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Spatial-Temporal Analysis of Land Cover Change and Flood Risk Detection in North Musi Rawas District, South Sumatra, Indonesia: Approach Gis and Sentinel Imagery

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Abstract:
This study aims to analyze the dynamics of land cover changes in North Musi Rawas Regency in the period 2017–2023 and triggers for flood risk using remote sensing and Geographic Information Systems (GIS) approaches. The research methods include Sentinel-2 satellite imagery classification using supervised classification techniques, accuracy validation, and spatial-temporal analysis to identify land conversion patterns and their relationship to hydrological dynamics. The results of the analysis show significant conversion of agricultural land vegetation (9,769 ha), built-up land (194 ha), shrubs (15,011 ha), and swamps (514.17 ha), which are driven by urbanization factors, expansion of the agricultural sector, and environmental degradation. These changes contribute to increased flood risk, with the area affected by the medium risk category reaching 133,586 ha, especially in Karang Dapo, Rupit, and Rawas Ilir Districts, while the low-risk area covers 31,397 ha. Meanwhile, areas with better vegetation cover show higher flood mitigation capacity. This study confirms that changes in land cover have a close correlation with increased flood risk, so that land management policies based on spatial data and the use of remote sensing technology are needed to support disaster mitigation and adaptation strategies more effectively.

Keywords: *Land cover, flood risk, remote sensing, Geographic Information System (GIS), land conversion, Sentinel-2, Musi Rawas Utara*

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INTRODUCTION

As one of the largest archipelagic countries in the world, Indonesia has more than 17,000 islands that show exceptional biodiversity and abundant natural resources (Margono et al., 2014). The island of Sumatra, as one of the main regions in the Unitary State of the Republic of Indonesia, includes a number of provinces, one of which is South Sumatra Province which has a strategic role both ecologically and economically. Significantly, the province has experienced an increase in population since the 1930s, which has had an impact on changes in land use and environmental dynamics (Gaveau et al., 2007). In addition, this province has a fairly large area of tropical forest, which has several functions, namely: as an absorber of carbon dioxide gas, controlling the hydrological cycle (Eddy et al., 2021), and support biodiversity, especially endemic species of flora and fauna (Leo et al., 2020). But the reality is that right now, South Sumatra Province is experiencing a massive expansion of deforestation, which can threaten environmental sustainability and community welfare (Rijal et al., 2016). Deforestation is generally caused by human factors such as large-scale land clearing, both as residential areas and large-scale forest fire disasters by natural and human factors (Singh & Yan, 2021). Another effect is that deforestation in South Sumatra can significantly damage the order of the ecological system, especially in coastal areas (Yunardy et al., 2024), and is a trigger for landslides and floods (Heo et al., 2024). During the rainy season, flooding is often a concern for various parties, because the ability of forests to absorb and control water is very limited (Whitfield, 2012). The expansion of oil palm plantations is one of the factors causing floods (Merten et al., 2020). Socio-economic activities, which generally depend on the availability of natural resources, are also under considerable pressure (Lambin & Meyfroidt, 2010). Deforestation and forest degradation are fundamental problems for the destruction of ecological systems in the South Sumatra Province region (Gaveau et al., 2014), so there needs to be Zero Deforestation Commitment to regulate private sector activities, so that the damage that may be caused can be reduced (Purnomo et al., 2023).

The problem of land cover change due to deforestation has generally reached all parts of the world (Lepers et al., 2005), of course, this needs serious attention for a newly developed nation like Indonesia, because its tropical forests are very extensive and have biodiversity (Murray et al., 2015). In addition, the increasing need for land to be used as agricultural land and settlements can further accelerate the occurrence of indirect deforestation (DeFries et al., 2010). In addition, the ability of forests to absorb surface water is reduced due to the increasingly uncontrolled exploitation of natural resources (Bruijnzeel, 2004). Of course, this can trigger natural disasters such as floods (De la Paix et al., 2013). The existence of remote sensing technology, such as Sentinel-2 Satellite Imagery, has become a means to carry out land cover monitoring very accurately and cost-effectively (Alonso et al., 2021). Li-Ping et al. emphasized the importance of remote sensing and GIS in monitoring and predicting land-use change, highlighting their role in providing up-to-date information that is important for environmental assessments. (Liping et al., 2018). This is supported by Junaid et al., who note that satellite data and GIS techniques are essential for analyzing temporal and geographic changes in land cover, especially in forested areas (Junaid et al., 2023).

