fahmiarif.fkip@unej.ac.id

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Research article

Monitoring Mining Impact for Geosites Using Time Series NDVI and Runoff in the Eastern Part of Southern Java Mountains, Indonesia

Fahmi Arif Kurnianto*, Elan Artono Nurdin, Era Iswara Pangastuti, Syintia Bella

Department of Geography Education, University of Jember, Jl. Kalimantan 37, Jember 68121, Indonesia

*) Correspondence: fahmiarif.fkip@unej.ac.id

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Abstract

Several geosites in the Eastern Part of the Southern Mountains of Java which are currently being mined are important geosites because they have recorded tectonic processes in the tertiary period. However, mining activities without environmental monitoring could be lead loss of rock outcrops and alteration of mineralscontained in the geosite. This study aims to monitor the vegetation index and run off in karst geosites and gold mined hills. We used Sentinel 2A Imagery on the Google Earth Engine (GEE) to get the vegetation index (NDVI) and run off values temporally. The Sentinel 2A data acquisition pro-cess in both 2018 and 2022 was carried out on the Google Earth Engine with specific steps consisting import data from cloud collection, cloud masking, and customing date acquistion. The results show that there has been a decrease in the vegetation index in the period 2018-2022 which is indicated by the decrease in the vegetation index value in the mined area. Another impact found is that there has been an increase in the run-off value in 2022 in both the Karst Puger Hills and the Tumpang Pitu Hills. The NDVI pattern on mined geosites has also changed significantly due to increasingly intense mining activities. The NDVI fluctuation pattern in the Karst Hills in 2018-2020 ranges from 0.41 to 0.74, while in 2021-2022 the fluctuation pattern is only in the range 0.05 to 0.4, respectively. The NDVI fluctuation pattern in the Tumpang Pitu Gold Hills in 2018-2019 is in the range 0.6 to 0.8, while in 2020-2022 it is in the range 0.38 to 0.52, respectively. Google Earth Engine is able to map the vegeta-tion index more efficiently by using a time series approach. These advancement is different compare to previous studies, where our study shows rapid acquisition during pre-processing, performing NDVI with rapid temporal analysis, and shows numerous degraded land in southern java mountains. Therefore, it can be concluded that there has been a decrease in the vegetation index and an increase in run off which can threaten the rock outcrop on the geosite. Furthermore, this study suggest that GEE should be considered as a main tool to identified degraded land, particularly for geosite conservation.

Keywords: Time series; NDVI; Run Off; Geosite; Google Earth Engine.

1. Introduction

Based on its tectonic setting, the eastern part of the Java Southern Mountains consists of various lithologies which are influenced by subduction and collision. During the early Cretaceous, this area was influenced by the collision between Eurasia and the East Java Micro Continent (Sapiie, 2017), in the middle part it was influenced by Quaternary volcanism (Utami *et al.*, 2019); and in the north there is a regression-transgression process (Lunt, 2019). During the Late Cretaceous to the Quaternary, this area was more influenced by subduction both during the Tertiary period which formed ancient volcanoes (Smyth *et al.*, 2008) and also during the Quaternary which formed Quaternary volcanoes (Aiuppa *et al.*, 2015; Nakada *et al.*, 2019). When compared to other regions, the eastern part of the southern mountains of Java is unique because it is influenced by the existence of the east java micro continent which is rifting from North Australia. East java micro continent is a part of Australia Continental Crust that rifted to Indonesian Island and it subducting to sundaland (Smyth *et al.*, 2007).

Based on tectonic evolution, the southern mountains of Java produce uplift processes in 2 cycles. In the first cycle it was able to lift metamorphic rocks in Bayat (Satyana, 2014) and in the second cycle it was able to lift limestone along the South East Java Coast (Lupi *et al.*, 2022; Negara *et al.*, 2021). The gold contained in the Tumpang Pitu Hills Geosite is the result of collision which in this process involved the old micro continent from North Australia which carried gold in the Cretaceous period, while the puger karst hills were the result of uplift due to subduction in the tertiary to quarterly periods. Li *et al.* (2022) also stated that in SW Borneo there are zircon and east java microcontinent movements originating from orogenic belts and cratons in northwestern and central Australia. In addition, Wu *et al.* (2019) stated that the mineralization materials of the Ciemas gold deposit originate from ancient continental crust.

Several studies related to the impact of mining in geopark areas show that poor mining management results in hydrological disasters (Briggs *et al.*, 2021); social conflict (Libassi, 2022; Tang & Liang, 2022); and damage to geodiversity (Muslim *et al.*, 2022; Portal, 2018). Therefore, several studies have used GIS to address problems in geopark areas, including GIS databases for geodiversity inventories (Santos *et al.*, 2022; Othman *et al.*, 2020; Luo, 2015), and GIS for geopark protection. from environmental damage (Ballesteros *et al.*, 2022; Leman *et al.*, 2016).

GEE has been used to map biophysical aspects of the earth's surface, including the integration of RUSLE-GEE to map erosion (Demir & Dursun, 2024), the use of sentinel 2 in GEE with NDVI analysis to map burned areas (Demir, 2023), and comparing them to MODIS which is included in GEE (Demir & Dursun, 2023). On erosion maps, GEE is effective for identifying average soil loss using a watershed approach. Furthermore, GEE has also been able to map burned areas rapidly both with a optical data such as Sentinel 2 as well as by integration with MODIS data. However, the context of this study focuses more on aspects of land cover change and land rehabilitation, so that studies related to land degradation in geosite areas are still not widely studied.

Apart from that, remote sensing has also been used in geopark areas to map geological structures related to disasters (Fu *et al.*, 2021); geopark potential development (Yongli & Weihong, 2017; Hoang *et al.*, 2016; Ummah *et al.*, 2018); and land use mapping in geopark areas (Shui & Xu, 2016; Avelar & Tokarczyk, 2014). These studies focus on disaster risk reduction and natural resource inventory. However, there are remain limited studies that focus on preserving geosites using the Google Earth Engine. The Tumpang Pitu Hills geosite has a very high scientific value because rock outcrops with gold alteration were found and its an evidence from deformation process since creatceous perioed in east java both collision process in cretaceaous and subduction process during tertiary until quaternary period. This study used the Google Earth Engine to measure the vegetation index and run off on the mined geosite. Therefore, this study aims to monitor the vegetation index and run off in karst geosites and gold mined hills.

2. Research Methods

2.1 Study Area

The eastern part of the southern mountains of Java was chosen because it has a very unique geodiversity and landscape. The diversity of geosites in this region is not only related to one tectonic process or volcanism, but rather a combination of several tectonic and volcanic processes and their very complex evolution. In general, the eastern part of the Java Southern Mountains is part of an ancient volcano and related to the geosite, this area has several outcrops that record tectonic evolution in the Cretaceous and Tertiary periods.

