Kırka Boron Works was established in 1970 with the name of Kırka Sodium Salt Site Management in Eskişehir-Kırka (Duran et al., 2020). The facility started to serve under Etibank which was established with the order of Atatürk to process underground resources in Turkey. Besides Etibank, facility also served under Eti Holding A.Ş. and Eti Mine Works General Management (Duran et al., 2020). Eti Maden

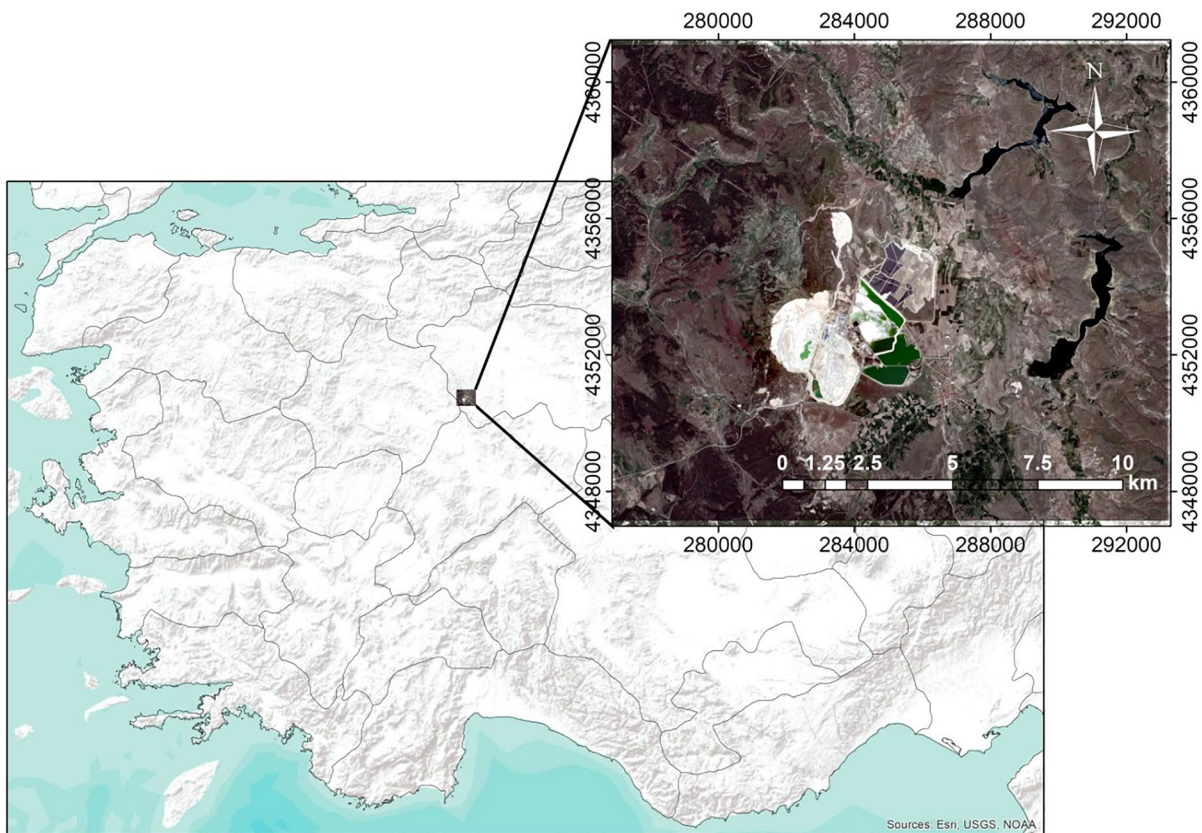
Works, a state-owned mining company, is still in charge of the mining activities in the area.

## 2.2 Methodology

Within scope of this study, the change in vegetation is detected in different temporal and spatial scales around the Kırka Sodium Salt Site Management through NDVI and NDRe analyses using Landsat and Sentinel imageries. ArcMap 10.7 Erdas Imagine 2014 programs were used for all the processes.

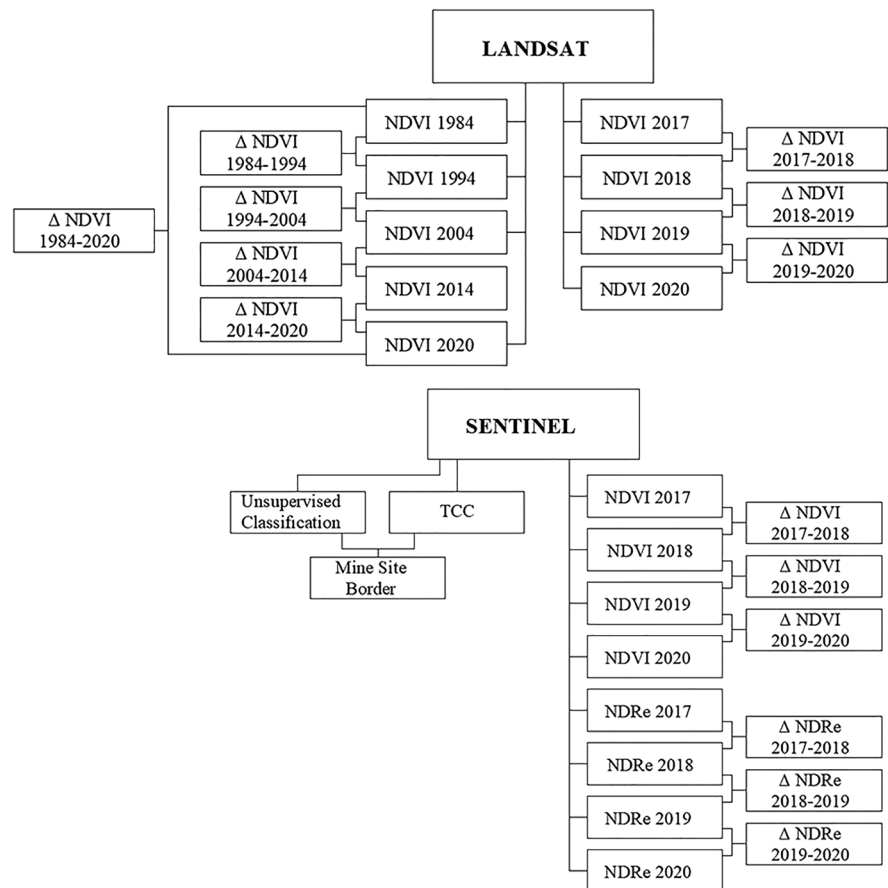
NDVI analysis through Landsat satellite imagery showed the long-term impact of the area, whereas Sentinel imageries demonstrate more recent impacts. In addition, Landsat and Sentinel data for 2017–2020 period were evaluated to compare satellite images at different scales (Fig. 2).

