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Assessment of mining impacts on environment in Muğla-Aydın (SW Turkey) using Landsat and Google Earth imagery

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Abstract Mining activities are important for the country's economy, but they cause serious threats to the environment. The geology of SW Turkey comprises Southern (Çine) Submassif of Menderes Metamorphic Massif and the Lycian Nappes. These geological units are unconformably overlain by lignite-bearing Miocene deposits, Upper Miocene–Pliocene conglomerates and Quaternary alluvial deposits. The aim of this study is to determine the geospatial change of mining activities in the Muğla-Aydın provinces, SW Turkey. For this purpose, Landsat-5 TM, Landsat-7 ETM, Landsat-8 OLI and Google Earth satellite image data for 1984, 1994, 2004, 2014 and 2018 have been used for change detection analysis. In 1984, only a Miocene lignite quarry was excavated. Then, in 1994, operations for the excavation of feldspar–quartz and marble quarries were started, and from 2004 to 2014, mining activities significantly accelerated. An aerial image of 2018 shows that an area of about 3800 ha has been exploited by mining at 149 quarries. Considering access roads to quarries, plants and dam reservoirs, the human impact extends over 3800 ha. The study area is home to several archaeological sites and endemic biota. Thus, there is an urgent need for the relocation and protection of archaeological heritages and endemic biota by creating special zones. Additionally, the rich geomorphologic features in the study area that require millions of years to form are at risk of totally disappearing.

Keywords Change detection · Landsat · Geomorphological formation · Environmental conservation · Muğla-Aydın · SW Turkey

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Introduction

The awareness for the conservation and protection of the environment has increased in both national and international spheres. The systematic preservation of all special components (flora, fauna, ancient ruins etc.) of the environment and the transfer of these natural and cultural heritages to future generations are of vital importance. Moreover, the preservation of geomorphological occurrences that require millions of years to form is an important part of earth sciences (Gül and Uslular 2017).

Civilization, urbanization and the increasing population bring a more demand to raw materials for housebuilding, cars, telephones, computers, household appliances, etc., which are indispensable for our everyday life. Their production requires geo-materials and minerals including iron, copper, zinc and lead. In addition, the majority of energy still needed to sustain life is obtained from fossil fuels. Therefore, we need efficient mining in today's world for sustainable surviving. Mining is defined as a way of extracting geo-materials from the earth's crust (Mossa and James 2013). Mining activities, whether large or small, require the removal of material from the earth's crust, which results in degradation of the environment in various ways through excavation, transportation or accumulation (Szczepanska and Twardowska 1999; Mossa and James 2013; Boengiu et al. 2016; Moeletsi and Tesfamichael 2018; Pericak et al. 2018; Kayet et al. 2019). Though mining has an important role for the economy of country, its areal distribution and regional impacts on socio-environment are not well known (Lobo et al. 2018). Modern mining techniques and heavy equipment cause dramatic irrevocable alterations in land cover. Some of these alterations due to quarries are the removal of vegetation, blasting, waste disposal and slope modification, which make mine regions vulnerable to geohazard (Mossa and James 2013). Airborne particulate matter from mining also cause several health problems (Espitia-Pérez et al. 2018). In addition, transportation of metal ores of salts, such as oxides, carbonates or sulphides, can cause dust which damages plant leaves (Kayet et al. 2019). Mossa and James (2013) reported that, worldwide, an area of up to half a million hectares was affected by mining activities in 1990. Recently, the modified land area is greater than this value. Moreover, heavy metal pollution, water contamination, destruction of aquifer layers and several other negative results have been reported because of mining particularly globally widespread lignite-coal quarries (Szczepanska and Twardowska 1999; Boengiu et al. 2016). Many countries have strict laws that ask rehabilitation of mining areas as fast as possible immediately after mining is over. However, this rehabilitation–remediation process takes a long time and in developing countries, the monitoring of these processes is not in the required level. Abandoned mines continue to threaten health and environment, such as unsafe open pits, leakages to groundwater (Mhlongo and Amponsah-Dacosta 2016). Environmental activists and local residents are opposed to the destructive effects of mining because the altered environment cannot provide ecosystem services since it cannot be reversed to its original situation.

Several studies have been done to determine the effect of open-pit mining areas (Menegaki and Kaliampakos 2006; Chen et al. 2015; Menegaki et al. 2015; Yu et al. 2018). Yu et al. (2018) computed the areal changes of land cover and determined their ecological, environmental and socioeconomic impacts against sustainable development. These studies make use of different visual programs and processes. For example, Menegaki and Kaliampakos (2006) used the ArcView software to extract the topographic alteration index; Chen et al. (2015) used high-resolution topography obtained from an unmanned aerial vehicle, a digital surface model, structure form motion and the slope local length of auto correlation (SLLAC) method; Menegaki et al. (2015) used chromatic contrast of the field view of a quarry area; Boengiu et al. (2016) used Landsat satellite images including vegetation cover index differentiation. All of these studies show the spatial change at a few or only one quarry. In addition, they are mostly concerned with production or development and give hardly any attention to the local geomorphology effects of each quarry.

Remote sensing data can provide information on changes of land cover over time, which is essential for environmental monitoring in mining areas as well as for environmental impact assessment due to their broad spectral range, affordable cost and rapid coverage of large areas. The synergistic use of remote sensing and ancillary data form geographical information systems (GIS) database, which can be used to store, process and retrieve environmental data (Charou et al. 2010). Remote sensing may be the sole way of acquiring information about the effects of remote mining locations in dense forested tracts which might be inaccessible on the ground (Malaviya et al., 2010). The integration of remote sensing with GIS can further strengthen the capabilities of environmental impact assessment of mining activities at both regional and local scales (Chevrel et al. 2001). Landsat and Google Earth images are widely used to determine land use/land cover (LULC) changes caused by mining activities. Malaviya et al. (2010) used LULC change analysis from 1972, 1992 and 2001 Landsat image data for quantification of land use and land cover changes (1972–2006) and habitat diversity in a mining area in Central India. Kayet et al. (2019) used Hyperion (hyperspectral) and Landsat data for spatial analysis of the vegetation dust cover near the mining site, transportation road, dumps and tailing ponds. Lobo et al. (2018) used Sentinel-2 images with Google Earth and GIS for determining the type, scale and status of mines in the Amazon, Brazil. Pericak et al. (2018) employed Landsat images and the Google Earth engine for developing an open-source model for regularly updating new surface mining that can be refined to capture mining reclamation in the future. The post-classification comparison method is the most common method used for land use/land cover change detection, which entails the comparison of independently produced classified images (Singh, 1989; Garai and Narayana, 2018). Kekovalı and Kalafat (2014) used Google Earth and Google Maps TruEarth® 15-m imagery for visualization and reported that satellite remote sensing can be efficiently used for the detection of mining and quarrying activities in Turkey. Numerous researches on environmental monitoring show that remote sensing observations are becoming an important tool for surveying different features at local, regional and global scales (Bochenek et al. 1997; Sunar and Ozkan 2001; Fensholt and Sandholt 2003; Vijdea et al. 2004; Belward and Skøien 2015; Ma et al. 2017).

