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The impact of nickel mining on vegetation index in Molawe Sub-district, North Konawe District, Southeast Sulawesi, Indonesia

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Abstract. *Adidharma MA, Supriatna, Takarina ND. 2023. The impact of nickel mining on vegetation index in Molawe Sub-district, North Konawe District, Southeast Sulawesi, Indonesia. Biodiversitas 24: 4581-4588.* Nickel mining activities in Molawe Sub-district, North Konawe District, Southeast Sulawesi, Indonesia have modified the land cover structure over time due to increased mining exploitation zones. This study intends to assess changes in land cover in the Molawe Sub-district, particularly around mining regions. The NDVI index was applied to Landsat 7 ETM+ satellite imagery data in 2001 to identify land cover conditions before mining activities, then to Landsat 8 OLI imagery data in 2015 and 2020 to identify land cover after mining activities. These data are then used to compute annual changes in the extent of each land cover. The NDVI classification produces four land cover types: non-vegetation, open soil, sparse vegetation, and moderate vegetation. The study shows that non-vegetation and open ground cover types experienced a significant increase in area from 2001 to 2015 and from 2015 to 2020. Meanwhile, sparse vegetation forest cover experienced a reduction in area from 2001 to 2015 and 2015 to 2020. In contrast to sparse vegetation, the moderate vegetation cover is experiencing a minor increase in area. Based on these results, relevant policymakers need to formulate policies to mitigate environmental impacts that may arise in the future.

Keywords: Molawe Sub-district, NDVI, nickel mining, vegetation

INTRODUCTION

The mining industry is an essential sector in the Indonesian economy, contributing 11% of Indonesia's GDP in 2020 (Laksana 2022). Based on data from the Indonesian Chamber of Commerce and Industry (2022), Indonesia's five largest types of mining products are nickel, gold and silver, bauxite, copper concentrate, copper ore, and tin. Nickel is the most produced mining product, amounting to 35.5 million metric tons. According to data from the Ministry of Energy and Mineral Resources for 2020, nickel mining activities in Indonesia are spread across several provinces, the largest in Southeast Sulawesi Province. Southeast Sulawesi has quite large nickel reserves. Based on data from the ESDM Office of Southeast Sulawesi Province, nickel reserves in Southeast Sulawesi reach 97 billion tons with a distribution area of 480 thousand hectares (Southeast Sulawesi Government 2021).

Because of the enormous nickel reserves in Southeast Sulawesi, nickel is the principal mining commodity in the province (Prasetyo et al. 2015), with production in 2018 totaling 16,926,763 tonnes and expected to reach 22,531,686 tonnes by 2020. The 143 nickel mining firms in Sulawesi Southeast contributed to the total nickel production. Based on data from the Central Bureau of Statistics for Southeast Sulawesi Province, in 2022, North Konawe District has the largest nickel mining activity in Southeast Sulawesi, where as many as 70 nickel companies operate in this area. Its mining activities are spread over several sub-districts, where eight nickel mining companies operate in the Molawe Sub-district. The magnitude of mining activities in this area contributes to employment and local regional income (Kurakova and Ponomarenko 2021). However, on the other hand, it is a driving factor for deforestation (Mbaya 2013; Kramer et al. 2023) due to the expansion of the exploited area from time to time. These deforestation activities cause several negative impacts, such as increasing the average air temperature (Prevedello et al. 2019; Wolff et al. 2021) related to global warming (Lawrence et al. 2022), reducing the organic carbon content in the soil and significantly causing the soil more unstable (Amoakwah et al. 2022). In mining sites, especially those that use open-pit mining techniques, landslides are a calamity that is very likely to happen. Due to the easily destroyed and unstable rock and soil conditions in the mining area, open-pit mining locations will have a very high level of erosion susceptibility. The geographical position in steep mountains (Momon et al. 2021) and the presence of natural variables, such as rainfall (Chen et al. 2023), can worsen the instability of this soil structure. Based on these effects, land cover monitoring is required to gather data and serve as a resource when developing policies to safeguard and conserve coastal and forest areas (Romijn et al. 2015).