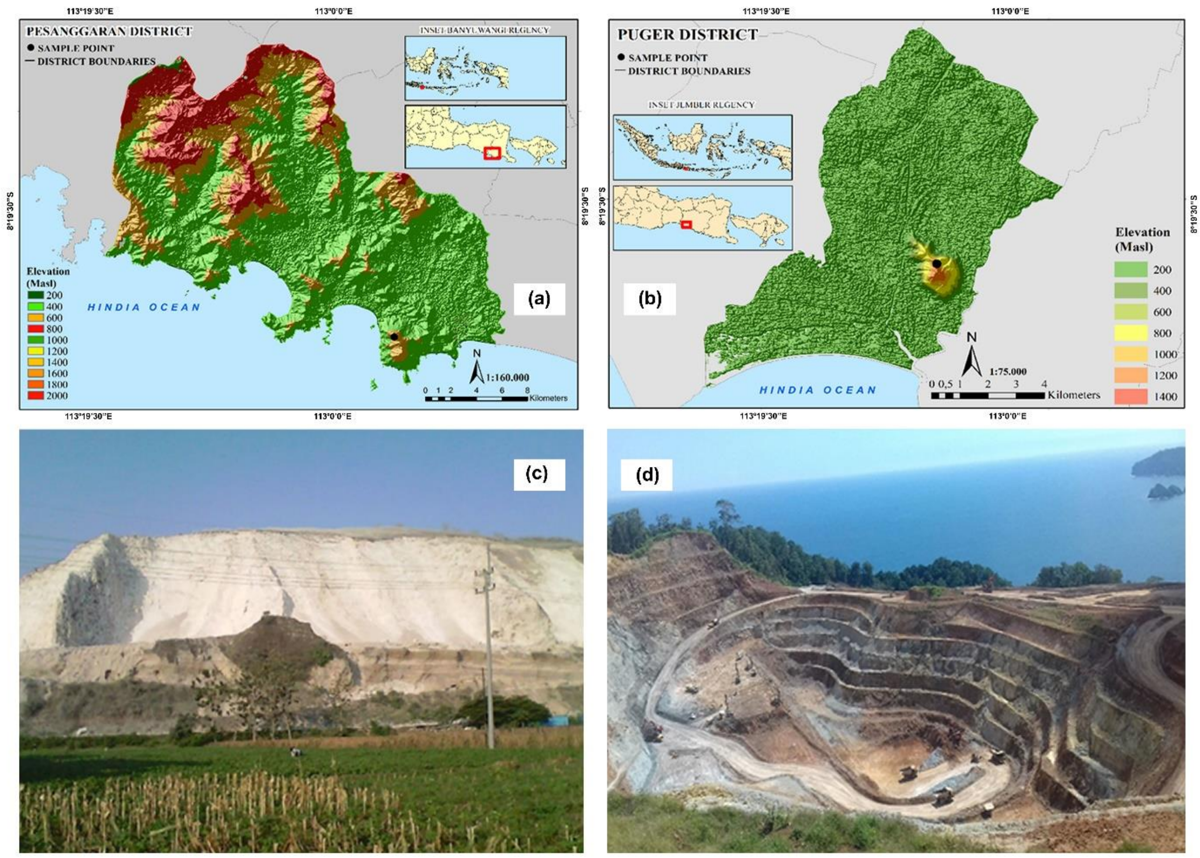

Figure 1. A. Study area in Pesanggaran, Banyuwangi; B. Study area in Puger, Jember; C. Mining area in Karst Hill, Puger, Jember; D. Gold mining area in Tumpangpitu Hill, Pesanggaran.

The study employed in East Java and is administratively included in Jember and Banyuwangi Regencies. This area has a tropical climate with hot and rainy seasons, with an average temperature of 28.2 C and an annual rainfall of 2808.4 mm. Elevation ranges from ±2 – 3300 masl based on 30 m Digital Elevation Model.

2.2. Data Acquisition

Sentinel 2A and MODIS data for 2018 and 2022 are used in this study due to sentinel 2 could be accessed by Google Earth Engine since 2018. Google Earth Engine was able to manage geospatial data rapidly and process it in one platform (Gorelick *et al.*, 2017). In terms of monitoring mine areas, we use the capabilities of Earth Engine including Sentinel 2A and MODIS image archives. The work of the Google Earth Engine used is a combination of the availability of satellite imagery and photo programming algorithms that are applied in monitoring mine land.

2.3 NDVI and Run Off Time Series Analysis

Vegetation index is a crucial data, representing sustainable development and natural resources management. These data were used not only for scientific purposes, however also thes used for another purposes, including collection of forest products, land use, water management, soil protection, analysis disaster, mining and so on (Julianto *et al.*, 2020). According to Kuchler, (1967) the landscape process are depent on vegetation pattern and density. In general, surface temperature was related to vegetation density, representing interaction between environmental conditions and climate (Dede *et al.*, 2019). NDVI is one of the parameters used to analyze conditions vegetation of an area. The NDVI considering relation between plants and radiation in the visible region of the spectrum, then the near infrared region also related to green plants at the surfaces. The NDVI calculation is as follows (Muzaky & Jaelani, 2019; Zhang *et al.*, 2017).

Sobrino *et al.* (2004) stated that the NDVI classification is divided becomes 3, namely (a) NDVI < 0.2 in this case, pixels are representing a bare land. Secondly, (b) NDVI > 0.5, i.e. pixels with an NDVI value higher than 0.5 are representing fully vegetated. Then (c) 0.2 ≤ NDVI ≤ 0.5, in this case, this pixel shows moderate condition. These classification reflecting calculated from a normalized transform of the NIR and red reflectance ratio, meanwhile the median value with a pixel which had the minimum cloudiness (Chen *et al.*, 2004; Hu *et al.*, 2018). In this study we also used MODIS to add rainfall and run off parameters. We classified NDVI and MODIS by using code at Google Earth Engine Platform at the following url : geescript. A visual representation of the methodological steps could be seen at Figure 2.