This study was carried out in Milas, Yatağan and Kavaklıdere (Muğla Province) and Çine and Bozdoğan (Aydın Province), towns located in SW Turkey (Fig. 1). This region contains core and cover geological units of the Southern (Çine) Submassif of the Menderes Metamorphic Massif (Okay 2001; Özer et al. 2001; Whitney and Bozkurt 2002). They are tectonically overlain by the Lycian Nappes and unconformably overlain by tertiary units (Okay 2001; Özer et al. 2001; Whitney and Bozkurt 2002). The core units of the Southern Massif can be seen along the Yatağan–Çine, the Milas–Söke and the Kavaklıdere–Bozdoğan highways (Alkanoğlu 1984; Oğuz 2011; Gül and Uslular 2014, 2015, 2016, 2017; Karaarslan et al. 2017). The region is also home to special biota that are under protection (Kahraman and Körbalta 2017; Lise 2017). The studied area has been a host to various civilizations since ancient times, which attract a quite large number of local and foreign visitors.

In addition to these natural and cultural riches, a large number feldspar, quartz and marble quarries are excavated in the core of the Southern Submassif and the Lycian Nappes. Lignite quarries are widely distributed in tertiary deposits in the western part of Yatağan town which are used for fuel to Yatağan thermic power plant. These are important income sources both for the local and national economy. While there are few researches on the marble quarry wastes from the region (Bilgin and Koç 2013; Altun 2014; Güler and Polat 2018), several studies have been carried out on geomorphological features and the area's potential as a geopark (Alkanoğlu 1984; Oğuz 2011; Gül and Uslular 2014, 2015, 2016, 2017; Karaarslan et al. 2017). These studies all emphasized the negative effects of mining activities. However, none of them mentioned the space- and time-dependent changes related to mining. Thus, this study aimed to determine the total deformed area due to mining activities and analyse the effect of mining on the environment along with the regional geomorphology.

Materials and methods

The study area covered roughly 440,000 ha within the towns of Milas, Yatağan and Kavaklıdere (Muğla) and Çine and Bozdoğan (Aydın). Multi-temporal Landsat data and high-resolution Google Earth data for the years 1984, 1994, 2004, 2014 and 2018 were used to determine the geospatial changes caused by mining (Tables 1 and 2) in the area. Imagery from the Landsat 5 Thematic Mapper (TM) for 1984 and 1994, the Landsat 7 Enhanced Thematic Mapper (ETM) for 2004 and the Landsat 8 Operational Land Imager (OLI) for 2014 and 2018 were acquired from the website https://earthexplorer.usgs.gov/ (Table 1). The Google Earth imagery data for 1984, 1994, 2004, 2014 and 2018 were acquired from Google Earth software. The initial mining activity was started in the Yatağan region in 1984. Then, the images of 1994, 2004 and 2014 were examined to observe the changes at 10-year intervals. The 2018 images were investigated to assess the magnitude of the quarries spreading using Arcgis, Envi and Google Earth software. The areas and perimeters of 149 quarries (seen white due to the deformed topography and destruction of the forest in the Google Earth images) were determined in the 2018 Google Earth images. The statistical evaluation was made with the Excel software and presented in detail. The types of quarries were determined based on geological maps, previous studies and field trips.

Geological setting

The Menderes Massif is one of the biggest metamorphic complexes that evolved due to the Alpine orogeny (Şengör et al. 1984; Bozkurt et al. 1995; Whitney and Bozkurt 2002). Southern (Çine) Submassif, which is part of the Menderes Massif, is exposed between the towns of Milas, Yatağan and Kavaklıdere (Muğla) and Çine and Bozdoğan (Aydın) in SW Turkey (Konak et al. 1987; Bozkurt et al. 1995; Bozkurt 2004; Erdoğan and Güngör 2004; Erdoğan et al. 2011; Koralay et al. 2012; Bozkurt et al. 2015; Seyitoğlu and Işık 2015). It extends

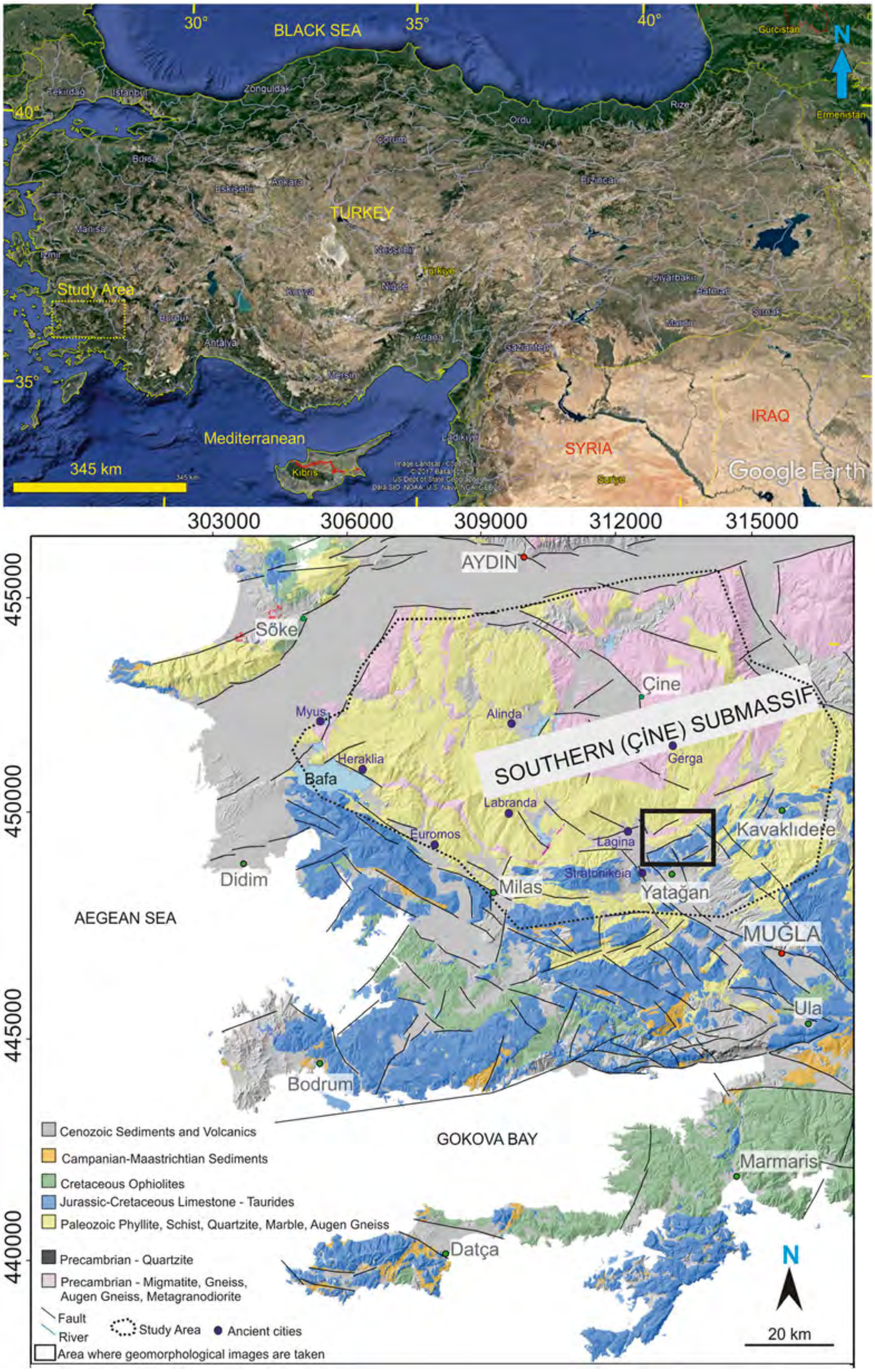


Fig. 1 Location map of the study area (Google Earth image) including general geological map and the digital elevation model (modified from Okay 2001; Özer et al. 2001; Whitney and Bozkurt 2002; Gül and Uslular 2016)