Normalized Difference Vegetation Index (NDVI) is an index commonly used to measure the level of greenness and density of vegetation to assess the temporal changes of vegetation (Gandhi et al. 2015; Huang et al. 2020). Besides providing an overview of the temporal dynamics of terrestrial ecosystems, NDVI can also provide information for ecosystem use and protection (Essaadia et al. 2022). According to Wang (2016) and Gao et al. (2022), human activity significantly impacts NDVI since different levels of human activity in land use might increase or decrease in NDVI. Studies have shown that using the NDVI to track land cover change yields accuracy ranging from 88% to 96%, according to research (Madasa et al. 2021). The spatial model's output from this study is anticipated to guide managing land and minimizing forest damage from nickel mining. According to the results, it is vital to use NDVI analysis to identify changes in land cover caused by mining activities. The study is anticipated to offer recommendations and feedback on forest regeneration techniques in nickel mining regions in the Molawe Sub-district

MATERIALS AND METHODS

Study area

The research area is the Molawe Sub-district, North Konawe District, Southeast Sulawesi Province, Indonesia (Figure 1). The Molawe Sub-district area stretches from north to south between 02º97' and 03º86' South and stretches from west to east between 121º49' and 122º49' East. Molawe Sub-district has an open nickel mining area in several village areas with mountainous, undulating, and hilly topography surrounding the lowlands (Central Bureau of Statistics for North Konawe Regency 2022). In addition, the Lasolo River Estuary is the largest river in North Konawe District. The Area of Interest (AOI) for observing land cover is limited to four areas: Tapunggaya, Tapuemea, Mandiodo, and Mowundo Villages. AOI is limited by digitizing to form polygons in Google Earth Pro Software (Atiqah et al. 2020). The restricted area is a mining area in the Molawe Sub-district area. The created polygons are then exported in KML format. The KML file is then imported into the ArcMap 10.8 software and converted into layers. The AOI layer is then re-exported and saved in the Shapefile (SHP). The AOI SHP file will later be used further in image cropping.

Procedures

Remote sensing data collection

The image data used in this study are level 2 Landsat 7 ETM+ and Landsat 8 OLI image data, which temporally represent periods prior to mining (2001) and following mining (2015 & 2020). Image data was downloaded from the website https://earthexplorer.usgs.gov/. Details of the remote sensing data used in this study are presented in Table 1. Landsat level 2 image data is selected based on the availability of image data that already contains surface reflectance data (Fawzi and Husna 2019; USGS 2022). Thus, there is no need for radiometric and atmospheric correction of the image. The image is selected based on the acquisition time criteria and cloud cover, which is a maximum of 20%.

Table 1. Satellite image data used in this research

Imagery File Name	Acquisition Date
LE07_L2SP_113062_20010121_20200917_02_T1	21 Jan 2001
LC08_L2SP_113062_20151120_20200908_02_T1	20 Nov 2015
LC08_L2SP_113062_20200829_20200906_02_T1	29 Aug 2020

