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OPTIMIZATION OF LAND USE MAPPING USING SENTINEL IMAGERY TO SUPPORT FLOOD DISASTER MITIGATION IN TORUE DISTRICT

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ABSTRACT

To mitigate risk, effective land use planning must consider these socioeconomic factors. Numerous natural disasters will be brought on by improper land modification—the interaction between climate change and land-use change, such as deforestation. Different types of land transformation, such as cultivation and reforestation, are understood in varying ways. This study aims to accurately map land use by utilising GIS and Sentinel-2 data to support disaster mitigation efforts in Torue District. This study adopts a spatial approach and a descriptive quantitative method. Descriptive statistics are employed in this study's data analysis to illustrate the spatial characteristics of the study region, based on satellite image interpretation and GIS data processing. The results obtained eight land use classes. High-quality satellite imagery is required for accurate classification. Similarly, between classes and high intra-class variation can complicate the classification process, requiring advanced techniques to improve accuracy. Land use mapping produced eight classes with a total area of 26,467 ha, achieving an Overall Accuracy of 94.43%.

Keywords: *classification; land use; mapping; optimization; sentinel*

INTRODUCTION

Mapping is one way to describe the current land use. Mapping land-use changes over time is crucial for understanding landscape dynamics, including deforestation, desertification, and urbanisation. This information supports conservation efforts and sustainable land management practices (Kapitza, Golding, & Wintle, 2022). In addition, mapping provides important data for urban planning, helping to identify areas with high and low land use intensity and supporting sustainable development (Pereira, Gomes, & Rocha, 2022; Szarek-Iwaniuk, Dawidowicz, & Senetra, 2022). Widyastuti et al. (2025) mention that through land use planning, it is essential to consider biophysical, economic, and social aspects, while also emphasising the integration of disaster vulnerability data into the land use mapping process. Careful mapping and determination of land functions, based on the impacts of past disasters, is also important to ensure the development of areas such as coastal regions. Remote sensing and Geographic Information Systems (GIS) are crucial in land-use mapping. This technology enables the collection and analysis of spatial data from satellite, drone, and other aerial imagery, providing up-to-date and high-resolution information on land use and land cover (Pande, Moharir, & Khadri, 2021; Rugel, Van Coillie, & Ochoa, 2021; Sharma & Chawla, 2023; Thepade & Bhalerao, 2023). Using high-resolution satellite imagery, such as Landsat and Sentinel, improves the accuracy and detail of land cover/land use maps. This imagery helps identify and monitor changes in land use over time (Issa & Sultan, 2024). Satellite imagery enables fast and realistic visualisation, saving time, effort, and cost. High-resolution imagery supports accurate topographic mapping and terrain modeling, which is essential for a wide range of scientific and practical applications (Backes & Teferle, 2020). Lindner et al (2023) utilize satellite photography to record and demonstrate the cost-effectiveness and scalability of cadastral data collection and digitization quickly. High-resolution satellite imagery (0.5-3 m) allows detailed visual analysis, identifying specific types of land cover and their changes over time (Lebedeva, Baldina, & Medvedev, 2022). Currently, GIS is used for land use mapping through various techniques, one of which is overlay. The overlay technique in GIS superimposes multiple layers of spatial data to examine phenomena that occur simultaneously. Traditional maps are primarily the result of overlay techniques that combine multiple layers of information, such as roads, buildings, and soil types. The overlay technique combines multiple data sets to provide a comprehensive perspective on spatial interconnectedness and change (Ahlqvist, 2009).

Different types of land transformation, such as cultivation and reforestation, are understood in varying ways. Changes in farmland are complex and require more effort to understand them accurately (Tarko, Tsendbazar, de Bruin, & Bregt, 2020). Land use that is not in accordance with its designation poses a risk of disaster. Inefficiencies in land use planning, such as delays in permitting approvals, inadequate monitoring, and weak regulatory enforcement, can lead to property development in high-risk areas, including swamps and waterways, thereby increasing the risk of flooding (Tasantab, 2019). Although disaster vulnerability maps are available, their integration into land use plans is often inadequate. Like Morales & de Vries

(2021), who mention a lack of integration that is claimed to be potentially dangerous, especially if not fully acknowledged in planning decisions, this increases vulnerability to disasters. A combination of various hazards, including floods and incidents involving hazardous materials, complicates land planning. Current methods often fail to account for these interconnections precisely, making it impossible to effectively compare and manage the various risks (Bofjäll, Hassel, & Cedergren, 2020).