Monitoring deforestation in South Sumatra is very important to be carried out, to prevent further damage to the environment. One of the most effective ways is to use remote sensing technology to predict such changes over a period of time (Margono et al., 2012). With the development of technology, particularly remote sensing, a variety of more effective methods for monitoring deforestation have been discovered (Taylor et al., 2020). Some researchers have previously used low-resolution satellite imagery from Landsat Satellite Imagery (Hadi et al., 2018), because of the image Landsat is now publicly accessible, so it is most commonly used for mapping and monitoring land cover (Alonso et al., 2021). There is another study, which attempts to take advantage of the Sentinel-2 satellite imagery with a better level of image sharpness accuracy (Phiri et al., 2020), The satellite image is relatively new, because it was only launched in 2015 (Li & Roy, 2017). Its advantages are mainly related to the analysis of land cover changes due to spatial resolution Minimum 10 m, 13 spectral bands, and wide acquisition coverage (Lefebvre et al., 2016). So it is highly recommended by several studies. Research with this method is very important to be carried out, considering that it has not been widely applied to deforestation cases in the South Sumatra region. The purpose of this research is expected to be an important input to the next land resource management policy (Fu et al., 2018), and improvements to the efficiency of deforestation tracking and control can be made (Khoi & Murayama, 2011). In addition, the benefits of this study include the provision of accurate and up-to-date spatial data to support decision-making processes, the enhancement of early detection capabilities for illegal deforestation activities, and contributions to environmental conservation efforts and sustainable development in the South Sumatra region.

METHOD

Research Location and Time

South Sumatra has 13 districts and 4 cities (Ministry of Home Affairs, 2023). Several areas in the Forest Reserve Area will experience an increase in the rate of deforestation in 2023 (South Sumatra Central Statistics Agency, 2023), Therefore, this study focuses on North Musi Rawas Regency (Figure 1) that has significantly experienced deforestation since 2019 (ANISA, 2019). The increase in deforestation contributes to the worsening of flood disasters in 2024, where flooding events have become a routine agenda every year at the study site (Disaster Management Agency, 2024). North Musi Rawas Regency is located in the Rawas sub-watershed (DAS) area. The Rawas sub watershed has an area of 586,769.30 ha, which covers 10.97 percent of the total area of the Musi watershed, making it one of the fourth largest sub-watersheds in the Musi watershed system (Chuzaimah et al., 2019).

This study covers the period 2017–2023 to analyze spatial and temporal changes in land cover. The selection of the time range was based on the availability of high-resolution Sentinel-2 satellite imagery (Phiri et al., 2020), which is considered relevant to illustrate the dynamics of land change. Analysis of land conversion trends was carried out at three different time points, namely 2017, 2020, and 2023, providing a comprehensive understanding of the spatial distribution and temporal dynamics of land use change (D. Liu et al., 2017). This approach allows researchers to identify patterns of urban expansion as well as agricultural land conversion (Rustiadi et al., 2021), which is an important aspect of supporting sustainable land management and better urban planning.