First, the change in vegetation is analyzed with Landsat imagery. Although the mining operations started in 1970, satellite images can be obtained from



**Fig. 1** Location map of the study area

Fig. 2 Workflow



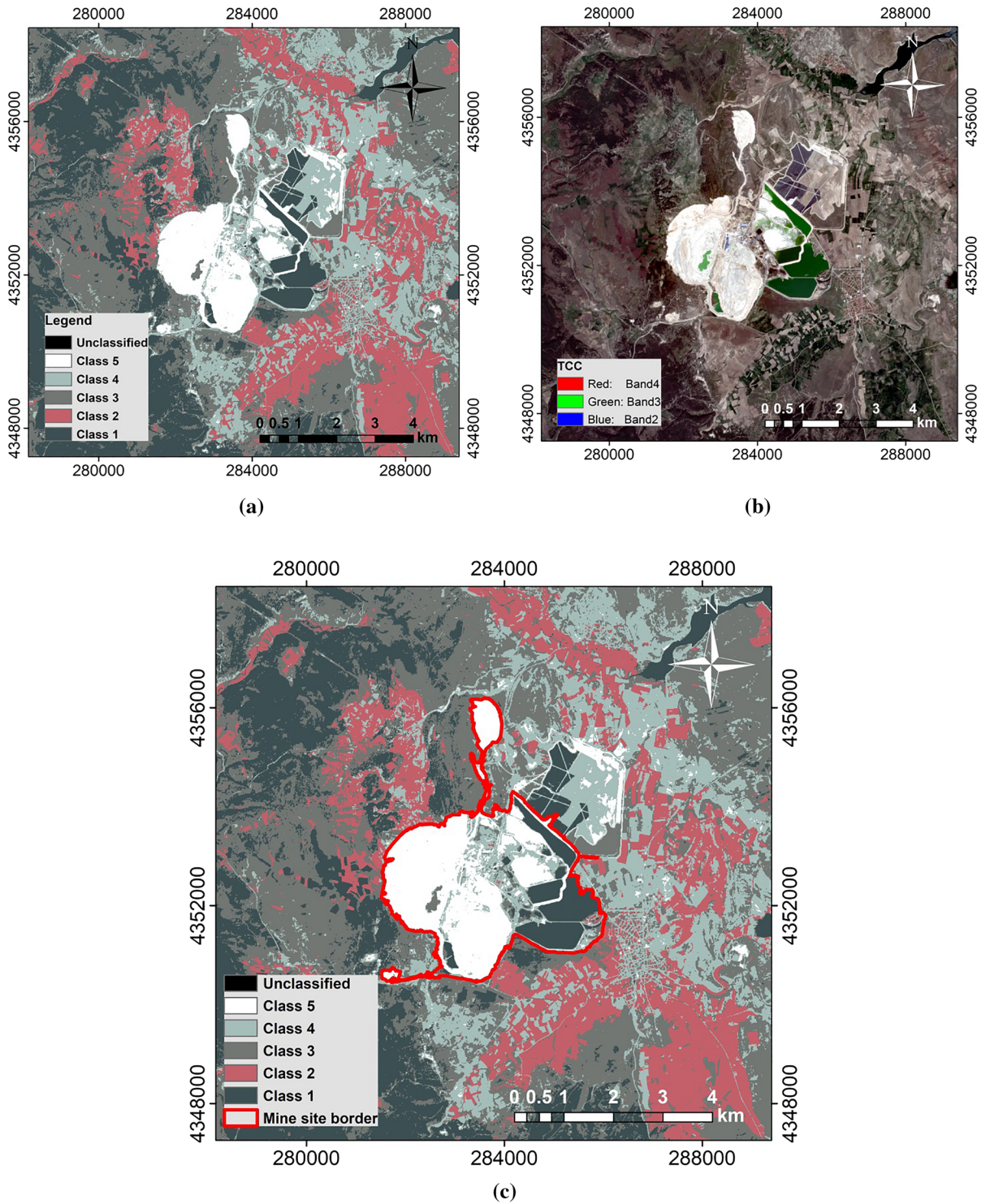
Landsat 5 satellite since 1984. The change occurred in 10-year periods from 1984 to 2014 and a remaining 6-year period from 2014 to 2020 is examined. The change occurred in 10-year periods from 1984 to 2014 and a remaining 6-year period from 2014 to 2020 is examined.

In order to determine the change in vegetation, NDVI analyses were conducted through Landsat satellite images with 30-m spatial resolution, and image extraction technique was applied to NDVI analysis in different time periods. NDVI is the ratio of the difference between Near-Infrared Range (NIR) and the red band (R) to their sums (Rouse et al., 1974).

$$\text{NDVI} = (\text{NIR} - \text{R}) / (\text{NIR} + \text{R}) \quad (1)$$

Image extraction technique is a process of extraction of overlapping pixel values of two images in different time periods. Thus, the areas changing in a negative and positive direction or unchanging areas

can be detected in a specific time period. Within the scope of this study, NDVI difference images were obtained by extracting NDVI images obtained from satellite images of 1984, 1994, 2004, 2014, and 2020 years from each other. The areas with positive and negative values which were obtained from NDVI difference images may not always give the real change, so a confidence interval must be determined in order to reach the correct result in the image obtained. Thresholding method which is widely used to separate changed and unchanged areas from each other was applied. Different intervals were used for detecting threshold values in the literature conducted. For example, Yuan and Elvidge (1998) used 0.25, 0.50, and 1 standard deviation ( $\sigma$ ) intervals in their work and they specified that 1  $\sigma$  interval is the most appropriate interval for NDVI change. Similarly, Morawits and his friends (Morawits et al., 2006) used 1  $\sigma$  interval as threshold value and they got high accuracy for NDVI changings.