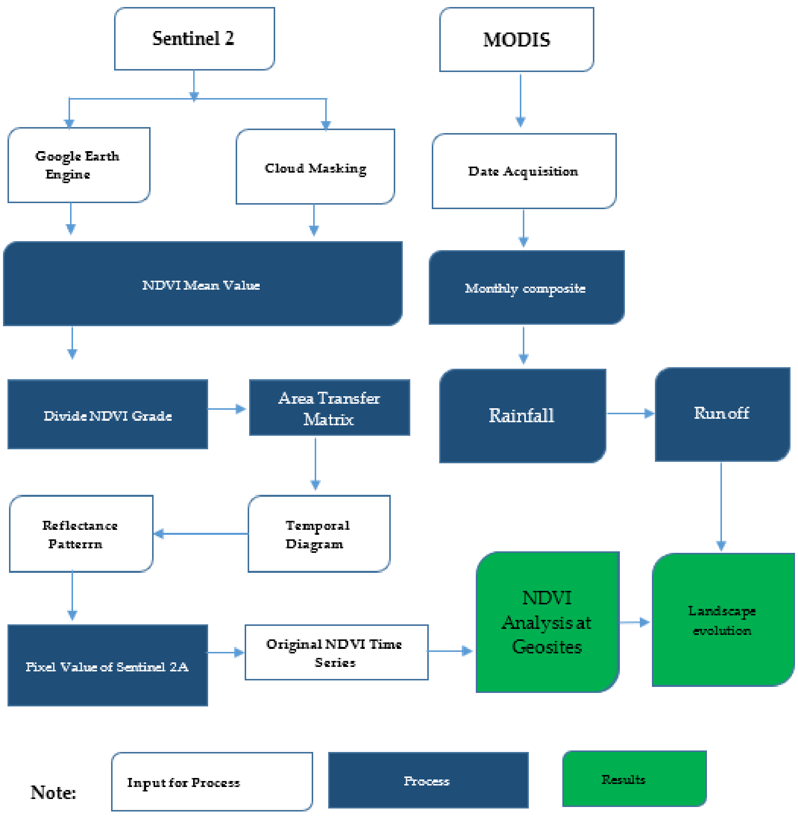

Figure 2. Research Framework

3. Results

3.1. NDVI Time Series

Figures 3A and 3B show a change in land cover from vegetation to bare land due to limestone mining within 4 years (2018-2022). Bare land increased significantly in the eastern part of the Puger karst hill with a low Vegetation index value (close to -1) and some others were found in the western part of the hill. The highest Vegetation index value is found in the middle of the hill with a value close to 1 because it has not been mined. Figures 4C and 4D show that in the middle of the Tumpang Pitu hill, there is additional vacant land with lower Vegetation index values over a period of 4 years (2018-2022). Figure 4D shows that some parts of the Tumpang Pitu hill have a very light color indicating a very low Vegetation index value. The color gradation also indicates a mining process, where a bright color means that mining has taken place intensively.

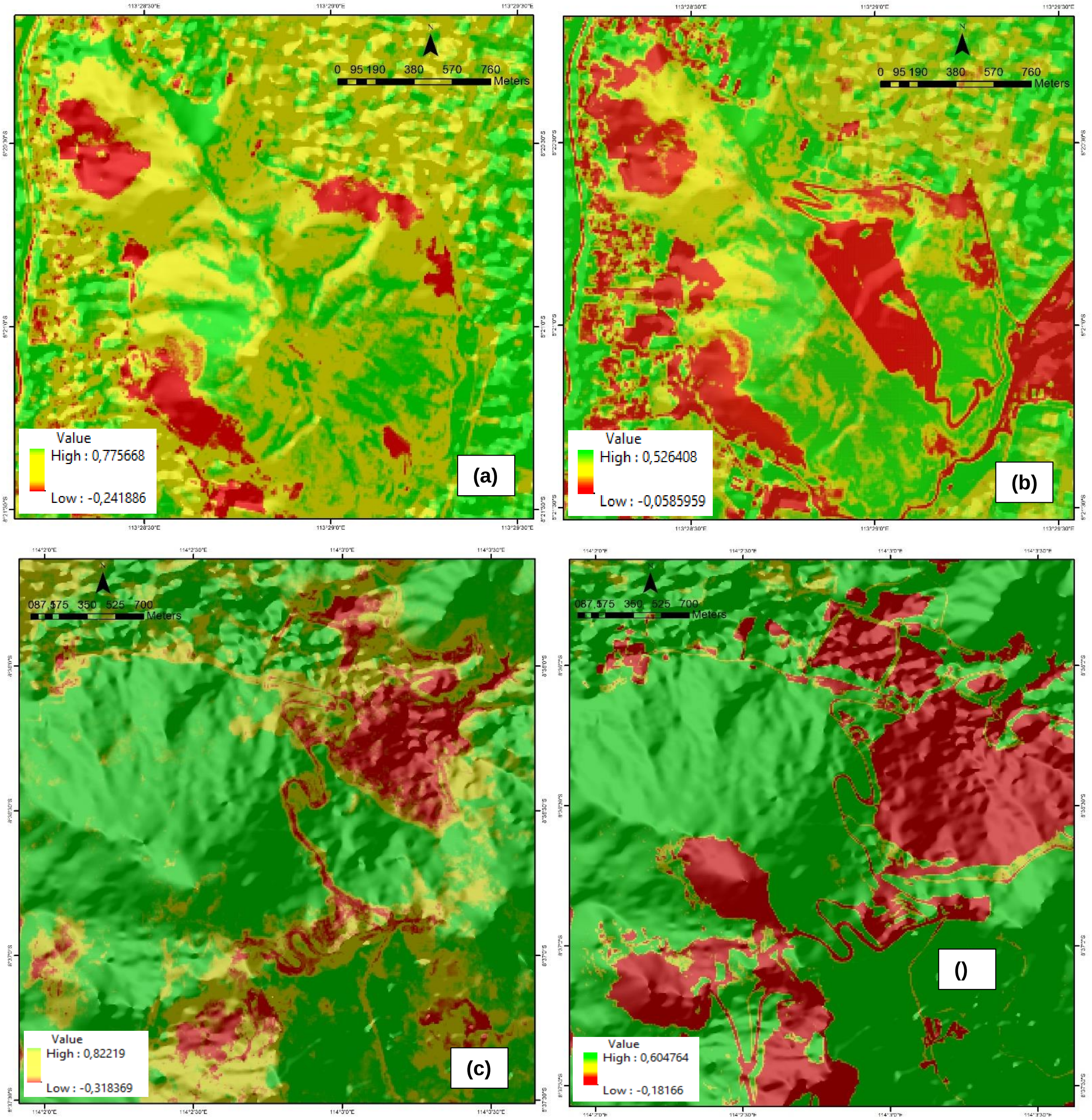

Figure 3. A. NDVI Map at Karst Hill (2018), B. NDVI Map at Karst Hill (2022), C. NDVI Map at Tumpang Pitu Hills (2018), D. NDVI Map at Tumpang Pitu Hills (2022).