Effective land use planning must consider these socioeconomic factors to reduce risk (Narendr, Vinay, Aithal, & Das, 2022). Improper land conversion will trigger various natural disasters. The interaction between climate change and land-use change, including deforestation and urbanisation, is complex. These interactions can exacerbate the frequency and intensity of natural disasters such as floods, landslides, and droughts, but the exact mechanisms and feedback cycles are not yet fully understood (Azadi, Barati, Nazari Nooghabi, & Scheffran, 2022; Dewi, Handayani, Rudiarto, & Artiningsih, 2022; Krishna & Mukherjee, 2022).

Urbanisation and land conversion, which contribute to hydrometeorological disasters (e.g., floods and storms), are still being addressed. Although there are known correlations, the processes and thresholds of detail that led to disasters are not yet fully clear (Dewi et al., 2022; P. B. Putra, Agus, Adi, Susanti, & Indrajaya, 2021). The impact of land-use changes on natural disasters can vary greatly from region to region due to differences in climate, topography, and socioeconomic factors. For example, the impacts observed in Central Java may not apply directly to other regions with different environmental and socioeconomic contexts (Dewi et al., 2022; Marino et al., 2023). Similarly, the long-term impact of land conversion on disaster risk has not been well-documented. Land-use changes can delay impacts on the frequency and severity of natural disasters, making it difficult to accurately predict future risks (Cheng, Zhang, & Song, 2024; Li, Jenkins, & Xu, 2022).

Ecosystem degradation due to land conversion, such as the loss of natural buffers against floods and landslides, is an area that needs attention. However, the specific ecological impact and its contribution to disaster risk have not been fully measured. For this reason, sophisticated monitoring and modelling techniques are needed to better understand and predict the impact of land conversion on natural disasters. Current models may not fully capture the complexity and uncertainty involved (Cheng et al., 2024; Krishna & Mukherjee, 2022). High rain intensity, if land use is not allocated, has the potential for repeated disasters. Urbanisation and land-use change significantly increase the risk of flooding and waterlogging. Increased waterproofing of surfaces leads to increased runoff and decreased infiltration, thereby exacerbating the risk of flooding (Pabi, Egyir, & Attua, 2021). Liu et al. (2021) suggest that urban growth and land-use change have increased the risk of flooding in various regions, including Shanghai, Beijing, and the Mediterranean coastal watershed.

This research is important because Torue Regency has experienced repeated flood disasters that have caused material losses and fatalities. The typology of Parigi Moutong Regency, with its complex geological structure and earthquake path, makes the area very vulnerable to natural disasters (earthquakes, floods, and landslides), such as flash floods accompanied by fatalities in Torue District in 2023 (http://bnpb.go.id/berita/banjir-terjang-parigi-moutong-3-orang-warga-ditemukan-meninggal-dunia). Land use maps help identify areas that are vulnerable to natural disasters such as floods, landslides, and tsunamis. As mentioned, Narendra et al. (2024) use land use characteristics and geomorphometry to classify watersheds on Lombok Island based on flood risk levels in their flood vulnerability mapping. Similarly, land-use mapping and morphometric analysis help identify flood-prone areas, which form the basis for land use planning for flood mitigation (Barkey et al., 2020). Accurate land use maps are essential for effective spatial planning, which is essential for disaster risk reduction. These maps provide detailed information about land cover, which can be used to plan and implement actions to reduce disaster risk (Danoedoro, Ananda, Kartika, Umela, & Indayani, 2020; Moayedi, Jamali, Gibril, Kok Foong, & Bahiraei, 2020). The solution involves the use of satellite images and Geographic Information Systems (GIS) processing. Satellite imagery provides extensive spatial data that can be stored and managed in a GIS platform. According to Mukhaiyar (2019), Satellite imagery can cover a large area, providing a comprehensive picture that is not possible with land-based surveys alone. This is particularly useful for environmental studies and large-scale land-use analysis. Integrating satellite imagery with GIS allows for better analysis and visualisation of spatial data, aiding in more informed decision-making processes (‘Audah et al., 2019; Vinuja & Devi, 2023). Tehsin et al. (2023) confirm that the quality and quantity of satellite data can vary significantly, affecting the accuracy of land-use classifications.

High-resolution imaging offers greater detail but requires substantial processing and error correction. In addition, the availability of (temporal) data makes it difficult to track changes over time. Additionally, issues including cloud cover, weather conditions, and sensor interference can reduce image quality. The purpose of this study is to accurately map land use by utilising GIS and satellite data to support disaster mitigation efforts using Sentinel-2 imagery in the Torue District.