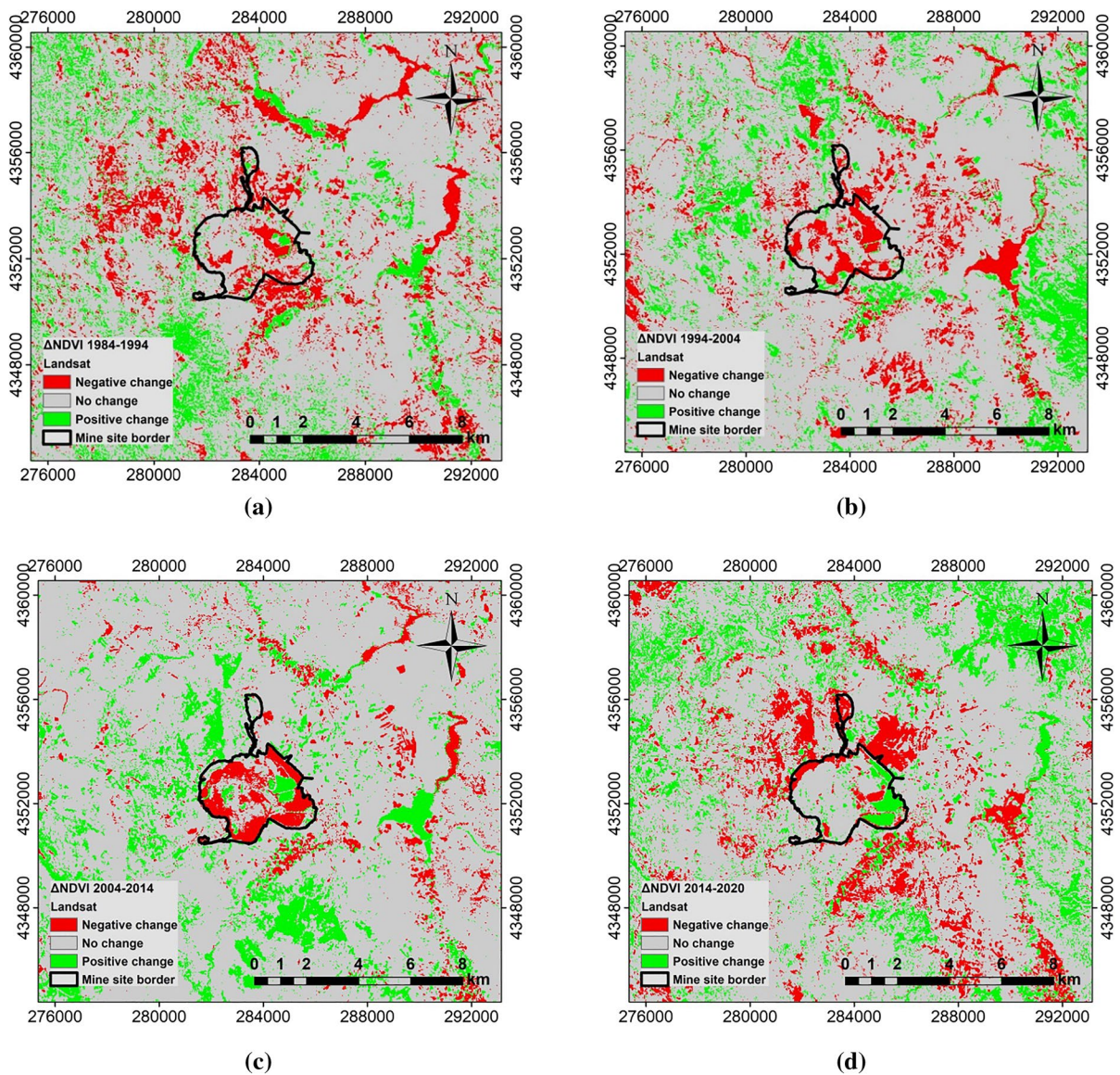


**Fig. 3** a Unsupervised classification result. b TCC. c Mine site border

Second, Sentinel is used to detect the changes in vegetation, and compare them to the Landsat results. Sentinel satellite images have 10-m and 20-m spatial resolution, and unlike of Landsat satellite images, they have red edge bands. However, Sentinel satellite images are available for only recent years, covering a comparably shorter time period. NDVI analysis were conducted using sentinel satellite images for the years 2017, 2018, 2019, and 2020 and image differencing technique was applied to determine the difference between years. Also, unsupervised classification method was used

to determine mine site border using Sentinel satellite images that was obtained in 2020. With unsupervised classification method, the study area was divided into 5 classes by using red, green, blue, and NIR bands of Sentinel satellite images with 10-m resolution.

The ore area, the clarifiers, and the transportation network between these areas in the mine site were manually separated from the image classified in 5 classes using the true color composite (TCC) band combination that produced as auxiliary data. Erdas Imagine 2014 program was used for these processes.



**Fig. 4** Change of NDVI values obtained using Landsat satellite

NDRe is a spectral index in which the red edge band is used. Index is similar to NDVI but more sensitive to maturation of crop than NDVI (Earth Observing Systems, 2021).

$$\text{NDRe} = (\text{R740} - \text{R705}) / (\text{R740} + \text{R705}) \quad (2)$$

NDRe analyses were conducted using Sentinel satellite images for the years 2017, 2018, 2019, and 2020. NDRe difference images were obtained from extracting of obtained NDRe images. In addition, NDVI analysis of the Landsat satellite for the years 2017, 2018, 2019, and 2020 was made to compare the competencies of Sentinel and Landsat satellites on the subject.

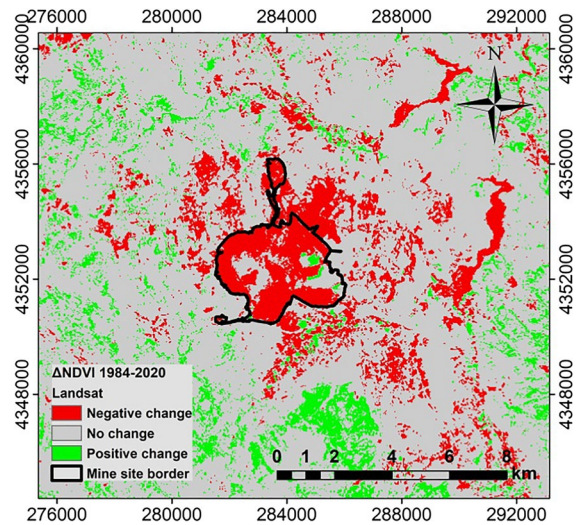
### 3 Results

To determine the boundaries of the mine site, Sentinel satellite image was reclassified in 5 classes (Fig. 3a). Apart from the ore extraction area, there are other uses such as management buildings, transportation network, and clarifiers in the site. Thus, the mine site is not composed of a single class. For this reason, the boundaries of the mine site were determined by the TCC (Fig. 3b). As a result, it was found that the mine site occupies 1144.5 ha area and 571.5 ha of which is devoted to ore extraction (Fig. 3c).

The change in NDVI values on mine sites and their environments were calculated using Landsat satellite images. In this context, the changes in the 10-year periods from 1984 to 2014 and in the 6-year period between 2014 and 2020 were examined (Fig. 4). According to the NDVI analysis for the 10-year periods, it is seen that the changes occurred not only in the mine site but also in the close vicinity. While the surrounding of the mining area tends to change positively, the period in which the significant amount negative change is experienced within the mining area is between 2004 and 2014.

Negative changes are observed in areas very close to the mine site boundaries; these changes cannot be separated from the site. For this reason, the change between 1984 and 2020 has been examined, to distinguish boundaries of the mine site in a more precise way (Fig. 5).

However, the boundary of the mine site is not clearly separated from the NDVI change analysis

