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Evaluation of land resilience against natural disasters using ecosystem services approach in Kendari City, Southeast Sulawesi, Indonesia

La Ode Restele*[1], Fitra Saleh*, L. M. Iradat*, Jufri Karim*, Noor Husna Khairisa*

* Universitas Halu Oleo, Jl. H.E.A. Mokodompit, Kodya Kendari, Sulawesi Tenggara, Indonesia
[1]Corresponding author, Email: laode.restele@uho.ac.id

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Abstract

Kendari City has multiple disasters hazard, especially floods and landslides. Consequently, the city requires systematic preventive efforts to minimize the potential disaster risk. This study aims to create a spatial model to determine the resilience of the land against floods and landslides with an ecosystem services approach. We used Sentinel-2 and DEMNAS (National Digital Elevation Model of Indonesia) as our primary data collection tools. Sentinel-2 was used to compile land use maps, and DEMNAS was the basis for compiling landform maps. The integration of the two was carried out by the analytic hierarchy process (AHP). The results showed that 8,259.98 acres (30.01 percent) of land in Kendari had low resilience to disasters. Those areas are located in a residential area on the TWH (Rocky hill over mixed sedimentary rocks) and KHY (Coalescent estuarine/riverine plain) landforms. The dominant disaster hazard in the area is inundation flooding that occurs almost every year in Kendari. Poor soil infiltration capacity is one factor affecting the area become vulnerable to flooding.

Keywords: land resilience; natural disaster; ecosystem services; Kendari

1. Introduction

Indonesia is vulnerable to multi-disaster hazards. Floods, landslides, erosions, earthquakes, volcanic eruptions, tsunamis, and forest fires are a series of disasters that occur almost every year in Indonesia. Indonesia's geological condition, as it is located in the plate confluence zone, causes geological disasters (Arifin, 2016; Pribadi et al., 2021). The potential for disasters is exacerbated by global climate change, which has become an international issue recently (Haggag, Yosri, El-Dakhakhni, & Hassini, 2022; Hansen, 2022). Indonesia's latest disaster was Poso Earthquake, with a magnitude of 6.6 MW carrying extraordinary effects on land and settlements (Sianipar, Daniarsyad, Priyobudi, Heryandoko, & Daryono, 2021). Furthermore, the relatively substantial change in Sulawesi's land use also has the potential to trigger floods and landslides (Yulianto et al., 2016).

Kendari City is one of the cities in Southeast Sulawesi which has multi-disaster hazards. Various studies report that Kendari is highly vulnerable to landslides and floods (Apdal, Saleh, & Mey, 2018; Bahir, Yunus, & Sawaludin, 2017; Musyawarah, Ili, & Tanjung, 2020). Land degradation is one of the leading factors that cause disasters in Kendari (T. R. M. Saleh & Setiadi, 2020). Sejati, Karim, and Tanjung (2020) stated that more than 14% of the Kendari area is highly vulnerable to landslides. At least four districts have high landslide susceptibility, namely Kendari, West Kendari, Nambo, Abeli, and Poasia (Saleh, Mey, & Salahudin, 2019). Furthermore, a study carried out by Kasnar, Hasan, Arfin, and Sejati (2020) shows that more than 28% of the Kendari area has high flood vulnerability. These data illustrate that the land of Kendari has begun to degrade and bear a threat to its population.

Land degradation is closely related to changes in land use (Alemu, 2015). Land-use changes can cause soil erosion, followed by changes in the surface hydrological cycle. That problem cannot be avoided but can be controlled (Maulana, Saputro, Suprajaka, & Sari, 2020). The land-use change phenomenon and poor planning will lead to incompatible land use with natural conditions, resulting in natural disasters. Consequently, it can reduce the water catchment areas, decrease soil infiltration power, and cause changes in the surface hydrological system. A strategic step to prevent land degradation is the implementation of a proper and integrated land-use plan (Maulana et al., 2017). Furthermore, landform data is needed to provide information on land units containing the area's physical characteristics. Through the landform data, it is possible to identify the physical characteristics of the land related to the potential for disasters in Kendari. Land-based analysis with an ecosystem services approach can be an alternative to assess the land's resilience to the multi-disaster hazard (Cerretelli et al., 2018).