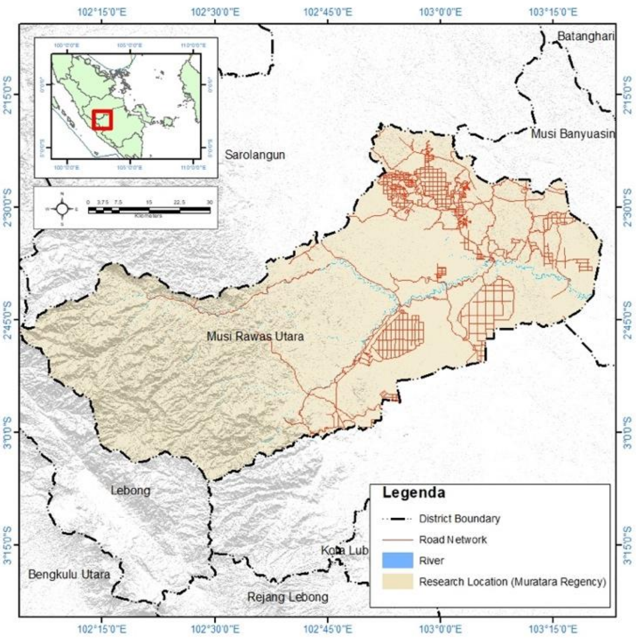

Figure 1. *Map created by the authors using ArcGIS, with shapefile data provided by BIG (2022).*

Data and Data Sources

Remote sensing has become a critical technology for large-scale land cover mapping, providing crucial data that supports environmental monitoring, urban planning, and resource management. The integration of remote sensing with Geographic Information Systems (GIS) has significantly improved the ability to monitor land use and land cover change (LULC) over a large area (Abebe et al., 2022). This approach offers timely and accurate spatial data, which is difficult to achieve through traditional field survey methods. (Hazeu et al., 2011; Liping et al., 2018; Wang et al., 2020; Size et al., 2020). This capability is especially important in areas experiencing rapid urbanization or environmental degradation, where a deep understanding of land cover dynamics is essential to support sustainable development. (Wang et al., 2020; Jiang et al., 2012).

The study used satellite imagery of Sentinel-2, which was developed under the European Space Agency's (ESA) Copernicus program (Phiri et al., 2020), as an important data source for detailed land cover analysis due to its high spatial resolution and superior multispectral capabilities. The Sentinel-2 mission consists of two satellites, Sentinel-2A and Sentinel-2B (Chen et al., 2018), which provides multispectral imagery with spatial resolutions of 10, 20, and 60 meters across 13 spectral bands (Marino, 2023); Li et al., 2021; X. Wang et al., 2023). This high resolution is particularly advantageous for applications such as land cover classification, where precise delineation of different types of land is crucial (Bilozor et al., 2024; Macharia et al., 2021; Bauer et al., 2024). In this study, land cover classification was conducted using a *supervised classification* method, which enables the identification of land cover categories based on pre-defined training samples.

As a complement, this study uses shapefile vector data from the National Mapping Agency and other geospatial institutions (Sarjakoski et al., 2002), which includes administrative boundaries, road networks, rivers, and other geographic features. Integration of Sentinel-2 raster data with shapefile vector data allows for more comprehensive analysis of land cover changes (Tran et al., 2020), as well as supporting the understanding of change patterns and their implications for the environment and regional planning.

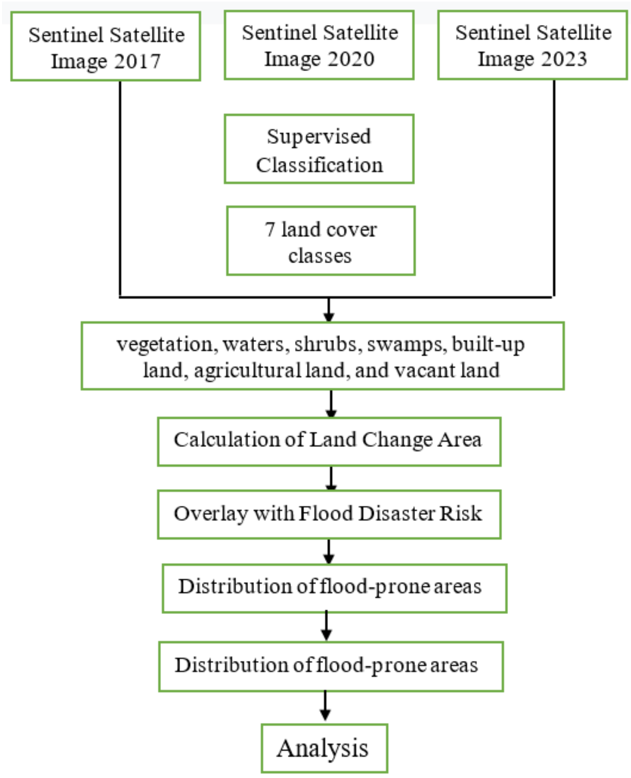

Figure 2. *This study proposes a customized classification workflow tailored to Sentinel-2 imagery.*