Table 1 Details of Landsat data used for study

Satellite	Sensor	Path/row	Year	Resolution (m)
Landsat	TM	180/034	1984	30
Landsat	ETM	180/034	1994	30
Landsat	ETM	180/034	2004	30
Landsat	OLI	180/034	2014	30
Landsat	OLI	180/034	2018	30

to the east. This submassif includes hills of 700–750-m-high hills at the centre and surrounding valleys. Candan et al. (2001) reported that the core part of this submassif contains metasediments, micaschist, orthogneiss, metagabbros and metanorite. This part was mapped as Precambrian quartzite, Precambrian migmatite, gneiss, augen gneiss and metagranodiorite in Fig. 1. The core units are overlain by the cover ones, including Palaeozoic phyllite, schist, quartzite and marble (Fig. 1; Okay 2001; Özer et al. 2001). Bozkurt (2004) defined a leucogranite intrusion (late Middle Eocene; Bozkurt et al. 2015) in the rectangular area (Fig. 1). The Alpine deformation produced HT/MP Barrovian-type regional metamorphism and greenschist retrograde metamorphism (Şengör and Yılmaz 1981; Şengör et al. 1984; Bozkurt and Satır 2000; Bozkurt and Oberhansli 2001; Rimmele et al. 2003; Bozkurt 2004). Southern movement of the Lycian Nappes including the blue-coloured Jurassic–Cretaceous limestone and Cretaceous ophiolite caused the development of metamorphism (Bozkurt 2004). This metamorphism and related geological processes generated the formation of industrial minerals such as feldspar (albite), quartzite and marble (Kuşçu 1992; Kun et al. 1999; Uygun and Gümüşçü 2000; Özer et al. 2001; Bağcı 2006; Yavuz et al. 2005, 2005a). All of these units are unconformably overlain by post-Oligocene lignite-bearing deposits, which filled the E–W and NNW–SSE grabens (Atalay 1980; Görür et al. 1995; Gürer and Yılmaz 2002; Gül 2015).

Features of the study area needing preservation and monitoring

The region hosts various remarkable geomorphological formations, several ancient cities and endangered biota. These features are in need of protection for both for present and future generations. This region is evaluated under the term of the Menteşe in the Aegean Region (W Turkey). The most important elevation in this area is the Beşparmak Mountain (1350 m), east of Lake Bafa. The northern and eastern parts of the study area are limited by alluviums of the Büyük Menderes River (Fig. 1; active graben). The slopes of the Menteşe Mountains are covered by oak, pine and chestnut forests, and the lower parts are with maquis. Agriculture (including olive, peanut pine etc.) and mining activities (marble, feldspar, lignite, quartzite) are the main sources of income for the local economy (Doğaner 2017). Due to the geomorphological occurrences and ancient cities, a geopark was planned to be constructed on an 18 thousand ha area between Yatağan (Muğla) and Çine (Aydın) (Lagina and Stratonikeia; Oğuz 2011) which encompasses a very small area in the south-eastern part of the studied 440 thousand ha large region. The geoparks are evaluated with their geological heritage properties. Because the region provides important information for the evolution of the earth's crust, such as fossil beds, tectonic structure, earth shape, mineral assemblage and mines, their subsequent visual transfer to future generations is important (Güngör 2012; Kazancı et al. 2012; http://www.jemirko.org.tr/tanimi/; access date: 22.12.2017).

Table 2 Spatial distribution of mine quarries at 2018 in Muğla-Aydın region (SW Turkey)

	Quarries between Milas and Çine (red regions in Fig. 6)		Quarries between Yatağan and Çine (yellow regions in Fig. 6)		Quarries between Kavaklıdere and Bozdoğan (blue regions in Fig. 6)	
Number of quarries	47		51		51	
Measurements	Area (ha)	Perimeter (km)	Area (ha)	Perimeter (km)	Area (ha)	Perimeter (km)
Average	24.12	2.69	39.00	2.78	13.31	1.52
Maximum	190.00	11.20	909.00	20.00	171.00	10.90
Minimum	1.68	0.53	1.24	0.43	0.41	0.24
Standard deviation	34.91	2.49	128.12	3.31	29.32	1.92
Territorial sum	1133.72	126.26	1988.90	141.57	678.60	77.32
Total	Area 3801.22 ha; perimeter 345.15 km					

Geomorphological occurrences

These occurrences are visually observed along the Yatağan–Çine highway. The bald hill, domes and pillar features with a flat top were classified as large-scale structures, whereas the weathering pits, polygonal cracks, tafoni, honeycombs, corestones, blocks, spheroidal weathering, exfoliation structures and flared slopes were defined as small-scale geomorphological features (Fig. 2; Gül and Uslular 2014, 2015, 2016, 2017). The structural properties, mineral alignment–foliation, mineral strength differences (quartz versus feldspar), climate condition, subsurface weathering, exhumation and weathering period were determined as the main controlling factors (Gül and Uslular 2014, 2015, 2016, 2017). An exhumation, metamorphism of rocks and mineral alignments, goes back to at least the Miocene (Gürer and Yılmaz 2002; Bozkurt 2004; Koralay et al. 2012). These large- and small-scale geomorphological occurrences exhibit an interesting scenery for geotourism and when combined with historical sites and endangered flora and fauna all add great value to the cultural tourism and ecotourism. Recently, however, it was revealed that they are threaten by dense mining activities (Gül and Uslular 2014, 2015, 2016, 2017; Karaarslan et al. 2017). Thus, at least the special and unique natural and cultural features must be protected both for present and future generations.

Flora and fauna

Olive orchards, maquis, frigana bushes and forests of *Pinus brutia*, *Quercus coccifera* and *Pinus pinea* have been observed in the study area (Kahraman and Körbalta 2017; Lise 2017). It is reported that this region is home to rare and endangered flora *Cyclamen mirabile*, *Arenaria cariensis*, *Silene splendens* and *Liquidambar orientalis* and fauna including the Caria lizard (Lise 2017). These have great importance in terms of the ecotourism potential of the study area. At the same time, they also positively promote cultural tourism and geotourism. Moreover, olive trees, *Pinus pinea* and *Liquidambar orientalis* have an economic importance for the local villagers. Some parts of the study area are preserved under legislation as a natural site (Kahraman and Körbalta 2017), but they are still under pressure from expanding mining activities.

Historical sites

Information obtained from the web pages of the Culture and Tourism Ministry of the Turkish Republic (http://www.aydinkulturturizm.gov.tr/TR,64399/muzeler-ve-orenyerleri.html: access date: 05.12.2017; http://www.muglakulturturizm.gov.tr/TR,157773/muzeler-ve-bagli-oren-yerleri.html: access date: 05.12.2017) revealed that this region hosts several ancient cities namely Stratonikeia and Lagina in Yatağan town; Labranda, Euromos, Latmos, Myus and Herakleia in Milas town; Alinda and Gerga in Çine town; and Köreteke Castle in Bozdoğan town dates back to 4000 years (Fig. 1). Most of those cities are also under pressure from expanding mining activities. For example, the largest lignite-mining quarry extends between the ancient cities of Stratonikeia and Lagina (Figs. 1 and 3). Stratonikeia also contains remnants belonging to the Anatolian Seljuk State (eleventh century), the Period of Emirates (twelfth Century) and the Ottoman Empire (until the beginning of 1900s) and operated until the early of the Turkish Republic (twentieth century) (Söğüt 2015). If these potential attractions are evaluated in geotourism and ecotourism manner, this region may become a new tourism centre.