Ecosystem service refers to the advantages or benefits obtained by humans from nature (Costanza et al., 2014; Kertész, Nagy, & Balázs, 2019; Malinga, Gordon, Jewitt, & Lindborg, 2015). Meanwhile, disaster prevention ecosystem services are one component of ecosystem services that can provide information on the resilience of land to disaster hazards. The function of disaster prevention can be extracted from land use, and landform data since each of them offer unique characteristics for identifying the typology of natural disasters (Ronchi & Arcidiacono, 2018). The disaster prevention function framework can help establish appropriate management and conservation strategies by determining which areas are most vulnerable to natural disaster risk and appropriate nature based solutions to restore them (McPhearson, Andersson, Elmqvist, & Frantzeskaki, 2015).

Many previous studies have examined the natural disaster vulnerability of Kendari City. Unfortunately, the studies have not considered the resilience aspect of the land in the face of multi-disaster hazards. Thus, this study focuses on assessing the land's ability to deal with multi-disaster hazards in Kendari City by analyzing the land use and identifying the landform. The integration of the two parameters produces an overview of the resilience level of the land against multi-disaster hazards. The results of the resilience index against multi-disaster hazards can be used as a basis for land use planning in the coming year.

2. Method

This research was conducted in Kendari City, Southeast Sulawesi, Indonesia ($3^{0}54''$-$4^{0}3'$ S and $122^{0}23'$-$122^{0}39'$ E). On the east side, Kendari faces Kendari Bay and is bordered by Konawe and South Konawe on the mainland. With 271.76 km^2 areas, Kendari has eleven districts. The dominant land uses are settlements, forests, and plantations (Alwan, Barkey, & Syafri, 2020). Due to its status as the capital city of the province, Kendari presents a relatively rapid population growth. Kendari is dominated by the flat to gentle slope class with a river in the middle, namely Wanggu. The settlement area is reported to be the area most often affected by floods.

This study used two primary data sources, namely Sentinel-2 Image with a resolution of 10 meters and DEMNAS (Digital Elevation Model National Indonesia) with a resolution of eight meters. Other additional data consisted of land system maps and geological maps as tools for identifying and naming landforms. Extraction of land use data from Sentinel-2 (recording year: 2021) was carried out using a guided classification system with a maximum likelihood classification algorithm (MLC) approach. The land use classification consists of eight classes, according to the existing land use in Kendari (Table 1). The classification results were initially in the form of raster data and converted into vector form to facilitate correction and accuracy testing of the produced map. Several accuracy assessments, such as producer accuracy, user accuracy, overall accuracy, and kappa coefficient, were carried out to test the accuracy of land use maps. AHP was carried out based on survey results involving fifteen experts integrated with land use data to determine the weight of land use on disaster prevention ecosystem services.

Table 1. Land Use Class of Kendari City in 2021

No	Category	Symbol	Description	Area (acre)
1	Forest land	F	A land dominated by more than three meters high trees	0.24
2	Settlement	ST	A Land covered by the buildings	0.06
3	Plantation	P	A land with woody production plants and usually producing fruits	0.17
4	Paddy field	PF	A land that is overgrown with rice plants with water flow or salt production	0.14
5	Shrubs	S	A land filled with shrubs that have small and low wood	0.09
6	Bare land	B	Areas with no vegetation nor exposed soils	0.07
7	Farming field	M	Dryland farming	0.14
8	Waterbody	W	Rivers, lakes, and other hydrological features	0.09