Figure 4A shows that in the 2019 Puger geosite most of the pixels are in the pixel value range of 0.41 to 0.74, which has a fairly high vegetation density. However in 2022 (Figure 4B) there has been a change in pixel values in the range of 0.05 to 0.4. This change indicates that there has been an expansion of mining or deeper dredging of the limestone hills. Figure 4C shows the Tumpang Pitu Hill geosite in 2019, most of the areas have pixel values in the range of 0.6 to 0.8 which indicates that most areas have dense vegetation. However Figure 4D shows that in 2022, pixel values with most areas in the range of 0.38 to 0.52 which means there has been a decrease in vegetation density. In addition, another important finding in Figure 4D is that there is an decrease in pixel values in some other areas which are included in the category of low vegetation density (below 0), its indicated by a range of -0.01 in 2019 to -0.17 in 2022 which indicates that reforestation indicating deforestation at this area.

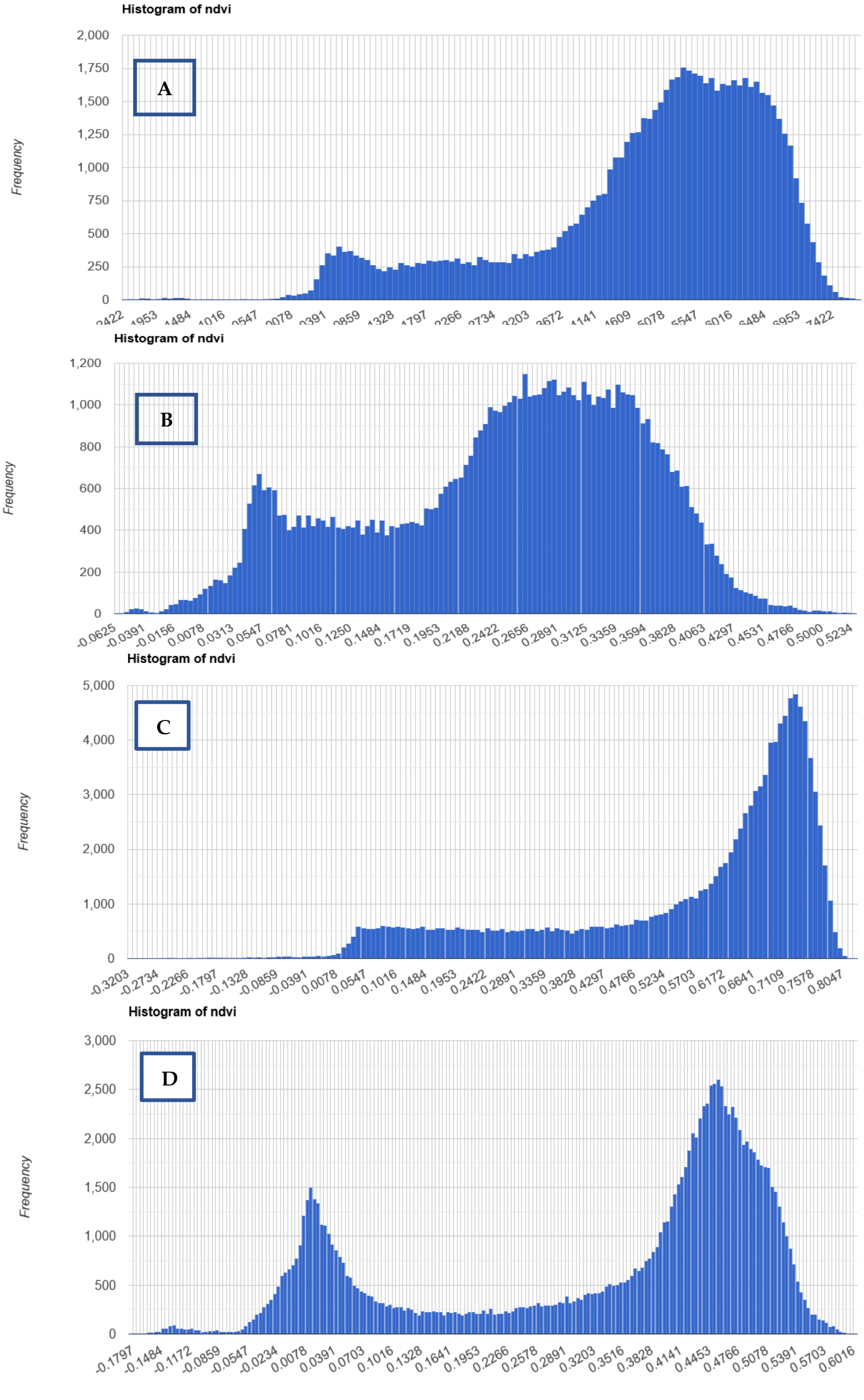

Figure 4. A. Pixel value at Karst Hill (2019), B. Pixel value at Karst Hill (2022), C. Pixel value at Tumpang Pitu Hill (2019), D. Pixel value at Tumpang Pitu Hill (2022)

Figure 5A shows that changes in the Vegetation index in the Puger karst hills occurred significantly in 2021. This indicates that in the 2021-2022 period there has been very intensive limestone mining. Another finding in Figure 5A is that there is a difference in the fluctuation pattern indicated by the fluctuation pattern between 0.2 to 0.6 in 2018-2020, whereas in 2021-2022 the fluctuation pattern is only in the range of 0.0 - 0.2. Figure 5B shows that there has been a significant change in the Vegetation index in the 2019-2020 range. This indicates that gold mining has been taking place very intensively as indicated by a decrease in the value of the Vegetation index from 0.8 to 0.1. Another finding in Figure 5B is that there has been a change in the fluctuation pattern, which in 2017-2019 was in the range 0.6 - 0.8, while in 2020-2022 it was in the range 0.0 - 0.1.