MATERIALS AND METHODS

This study uses a descriptive quantitative method with a spatial approach. The data analysis of this study employs descriptive statistics to illustrate the spatial characteristics of the research area, based on the interpretation of satellite images and data processing using a Geographic Information System. The research location is in Torue District, Parigi Moutong Regency. It has a varied topography, ranging from mountains and hills to alluvial plains and the coast, including the coastal area of Tomini Bay, as shown in **Figure 1**.

Land cover extraction using Sentinel 2A in 2020 and 2024. Satellite image analysis is a composite of Band 3 (Red), Band 2 (Green), and Band 1 (Blue), which visualises the natural appearance of the image and facilitates the interpretation of land cover classes. Next, it corrects the Geometric and Radiometric corrections. Geometric correction is not carried out, as the 10-meter spatial resolution Sentinel 2A has already been geometrically corrected using Ground Control Points (GCPs), allowing it to be used in conjunction with other spatial data. The radiometric correction in the Sentinel-2A satellite image has been atmospheric, but it has

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not been corrected in terms of surface reflectance. In making maps and land cover data, it has a limited influence on radiometric correction because it does not use pixel values as input. The Supervised Classification is carried out in accordance with the Land Cover Classification SNI 7645-1 of 2014, using the Maximum Likelihood technique.

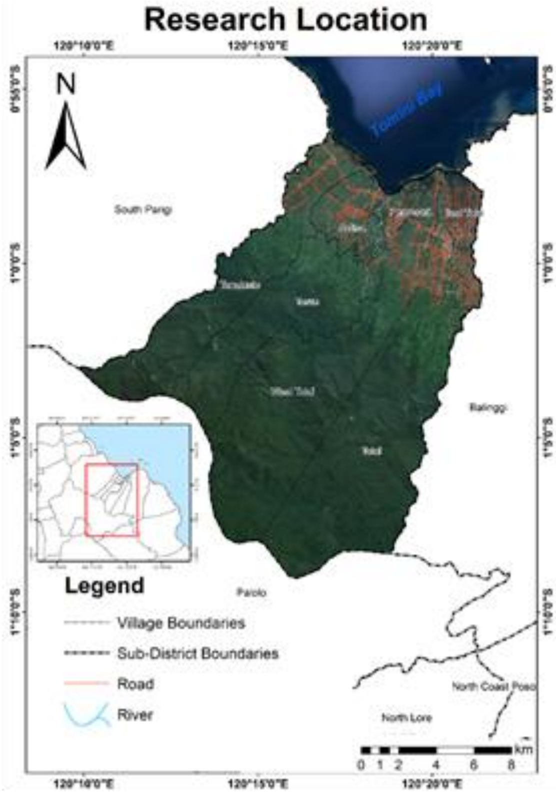

Figure 1. Research Area
Source: Google Earth Imagery, 2023

The classification results were evaluated for accuracy using the accuracy assessment method. This accuracy test is presented in the form of an error matrix, comparing the results of the classification (training sample area) with those of the test sample. Samples used as training areas and samples used for accuracy tests must be taken from different places (Pande et al., 2024; Rizaldi et al., 2022). The next step is to calculate the overall accuracy and the accuracy kappa. Currently, the recommended accuracy is kappa accuracy, as overall accuracy tends to overestimate values in general (Fikri et al., 2022). To obtain a field inspection, land cover is carried out to check the results of the area interpretation. Fieldwork was conducted at a predetermined sampling point. Data analysis is carried out according to the stages of generating new information in the form of maps, tabulations, and diagrams. Field observations consider accessibility and the ability to know and understand the location in Torue District. The data were analysed using ArcGIS (GIS) with land cover overlay techniques, supplemented by supporting maps and Google Earth imagery for fieldwork. Overall, the stages of research are as shown in **Figure 2.**