Analysis Method

The application of guided image classification using Sentinel satellite imagery can improve the accuracy and reliability of land cover classification (Ghayour et al., 2021). Guided image classification involves labeling different types of land cover based on training data obtained from satellite imagery (Koda et al., 2018). Techniques such as Maximum Likelihood and K-nearest neighbor are commonly used to classify pixels in an image (Dutta et al., 2024). The land cover categories analyzed consisted of seven categories, namely water bodies, vegetation, wetlands, agricultural land, built land, vacant land, and shrubs. These categories were chosen to cover the different types of land cover in the study area, as well as to analyze changes in land cover dynamics that occurred throughout the study period.

Classification validation is carried out by utilizing reference data obtained from the National Mapping Agency (BIG) (Y. Liu et al., 2018). The data was used to measure the accuracy of the satellite image classification results by comparing the land cover categories identified through image analysis with official map data or field information issued by BIG. This validation process is a crucial step to ensure the accuracy and validity of the classification results, so that they can objectively reflect actual conditions in the field.

Analysis of land cover change was conducted to evaluate the dynamics of land use change and closure in the study area by comparing classification maps in 2017, 2020, and 2023. Change Detection Method, especially Post-Classification Comparison (PCC) (Xie & Niculescu, 2021), applied to identify conversions between land cover categories and monitor spatial and temporal changes. The results of this analysis provide insight into patterns of land cover change, such as the conversion of forests to agricultural land or the expansion of built-up areas (Dadashpoor et al., 2019), which is very useful in decision-making related to spatial planning and natural resource management.

Spatio-temporal analysis combines spatial and temporal approaches to comprehensively understand the dynamics of land cover change. The spatial approach uses GIS techniques such as overlays and spatial statistics to identify spatial patterns and factors that cause change, while temporal analysis observes trends of change from year to year. The integration of these two approaches provides deep insights into the extent of flood-prone areas and their distribution (Ogato et al., 2020), as well as helping to formulate more effective environmental management strategies, including in disaster mitigation.

RESULTS AND DISCUSSION

Description of Satellite Image Data

This study uses Sentinel-2 satellite imagery for 2017, 2020, and 2023, obtained from the Esri Land Use Land Cover time series (Venter et al., 2022). The data has gone through the necessary processing and classification process, so it does not require additional corrections. The Sentinel-2 image has a spatial resolution of 10 meters on the optical main band, which allows for a high level of detail analysis of land cover. In addition, with a temporal resolution of 5 days, these images allow monitoring of changes in land cover in relatively short time intervals.

Land Cover Classification

This study uses the supervised classification method to classify the Sentinel-2 satellite imagery (Abida et al., 2022), following the guidelines provided by ESRI in the 10 m Annual Land Cover (2017-2023) (Figure 3). The guidelines include 9 definitions of land cover classes that refer to specific criteria for each category of cover (Gautama et al., n.d.). In this study, the results of the classification produced 7 types of land cover which include: vegetation, waters, shrubs, swamps, built land, agricultural land, and vacant land. The classification process is carried out by selecting a representative training area for each land cover class, which is then used to classify the entire image based on the spectral value and characteristics of each class (Yang et al., 2018). This approach ensures that each land cover class is grouped with high precision, according to the criteria set by the ESRI guidelines, resulting in an accurate and reliable land cover map.