Figure 5. A. NDVI Time Series at Karst Hill , B. NDVI Time Series at Tumpang Pitu Hill

3.2 Run Off Time Series

Figures 5A and 5B show that there are differences in run-off with the same rainfall conditions caused by changes in the Vegetation index value from Dense to tenuous. This is influenced by the decreased soil infiltration capacity due to changes in vegetation land cover to vacant land. Furthermore, this increase in vacant land will also have an impact on the loss of outcrops of limestone, volcanic rock, and clastic sedimentary rock that should form stratigraphy. Figures 5C and 5D show that under the same rainfall conditions, the run off in 2019 and 2022 shows the same value. This was caused by reforestation carried out by miners on some land with a low Vegetation index replace some rock outcrops along with mineral alteration in this geosite.This run-off control can reduce environmental impacts such as floods and droughts, but cannot**.**

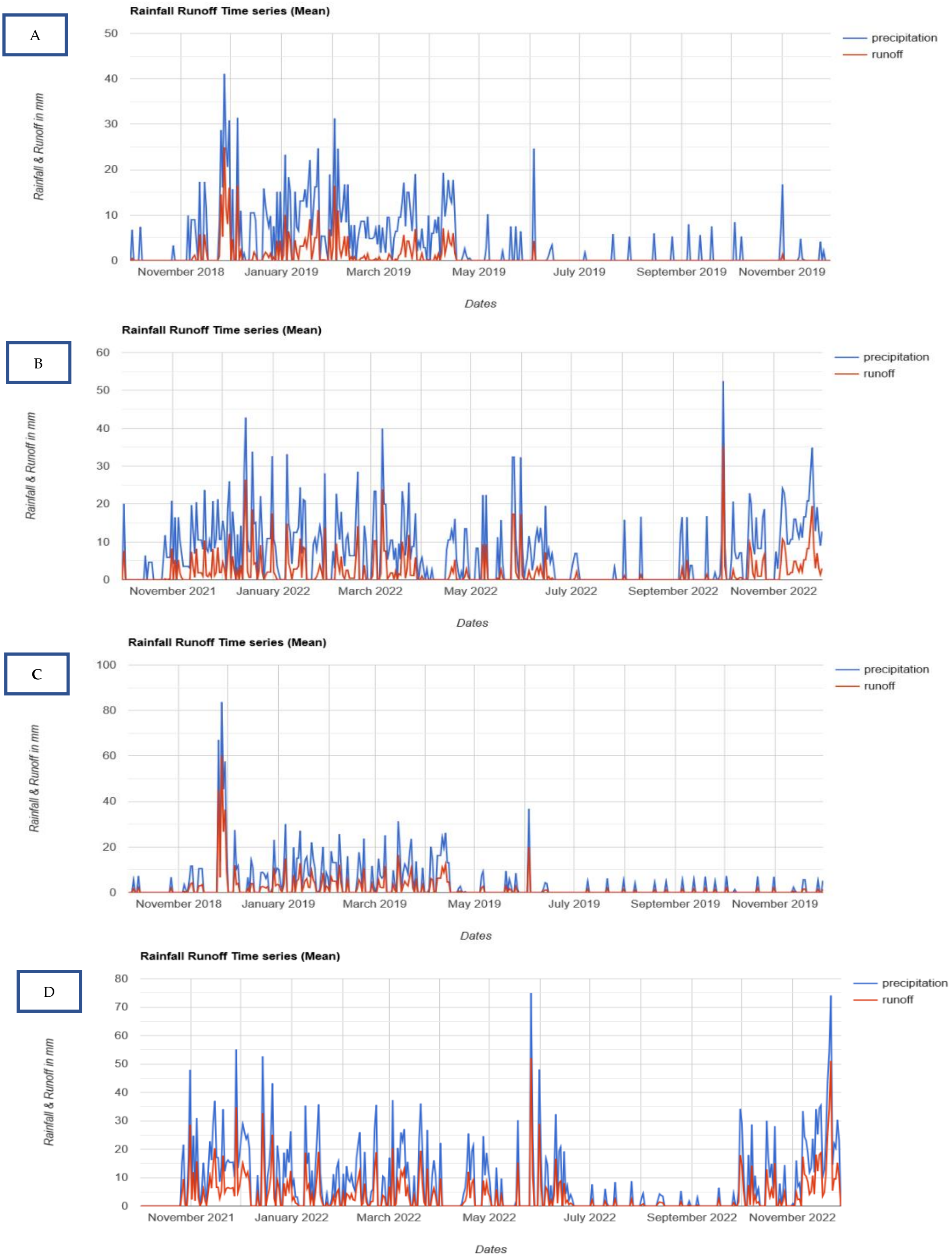

Figure 6. A. Run off at Karst Hill (2019), B. Run off at Karst Hill (2022), C. Run off at Tumpang Pitu Hill (2019), D. Run off at Tumpang Pitu Hill (2022).

4. Discussion

Our findings show both spatial and temporal data could improve monitoring methods towards several geosites in Karst Hill, Puger Jember as well as in Tumpang Pitu Hill Banyuwangi. In addition, whole process could be done rapidly due to whole data and these acquisition has been developed by the Google Earth Engine (GEE). Therefore, our finding contribute towards monitoring geodiversity in Eastern Pasrt of Southern Java Mountain, particularly to support survey methods that requires numerous resources. The findings in this study are supported by research by Lei *et al.* (2016) and Tian *et al.* (2013) which stated that MODIS-NDVI is able to detect the

impact of mining activities temporally and is able to relate it to rainfall. Yang *et al.* (2022); Fabre *et al.* (2020) were able to create clusters of vegetation indexes in mining areas with an accuracy of 79% using unsupervised NDVI time series monitoring. GEE with Sentinel 2A is able to efficiently map mining impacts at a more detailed spatial resolution. In the context of coastal areas of Southern Java, the findings of this study are able to better detect changes in the vegetation index on overlapping hills more quickly. This is supported by the research of Sunarta & Saifulloh (2020) which shows that NDVI in GEE is able to detect changes in the vegetation index within 5 years.

A decrease in the vegetation index in both the Puger Karst Hills and the Tumpang Pitu Hills can cause changes in the landscape and temperature in the area around this geosite. This is supported by the research of Singh *et al.* (2021) which states that a geosite must be able to provide comfort to visitors and learn about the geosite. In addition, the decrease in the vegetation index will also reduce the potential for both geosites to become global geoheritage which is in accordance with the study of Shrestha *et al.* (2021) which shows that NDVI is able to detect that animal diversity has a high correlation with a high vegetation index. In general, our finding shows significant contribution towards rapid mapping in mining areas, however several limitations such as type of mineral rocks as well as detail of ground deformation due to mining activities should be addressed using another imagery or machine learning algoritm.

This finding related to study from Sun *et al.* (2022) which showed that a decrease in the vegetation index will have an impact on topographic changes and also cause drought. Vegetation index fluctuations in both the Puger Karst Hills and the Tumpang Pitu Gold Hills can be monitored within 2-4 years. Juanda *et al.* (2021) stated that the vegetation index in the tropics can be monitored with sentinel 2A within 4 years. In contrast, Kimijima *et al.* (2021) found changes in the vegetation index in gold mines over 11 years (2011-2020) using Landsat. Therefore the use of sentinel 2 with GEE in this study was able to detect changes in the vegetation index in more detail and quickly.