Digital image analysis and geospatial change of mining activities

The Landsat and Google Earth images were used for analysing the geospatial change of the mining activities in the area. Google Earth images with 0.50-m resolution and Landsat images with 30-m resolution were used for digitizing. The subset process was performed on the Landsat and Google Earth images to extract the study area by taking geo-referenced outline boundaries. The visual interpretation method was used for the Google Earth images and the unsupervised classification was employed for the Landsat images. The boundaries of potential mining areas were manually digitized from the Google Earth images from 1984, 1994, 2004, 2014 and 2018 using the visual interpretation method. First, the Landsat images of the study area were calibrated geometrically and radiometrically, followed by the unsupervised classification. The boundaries of potential mining areas were digitized from the classified Landsat images for 1984, 1994, 2004, 2014 and 2018. The digitized potential mining areas from the images were verified

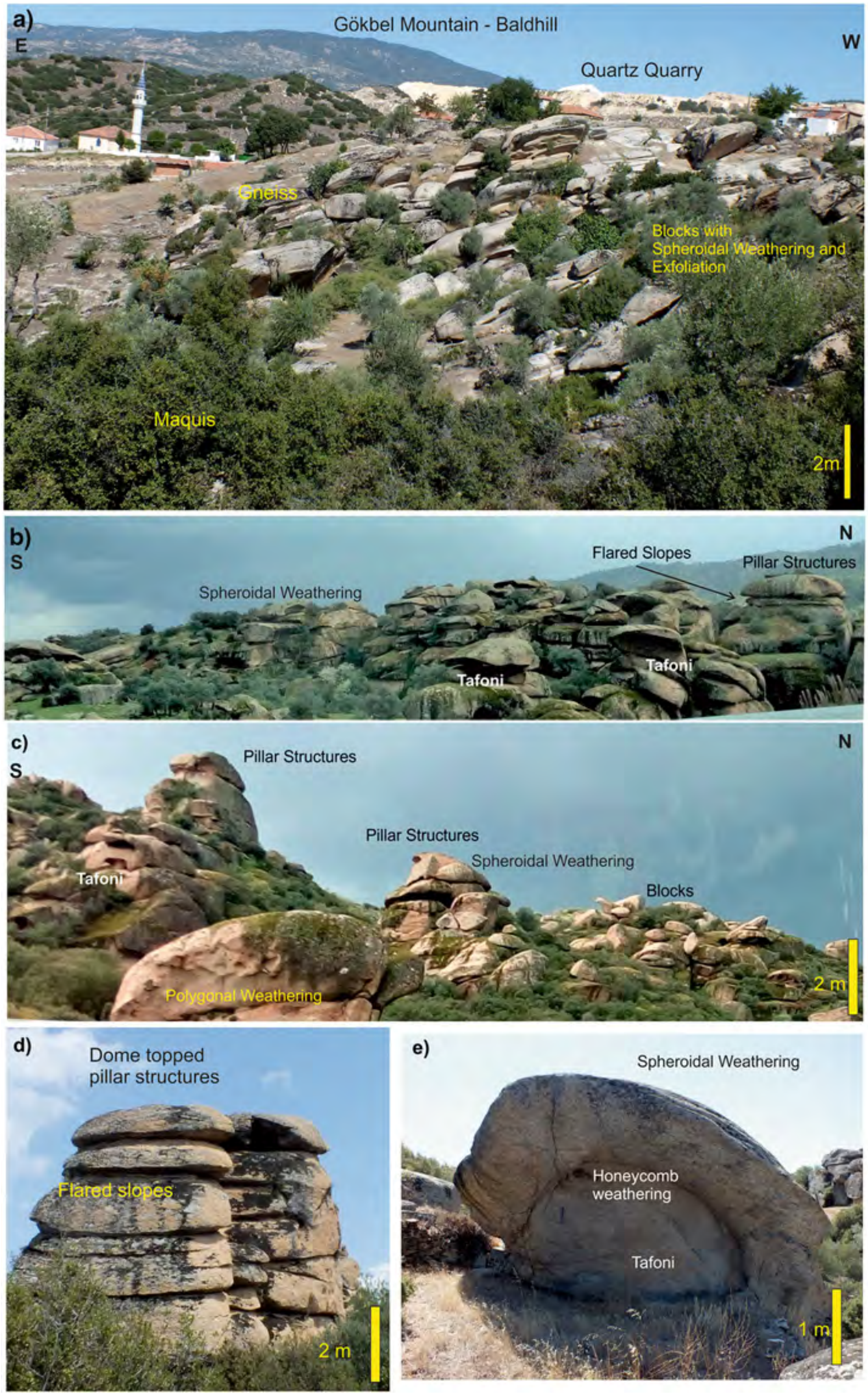


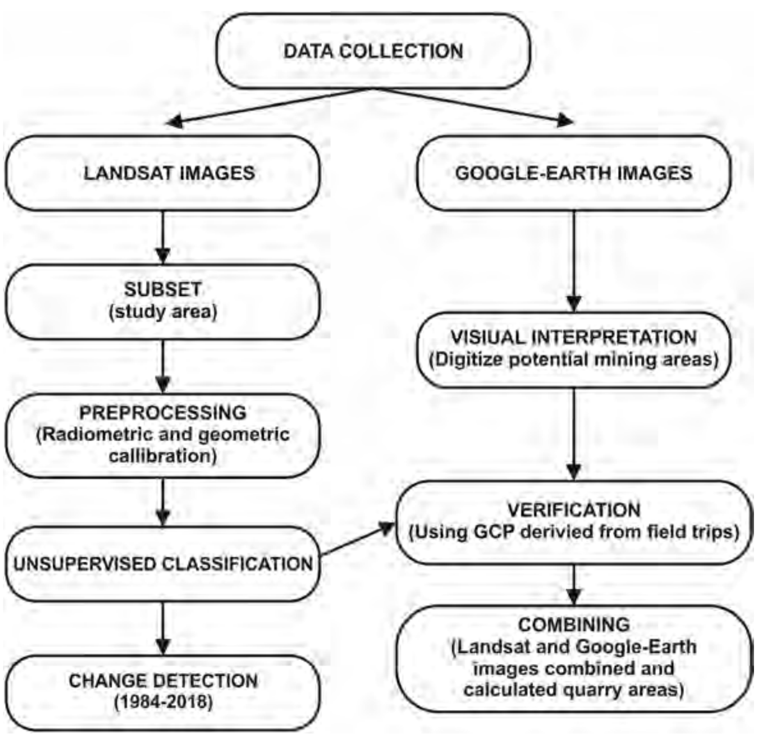
Fig. 2 Special geomorphological occurrences of the study area. (a) Gökbel Mountain (reported as bald hill by Gül and Uslular (2016)) in SE of the study area is surrounded by the valley. A quartz quarry is active SE of Gökbel Mountain. (b) Skirt of Gökbel Mountain contains various sized pillar structures with small-scale features. (c) Spheroidal weathering, polygonal weathering and tafoni structures were observed in and on the pillar structures. (d) Spheroidal weathering led to development of the dome-topped structures with flared slopes. (e) Honeycomb weathering can be observed inside the tafoni

Fig. 3 The ancient cities of Stratonikeia and Lagina are located very close to the Yatağan lignite quarry

via ground control points (GCP) which were obtained from field trips. The mining areas obtained from the Landsat and Google Earth images were then finally combined for calculating the annual exploited mining area (Fig. 4). Enhancement techniques like contrast stretching, histogram adjustment, filtering and changes in band combinations were applied when interpreting the dataset. To understand the changes in the study area due to mining activities, change detection was performed on the Landsat 5 TM image from 1984 and the Landsat 8 OLI image from 2018.