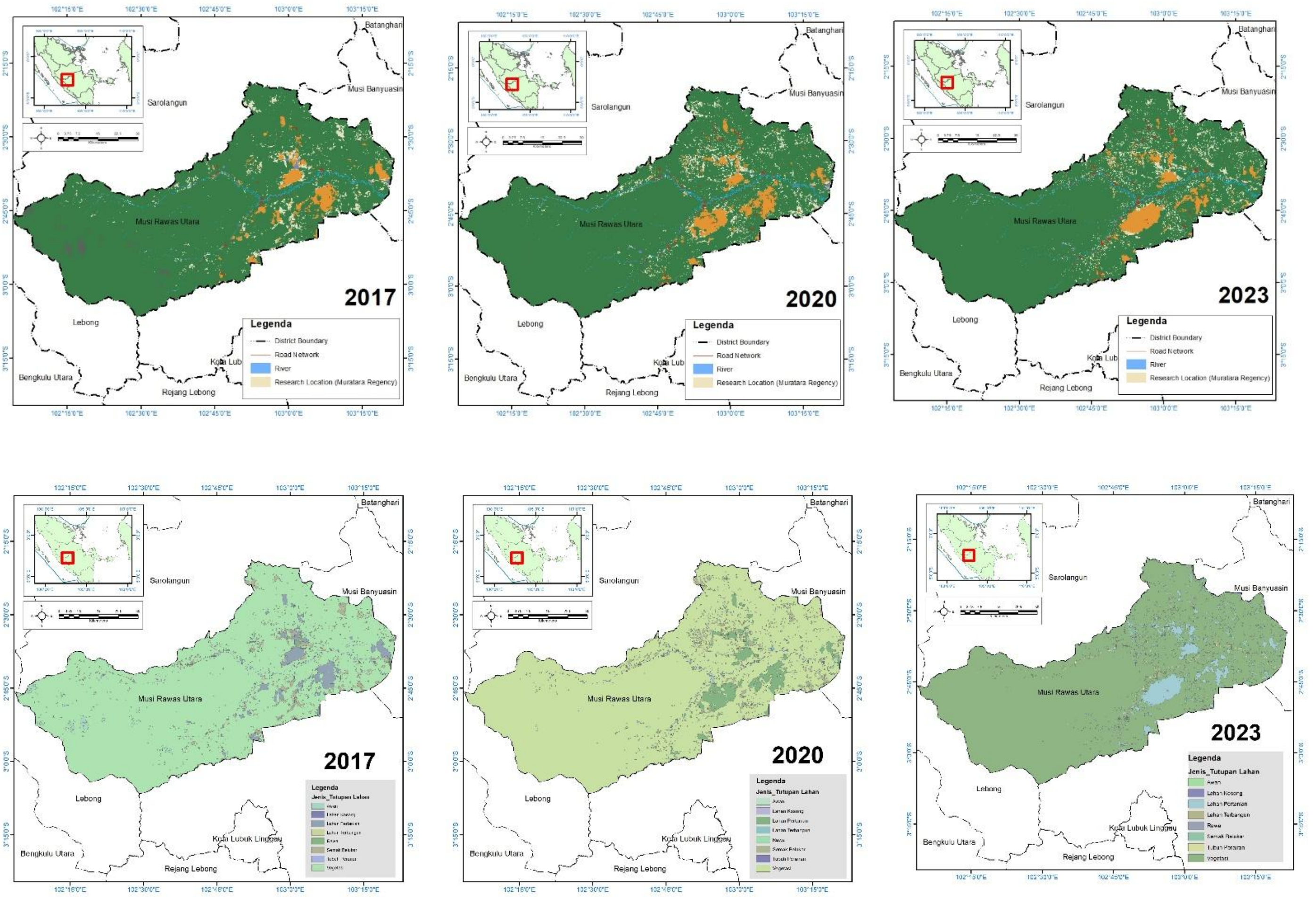

Figure 3. *Land cover classification maps of Musi Rawas Utara Regency in 2017, 2020, and 2023 based on Sentinel-2 imagery. The top row shows vegetation cover changes, while the bottom row displays classified land cover types.*
Source: *Processed by the author using ArcGIS, with Sentinel-2 imagery from ESA Copernicus and shapefile data from BIG (2022).*