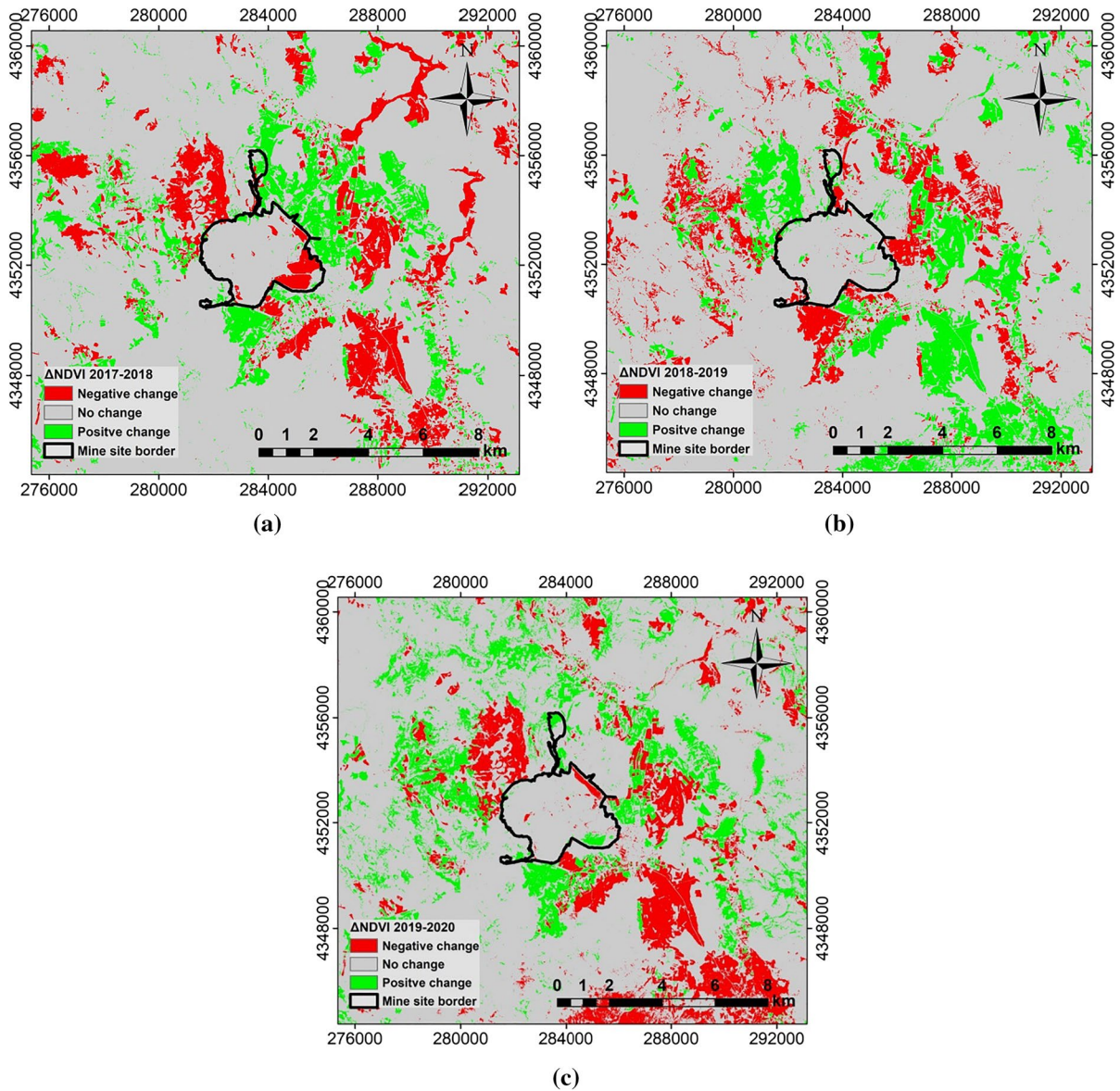


**Fig. 5** Change of NDVI values between 1984 and 2020 obtained using Landsat satellite images

conducted between 1984 and 2020, as demonstrated in Fig. 5. There is a solar power plant outside the North-West border of the mine site, where negative change is observed between the installation area of this facility and the boundary of the mine site. In addition, areas with no changes and positive NDVI changes were identified within the mine site. Therefore, the mine site boundaries could not be determined by using the NDVI method in the study area. It is concluded that NDVI method, which is used to determine land degradation, did not work efficiently within the scope of this study, which can be explained by NDVI value changes outside of the mine site and the low density of vegetation cover in the land use.

Sentinel satellite images with higher spatial resolution than Landsat satellite images were used to investigate the change of NDVI values in the study area. The changes in NDVI analyses for the years 2017, 2018, 2019, and 2020 using sentinel satellite images are given in Fig. 6.

Therefore, Sentinel images examining the annual changes from 2017 to 2020 are examined (Fig. 6), and compared to the annual changes in the same period conducted with Landsat images (Fig. 7). Similar results were obtained with the analyses of the two satellite images. Nevertheless, more detailed results were obtained with sentinel satellite images due to the higher resolution. The differences detected in the analyses are considered to be resulting from the images not captured on the same days in the two satellites.



**Fig. 6** Change of NDVI values obtained using Sentinel satellite images

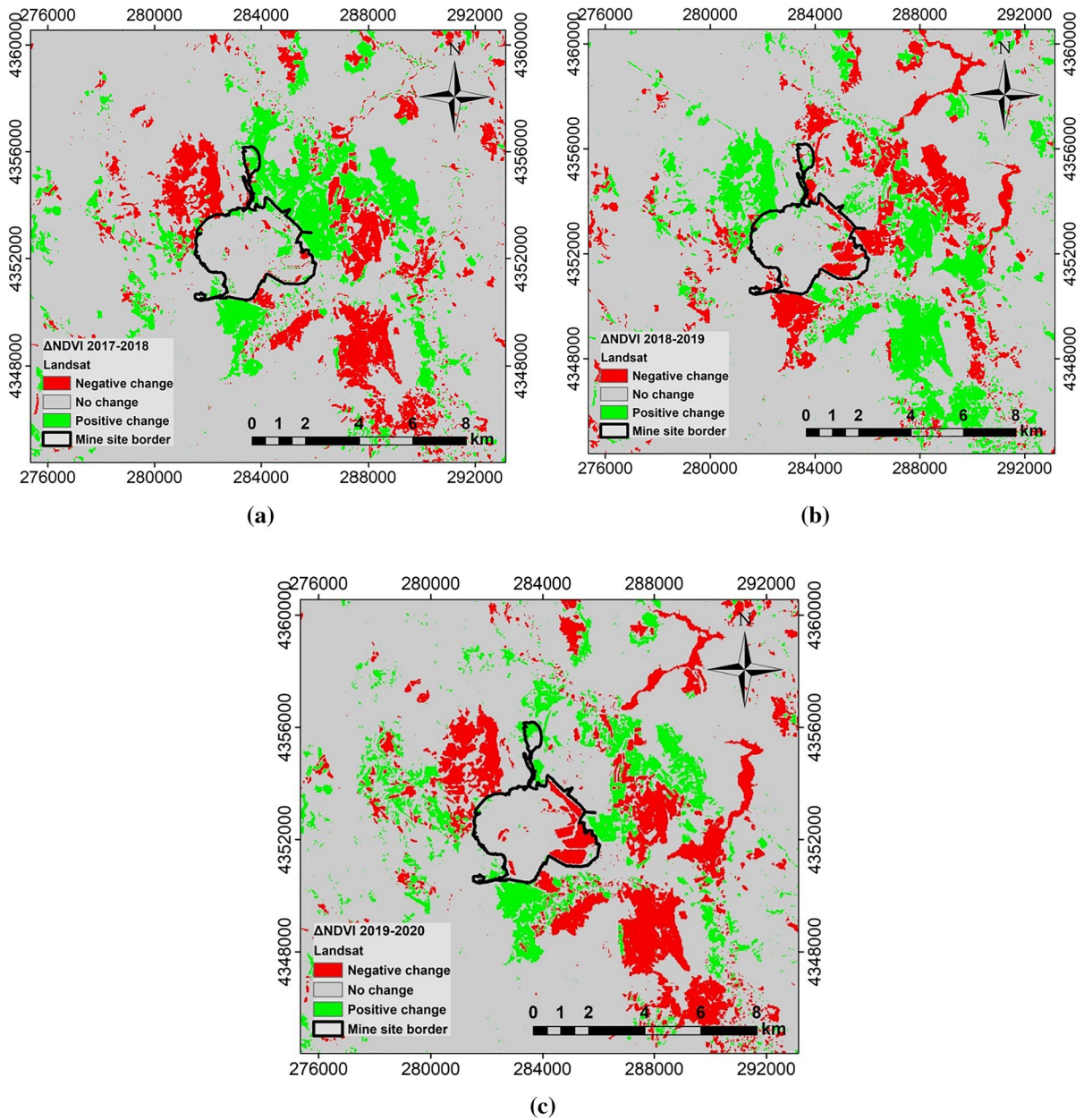
Apart from these, NDRe analyses were performed using red edge bands on the Sentinel satellite (Fig. 8) and these analyses were compared to NDVI results.