The satellite images were analysed in detail, where forestry areas are shown in green colour, lakes, rivers and sea areas are in dark blue and rocky areas are in red, dark pink and brown tones depending on the rock types. The areas used as flatland and agricultural areas are generally seen in light green tones with regular boundaries. The mining activity areas can be easily distinguished from other areas as white coloured, smooth geometric areas due to the breakage of rocks (Figs. 5, 6 and 7). Their depths vary between 0 and 200–300 m. The images from 1984–1994–2004–2014 were used to

Fig. 4 Flowchart of data analysis



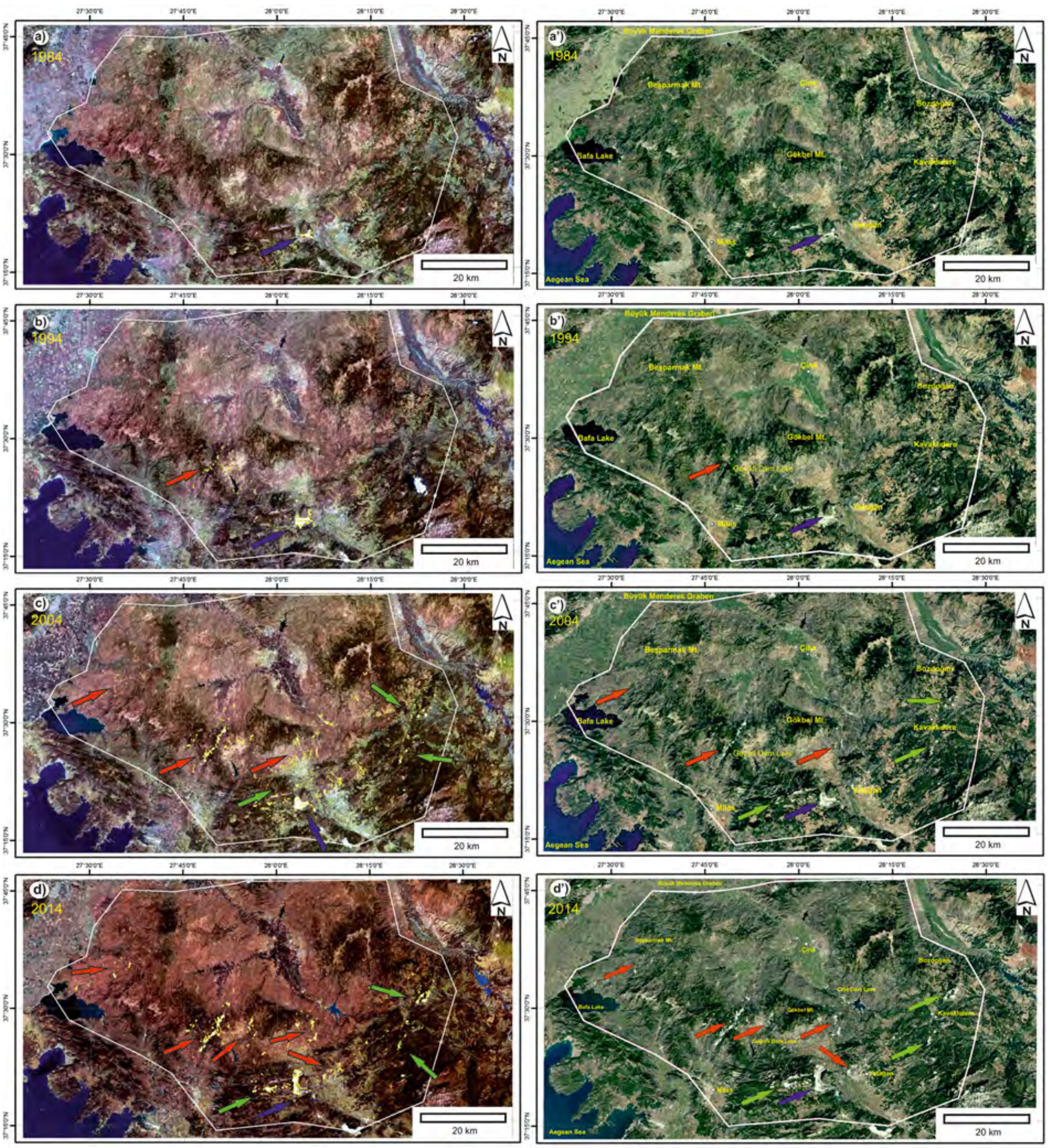


Fig. 5 (a–a′) The only mining activity is in the Yatağan lignite quarry (purple arrow). (a) 1984 Landsat 5 TM. (a′) Google Earth images. (b–b′) The lignite quarry was enlarging (purple arrow) and the feldspar–quartzite quarries started operation north of Milas (red arrow). (b) 1994 Landsat 7 ETM. (b′) Google Earth images. The Geyikli Dam Lake appeared between the Milas town and Gökbel Mountain. (c–c′) The lignite quarry continued to expand (purple arrow) and feldspar–quartzite quarries were observed NNW of Milas town (red arrow), and marble quarries were found between Milas and Yatağan and Kavaklıdere towns (green arrows). (c) 2004 Landsat 7 ETM. (c′) Google Earth images. (d–d′) The lignite quarry was continuing to expand to the north (purple arrow) and feldspar–quartzite quarries increased NNW of Milas town (red arrow) and west of Lake Bafa, and the marble quarries increased between Milas and Yatağan and Kavaklıdere towns (green arrows). (d) 2014 Landsat 8 OLI. (d′) Google Earth images. In addition, Çine Dam Lake appeared west of Gökbel Mountain