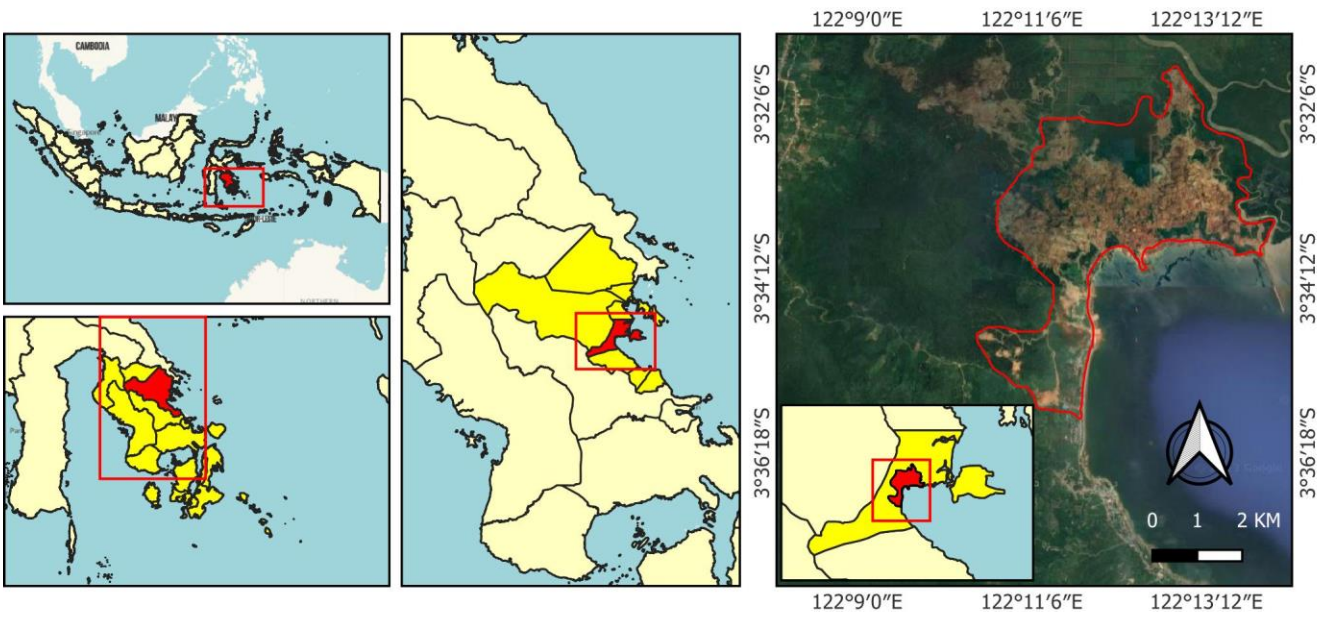

Figure 1. Location of AOI in Molawe Sub-district, North Konawe District, Southeast Sulawesi Province, Indonesia

NDVI classification

Land cover change analysis was conducted using Normalized Difference Vegetation Index (NDVI) analysis. A high NDVI index value will indicate forest, agricultural, and plantation areas, while a low value indicates vacant land or land without crops (Mohajane et al. 2017). NDVI classification is made by selecting well-defined class intervals with a specific color for each class (Essaadia et al. 2022). The NDVI formula is as follows:

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \quad (1)$$

NDVI analysis can be performed using ArcMap 10.8 on the Raster Calculator tool. The bands used are bands 3 (red) and 4 (NIR) on Landsat 7 ETM+ and bands 4 (red) and 5 (NIR) on Landsat 8 OLI (Gessesse and Melesse 2019; Gutman et al. 2021). The results of the NDVI analysis of the images are then exported in TIFF format. The TIFF file is then imported into ArcMap 10.8 software for further analysis. The resulting NDVI image imported to ArcMap 10.8 is cropped according to the AOI area previously created using the Arc Toolbox > Data Management Tool > Raster > Raster Processing > Clip. After the image cropping process, the NDVI value is classified according to the NDVI range values (Kuzevic et al. 2022).

Calculating land cover area/vegetation density

Calculation of land cover area using the reclassify tool. Reclassification can be used to reclassify the variable's value on the raster gained value basis (Jebur et al. 2015). The NDVI results are in raster format on ArcMap, then were reclassified using ArcToolbox > Spatial Analyst Tools > Reclass. In reclassifying the raster, manual classification was according to the range of NDVI values, as presented in Table 2. After reclassifying, we convert the reclassified raster into polygons using the Conversion Tools > From Raster > Raster to Polygon tool. The converted polygon file will then limit the cover area according to the classification value in Table 2. Using the Start Editing command button, We merge all the polygons according to their respective grid codes in the data attribute table. After all the polygons are put together according to their respective grid codes, we create a new column (add field) in the data attribute table with Double type. Then, do Calculate Geometry on that column and determine the area unit to be used. Calculate Geometry is a tool that can calculate a polygon's coordinates, length, and area (Sobatnu et al. 2017). The area calculation results will appear in the column.