Table 2. Landform Class of Kendari City

No	Symbol	Name	Description	Area (acre)
1	BPD	Bukit Pandan	Precipitous orientated metamorphic mountain ridges	0.16
2	GBJ	Gunung baju	Karstic rocky hill	0.08
3	KHY	Kahayan	Coalescent estuarine/riverine plain	0.07
4	KLG	Kalung	Karstic hills over marble and limestone	0.11
5	LBS	Lubuksikaping	Gently sloping non-volcanic alluvial fan	0.12
6	LWW	Lawanguwang	Undulating to rolling mixed sedimentary plain	0.11
7	SBG	Sebangau	Meander belt of large rivers with broad levees	0.09
8	SFO	Sungai fauro	Rolling plain with hilly rocks on marl and limestone	0.18
9	TWH	Teweh	Rocky hill over mixed sedimentary rocks	0.08

The landform information was extracted from DEMNAS data by visual interpretation and manual detection techniques. Identification was carried out in six stages and was started by identifying morphology to distinguish the shape, direction, length, and degree of slope. Furthermore, information on genesis was extracted to obtain the origin of the constituent materials of the landform by considering local geological conditions. Then, the chronology of land unit formation was identified. In the fourth stage, we identified the arrangement between land units. Lastly, we named each land unit by considering the naming of the land system. The field survey was conducted to check the accuracy of the tentative analysis results and redistributed the landform map. The weighting was carried out using AHP and integrated with spatial landform data (Table 2).

The assessment of the total disaster prevention ecosystem services index (ES_{total}) was obtained from a simple overlay between the land use map (ES_{lc}) and the landform map (ES_{lf}). The total value was obtained by calculating the data attribute between the roots of ES_{lc} and ES_{lf}, and divided by the maximum value between ES_{lc} and ES_{lf} times the roots of ES_{lc} and ES_{lf}.The detailed formula can be seen in equation 1 (Riqqi et al., 2018). The analysis results are classified into five classes of the Likert scale, namely very low, low, medium, high, and very high. A very low value indicates poor resilience of the land to multi-disaster hazards.

$$ES_{total} = \frac{\sqrt{(ESlc \ x \ ESlf)}}{Maks\ (\sqrt{ESlc \ x \ ESlf})} \qquad (1)$$

Information:
ES_{total} = total disaster prevention ecosystem services index
ES_{lc} = the land use map
ES_{lf} = the landform map

3. Results and Discussion

3.1. Land Use Setting of Kendari

The land is essential because it becomes a place for living beings to live and carry out activities. Land use is an abiotic element that covers land and carries effects on the land. Spatially, vegetation (especially forest) was observed to occupy the north and south sides of Kendari, which has an undulating to hilly relief. Forest areas on these lands are better protected due to several factors, such as the land's morphological barriers to being developed into built-up land, and some areas are classified as legal forest areas. As the plants in the legal forest are protected by the government agency, the designation of a legal forest can prevent changes in land use because. Furthermore, human pressure on land is also relatively weak, considering it has a relatively great distance from the city center. Overall, the total forest in Kendari is 10,537.90 ha (38.28%) and becomes the most extensive land use in Kendari (Table 3).

Table 3. Percentage of Kendari Land Use

No	Category	Symbol	Area (acre)	Percentage (%)
1	Forest land	F	10,537.90	38.28
2	Plantation	P	4,156.44	15.10
3	Paddy field	PF	3,462.39	12.58
4	Shrubs	S	2,701.19	9.81
5	Bare land	B	916.06	3.33
6	Farming field	M	1,863.10	6.77
7	Water body	W	90.96	0.33
8	Settlement	ST	3,799.87	13.80
Total			27,527.91	100.00

In addition, plantations, fields, and rice fields dominate the sloping to sloping land. The plantations are dominated by three primary commodities, namely coconut (*cocos nucifera*), coffee (*coffea*), and cocoa (*theobroma cacao l.*). The best plantation product from Kendari is coconut, with a production of 724.05 tons in 2020, followed by cocoa, with 188.87 tons production (BPS, 2022). Coconuts can grow well in Kendari because it needs to be planted on land <600 meters above sea level, while Kendari fulfills that criteria. Rice (*oryza sativa l.*) also grows well in Kendari, with a tendency to increase every year. However, the existing paddy fields are threatened by the development of residential areas, which often change the agricultural land's function.