Land cover mapping in mining areas is very important because it is able to map environmental changes more efficiently. This finding is supported by research by Jankowski *et al.* (2020) which states that land cover mapping in geopark areas can be done efficiently with multicriteria analysis. In addition, the results of research by Ahmadi *et al.* (2022) states that the grid-fuzzy method is able to map the distribution and vulnerability of geosite damage due to human activities.The reduction in the area of vegetation around the Tumpang Pitu hill has occurred within 7 years and some areas have not been properly rehabilitated as indicated by the increasing area of vacant land and the presence of standing water around the vacant land. Land cover in 2022 will potentially increase surface runoff and reduce soil nutrients. This finding is supported by the results of Scarsi *et al.* (2019); Reverte *et al.* (2020) which states that environmental changes occur very quickly in areas with high geodiversity.

Reduced vegetation due to gold mining on Mount Tumpang Pitu needs attention from stakeholders because it is part of a very rare geodiversity in Indonesia. This finding is supported by the research of Herrera-Franco *et al.* (2022); Jia *et al.* (2023); and Nazarudin (2017) which stated that the presence of mining in surrounding areas with high geodiversity needs to be monitored so that it does not have an impact on the occurrence of disasters and community empowerment is needed to participate in maintaining geodiversity. In addition stated that monitoring of the Ciletuh Geopark has succeeded in detecting changes in land use from agricultural land to housing for tourism purposes. This is related to the landscape in the geopark area which has the potential to be used as a tourism area. Kariuki e*t al.* (2021) found that agricultural and urban expansion occurred in the geopark area in northern Tanzania.

4. Conclusion

Changes in the vegetation index have been monitored more efficiently through the NDVI and MODIS time series with the Google Earth Engine. There is a decrease in vegetation density as indicated by a decrease in the value of the vegetation index. The vegetation index pattern also underwent significant changes after 2021 in the Karst Puger Hills and after 2020 in the Tumpang Pitu Hills. An increase in run off was found in both geosites which also indicated a decrease in the outcrop which is evidence of the tectonic evolution of the Cretaceous to the Quaternary in the

Southern Mountains of Java. This study show several implications, particularly regarding water quality due to mining activities, therefore these issues could be addressed by the future studies. In addition, involving another hyperspectral remote sensing or multi-sensor data could be beneficial to identify surfaces areas including mineral type and ground deformation in mining areas and its surrounding.

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Author Contributions

Conceptualization: Kurnianto, F. A., Nurdin, E. A., Pangastuti, E. I., & Bella, S; **methodology**: Kurnianto, F. A., Bella, S ; **investigation**: Kurnianto, F. A., Pangastuti, E. I.; **writing—original draft preparation**: Kurnianto, F. A., Nurdin, E. A.; **writing—review and editing**: Kurnianto, F. A., Bella, S; **visualization**: Kurnianto, F. A., Nurdin, E. A. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.

Data availability

Data is available upon Request.

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References

Ahmadi, M., Derafshi, K., Mokhtari, D., Khodadadi, M., & Najafi, E. (2022). Geodiversity Assessments and Geoconservation in the Northwest of Zagros Mountain Range, Iran: Grid and Fuzzy Method Analysis. *Geoheritage*, 14(4), 1-16.

Aiuppa, A., Bani, P., Moussallam, Y., Di Napoli, R., Allard, P., Gunawan, H., ... & Tamburello, G. (2015). First determination of magma-derived gas emissions from Bromo volcano, eastern Java (Indonesia). *Journal of Volcanology and Geothermal Research*, 304, 206-213. doi: 10.1016/j.jvolgeores.2015.09.008

Avelar, S., & Tokarczyk, P. (2014). Analysis of land use and land cover change in a coastal area of Rio de Janeiro using high-resolution remotely sensed data. *Journal of Applied Remote Sensing*, 8(1), 083631. doi: 10.1117/1.JRS.8.083631

Ballesteros, D., Caldevilla, P., Vila, R., Barros, X. C., Rodríguez-Rodríguez, L., García-Ávila, M., ... & Alemparte, M. (2022). A GIS-supported Multidisciplinary Database for the Management of UNESCOGlobal Geoparks: the Courel Mountains Geopark (Spain). *Geoheritage*, 14(2), 1-34.

Briggs, A., Dowling, R., & Newsome, D. (2021). Geoparks–learnings from Australia. *Journal of Tourism Futures*, 9(3), 351-365.

Chen, J., Jönsson, P., Tamura, M., Gu, Z., Matsushita, B., & Eklundh, L. (2004). A simple method for reconstructing a high-quality NDVI time-series data set based on the Savitzky–Golay filter. *Remote sensing of Environment*, 91(3-4), 332-344.

Dede, M., Pramulatsih, G. P., Widiawaty, M. A., Ramadhan, Y. R. R., & Ati, A. (2019). Dinamika suhu permukaan dan kerapatan vegetasi di Kota Cirebon. *Jurnal Meteorologi Klimatologi dan Geofisika*, 6(1), 23-31.

Demir, S. (2023). Identification of burned areas using different threshold values of NDVI with Sentinel-2 satellite images on Google Earth Engine. *Turkish Journal of Remote Sensing and GIS*, 4(2), 262-275.

Demir, S., & Dursun, İ. (2023). Determining burned areas using different threshold values of NDVI with Sentinel-2 satellite images on GEE platform: A case study of Muğla province. *Uluslararası Sürdürülebilir Mühendislik ve Teknoloji Dergisi*, 7(2), 117-130.

Demir, S., & Dursun, İ. (2024). Assessment of pre-and post-fire erosion using the RUSLE equation in a watershed affected by the forest fire on Google Earth Engine: the study of Manavgat River Basin. *Natural Hazards*, 1-29.

Fabre, S., Gimenez, R., Elger, A., & Rivière, T. (2020). Unsupervised monitoring vegetation after the closure of an ore processing site with multi-temporal optical remote sensing. *Sensors*, 20(17), 4800. doi: 10.3390/s20174800

Fu, H., Fu, B., Shi, P., & Zheng, Y. (2021). International geological significance of the potential Al-Medina volcanic UNESCO Global Geopark Project in Saudi Arabia revealed from multi-satellite remote sensing data. *Heritage Science*, 9(1), 1-10.