The land cover maps produced for 2017, 2020, and 2023 reveal significant transformations in the land use structure in North Musi Rawas Regency (Figure 3), with spatial analysis showing that the conversion of land from vegetation to agricultural land was the dominant change in an area of 9,769 hectares (Table 1), which may be triggered by the increase in the economic needs of local communities for agricultural activities, while the conversion of vegetation into 194 hectares of built-up land reflects the process of urbanization or infrastructure development due to population growth and regional development policies; On the other hand, the conversion of vegetation into scrub covering an area of 15,011 hectares can be attributed to land degradation due to unsustainable land management practices or natural factors such as erosion and climate change, while the change of vegetation into swamps covering an area of 514.17 hectares indicates hydrological dynamics that may be influenced by anthropogenic factors, such as improper drainage systems, as well as changes in rainfall patterns, So that overall this pattern of change reflects the complex interaction between socio-economic factors, such as population pressures and government policies, as well as environmental biophysical conditions that affect the dynamics of land cover in the region.

	2023									
	Jenis Tutupan Lahan	**Awan**	**Lahan Kosong**	**Lahan Pertanian**	**Lahan Terbangun**	**Rawa**	**Semak Belukar**	**Tubuh Perairan**	**Vegetasi**	**Grand Total**
2017	Awan						12.73894331	0.381976264	40.00944697	53.13036654
	Lahan Kosong		42.3726831					0.025564864	15.63713023	58.03537819
	Lahan Pertanian	0.771147389	8.008332449	10727.11876	11.91681394	144.1560178	2280.494509	0.076674034	14709.21309	27881.75534
	Lahan Terbangun	92.5456886	21.67078313	179.0385955	1165.737285	7.566060769	131.4128356	8.169944883	1679.657202	3285.798395
	Rawa			12.41138392		40.29437622	24.79720297	24.17183279	83.27266973	184.9474656
	Semak Belukar	6.698081749	69.9283267	715.0088075	6.114504345	164.5329569	3140.285213	29.66921311	17611.10083	21743.33793
	Tubuh Perairan		14.91406928	31.60092597	10.92108886	24.77163811	79.41507717	1773.606208	671.6423823	2606.871389
	Vegetasi	4573.506082	139.5162416	9769.374763	194.5826996	514.1797181	15011.00392	525.6974179	506546.5297	537274.3906
	Grand Total	4673.521	296.4104363	21434.55324	1389.272391	895.5007678	20680.14771	2361.798832	541357.0625	593088.2668

Table 1. *Probability matrix of land cover changes*
Source: *Land cover area statistics based on Sentinel-2 classification, processed by the author using ArcGIS.*

Flooding and Its Relationship to Changes in Land Cover

Flooding is increasingly recognized as a significant environmental threat, exacerbated by land cover and land use change (LULC). The relationship between these changes and flooding is complex, involving a variety of hydrological and ecological processes. This synthesis aims to explore how changes in land cover can contribute to the occurrence of flooding, with reference to various studies highlighting the mechanisms involved. Changes in the physical properties of the soil and ground cover due to changes in land use can lead to increased flooding (Wells et al., 2016). The conversion of wetlands and floodplains to built-up areas has been identified as one of the main factors contributing to the increase in the frequency and intensity of flooding (Idowu & Zhou, 2023). Loss of natural land cover reduces the capacity of the landscape to absorb rainfall, which in turn increases surface runoff and increases the risk of flooding.

Based on data from the National Disaster Management Agency (BNPB), the flood that occurred on April 16, 2024 in Karang Jaya District was caused by moderate to high intensity rainfall, which increased the discharge of the Rupit River and Rawas Rivers, resulting in overflow of water to settlements around the watershed (DAS). This flood also extended to the Rupit, Karang Dapo, and Rawas Ilir sub-districts, causing significant disruption to community activities and potentially causing social and economic losses. Land-use change, especially the conversion of forests and wetlands to built-up areas or intensive agricultural land, has contributed to increased flood risk as it reduces soil infiltration capacity and increases surface runoff volume. Therefore, the analysis of land cover change based on Sentinel-2 satellite imagery is very important to understand the dynamics of land change and its implications for flood risk, in order to support more effective mitigation planning in North Musi Rawas Regency.