The settlements were observed occupying flat to sloping land areas in the central part of Kendari. The most populous area is in Kendari Barat District, with a total population of 42.23 thousand people, followed by Poasia and Puuwatu, with a density of 40.66 and 40.00 thousand people, respectively. Meanwhile, the highest development occurs in Baruga District, with a 5.38% population in the last ten years (Badan Pusat Statistik (BPS), 2022). The most densely populated area is the Kadia District, with a density of 5,650 per sq km. This high growth of population and settlement is presumed to be induced by the area's proximity to the economic and government centers. The easy access to facilities and a good road network also supports the development of settlement areas in the central part of Kendari. The spatial distribution of Kendari land use obtained from the analysis is presented in Figure 1.

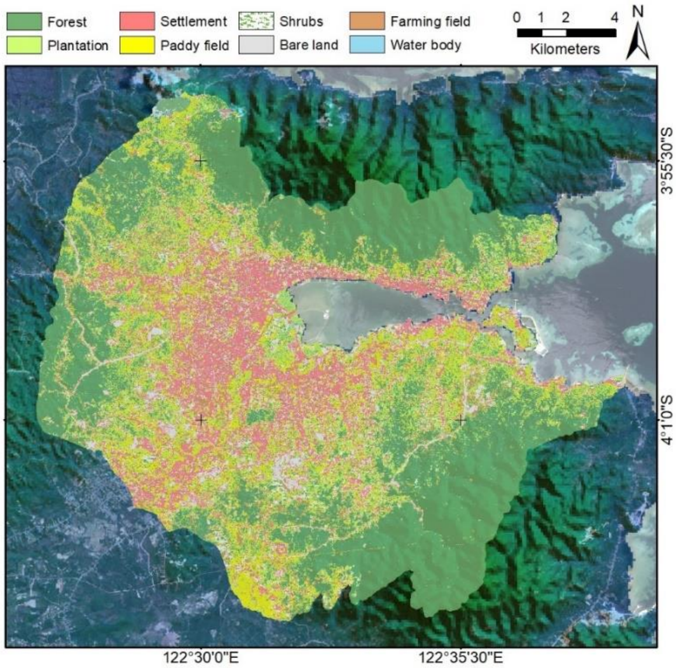

Figure 1. Land Use Map of Kendari

The land use map produced from the guided classification analysis using the MLC algorithm had a total accuracy of 87.24%, with a kappa index of 0.86. According to Sutanto (2010), our analysis results have met the minimum accuracy requirements of >85% and a kappa value of >0.8. Errors in the form of omissions were often found in land use, such as in the forests and plantation areas. The appearance, hue, color, and pixel size factors are deemed to be the cause of some omissions occurrence, especially in the middle slope. Additionally, the commission error, in the form of fields and shrubs, occurred in land use. The image of Sentinel-2 we adopted in this study was recorded during the dry month so that the bushes and fields have a brownish-green color and hue. This result presented challenges in the digital classification system.

3.2. Landform Setting of Kendari

The Kendari landform comprises three primary geneses, namely structural, fluvial, and fluvio-marine. Structural hills dominate the north and south areas of Kendari. The central land unit with structural hills is BPD, with an area of 7,211.02 ha (26.20%). Meanwhile, the surface material comprises four types, namely shale, mudstone, sandstone, and conglomerate. The soil types in the area are dystropepts and eutropepts from the order of inceptisol. These two soil types are the typical ridge soils in structural hills, predominantly found in Southeast Sulawesi. The soil texture tends to be fine, with good drainage. BPD has a fairly good nutrient content and is suitable to be developed to grow annual crops. Surface geomorphic processes, such as erosion and landslides, do not occur so quickly in this area because it has relatively great forest land. Spatially, the appearance of the Kendari landform can be seen in Figure 2.