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote sensing of Environment*, *202*, 18-27. doi: 10.1016/j.rse.2017.06.031

Herrera-Franco, G., Apolo-Masache, B., Escandón-Panchana, P., Jácome-Francis, K., Morante-Carballo, F., Mata-Perelló, J., & Carrión-Mero, P. (2022). Perception of the Geological-Mining Heritage to Promote Geotourism in Guayaquil, Ecuador. *Geosciences*, 12(9), 322. doi: 10.3390/geosciences12090322

Hoang, Y. C., Yoshida, K., Tung, N. T., Danh, P. N., Ba, N., Hung, T. M. D., ... & Quy, N. T. M. (2018). Geological values of lava caves in Krongno volcano geopark, Dak Nong, Vietnam. *Vietnam Journal of Earth Sciences*, *40*(4), 299-319. doi: 10.15625/0866-7187/40/4/13101

Hu, Y., & Dong, Y. (2018). An automatic approach for land-change detection and land updates based on integrated NDVI timing analysis and the CVAPS method with GEE support. *ISPRS journal of photogrammetry and remote sensing*, 146, 347-359. doi: 10.1016/j.isprsjprs.2018.10.008

Jankowski, P., Najwer, A., Zwoliński, Z., & Niesterowicz, J. (2020). Geodiversity assessment with crowdsourced data and spatial multicriteria analysis. *ISPRS International Journal of Geo-Information*, 9(12), 716. doi: 10.3390/ijgi9120716

Jia, Z., Wu, F., & Hou, D. (2023). Geodiversity, Geotourism, Geoconservation, and Sustainable Development in Longyan Aspiring Geopark (China). *Geoheritage*, 15(1), 1-13.

Juanda, E. T., Martono, D. N., & Saria, L. (2021). Analysis vegetation change on coal mine reclamation using Normalized Difference Vegetation Index (NDVI). In *IOP Conference Series: Earth and Environmental Science*, 716, 012035. doi: 10.1088/1755-1315/716/1/012035

Julianto, F. D., Putri, D. P. D., & Safi'i, H. H. (2020). Analisis Perubahan Vegetasi dengan Data Sentinel-2 menggunakan Google Earth Engine (Studi Kasus Provinsi Daerah Istimewa Yogyakarta). *Jurnal Penginderaan Jauh Indonesia*, 2(2), 13-18.

Kariuki, R. W., Munishi, L. K., Courtney-Mustaphi, C. J., Capitani, C., Shoemaker, A., Lane, P. J., & Marchant, R. (2021). Integrating stakeholders' perspectives and spatial modelling to develop scenarios of future land use and land cover change in northern Tanzania. *PloS One*, 16(2), e0245516. doi: 10.1371/journal.pone.0245516

Kimijima, S., Sakakibara, M., Nagai, M., & Gafur, N. A. (2021). Time-Series Assessment of Camp-Type Artisanal and Small-Scale Gold Mining Sectors with Large Influxes of Miners Using LANDSAT Imagery. *International Journal of Environmental Research and Public Health*, 18(18), 9441. doi: 10.3390/ijerph18189441

Kuchler, A. W. (1967). *Vegetation Mapping. New York*: Ronald Press Co.

Lei, S., Ren, L., & Bian, Z. (2016). Time–space characterization of vegetation in a semiarid mining area using empirical orthogonal function decomposition of MODIS NDVI time series. *Environmental Earth Sciences*, 75, 1-11. doi: 10.1007/s12665-015-5122-z

Leman, N., Ramli, M. F., & Khirotdin, R. P. K. (2016). GIS-based integrated evaluation of environmentally sensitive areas (ESAs) for land use planning in Langkawi, Malaysia. *Ecological indicators*, 61, 293-308. doi: 10.1016/j.ecolind.2015.09.029

Li, S., Sun, S., Yang, X., Sun, W., & Wu, Z. (2022). Detrital zircon U-Pb age perspective on the sediment provenance and its geological significance of sandstones in the Lamandau region, SW Borneo, Indonesia. *Journal of Oceanology and Limnology*, 40(2), 496-514.

Libassi, M. (2022). Gold conflict and contested conduct: Large-and small-scale mining subjectivities in Indonesia. Geoforum, 148, 103648. doi : 10.1016/j.geoforum.2022.10.005

Lunt, P. (2019). The origin of the East Java Sea basins deduced from sequence stratigraphy. *Marine and Petroleum Geology*, 105, 17-31. doi: 10.1016/j.marpetgeo.2019.03.038

Luo, X. (2015). An Integrated WebGIS-Based Mangement Platform of Geopark. The Open Construction & *Building Technology Journal*, 9(1).

Lupi, M., De Gori, P., Valoroso, L., Baccheschi, P., Minetto, R., & Mazzini, A. (2022). Northward migration of the Javanese volcanic arc along thrust faults. *Earth and Planetary Science Letters*, 577, 117258. doi: 10.1016/j.epsl.2021.117258

Muslim, D., Zakaria, Z., Rachmat, H., Iqbal, P., Muslim, G. O., Sadewo, M. S., & Muslim, F. N. (2022). Identification of Geodiversity and Geosite Assessment around Geohazard Area of Suoh Aspiring Geopark in West Lampung, Sumatra, Indonesia. *Resources*, 11(11), 104. doi: 10.3390/resources11110104

Muzaky, H., & Jaelani, L. M. (2019). Analisis Pengaruh Tutupan Lahan terhadap Distribusi Suhu Permukaan: Kajian Urban Heat Island di Jakarta, Bandung dan Surabaya. *Jurnal Penginderaan Jauh Indonesia*, 1(2), 45-51.

Nakada, S., Maeno, F., Yoshimoto, M., Hokanishi, N., Shimano, T., Zaennudin, A., & Iguchi, M. (2019). Eruption scenarios of active volcanoes in Indonesia. *Journal of Disaster Research*, 14(1), 40-50. doi: 10.20965/jdr.2019.p0040

Nazaruddin, D. A. (2017). Systematic studies of geoheritage in Jeli district, Kelantan, Malaysia. *Geoheritage*, 9(1), 19-33.

Negara, L. P., Lestari, D., Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2021). An overview of depositional environment between the mountains of southern java and the fold mountain of north java. In *IOP Conference Series: Earth and Environmental Science*, 683(1), 012005. doi: 10.1088/1755-1315/683/1/012005

Othman, H., Abdul Rasam, A. R., & Jaini, N. (2020). *GeoPark Management and GIS: Geospatial Tree Information Inventory System.* In Charting the Sustainable Future of ASEAN in Science and Technology (pp. 553-567). Springer, Singapore.