It has been determined that NDVI and NDRe analyses differ on water surfaces, but the changes in other areas overlap. NDVI and NDRe analyses are 91% overlapping in 2019–2020 period. The bands used for NDVI analysis have a spatial resolution of 10 m, and the bands used in NDRe analysis have 20-m resolution. The differences in the areas other

than the water surfaces in the analysis are expected to be resulting from the differences in resolution of the two data.

Figure 9 shows the constantly undergoing positive NDVI and NDRe changes that produced from the Sentinel and Landsat satellites. In the analyses, it is seen that the positive changes occurring in all the periods are concentrated in agricultural areas and water surfaces. No positive change was detected in areas with natural vegetation.





**Fig. 7** Change of NDVI values obtained using Landsat satellite images

#### 4 Discussions

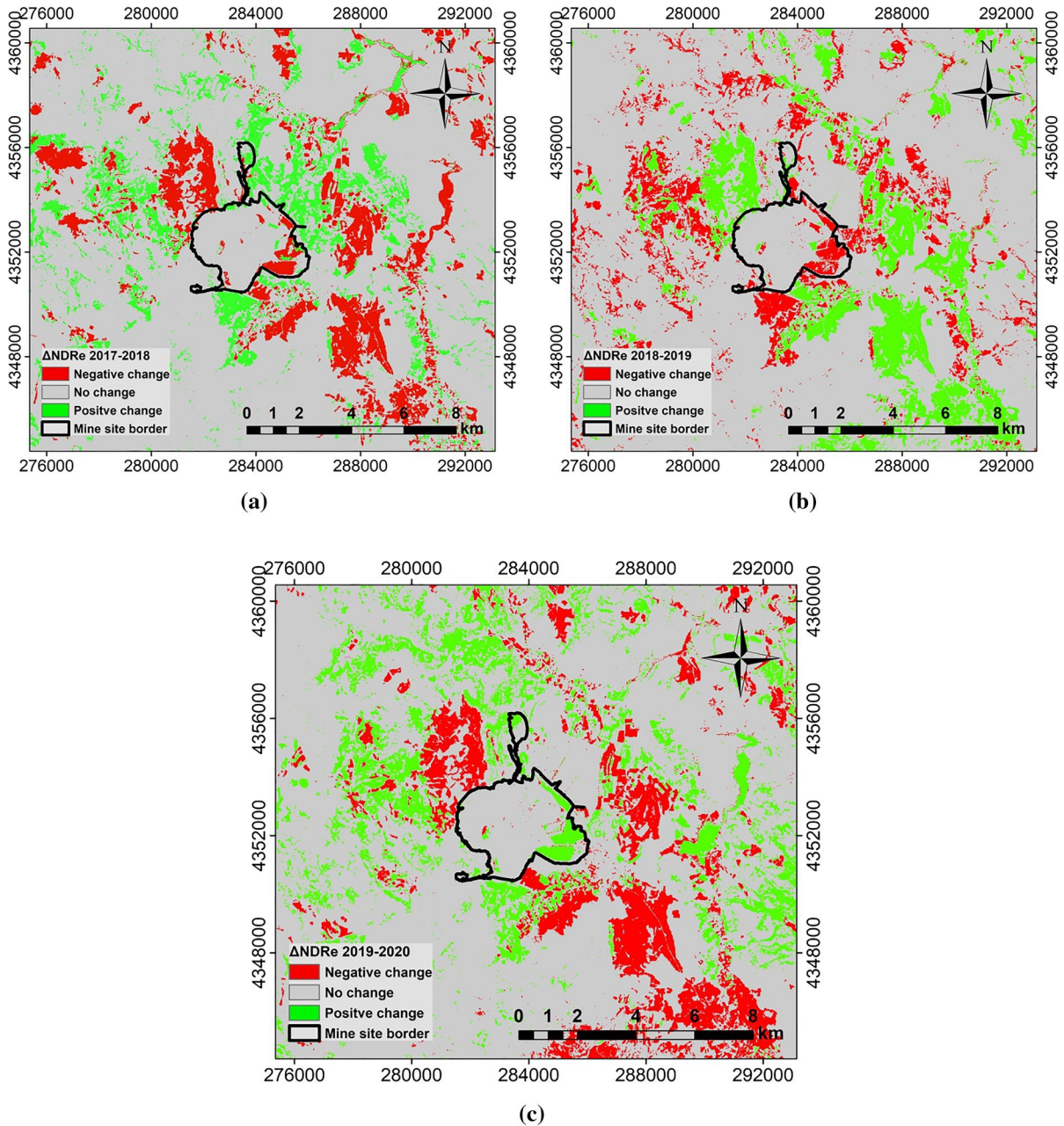
Vegetation is one of the important parts of the environment. Apart from its physiological characteristics, vegetation is important in many aspects such as animal communities in and around it, preventing erosion, soil formation, and preserving water. Mining activities can cause land degradation (Haryani

et al., 2018; Qian et al., 2014; Werner et al., 2019). As a result, vegetation at and around the mine site can be significantly affected. Monitoring of mining sites through the years helps to detect changes in vegetation cover. Within the scope of the study, the change occurring in the vegetation cover in the example of Kirka Boron Mine Site was examined in different temporal and spatial scales. In addition,

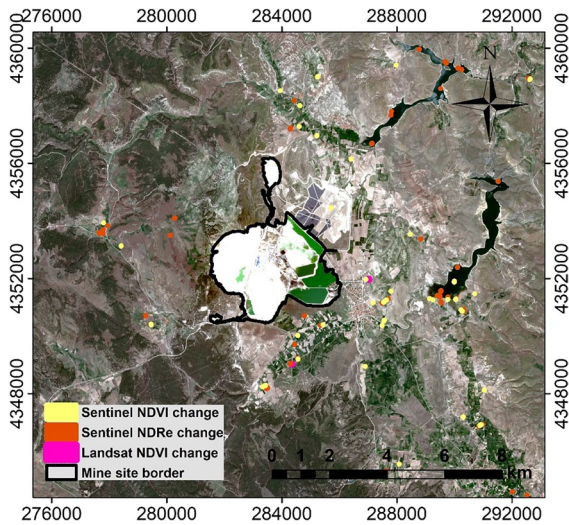
the adequacy of the satellite images obtained from different satellites within the scope of the study was tried to be determined.

In this context, analyses were made for 10-year and 1-year periods by using remote sensing technologies. Two different satellite images, Landsat and Sentinel, with 30- and 10-m spatial resolutions, were used.