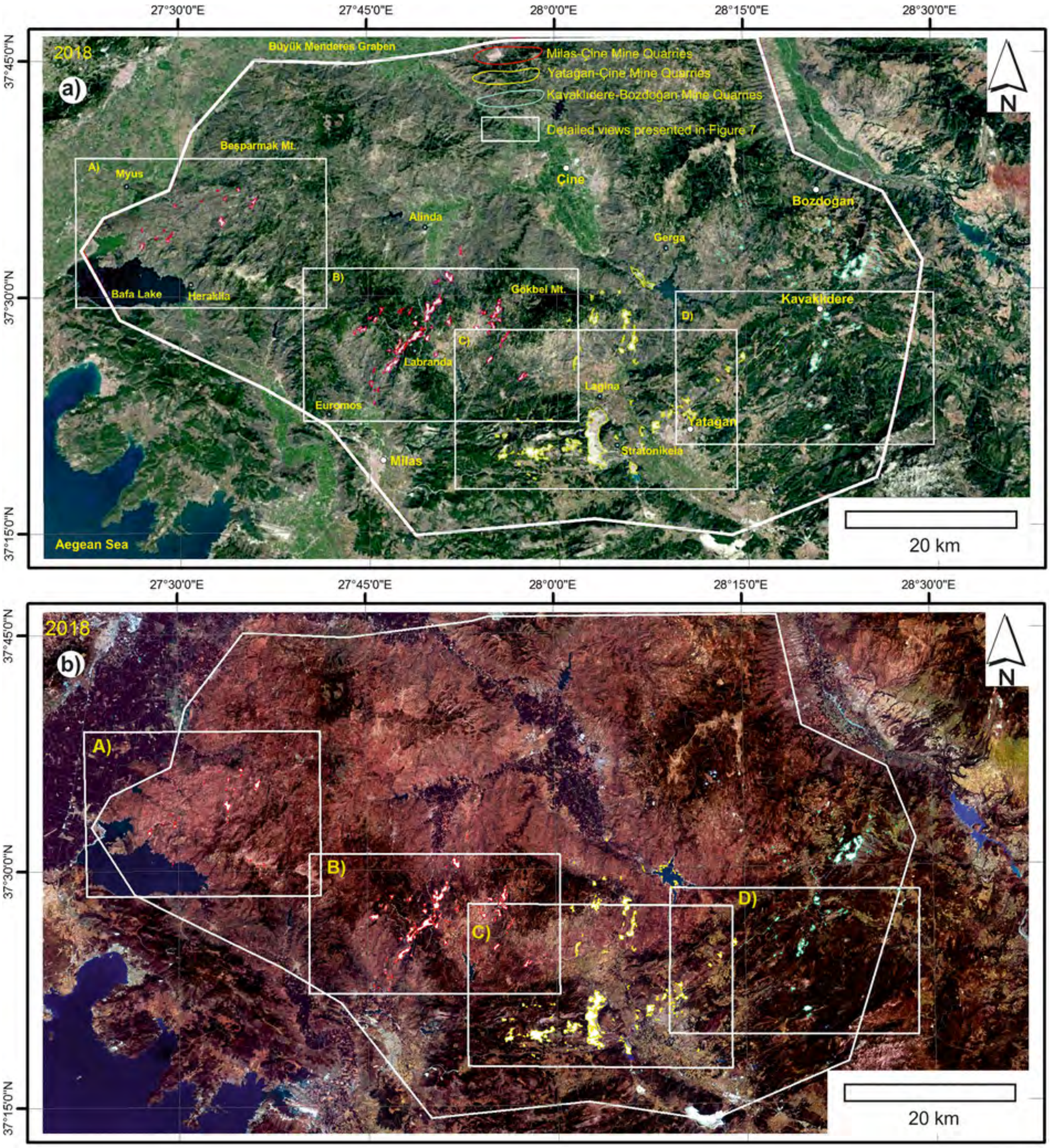


Fig. 6 (a) Google Earth and (b) Landsat 8 OLI views of the study site in 2018. Three different regions were defined based on geographical provinces and dominant quarry types. The Kavaklıdere region (blue) includes marble quarries. The region among the Çine town, Milas town, Lake Bafa and Beşparmak Mountain (red) contains feldspar–quartzite quarries. The largest yellow area between the ancient cities of Stratonikeia and Lagina is a lignite quarry; yellow regions north of this are feldspar–quartzite quarries; the remaining yellow regions are marble quarries. Detailed 2018 views (a, b, c, d) (rectangular areas) are presented in Fig. 7

express 10 years of visual change, while the 2018 images were used for a recent view and to determine the spatial distribution of mining activities.

The images from 1984 revealed the only significant mining activity at the lignite quarry in the western part of the town of Yatağan, which is near the ancient city of

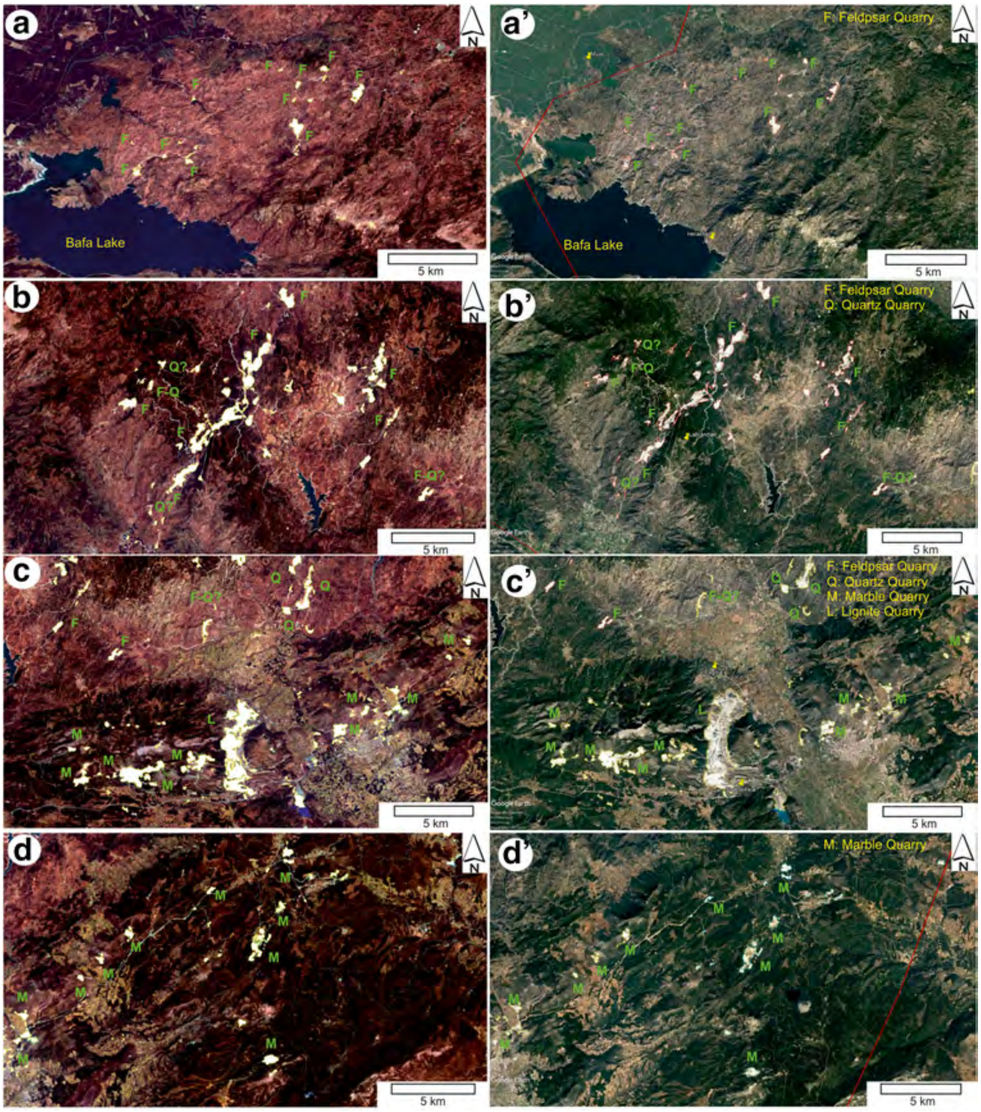


Fig. 7 Detailed Landsat 8 OLI images (a, b, c, d) and Google Earth views (a′, b′, c′, d′) of the study region in 2018. (a–a′) View of bare topography and view with quarries boundary north of Milas town. (b–b′) View of bare topography and view with quarries boundary east of Milas town. (c–c′) View of bare topography and view with quarries boundary west of Yatağan town. (d–d′) View of bare topography and view with quarries boundary of Kavaklıdere town

Stratonikeia. Apart from this, no mining activity was observed in the study area. The lignite deposits have been used in the Yatağan Thermic Power Plant which is located between the quarry and the town of Yatağan (Fig. 5(a–a′)).

After 10 years, the mining at the lignite quarry in the Yatağan region was expanded (Fig. 5(a–a′, b–b′)). With detailed examination, small white spots were detected near Yatağan centre that indicate marble quarries and spots around the ancient city of Labranda in the northern part of the town of Milas indicate feldspar–quartz quarrying activities (Fig. 5(b–b′)). In this period, the Geyikli Dam Lake appeared between the town of Milas and Gökbel Mountain, which is another anthropogenic impact observed in the 1994 image (Fig. 5(b–b′)).