Relationship between distance from mine and vegetation density

The distance from the mine area and the vegetation density were correlated using a simple linear regression analysis in Microsoft Excel 2019. The distance is measured every 200 meters from the mine, especially on the west and north sides of the mining region. The analysis results are then given graphically in the form of a scatter plot, along with the coefficient of determination (R^2) value, which indicates the level of the relationship.

RESULTS AND DISCUSSION

Land cover in 2001, 2015 and 2020

The analysis results show that four land cover types are produced, i.e., non-vegetation, open soil, sparse vegetation, and moderate vegetation. Sparse vegetation is the widest land cover type, i.e., 19.893 km^2 in 2001, 13.650 km^2 in 2015, and 11.358 km^2 in 2020. Non-vegetation and open soil types have an area of 0.003 and 0.155 km^2 in 2001, 2.892 and 2.590 km^2 in 2015, and 4.910 and 2.620 km^2 in 2020. Moderate vegetation cover type had an area of 0.287 km^2 in 2001, 1.206 km^2 in 2015, and 1.450 km^2 in 2020. The distribution pattern of land cover, area, and percentage in 2001, 2015, and 2020 has been presented in Figures 2 and 3, Tables 3 and 4.

Land cover area changes

The non-vegetation and open soil cover increased 2.889 and 2.435 km^2 from 2001 to 2015 and 2.018 and 0.030 km^2 from 2015 to 2020. Sparse and moderate vegetation cover experienced different things, where sparse vegetation decreased by 6.243 in the 2001 period to 2015 and 2.292 km^2 in the period 2015 to 2020, while moderate vegetation increased by 0.919 km^2 in the period 2001 to 2015 and 0.244 km^2 in the period 2015 to 2020. Data on changes in the land cover area have been presented in Table 5 and Figure 4.

Table 2. NDVI value class

No.	Cover Type	NDVI Value
1	Non-Vegetation	NDVI<0.1
2	Open Soil	0.1<NDVI<0.2
3	Sparse Vegetation	0.2<NDVI<0.4
4	Moderate Vegetation	0.4<NDVI<0.6
5	Dense Vegetation	0.6<NDVI<1

Table 3. The area of each land cover

Cover Type	Cover Area (km^2)		
	2001	2015	2020
Non-vegetation	0.003	2.892	4.910
Open soil	0.155	2.590	2.620
Sparse vegetation	19.893	13.650	11.358
Moderate vegetation	0.287	1.206	1.450
Dense vegetation	0	0	0
Total		20.338	

Table 4. Percentage of each land cover area

Cover Type	Cover Percentage (%)		
	2001	2015	2020
Non-vegetation	0.01	14.22	24.14
Open soil	0.76	12.73	12.88
Sparse vegetation	97.81	67.12	55.85
Moderate vegetation	1.41	5.93	7.13
Dense vegetation	0	0	0