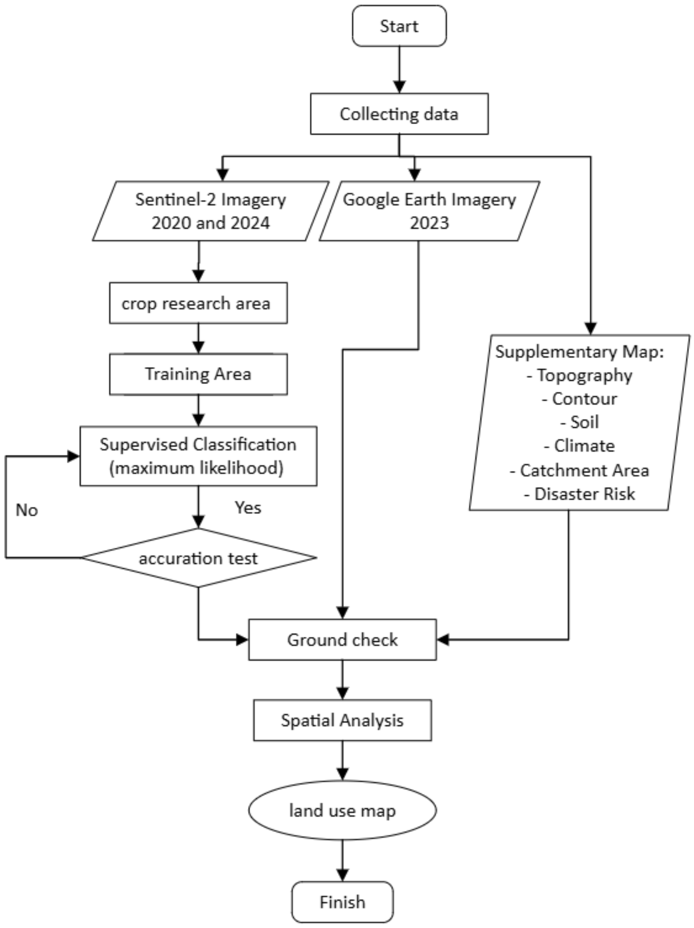

Figure 2. Diagram of The Stages of The Research
Source: Researcher Analysis, 2025

RESULTS AND DISCUSSION

Torue District is an area with a high risk of disasters, especially floods. This is evident from the recurring flood events that have occurred from 1987 to the present. The repeated occurrence of floods indicates that identifying land use changes is necessary to provide a comprehensive understanding of the potential impacts on water catchment areas and flood flow paths.

The results of the study, using Sentinel-2 imagery from 2020 and 2024, are shown in **Figure 3**. The analysis reveals eight land use classes (Table 1), indicating significant changes in land use dynamics across several land cover classes. The area of primary forests has decreased by approximately 929 hectares, from 13,231,001 hectares (2020) to 12,302,052 hectares (2024). A reduction followed this decline in shrubs of about 978 ha, as well as a decrease in a 64 ha pond and a 60 ha dryland field. On the other hand, several other classes increased, including: A mix of 641 ha, rice fields around 16 ha and settlements around 48 ha in the same period, while the total area remained constant at 26,492,625 ha.

Table 1. Comparison of Land Use Area (Ha)

Name	2020	2024	Description	
Hutan Primer/Primary Forest	13231,001	12302,052	-929	decrease
Hutan Sekunder/Secondary Forest	6349,303	7522,447	1173	increase
Kebun Campuran/Mixed Plantation	1444,864	2085,807	641	increase
Permukiman/Settlement	667,022	714,903	48	increase
Sawah/Rice Field	3417,838	3586,818	169	increase
Semak Belukar/Shrubs	1011,385	33,449	-978	decrease
Tambak/Pond	137,344	73,578	-64	decrease
Tegalan/Dryland Field	233,868	173,570	-60	decrease
TOTAL	**26492,625**	**26492,625**		

Source: Analysis data, 2024-2025

This pattern of change indicates a shift in land use from primary forests and shrublands to secondary forests, mixed gardens, cultivated land (including rice fields and moors), and settlements. Hydrologically, the reduction of primary forests and shrubs, which initially functioned as catchment areas and buffers for surface flows, has the potential to decrease infiltration capacity and increase surface runoff. In addition, the mapping results also show that there has been an increase in the area of mixed gardens, rice fields, and settlements, especially if they are in floodplains and along river borders, which can increase the risk of flooding because the land surface becomes more open or experiences soil compaction, so that rainwater flows faster into the river body.