The mining activities have increased considerably during the 10-year period after 1994 (Fig. 5(c–c′)). It is clearly observed that all the mining fields that have been operating since 1994 have boosted. In addition to these, new feldspar–quartzite quarries started to operate between the towns of Çine and Milas and between Yatağan and Çine (Fig. 5(c–c′)) along with. Numerous marble quarries were operating between Yatağan and Milas and around the town of Kavaklıdere (Fig. 5(c–c′)).

The spatial distribution of the mining activities has doubled in 10 years after 2004 (Fig. 5(d–d′)). This significant increase can be viewed through the feldspar–quartzite quarries in the region, which are located between Yatağan, Milas and Çine (Fig. 5(d–d′)). A similar expansion is also valid for the marble quarries between Yatağan and Milas and around Kavaklıdere (Fig. 5(d–d′)). In addition to the growth of these existing minefields, new feldspar–quartzite–marble quarries were also started operating (Fig. 5(d–d′)). The Çine Dam Lake appeared in the 2014 Google Earth image in the southern part of the town of Çine (Fig. 5(d–d′)).

The Landsat 8 OLI and Google Earth images from 2018 were used to determine the quarry areas in different regions. These areas cover roughly 440,000 ha and are spread to the towns of Milas, Yatağan and Kavaklıdere (Muğla) and Çine and Bozdoğan (Aydın). Three different regions were examined based on the geographical province boundaries and dominant types of mining activities (Fig. 6; Table 2).

The areas marked in red between Milas, Lake Bafa, Beşparmak Mountain and Çine are feldspar and quartzite quarries (Figs. 6 and 7). They started operation after 1994 (Fig. 5(b–b′)). A total of 47 large and small feldspars–quartzite quarries were determined. They vary in size between 1.68 and 190 ha and have a total area of 1133.72 ha (Figs. 6 and 7; Table 2). The presence of unmarked, small-scale quarries and numerous wind farms built after 2014 (not marked) indicate that the human intervention is greater than the measured value (Figs. 6 and 7; Table 2).

The sizes of the 51 quarries between Yatağan and Çine, marked in yellow, are between 1.24 and 909 ha and sum up to 1988.90 ha. The largest one with 909 ha is a lignite quarry between the ancient cities of Lagina and Stratonikeia (Figs. 6 and 7). Some sites have been rehabilitated with olive trees by enterprises. Twelve quarries in the northern part of the lignite area were evaluated as feldspar–quartzite quarries, covering a total of 366.73 ha which vary from 3.96 to 102 ha. Roughly 717.13 ha in this region are located in the western part of the lignite areas which are covered by the units of the Southern Submassif and the Lycian Nappes limestone and were evaluated as marble quarries (Figs. 6 and 7).

The areas marked in blue are in the vicinity of Kavaklıdere, between Kavaklıdere and Bozdoğan, and mainly indicate marble quarries excavated in cover units of the Southern Massif and Lycian Nappes limestone. The size of the 51 marked quarries varies from 0.41 to 171 ha, and they cover a total area of 678.70 ha (Figs. 6 and 7; Table 2).

In this study, 149 quarries were taken into consideration. Their total size was determined as 3801.22 ha, of which 909 ha are lignite quarries. Roughly 1500 ha are feldspar–quartzite quarries and are located near the towns of Milas, Yatağan and Çine and Lake Bafa, while 1391.8 ha are marble quarries between Milas and Yatağan, and around Kavaklıdere (Figs. 6 and 7; Table 2).

The mining activities have irreversibly destroyed roughly 3800 ha of the 440,000 ha study area's morphology. The effects of these mining activities are evidently seen from the change detection image (Fig. 8). The black-coloured areas in Fig. 8 show the most damaged spots by mining activities from 1984 to 2018 (Fig. 8). In addition to the mining activities, the dam lake, wind farms, road constructions for the quarry areas and numerous small quarries have not been calculated in this study. As well as the local geomorphology, these also have an adverse anthropogenic impact on the environment. For example, the size of the Çine Dam Lake south of Çine is 163 ha, while the Geyikli Dam Lake in the southern part of the ancient city of Labranda covers 217 ha. The irreversible destruction of the morphology is evident over more than in 4000 ha. Most of those changes have occurred in a very short time, precisely after 2004. Mining activities and related infrastructure including electricity and transportation networks may increase the destruction of the morphology and cause further environmental damage in the near future.

Evaluation in terms of environmental impact

Within the scope of this study, geospatial changes of mining in the region among the towns of Çine, Bozdoğan (Aydın), Milas, Yatağan and Kavaklıdere (Muğla) in SW Turkey were investigated (Figs. 1, 2, 3, 4, 5, 6, 7, 8 and 9). Feldspar and quartz quarries have been opened in the metamorphic rocks of the Southern (Çine) Submassif and marble quarries have been excavated in cover units of the Southern (Çine) Submassif and the Lycian Nappes (Figs. 1, 7 and 9). The largest lignite quarry (909 ha) is operated in tertiary cover of these units (Figs. 1, 7, 9, 10 and 11).

Large feldspar–quartz quarries have deformed a 1500-ha land in the central and southern parts and the

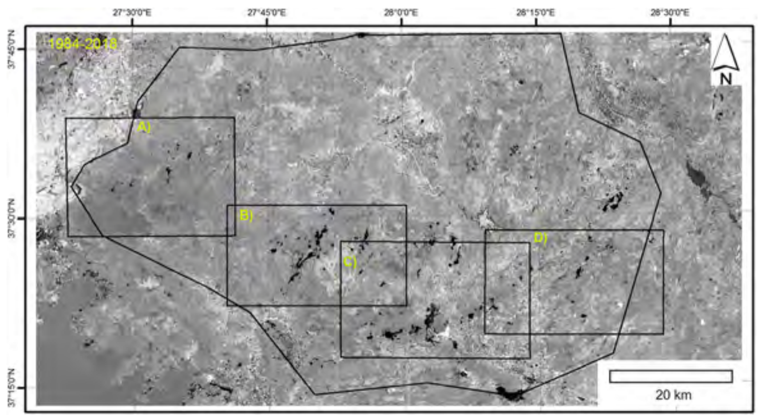


Fig. 8 Changes of mining areas from 1984 to 2018 with using the Landsat images (black areas greatly changed). Detailed 2018 views (a, b, c, d) (rectangular areas) are presented in Fig. 7

cover of the Southern (Çine) Submassif (Figs. 1, 6, 7 and 8(d)). In addition to the morphological disturbance, particulate matter, noise and surface contamination are other negative effects originated from these quarries. A 18,000 ha of the SE part of this region, planned as a geopark, contains important geomorphologic occurrences (Alkanoğlu 1984; Oğuz 2011; Gül and Uslular 2014, 2015, 2016, 2017; Karaarslan et al. 2017). The geopark region and the rest of the massif contain endangered species of flora and fauna and many historical sites. If they are evaluated together, this region has great potential in terms of biotourism, ecotourism, geotourism and cultural tourism.