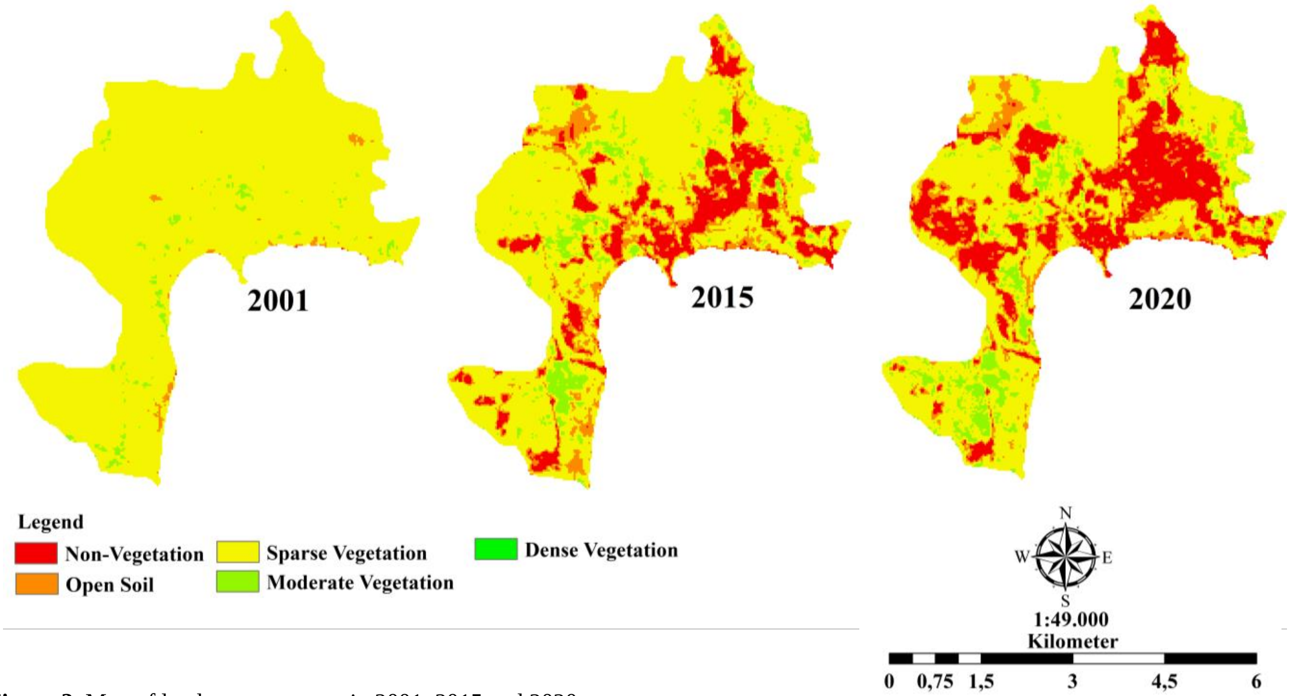

Figure 2. Map of land cover patterns in 2001, 2015 and 2020

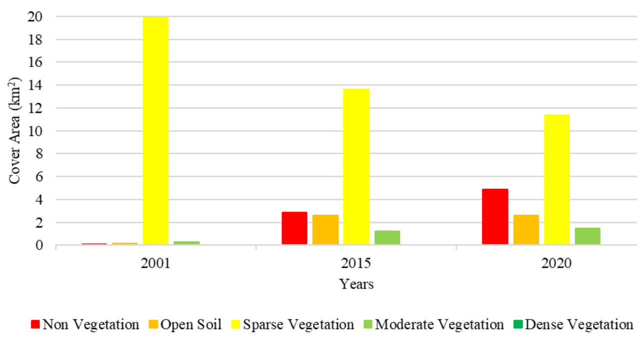

Figure 3. Comparison of land cover areas in 2001, 2015 and 2020

Table 5. Changes in the land cover area in the 2001-2015 and 2015-2020 periods

Cover Type	Period	
	2001-2015 (km^2)	2015-2020 (km^2)
Non-vegetation	2.889	2.018
Open soil	2.435	0.030
Sparse vegetation	-6.243	-2.292
Moderate vegetation	0.919	0.244
Dense vegetation	0	0

Discussion

The land cover classification produces four types: non-vegetation, open soil, sparse vegetation, and moderate vegetation. The results of measuring the area of land cover types in 2001, 2015, and 2020 produce different variations each year (Figure 4). In 2001, the land cover was dominated by sparse vegetation (97.81%) with an area of 19.893 km^2. Non-vegetation land cover types (0.01%), open soil (0.76%), and moderate vegetation (1.41%) have an area of 0.003, 0.155, and 0.287 km^2, respectively. In 2015, all land cover categories experienced changes in the area, where sparse vegetation (67.12%) was still dominant with an area of 13.650 km^2, non-vegetation (14.22%) covering 2.888 km^2, open soil (12.73%) covering 2.590 km^2 and moderate vegetation (5.93%) covering an area of 1.206 km^2. In 2020, sparse vegetation (55.85%) and non-vegetation (24.14%) dominated with an area of 11.358 and 4.910 km^2, respectively. While another cover, such as open soil (12.88%), covers an area of 2.620 km^{2,} and moderate vegetation (7.13%) covers an area of 1.450 km^2.