Portal, C. (2018). Geodiversity and Anthropocene Landscapes: New Perceptions and Aesthetic Renewal of Some European "Coalscapes*". Environment, Space, Place*, 10(1), 89-110. doi: 10.5749/envispacplac.10.1.0089

Putri, R. A., & Supriatna, S. (2021). Land cover change modeling to identify critical land in the Ciletuh Geopark tourism area, Palabuhanratu, Sukabumi Regency. In *IOP Conference Series: Earth and Environmental Science*, 623(1), 012081. doi: 10.1088/1755-1315/623/1/012081

Reverte, F. C., Garcia, M. D. G. M., Brilha, J., & Pellejero, A. U. (2020). Assessment of impacts on ecosystem services provided by geodiversity in highly urbanised areas: A case study of the Taubaté Basin, Brazil. *Environmental Science & Policy*, 112, 91-106. doi: 10.1016/j.envsci.2020.05.015

Santos, D. S., Mansur, K. L., & Seoane, J. C. S. (2022). Classification Scheme for Geomorphosites' GIS Database: Application to the Proposed Geopark Costões e Lagunas, Rio de Janeiro, Brazil. *Geoheritage*, 14(3), 1-15.

Sapiie, B., Nugraha, M. A., Wardana, R. K., & Rifiyanto, A. (2017). Fracture Characteristics of Melange Complex Basement in Bantimala Area, South Sulawesi, Indonesia. *Indonesian Journal on Geoscience*, 4(3), 121-141.

Satyana, A. H. (2014). New Consideration on The Cretaceous Subduction Zone of Ciletuh-Luk Ulo-Bayat-Meratus: Implications for Southeast Sundaland Petroleum Geology. Retrieved from https://geologi.fitb.itb.ac.id/wp-content/uploads/sites/63/2021/09/IPA14-G-129.pdf

Scarsi, M., Crispini, L., Malatesta, C., Spagnolo, C., & Capponi, G. (2019). Geological map of a treasure chest of geodiversity: the Lavagnina Lakes Area (Alessandria, Italy). *Geosciences*, 9(5), 229. doi: 10.3390/geosciences9050229

Shrestha, A., Liang, D., Qu, Y., Ghimirey, Y., Panthi, S., Innes, J. L., & Wang, G. (2021). Mapping distribution and identifying gaps in protected area coverage of vulnerable clouded leopard (Neofelis nebulosa) in Nepal: Implications for conservation management. *International Journal of Geoheritage and Parks*, 9(4), 441-449. Doi: 10.1016/j.ijgeop.2021.11.001

Shui, W., & Xu, G. (2016). Analysis of the influential factors for changes to land use in China's Xingwen Global Geopark against a tourism development background. *Geocarto International*, 31(1), 22-41.

Singh, B. V. R., Sen, A., Verma, L. M., Mishra, R., & Kumar, V. (2021). Assessment of potential and limitation of Jhamarkotra area: A perspective of geoheritage, geo park and geotourism. *International Journal of Geoheritage and Parks*, 9(2), 157-171. doi: 10.1016/j.ijgeop.2021.04.001

Smyth, H. R., Hall, R., & Nichols, G. J. (2008). Cenozoic volcanic arc history of East Java, Indonesia: The stratigraphic record of eruptions on an active continental margin. *Special Papers-Geological Society of America*, 436, 199.

Smyth, H. R., Hamilton, P. J., Hall, R., & Kinny, P. D. (2007). The deep crust beneath island arcs: inherited zircons reveal a Gondwana continental fragment beneath East Java, Indonesia. *Earth and Planetary Science Letters*, 258(1-2), 269-282. doi: 10.1016/j.epsl.2007.03.044

Sobrino, J. A., Jiménez-Muñoz, J. C., & Paolini, L. (2004). Land surface temperature retrieval from LANDSAT TM 5. *Remote Sensing of environment*, 90(4), 434-440. doi: 10.1016/j.rse.2004.02.003

Sun, X., Yuan, L., Liu, M., Liang, S., Li, D., & Liu, L. (2022). Quantitative estimation for the impact of mining activities on vegetation phenology and identifying its controlling factors from Sentinel-2 time series. *International Journal of Applied Earth Observation and Geoinformation*, 111, 102814. doi: 10.1016/j.jag.2022.102814

Sunarta, I. N., & Saifulloh, M. (2022). Coastal Tourism: Impact For Built-Up Area Growth And Correlation To Vegetation And Water Indices Derived From Sentinel-2 Remote Sensing Imagery. *Geo Journal of Tourism and Geosites*, 41(2), 509-516. doi: 10.30892/gtg.41223-857

Tang, Y., & Liang, Y. (2022). Staged authenticity and nostalgia of mining tourists in the Jiayang mining Geo-park of China. *Journal of Tourism and Cultural Change*, 1-19. doi: 10.1080/14766825.2022.2090259

Tian, F., Wang, Y., Fensholt, R., Wang, K., Zhang, L., & Huang, Y. (2013). Mapping and evaluation of NDVI trends from synthetic time series obtained by blending Landsat and MODIS data around a coalfield on the Loess Plateau. *Remote Sensing*, 5(9), 4255-4279. doi: 10.3390/rs5094255

Ummah, K., Sukiyah, E., Rosana, M. F., & Alam, B. Y. C. S. (2018). Remote sensing identification of possible meteorite impact crater on Ciletuh, West Jawa. *International Journal on Advance Science Engineering Information Technology*, 8(0), 5.

Utami, S. R., Mees, F., Dumon, M., Qafoku, N. P., & Van Ranst, E. (2019). Charge fingerprint in relation to mineralogical composition of Quaternary volcanic ash along a climatic gradient on Java Island, Indonesia. *Catena*, 172, 547-557.

Wu, C., Zhang, Z., Rosana, M. F., Shu, Q., Zheng, C., Xu, J., ... & Jin, Z. (2019). The continental crust contributes to magmatic hydrothermal gold deposit in Ciemas, West Java, Indonesia: Constraints from Hf isotopes of zircons and in situ Pb isotopes of sulfides. *Ore Geology Reviews,* 112, 103010.

Xulu, S., Phungula, P. T., Mbatha, N., & Moyo, I. (2021). Multi-Year Mapping of Disturbance and Reclamation Patterns over Tronox's Hillendale Mine, South Africa with DBEST and Google Earth Engine. *Land,* 10(7), 760.

Yang, Z., Shen, Y., Li, J., Jiang, H., & Zhao, L. (2021). Unsupervised monitoring of vegetation in a surface coal mining region based on NDVI time series. *Environmental Science and Pollution Research*, 1-10. doi: 10.1007/s11356-021-17696-9

Yongli, W. A. N. G., & Weihong, D. (2017). Application of ZY1-02C remote sensing data to the investigation of geoparks: taking Jixian County, Tianjin City for example. *Remote Sensing for Natural Resources,* 29(1), 95-100.

Zhang, X., Estoque, R. C., & Murayama, Y. (2017). An urban heat island study in Nanchang City, China based on land surface temperature and social-ecological variables. *Sustainable cities and society*, 32, 557-568. doi: 10.1016/j.scs.2017.05.005