The map shown (Figure 4) is the result of a compilation of disaster data from a platform owned by the National Disaster Management Agency (BNPB) as well as RBI vector data managed by the Geospatial Information Agency (BIG). The results of data processing show the distribution of areas based on the level of flood risk, ranging from low to moderate. Most of the medium-risk areas are located in residential areas and along the road network, covering an overall area of 133,586 hectares. Meanwhile, low-risk areas are mostly in the southern part of Rawas Ilir and Karang Dapo Districts, with an area of 31,397 hectares. On the other hand, the western part of Musi Rawas Regency generally does not have a flood risk as it is still dominated by dense vegetation cover, which plays an important role in increasing rainwater infiltration capacity and reducing surface runoff, so that the potential for flooding can be minimized.

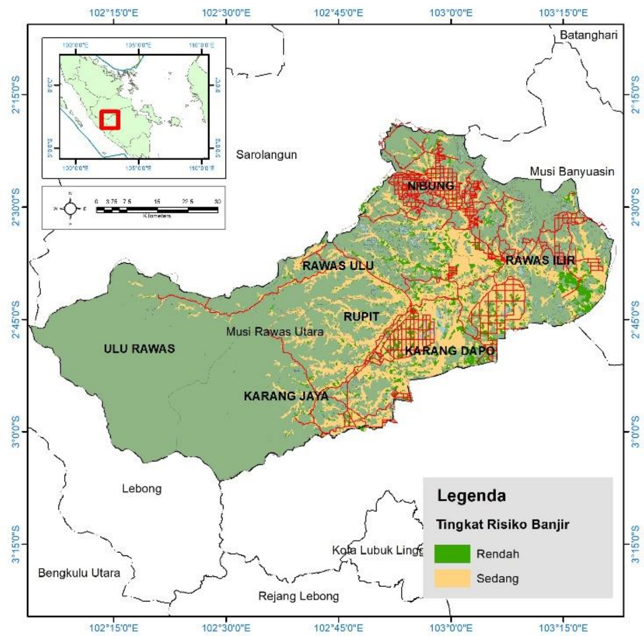

Figure 4. Flood Risk Map of North Musi Rawas Regency, South Sumatra, Indonesia. Source: Processed by Author Based on BNPB Data (2025)

North Musi Rawas Regency consists of seven sub-districts, namely Ulu Rawas, Karang Jaya, Karang Dapo, Rawas Ulu, Rawas Ilir, Rupit, and Nibung. The results of the analysis showed that the sub-districts with the highest level of flood risk included Karang Dapo, Rupit, and Rawas Ilir, while Ulu Rawas was not identified as having a flood risk. These findings can serve as a reference for the government in developing more sustainable land use planning and more effective disaster mitigation strategies to minimize the impact of flooding in the region.

CONCLUSION

This study reveals the dynamics of land cover change in North Musi Rawas Regency for the 2017–2023 period using Sentinel-2 imagery and GIS approaches. The results of the analysis showed that the dominant conversion of vegetation into agricultural land covered an area of 9,769 hectares, built land covered an area of 194 hectares, scrubland covered an area of 15,011 hectares, and swamps covered an area of 514.17 hectares. These changes are influenced by economic factors, urbanization, land degradation, and hydrological changes. The change in land cover has a significant impact on flood risk. Most of the areas with moderate risk are located in residential areas and along the road network, with a total area of 133,586 hectares, mainly in Karang Dapo, Rupit, and Rawas Ilir Districts. Meanwhile, low-risk areas are mostly in the southern part of Rawas Ilir and Karang Dapo Districts, covering an area of 31,397 hectares. On the other hand, the western region and Ulu Rawas are relatively safe from flood risk as they are still dominated by dense vegetation that supports water infiltration and reduces surface runoff. These findings recommend sustainable land management policies through land conversion control, vegetation protection, spatial data optimization, and the use of remote sensing technology for periodic monitoring and environmental risk mitigation. Furthermore, flood mitigation and environmental management policies should include the revitalization of degraded watersheds, the implementation of green infrastructure in urban planning, the enforcement of buffer zones along rivers and wetlands, and the integration of ecosystem-based adaptation measures in regional development plans.

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