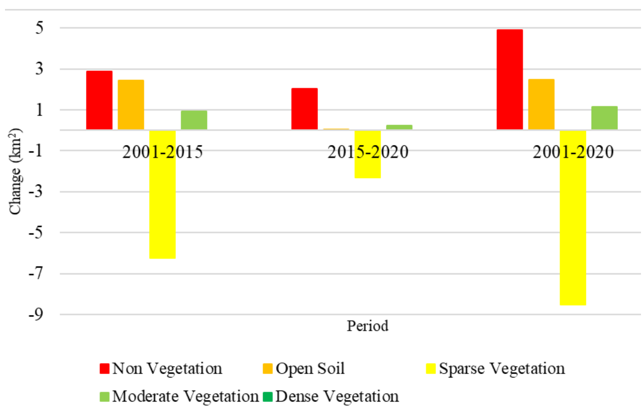

Figure 4. Changes in the land cover area in the 2001-2015 and 2015-2020 periods

The land cover change analysis shows, in general, there has been an increase in the area of the mining area, which is assumed to be a non-vegetation area increasing. Meanwhile, sparsely vegetated areas continued to experience a significant decrease from 2001 to 2020. Sparsely vegetated areas decreased by 6.243 km^2 from 2001 to 2015 and 2.292 km^2 from 2015 to 2020. Vegetation is experiencing a slight increase in area, namely 0.919 km^2 from 2001 to 2015 and 0.244 km^2 from 2015 to 2020. Meanwhile, 2.889 km^2 of non-vegetation increased from 2001 to 2015, and an additional 2.018 km^2 from 2015 to 2020 due to the opening of mining land. The open soil area assumed to be a non-vegetated area also increased by 2.435 km^2 from 2001 to 2015 and a minor 0.030 km^2 from 2015 to 2020. This decrease in vegetation cover was due to the open-pit mining method applied in this area. The open-pit mining method damages the landscape and forests at the mining site because trees, plants, and topsoil are cleared from the area to be mined (Stracher, 2019). Reducing vegetation due to mining activities also occurs in the Sungun mine area in Iran, the Athabasca mine in Canada, and the Hambach mine in Germany. The Sungun mining area in Iran experienced a forest reduction of 4.05 km^2 during the period 1989-2019, the Athabasca mine in Canada experienced a forest reduction of 9.05 km^2 from 1999-2019, and the forest at the Hambach mine in Germany decreased by 46.39 km^2 during 1989-2017 (Firozjaei et al. 2021).

Based on the land cover map, mining areas are developing in the coastal areas of Tapunggaya and Tapuemea Villages. This development in the coastal area is thought to be caused by the influence of the availability of transportation infrastructure because the connecting road to the locations of Tapunggaya and Tapuemea Villages is along the coast. In addition, the availability of land roads greatly supports the development of the mining industry because it will be vital for logistics distribution (Zhang and Wu 2022; Zhang and Cheng 2023).

Most mining areas in the study area are in the Mandiodo, Tapuemea, and Tapunggaya Village Molawe Sub-districts. This is thought to be caused by the distribution of nickel laterite deposits, which are more abundant in all three villages. Nickel laterite deposits in the Molawe Sub-district have different thicknesses at each point or area, with the highest thickness being in the central to eastern sides, namely 5-13 meters, while in the western sides, they only have a relatively lowest, namely 1-2 meters (Raivel and Hasrianto 2023).