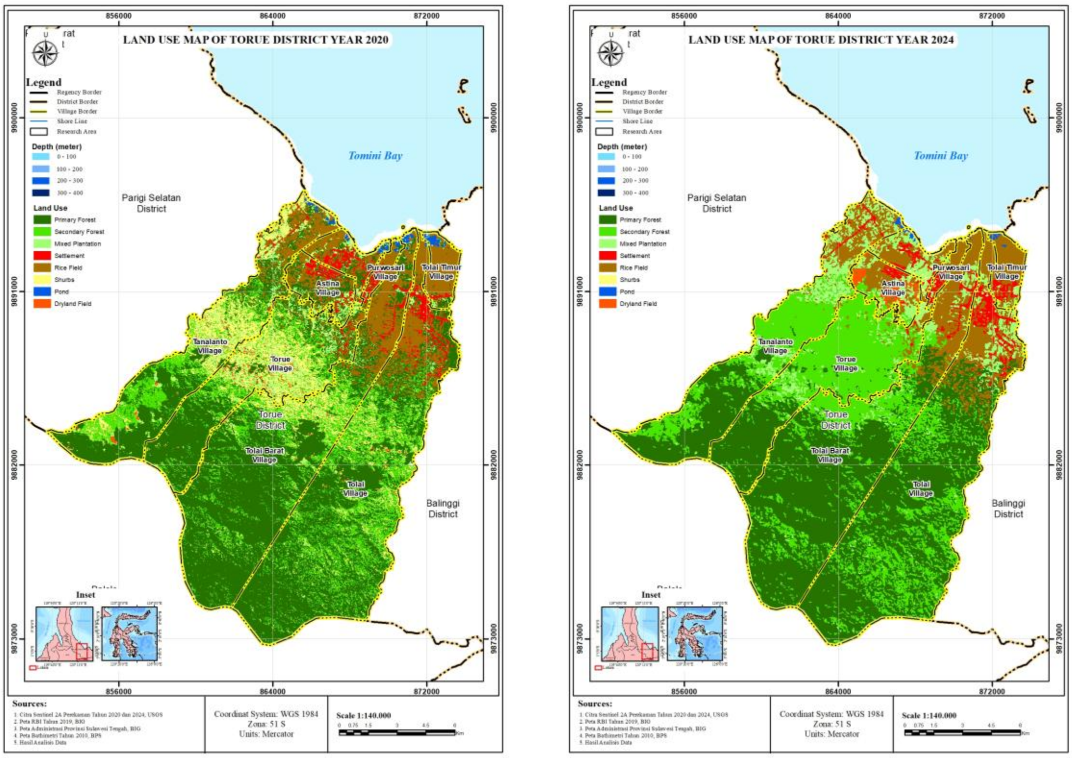

Figure 3. Land Use Map of Torue District
Source: Researcher Analysis, 2025

Data processing using high-quality satellite imagery is required for accurate classification (Pande et al., 2024; Tehsin et al., 2023). Likewise, similarities between classes and high intra-class variation can complicate the classification process, requiring advanced techniques to improve accuracy (Tehsin et al., 2023). When classifying unknown pixels, this approach offers the benefit of statistically assessing the variance and correlation of spectral response patterns (Islami, Tarigan, Wahjunie, & Dasanto, 2022)

An accuracy test was conducted to evaluate the classification results' accuracy by comparing the coordinate points obtained in the field with those from the classification of Landsat images. The accuracy test uses a confusion matrix test (**Table 3**).

Table 3. Test Accuracy With Matrix Confusion

Ground Truth (Pixels)									
Class	**SE**	**RF**	**PF**	**MP**	**SF**	**SU**	**DF**	**PO**	**Total (Ha)**
SE	**265**	0	0	7	0	0	0	0	272
RF	11	**271**	9	0	1	1	0	0	293
PF	0	17	**1290**	0	4	1	0	0	1312
MP	0	13	0	**461**	14	0	0	0	488
SF	0	22	15	0	**830**	9	0	0	876
SU	0	5	0	0	1	**249**	0	0	255
DF	0	28	14	0	16	0	**102**	0	160
PO	0	0	26	0	0	0	0	**160**	186
Total	276	356	1354	468	866	260	102	160	**3842**

Information: SE = Settlements; RF = Rice field; PF = Primary forest; MP = Mix plantation; SF = Secondary forests; SU = Shrubs; DF = Dryland field; PO = Pond