The marble quarries have deformed a 1390-ha area in the southern cover part of the Southern (Çine) Submassif and the Lycian Nappes (Figs. 1, 6, 7 and 9). This part is also home to endangered flora and fauna species and many historical sites. In addition to the morphological disturbance, wastes have increased at quarries and rock processing plants during the marble

Fig. 9 (a) Field view of the marble quarry that includes 5–8-m steps. (b) Randomly dispersed marble waste including palladian, marble dust and blocks caused visual contamination. (c) Various sized residual material can be form during the mining operations; the blocks is one of coarser residual material. (d) Grinding of the marble led to finer-grained product that can be used in thermic power plant, cement industry etc. They cause visual contamination and air pollution

Fig. 10 (a) General view of the feldspar–quartz quarry. They deform the square kilometres region. (b) The mining operation contains 5–8-m bench, clean raw material transported to the plant and contaminated part is poured to the stripping site. They also deform the recent morphology and cause visual contamination and air pollution

excavation process. For example, wastes that have increased during marble mining are debris, palladian, marble slurry and marble dust (Bilgin and Koç 2013; Altun 2014; Gül 2015a). These wastes cause vegetation loss, noise and visual pollution (Fig. 9), surface and ground water contamination, soil contamination and

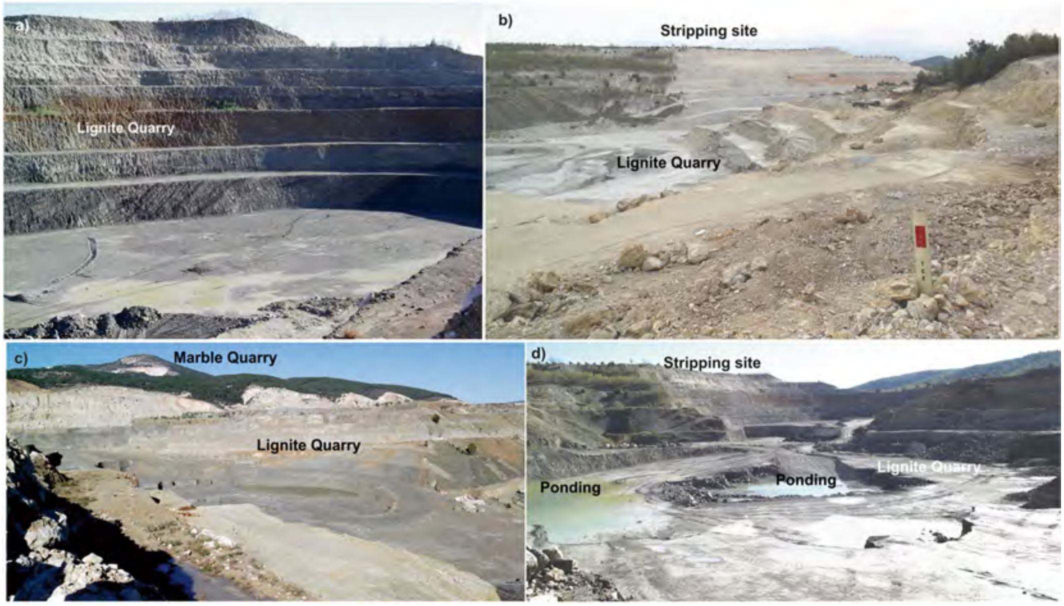


Fig. 11 (a) General view of the lignite quarry that includes 5–8-m steps. It has deformed all tertiary units west of Yatağan. Lignite transported to the thermic power plant via trucks or kilometres long conveyor belt. (b) Cover units on lignite have been excavated and transported to the stripping site. They also deform the recent morphology. (c) In west of Yatağan town, marble and lignite quarries operate close to each other. (d) Small ponding evolves during the lignite operation

atmospheric pollution (Bilgin and Koç 2013; Rajgor et al. 2013). Similar environmentally adverse effect can be observed in the Menderes Massif feldspar–quartzite quarries (Fig. 10).

Roughly 900 ha of the lignite-bearing tertiary units in the Yatağan region have been deformed by the lignite quarry (Figs. 1, 6, 7 and 11). Coal-mining has been reported as a major geomorphic activity in the USA (Mossa and James 2013). The change of the original profile also results in potential instabilities (Boengiu et al. 2016). Waste from coal-mining has caused water deterioration due to leaching (Szczepanska and Twardowska 1999). The use of low calorific value lignite in the Yatağan Thermic Power Plant has led to a great quantity of waste, which was deposited in waste disposal after long transportation (Baba 2001, 2003; Baba et al. 2003). This lignite waste, after combustion, has caused the ground water contamination (Baba 2001). This happens through water mixing with the alluvial aquifer (Baba 2001) and water use in agriculture. All of these negative effects add to the undesirable outcomes due to mining in terms of environmental issues. Recent enterprise planning in underground mining in the Yatağan region (Güney and Gül, 2018) caused potential subsidence, which is another adverse effect on the regional geomorphology. The deformed part has been partially rehabilitated, mostly through the planting of olive trees by a previous state company and later a private enterprise.

Mhlongo and Amponsah-Dacosta (2016) reported the detrimental effects of abandoned mining in terms of health, safety, environmental stress and social effects in South Africa. Thus, similar effects will mostly likely to be soon seen in the study area.

Destruction of the local geomorphology, visual pollution, noise–dust–particulate matter, destruction of the forestry area and soil–water–atmospheric contamination are all threatening the morphology, ancient cities, flora and fauna and tourism activities which are closely related to these assets. Although moving ancient ruins to safe places, and keeping flora and fauna alive in favourable conditions can be undertaken, these activities are impossible, for geomorphological formations when they are lost. They must be protected from mining and other negative disturbances. In addition to the protection of endangered biota, local protection sites for archaeological ruins and the geopark proposal (previously reported by Oğuz, 2011) in the study area must be realized immediately by local beneficiaries and government agencies for the protection of those geomorphological occurrences.

Mining should be initiated carefully considering the environmental impact (Mossa and James 2013). From 1984 to the present day, the geospatial increase of mining areas clearly shows the importance of mining in terms of the local economy. Thus, abandoning them in the near future is inappropriate as they are essential for local income and energy production. The mining activities in the study area are mostly intended to extract the most profitable part of the mine (wild mining), except a few good examples. In total, 3800 ha has already been lost. Moreover, if we take into consideration also the road access to quarry areas, dam reservoirs and other human construction, the destroyed area is greater than calculated 3800 ha. Thus, local governments (governorships, district governors, municipalities), mining companies and universities should urgently cooperate for more environmentally friendly mining. Once specific mining areas have been identified, integrated and innovative management plans should be developed, including access, development and promotion of these areas. Cultural tourism facilities such as geoparks should be implemented as an alternative income source for the local economy. Cultural tourism facilities should be constructed by taking into account the geomorphological characteristics of the region, its archaeological and historical significance, and the biota.

Conclusion

Landsat with 30-m and Google Earth with 0.5-m resolution images have been used for detecting the impacts of mining on the environment in the provinces of Muğla and Aydın (Turkey). The study shows the increasing trend of land cover changes caused by mining activities over the last 34 years. The combination of the low-resolution multispectral Landsat images and the high-resolution Google Earth images provides a highly convenient means of defining the boundaries of quarries. From 1984 to 2018 (especially the last 14 years), mining activities have increased between the towns of Yatağan, Milas and Kavaklıdere (Muğla) and Çine and Bozdoğan (Aydın) in SW Turkey. A total of 3800 ha out of the 440,000 ha has been demolished due to the mining activities. 1500 ha has been destroyed by feldspar–quartzite quarries, 1390 ha by marble quarries and 900 ha by the lignite quarry. All of these threaten the region by destroying ancient cities as well as the province's flora and fauna. In addition, the feldspar–quartz quarries have been demolishing large- and small-scale geomorphological occurrences. The increasing mining activities in this region revealed the importance of mining for the local and national economy. But necessary precautions for the protection of the special features of the studied region must be taken into immediate consideration for preserving natural and cultural heritages for present and future generations.

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