The effect of decreasing vegetation cover due to mining activities usually occurs around mined areas, while areas outside mining areas have relatively better vegetation cover. According to Pour et al. (2021), the direct and indirect effects of mining activities on the growth and health of plant vegetation generally decrease linearly, followed by increasing the distance of vegetation from the mine to at least 600 m. Research Fakhimi (2020) also suggests that increasing the distance of vegetation from the mining area can significantly increase the cover percentage for several plant species, including Asteraceae, Fabaceae, Poaceae, Chenopodiaceae, and Lamiaceae. The difference in vegetation cover affected by the distance of vegetation to the mine site is due to the relatively better soil quality in areas far from the mine. The soil near mining sites generally contains more contaminants due to the heavy metal residues released into the soil (Fashola et al. 2016).

The correlation analysis results between the distance from the mine and the vegetation cover (Figure 5) at the study site show an R^2 value of 0.052. This value indicates no linear relationship between the distance from the mine and the vegetation cover. This is due to the increasingly widespread conversion of forest functions around mines to other uses, such as residential areas and agriculture development. Based on Figures 6 and 7, the north side of AOI has been converted into plantation and agricultural development, while the east side is a mangrove forest that is starting to turn into an aquaculture area, and the west side is a forest area that has uneven coverage. Uneven forest cover on the western side of the AOI is caused by several factors, including the effects of mining, which reduces fertility will further inhibit vegetation growth (Prematuri et al. 2020) and differences between vegetation types, vegetation ages, and environmental conditions (Fang et al. 2014).

The area on the north side of AOI, which is in the administrative area of Andowia sub-district, has mostly been converted into oil palm plantation land owned by PT. Sultra Prima Lestari (SPL) and community agricultural land. Agricultural development in rural areas is strongly tied to most rural communities that work as farmers (Moomen and Dewan 2015) and will heavily rely on the agricultural industry (Waddington et al. 2014). Aside from the agricultural sector, settlement is expanding around mining locations. The increasing need for residential areas for local communities and migrant workers from outside the area to support ease of access and proximity to workplaces is a driving force for residential development. According to Pratama et al. (2019), settlements that emerge in mining areas tend to develop relatively quickly due to the strong demand for residential areas and suitable services and infrastructure availability. Moreover, several mining companies in North Konawe have allocated their Corporate Social Responsibility (CSR) funds to develop several village infrastructures, educational and religious infrastructure (Kasmudin et al. 2018; Masri et al. 2019).