Overall Accuracy = (3628/3842) = 94,43%
Kappa Coefficient = 0,912

Land use classes, influenced by specific types of land use, such as agriculture, logging, and reforestation, are more difficult to interpret consistently. This type requires more effort and resources to interpret accurately (Tarko et al., 2020). Land use that deviates from its designated purpose carries a high risk of exacerbating the potential for natural disasters, including floods, landslides, droughts, and forest fires. Inappropriate land use, such as development in flood-prone areas, increases vulnerability to flooding. It is essential to examine areas where land use planning overlooks flood hazards, leading to significant flood damage and mortality (Der Sarkissian et al., 2022; Narendran et al., 2022). Moreover, the level of community awareness and preparedness for disaster management shows that, across all informants, there are still people who do not know how to be prepared or what to do before, during, and after a disaster (Novarita, Rahmawati, & Putra, 2025; E. Putra, Fitriana, Nutfa, & Teguh, 2025). The findings of land use changes in Torue District in the 2020–2024 period not only illustrate the dynamics of space use but also provide an important basis for flood mitigation efforts in this region. The decline in primary forests and shrubs, accompanied by an increase in secondary forests, mixed plantations, rice fields, and settlements, indicates that the ecological function of specific areas as catchment areas and hydrological buffers is being compromised. Therefore, the flood mitigation strategy in Torue District needs to be directed not only at structural aspects (river normalisation, flood control buildings), but also at more sustainable land-use management practices. **First**, these results indicate the need for the protection and rehabilitation of forest areas, particularly in upstream and slope areas that contribute to surface flows to lowland settlements. Areas identified as having been converted from primary forests/shrubs to cultivated land need to be mapped as priority zones for rehabilitation through *reforestation* or *agroforestry* conservation. This effort is expected to restore the water absorption function, reduce erosion, and contain surface runoff rates, thereby suppressing peak discharge during heavy rains. **Second**, the improvement of settlements and cultivated land around floodplains and river boundaries should be used as a basis for reviewing spatial arrangements and river boundaries. The results of land use change can be used to identify developing settlements in high-risk areas, so that local governments and stakeholders can formulate mitigation measures such as: enforcement of river boundary lines, restrictions on new development permits in vulnerable zones, rearrangement of residential drainage, and development of green infrastructure (e.g. green open spaces, absorption gardens, and river border green strips) that can help hold and absorb rainwater runoff. **Third**, the dynamics of increasing agricultural land (rice fields and mixed plantations) also require conservation agricultural practices as part of mitigation strategies. The use of terraces on sloped land, planting cover crops, micro-drainage systems in rice fields, and proper management of plant residues can reduce the rate of surface flow and sedimentation to the river body. Thus, the agricultural sector is not only a land user but also a key factor in reducing flood risk through environmentally friendly cultivation practices. **Fourth**, this information on land use change can be integrated into early warning systems and contingency planning. Maps of land cover change that show critical areas (e.g., areas that have lost significant vegetation cover or experienced increased settlement near rivers) can be used as a basis for determining evacuation routes, safe gathering point locations, and socialisation priorities within the community. Community involvement in understanding how changes in land use around them contribute to flooding is also important for building awareness and participation in maintaining vegetation cover, not closing drainage channels, and avoiding construction in areas that are clearly in the path of flood flows.

Land use planning must consider the potential risk of natural disasters. Effective spatial planning, community engagement, and nature conservation must be integral to land use planning to minimise the impact of natural disasters. Dandoulaki et al. (2023) emphasise that integrating disaster risk management into spatial planning is essential. It involves stakeholders collaborating to reduce disaster risk. However, there is often a lack of consistency in land use planning practices, which can lead to increased disaster vulnerability (Maund, Maund, & Gajendran, 2022). Flood incidents that often occur in flat areas of Torue District necessitate the repetition of disaster prevention strategies. Climate change, urbanisation, and inadequate land use planning have contributed to increased frequency and severity of flooding in low-lying areas (Debnath et al., 2024; Rainey et al., 2021). Therefore, data-driven methods and geospatial analysis are employed to mitigate and manage floods, thereby improving decision-making (Assaf & Assaad, 2024). Land use maps are crucial for managing resources effectively. These maps help identify areas that require protection and those that can be developed, ensuring the sustainable use of resources while minimising disaster risk (Moayedi et al., 2020). Many other areas in Indonesia still require land use planning based on flood vulnerability mapping.

CONCLUSION

Disaster mitigation through land use mapping is a strategic approach to encourage sustainable land management and reduce disaster risk. This study demonstrates that integrating Sentinel 2 and Google Earth imagery with GIS-based overlay analysis provides a cost-effective approach to land use mapping in the context of disaster mitigation. However, to achieve higher accuracy, integration with multitemporal datasets and advanced classification techniques (e.g., Random Forest, SVM, or CNN) is recommended. Further research should combine hydrological, seasonal variability, and socioeconomic variables to develop a flood risk prediction model.

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