RS and GIS have been used in explorations, assessing environmental impacts in mining sector (Winde et al., 2019) besides land management, monitoring changes, assessment, and policy making (Cetin, 2015a, b, c; Kaya, 2009, 2010; Kaya et al., 2016; Malaviya et al., 2010). RS and GIS data are widely used for detecting and modeling land cover and land



**Fig. 8** Change of NDRe values obtained using Sentinel satellite images



**Fig. 9** Constantly undergoing positive NDVI and NDR changes

use change (Cetin, 2015a, b, c, 2016a, b, c; Cetin et al., 2018, 2021b, 2022a, b; Orimoloye & Ololade, 2020; Busayo et al., 2019; Garai & Narayana, 2018; Latifovic et al., 2005; Yildirim et al., 2020; Ortakavak et al., 2020; Obodai et al., 2019; Kahangwa et al., 2020), spatial planning (Busayo et al., 2019; Cetin, 2015a, b, c; Cetin et al., 2018), vegetation cover (Fisher et al., 2021; Akanwa et al., 2017; Aksoy et al., 2022a, b), climate change (Saintilan et al., 2021), habitat diversity (Malaviya et al., 2010), land surface thermal characteristics (Gungor et al., 2021; Willie et al., 2019; Adiguzel et al., 2022; Bozdogan Sert et al., 2021; Zeren Cetin & Sevik, 2020; Zeren Cetin et al., 2020; Kaya & Coşkun, 2019; Kaya et al., 2018, 2009; Cetin, 2019, 2020a, b), forest fire risks (Kavlak et al., 2021), and water quality (Batbayar et al., 2019); although in some cases, it is not possible to assess impacts using RS and GIS data especially for the studies related to chemical and biological changes (Cesur et al., 2022; Cetin & Jawed, 2022; Orimoloye & Ololade, 2020; Latifovic et al., 2005; Kaya, 2009, 2010; Kaya & Coşkun, 2019; Kaya et al., 2009, 2016, 2018; Sahin et al., 2022; Aşikkutlu et al., 2021; Cicek et al., 2022). RS and GIS can also be used in many new areas such as ecological footprint (Bilge Ozturk et al., 2022; Cetin et al., 2021a), and organic carbon (Pekkan et al., 2021).

There has been recent research on land-use and land cover change in mining areas using RS and GIS

to analyze mining impacts. For example, Orimoloye and Ololade (2020) conducted a research to assess the land use and land cover changes over time using RS and GIS in a gold mining area in South Africa using Landsat 5 data for 1984, 1994, and 2004 and Landsat 8 data for 2014 and 2019. The results showed that mining and other anthropogenic activities cause changes in some areas in land cover and land use (areas affected increased and decreased during the study period). It was concluded that RS and GIS data and analyses should be used to monitor changes over time in mining areas but on-site timely monitoring would help to accurately identify impacts.

Yenilmez et al. (2011) researched the impact of coal mining in an abandoned coal mine site in Turkey using GIS with respect to topography and surface runoff pathways. They created a DEM with ASTER imagery, and detected the spatial concentrations of pollutants in a previously active, now deserted mine area. Khalil et al. (2014) conducted a GIS-based analysis to evaluate the pollution in an abandoned mining site in Morocco. They utilized Quickbird satellite imagery and used supervised classification for the analysis of land cover, besides the discussion on geochemical, hydrochemical, hydrological, geological, and climate data. They concluded that GIS and RS techniques are efficient in the assessment of the environmental problems in previously active mine sites.

Akanwa et al. (2017) carried out a study focusing on the impacts of mining activities on vegetation cover in 27 selected mining areas in Ebonyi State. The study area falls within the rainforest and savannah region of Nigeria (South-eastern part). Researchers used 1-m spatial resolution Geo-Eye-1 satellite image from 2015. Results indicated that mining activities caused over 400 ha green cover loss as well as degradation in arable lands.

## 5 Conclusions

Two different methods have been used to determine the mine site: unsupervised classification and vegetation index (NDVI). Although NDVI analysis is a frequently used method in land cover changes, it has not yielded accurate results within the scope of the study. The working area is not covered with dense vegetation. Therefore, mining activities did not cause significant vegetation damage. For this reason, it is

possible to say that NDVI analyses do not yield accurate results in areas with no dense vegetation. On the other hand, it was determined that the classification made with the unsupervised classification technique gave more accurate results within the scope of the study. The use of the supervised classification technique in land cover classification provides more detailed information than the unsupervised classification. On the other hand, supervised classification requires more intensive and more detailed study. Within the scope of this study, unsupervised classification enabled to get results faster.

The similar results were obtained for the NDVI analysis using Sentinel and Landsat satellite images between 2017 and 2020, except for the water surfaces. The differences observed other than water surfaces can be resulting from the differences in resolution and the fact that the satellite images do not belong to the same date. It has been determined that more details can be reached due to the higher spatial resolution of Sentinel satellite images.

It was determined that the studies conducted with NDVI and NDRe analyses show differences in water surfaces but overlap in other areas. In addition, in the analyses made using the Sentinel and Landsat satellites, the area with periodic positive NDVI or NDRe changes in the natural vegetation was not detected.

**Author Contribution** OIP, MC, MASK, TK, GBO, and AC designed the study and performed the experiments; OIP, MC, MASK, TK, GBO, AC, and MC performed the experiments, analyzed the data, and wrote the manuscript.

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**Data Availability** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

#### Declarations

**Ethics Approval and Consent to Participate** Not applicable.

**Consent for Publication** Not applicable.

**Conflict of Interest** The authors declare no competing interests.

## References

- Adiguzel, F., Bozdogan Sert, E., Dinc, Y., Cetin, M., Gungor, S., Yuka, P., Sertkaya Dogan O, Kaya E, Karakaya K., & Vural, E. (2022). Determining the relationships between climatic elements and thermal comfort and tourism activities using the tourism climate index for urban planning: a case study of Izmir Province. *Theoretical and Applied Climatology*, 147(3), 1105–1120. <https://doi.org/10.1007/s00704-021-03874-9>. Accessed 15 Jan 2022
- Aksoy, T., Dabanli, A., Cetin, M., Senyel Kurkuoglu, M. A., Cengiz, A. E., Cabuk, S. N., Agacsapan, B., & Cabuk, A. (2022a). Evaluation of comparing urban area land use change with Urban Atlas and CORINE data. *Environmental Science and Pollution Research*, 29(19), 28995–29015. <https://doi.org/10.1007/s11356-021-17766-y>. Accessed 17 Feb 2022
- Aksoy, H., Kaptan, S., Varol, T., Cetin, M., & Ozel, H. B. (2022b). Exploring land use/land cover change by using density analysis method in yenic. *International Journal of Environmental Science and Technology*, 1-18. <https://doi.org/10.1007/s13762-021-03847-5>
- Akanwa, A. O., Okeke, F. I., Nnodu, V. C., & Iortyom, E. T. (2017). Quarrying and its effect on vegetation cover for a sustainable development using high-resolution satellite image and GIS. *Environmental Earth Sciences*, 76(14), 1–12.
- Aşıkutlu, H. S., Aşık, Y., & Kaya, L. G. (2021). Determination of temporary shelter areas by the analytic hierarchy process method: The case of Burdur City Center, Turkey. *Turkish Journal of Agriculture-Food Science and Technology*, 9(4), 807–813.
- Batbayar, G., Pfeiffer, M., Kappas, M., & Karthe, D. (2019). Development and application of GIS-based assessment of land-use impacts on water quality: A case study of the Kharaa River Basin. *Ambio*, 48(10), 1154–1168.
- Bilge Ozturk, G., Ozenen Kavlak, M., Cabuk, S. N., Cabuk, A., & Cetin, M. (2020). Estimation of the water footprint of kiwifruit: In the areas transferred from hazelnut to kiwi. *Environmental Science and Pollution Research*, 2022. <https://doi.org/10.1007/s11356-022-21050-y>
- Busayo, E. T., Kalumba, A. M., & Orimoloye, I. R. (2019). Spatial planning and climate change adaptation assessment: Perspectives from Mdantsane Township dwellers in South Africa. *Habitat International*, 90, 101978.
- Bozdogan Sert, E., Kaya, E., Adiguzel, F., Cetin, M., Gungor, S., Zeren Cetin, I., & Dinc, Y. (2021). Effect of the surface temperature of surface materials on thermal comfort: A case study of Iskenderun (Hatay, Turkey). *Theoretical and Applied Climatology*, 144(1), 103–113.
- Cicek, N., Erdogan, M., Yuçedag, C., & Cetin, M. (2022). (2022) Improving the detrimental aspects of salinity in salinized soils of arid and semi-arid areas for effects of vermicompost leachate on salt stress in seedlings. *Water, Air, and Soil Pollution*, 233, 197. <https://doi.org/10.1007/s11270-022-05677-8>
- Cetin, M. (2015a). Using GIS analysis to assess urban green space in terms of accessibility: Case study in Kutahya.