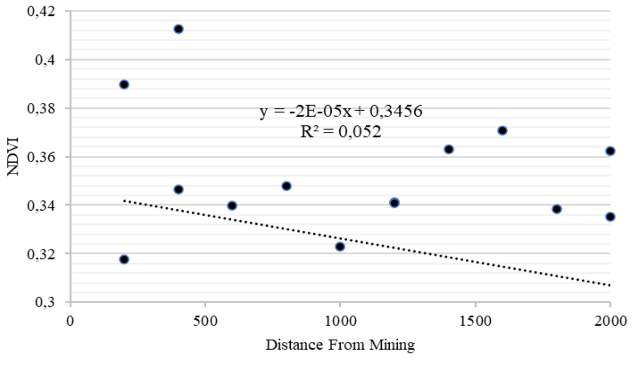

Figure 5. The relationship between distance from the mine and image reflectance

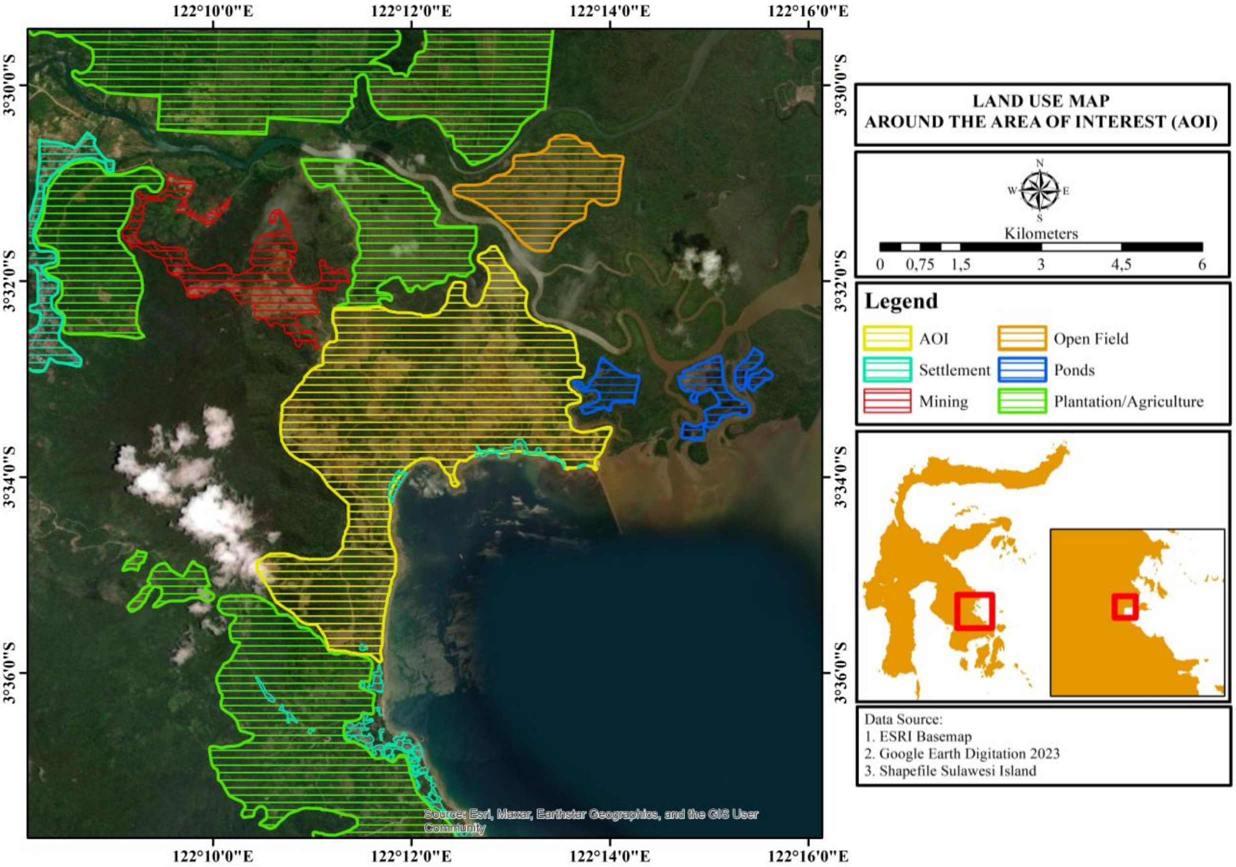

Figure 6. Map of land cover around the area of interest (AOI)

0.318	0.347	0.340	0.348	0.323	0.341	0.363	0.371	0.339	0.335	North
0.390	0.413	0.285	0.264	0.271	0.341	0.227	0.277	0.231	0.362	West
200	400	600	800	1000	1200	1400	1600	1800	2000	Distance (m)

Figure 7. NDVI pattern based on distance from north and west mine side

Forest degradation caused by mining activities in the Molawe Sub-district requires the Central and Regional Governments' attention to mitigate the significant impact in the future. Consider that the mining area in the Molawe Sub-district is mountainous, close to settlements, and borders Lasolo Bay. Landslides are a disaster that can be produced by mining in this area (Mu et al. 2021) because the soil is more unstable after extra mining activities in various North Konawe’s nickel mining locations (Barus et al. 2022). The presence of mines on the mainland directly impacts Lasolo Bay. In addition to water, mining can also pollute groundwater sources. Research by Ullah et al. (2022) reveals that groundwater sources in areas close to mining experience heavy metal contamination in the groundwater. This can impact the health of the people who live around it. Based on several examples of impacts that can occur as a result of mining, all stakeholders need to carry out management that is conserving and realizing environmental sustainability because preserving the environment of settlements in mining areas must be given attention to social, economic, environmental and policy (Sushanti et al. 2020).

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