- International Journal of Sustainable Development & World Ecology*, 22(5), 420–424.
- Cetin, M. (2015b). Evaluation of the sustainable tourism potential of a protected area for landscape planning: A case study of the ancient city of Pompeipolis in Kastamonu. *International Journal of Sustainable Development & World Ecology*, 22(6), 490–495.
- Cetin, M. (2015c). Consideration of permeable pavement in landscape architecture. *Journal of Environmental Protection and Ecology*, 16(1), 385–392.
- Cetin, M. (2016a). Sustainability of urban coastal area management: A case study on Cide. *Journal of Sustainable Forestry*, 35(7), 527–541.
- Cetin, M. (2016b). A change in the amount of CO<sub>2</sub> at the center of the examination halls: Case study of Turkey. *Studies on Ethno-Medicine*, 10(2), 146–155.
- Cetin, M. (2016c). Peyzaj Planlamada Biyoklimatik Konfor Alanların Belirlenmesi: Cide Kıyı Şeridi Örneği. *Türk Tarım-Gıda Bilim Ve Teknoloji Dergisi*, 4(9), 800–804.
- Cetin, M. (2019). The effect of urban planning on urban formations determining bioclimatic comfort area's effect using satellitia imagines on air quality: A case study of Bursa city. *Air Quality, Atmosphere & Health*, 12(10), 1237–1249.
- Cetin, M. (2020a). Climate comfort depending on different altitudes and land use in the urban areas in Kahramanmaraş City. *Air Quality, Atmosphere & Health*, 13(8), 991–999.
- Cetin, M. (2020b). The changing of important factors in the landscape planning occur due to global climate change in temperature, rain and climate types: A case study of Mersin City. *Turkish Journal of Agriculture-Food Science and Technology*, 8(12), 2695–2701.
- Cetin, M., Aksoy, T., Cabuk, S. N., Kurkcuoglu, M. A. S., & Cabuk, A. (2021b). Employing remote sensing technique to monitor the influence of newly established universities in creating an urban development process on the respective cities. *Land Use Policy*, 109, 105705.
- Cetin, M., & Jawed, A. A. (2022). Variation of Ba concentrations in some plants grown in Pakistan depending on traffic density. *Biomass Conversion and Biorefinery*, 1–7. <https://doi.org/10.1007/s13399-022-02334-2>. Accessed 12 Feb 2022
- Cetin, M., Aljama, A. M. O., Alrabiti, O. B. M., Adiguzel, F., Sevik, H., & Zeren Cetin, I. (2022b). Determination and mapping of regional change of Pb and Cr pollution in Ankara City Center. *Water, Air, & Soil Pollution*, 233(5), 163, 1-10. <https://doi.org/10.1007/s11270-022-05638-1>
- Cesur, A., Zeren Cetin, I., Cetin, M., Sevik, H., & Ozel, H. B. (2022). The Use of Cupressus arizonica as a biomonitor of Li, Fe, and Cr pollution in Kastamonu. *Water, Air, & Soil Pollution*, 233(6), 193, 1-9. <https://doi.org/10.1007/s11270-022-05667-w>
- Cetin, M., Zeren, I., Sevik, H., Cakir, C., & Akpinar, H. (2018). A study on the determination of the natural park's sustainable tourism potential. *Environmental Monitoring and Assessment*, 190(3), 1–8.
- Cetin, M., Agacsapan, B., Cabuk, S. N., Senyel Kurkcuoglu, M. A., Isik Pekkan, O., Baran Argun, E., ..., & Cabuk, A. (2021a). Assessment of the ecological footprint of Eskisehir Technical University–İki Eylül Campus. *Journal of the Indian Society of Remote Sensing*, 49(10), 2311–2327.
- Cetin, M., Aljama, A. M. O., Alrabiti, O. B. M., Adiguzel, F., Sevik, H., & Zeren Cetin, I. (2022a). Determination and mapping of regional change of Pb and Cr pollution in Ankara City Center. *Water, Air, & Soil Pollution*, 233(5), 1–10.
- Crowley, M. A., & Cardille, J. A. (2020). Remote sensing's recent and future contributions to landscape ecology. *Current Landscape Ecology Reports*, 5, 45–57.
- Duran, T. M., Oğuz, O. Ç., Dedeoğlu, B., Erkal, Y., & Seven, Y. (2020). Eti Maden İşletmeleri Kırka Bor İşletmesi. Kudret Emiroğlu, HIST 200–6 (2019–2020 Fall), 3. <http://repository.bilkent.edu.tr/handle/11693/53866#YHe4irFzAdM.mendeley>. Accessed 12 Jan 2022
- Earth Observing Systems. (2021). Normalized difference rededge, Retrieved May, 2021 from <https://eos.com/industries/agriculture/ndre/>. Accessed 12 Jan 2022
- Fisher, A. G., Mills, C. H., Lyons, M., Cornwell, W. K., & Letnic, M. (2021). Remote sensing of trophic cascades: Multi-temporal landsat imagery reveals vegetation change driven by the removal of an apex predator. *Landscape Ecology*, 36(5), 1341–1358.
- Garai, D., & Narayana, A. C. (2018). Land use/land cover changes in the mining area of Godavari coal fields of southern India. *The Egyptian Journal of Remote Sensing and Space Science*, 21(3), 375–381.
- Gitelson, A., & Merzlyak, M. N. (1994). Spectral reflectance changes associated with autumn senescence of Aesculus hippocastanum L. and Acer platanoides L. leaves. Spectral features and relation to chlorophyll estimation. *Journal of Plant Physiology*, 143(3), 286–292.
- Gungor, S., Cetin, M., & Adiguzel, F. (2021). Calculation of comfortable thermal conditions for Mersin urban city planning in Turkey. *Air Quality, Atmosphere & Health*, 14(4), 515–522.
- Haryani, N. S., Prasasti, I., Fitriana, H. L., Priyatna, M., & Khomarudin, M. R. (2018). Detecting the area damage due to coal mining activities using landsat multitemporal (Case study: Kutai Kartanegara, East Kalimantan). *International Journal of Remote Sensing and Earth Sciences*, 14(2), 151–158.
- Karan, S. K., Samadder, S. R., & Maiti, S. K. (2016). Assessment of the capability of remote sensing and GIS techniques for monitoring reclamation success in coal mine degraded lands. *Journal of Environmental Management*, 182, 272–283.
- Kaya, L. G. (2010). Application of collaborative approaches to the integrative environmental planning of Mediterranean coastal zone: Case of Turkey. *Journal of Faculty of Bartın Forestry*, 12(18), 21–32.
- Kaya, L. G., Cetin, M., & Doygun, H. (2009). A holistic approach in analyzing the landscape potential: Porsuk Dam Lake and its environs, Turkey. *Fresenius Environmental Bulletin*, 18(8), 1525–1533.
- Kaya, L. G., Yücedağ, C., Aşikkutlu, H. S., & Çokyığıt, H. (2018). Spatial design approaches to prevent damages from earthquake inside the buildings. *Mehmet Akif Ersoy Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 9(1), 55–62.

- Kaya, L. G. (2009). Assessing forests and lands with carbon storage and sequestration amount by trees in the State of Delaware, USA. *Scientific Research and Essays*, 4(10), 1100–1108.
- Kaya, L. G., & Coşkun, A. (2019). Kentleri dayanıklı yapmak için hesap verilebilirliğin artırılması ve yüksek denetleme kurullarının rolü. *Mehmet Akif Ersoy Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 9(19), 445–456.
- Kaya, L. G., Elinc, Z. K., Baktir, I., & Elinc, H. (2016). Utilization potentials of maquis shrubland in sustainable landscape design. *Journal of Environmental Protection and Ecology*, 17(4), 1357–1369.
- Kahangwa, C., Nahonyo, C., & Sangu, G. (2020). Monitoring land cover change using remote sensing (RS) and geographical information system (GIS): A case of golden pride and Geita gold mines, Tanzania. *Journal of Geographic Information System*, 12(5), 387–410.
- Kavlak, M. O., Cabuk, S. N., & Cetin, M. (2021). Development of forest fire risk map using geographical information systems and remote sensing capabilities: Ören case. *Environmental Science and Pollution Research*, 28(25), 33265–33291. <https://doi.org/10.1007/s11356-021-13080-9>
- Khalil, A., Hanich, L., Hakkou, R., & Lepage, M. (2014). GIS-based environmental database for assessing the mine pollution: A case study of an abandoned mine site in Morocco. *Journal of Geochemical Exploration*, 144, 468–477.
- Latifovic, R., Fytas, K., Chen, J., & Paraszczak, J. (2005). Assessing land cover change resulting from large surface mining development. *International Journal of Applied Earth Observation and Geoinformation*, 7(1), 29–48.
- Li, Y., Jia, Z., Sun, Q., Zhan, J., Yang, Y., & Wang, D. (2016). Ecological restoration alters microbial communities in mine tailings profiles. *Scientific Reports*, 6(1), 1–11.
- Ma, Q., He, C., & Fang, X. (2018). A rapid method for quantifying landscape-scale vegetation disturbances by surface coal mining in arid and semiarid regions. *Landscape Ecology*, 33(12), 2061–2070.
- Malaviya, S., Munsri, M., Oinam, G., & Joshi, P. K. (2010). Landscape approach for quantifying land use land cover change (1972–2006) and habitat diversity in a mining area in Central India (Bokaro, Jharkhand). *Environmental Monitoring and Assessment*, 170(1), 215–229.
- Morawitz, D. F., Blewett, T. M., Cohen, A., & Alberti, M. (2006). Using NDVI to assess vegetative land cover change in central Puget Sound. *Environmental Monitoring and Assessment*, 114, 85–106.
- Obodai, J., Adjei, K. A., Odai, S. N., & Lumor, M. (2019). Land use/land cover dynamics using landsat data in a gold mining basin-the Ankobra, Ghana. *Remote Sensing Applications: Society and Environment*, 13, 247–256.
- Orimoloye, I. R., & Ololade, O. O. (2020). Spatial evaluation of land-use dynamics in gold mining area using remote sensing and GIS technology. *International Journal of Environmental Science and Technology*, 17, 4465–4480.
- Ortakavak, Z., Çabuk, S. N., Cetin, M., Senyel Kurkuoğlu, M. A., & Cabuk, A. (2020). Determination of the nighttime light imagery for urban city population using DMSP-OLS methods in Istanbul. *Environmental Monitoring and Assessment*, 192(12), 1–17.
- Qian, T., Bagan, H., Kinoshita, T., & Yamagata, Y. (2014). Spatial-temporal analyses of surface coal mining dominated land degradation in Hologol, Inner Mongolia. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 7(5), 1675–1687.
- Pekkan, O. I., Kurkuoğlu, M. A. S., Cabuk, S. N., Aksoy, T., Yilmazel, B., Kucukpehlivan, T., ..., & Cetin, M. (2021). Assessing the effects of wind farms on soil organic carbon. *Environmental Science and Pollution Research*, 28(14), 18216–18233.
- Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. *NASA Special Publication*, 351, 309.
- Sahin, G., Cabuk, S. N., & Cetin, M. (2022). The change detection in coastal settlements using image processing techniques: A case study of Korfez. *Environmental Science and Pollution Research*, 29(10), 15172–15187. <https://doi.org/10.1007/s11356-021-16660-x>. Accessed 15 Jan 2022
- Saintilan, N., Bowen, S., Maguire, O., Karimi, S. S., Wen, L., Powell, M., ..., & Rodriguez, J. (2021). Resilience of trees and the vulnerability of grasslands to climate change in temperate Australian wetlands. *Landscape Ecology*, 36(3), 803–814.
- Waring, R. H., Coops, N. C., & Running, S. W. (2011). Predicting satellite-derived patterns of large-scale disturbances in forests of the Pacific Northwest Region in response to recent climatic variation. *Remote Sensing of Environment*, 115(12), 3554–3566.
- Werner, T. T., Bebbington, A., & Gregory, G. (2019). Assessing impacts of mining: Recent contributions from GIS and remote sensing. *The Extractive Industries and Society*, 6, 993–1012. <https://doi.org/10.1016/j.exis.2019.06.011>
- Winde, F., Hoffmann, E., Espina, C., & Schüz, J. (2019). Mapping and modelling human exposure to uranium mine waste using a GIS-supported virtual geographic environment. *Journal of Geochemical Exploration*, 204, 167–180.
- Willie, Y. A., Pillay, R., Zhou, L., & Orimoloye, I. R. (2019). Monitoring spatial pattern of land surface thermal characteristics and urban growth: A case study of King Williams using remote sensing and GIS. *Earth Science Informatics*, 12(4), 447–464.
- Yenilmez, F., Kuter, N., Emil, M. K., & Aksoy, A. (2011). Evaluation of pollution levels at an abandoned coal mine site in Turkey with the aid of GIS. *International Journal of Coal Geology*, 86(1), 12–19. <https://doi.org/10.1016/j.coal.2010.11.012>
- Yenmez, N. (2009). Stratejik bir maden olarak bor minerallerin Türkiye için önemi. *Coğrafya Dergisi*, 19, 59–94.
- Yıldırım, H., Aşikkutlu, H. S., & Kaya, L. G. (2020). Arazi Sanatı Sanal Uygulaması ile Farkındalık Yaratma: Burdur Gölü Örneği. *Journal of the Institute of Science and Technology*, 10(3), 2037–2046.
- Yuan, D., & Elvidge, C. (1998). NALC land cover change detection pilot study: Washington DC area experiments. *Remote Sensing of Environment*, 66(2), 166–178.

Zeren Cetin, I., & Sevik, H. (2020). Investigation of the relationship between bioclimatic comfort and land use by using GIS and RS techniques in Trabzon. *Environmental Monitoring and Assessment*, 192(2), 1–14.

Zeren Cetin, I., Ozel, H. B., & Varol, T. (2020). Integrating of settlement area in urban and forest area of Bartın with

climatic condition decision for managements. *Air Quality, Atmosphere & Health*, 13(8), 1013–1022.

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