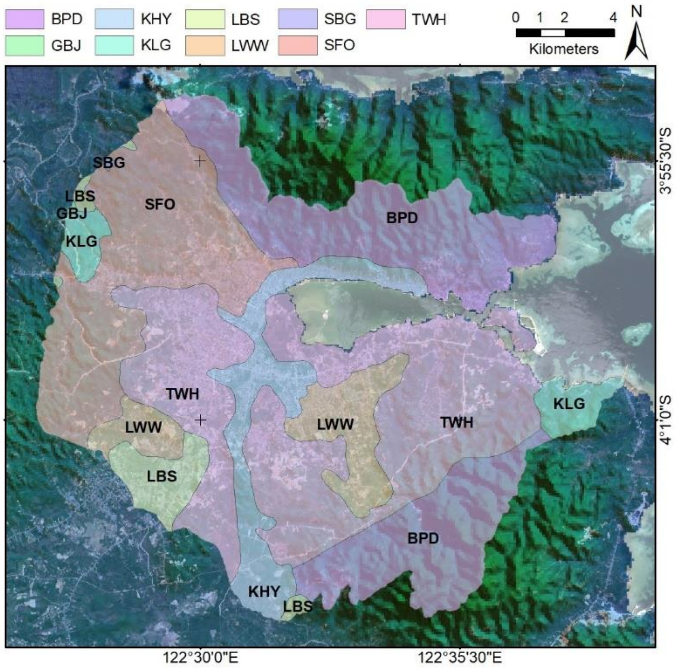

Figure 2. Landform Map of Kendari

The fluvio-marine origin was observed to occupy the eastern part of Kendari. This area cannot be detected at a mapping scale of 1:50,000 because of its tiny size, so the boundaries are generalized to TWH and KHY. Fluvio marine in Kendari is used for settlements and ponds, with its small part being overgrown with shrubs. This area is prone to inundation, especially in Poasia, Kambu, and Mondoga sub-districts. Surface land material in this area tends to be fertile because it is a place of upstream sediment deposition. Organic materials, nutrients, and fine materials that have been sorted undergo sedimentation in this area. Unfortunately, this area is already filled with settlements, so it cannot be used as a shield to protect coastal ecosystems and minimize the risk of disasters such as inundation and tidal flooding.

The fluvial landform is the dominant landform in Kendari, with at least more than 50% of the Kendari area being controlled by fluvial processes. The fluvial origin is spread over land units in the form of LWW, TWH, KHY, SFO, and LBS. The TWH is the largest area in Kendari, with an area of 8,895.28 ha (32.31%). It is composed of shale, mudstone, sandstone, and conglomerate. Even if this area is quite fertile, most of this area is used for settlements. The land in the upper part that is still vacant is used for agricultural and plantation activities with pretty good productivity. Land management in TWH must be adequately planned so that the surface soil layer is not easily eroded. With a tendency for high sedimentation process downstream, it is feared to affect the quality of the surface soil and can trigger flooding downstream and landslides upstream. Further, if the erosion process has progressed to ditch erosion, it may affect the surface hydrology pattern. Details of the Kendari landform area are presented in Table 4.

Table 4. Percentage of Kendari Landform

No	Symbol	Name	Description	Area (acre)	Percentage (%)
1	BPD	Bukit Pandan	Precipitous orientated metamorphic mountain ridges	7,211.02	26.20
2	GBJ	Gunung baju	Karstic rocky hill	10.96	0.04
3	KHY	Kahayan	Coalescent estuarine/riverine plain	2,251.88	8.18
4	KLG	Kalung	Karstic hills over marble and limestone	892.29	3.24
5	LBS	Lubuksikaping	Gently sloping non-volcanic alluvial fan	979.97	3.56
6	LWW	Lawanguwang	Undulating to rolling mixed sedimentary plain	1,920.06	6.97
7	SBG	Sebangau	Meander belt of large rivers with broad levees	15.92	0.06
8	SFO	Sungai fauro	Rolling plain with hilly rocks on marl and limestone	5,350.53	19.44
9	TWH	Teweh	Rocky hill over mixed sedimentary rocks	8,895.28	32.31
Total				27,527.91	100

3.3. Land Resilience Towards the Disaster Hazard in Kendari

To obtain the land resilience information, the land use maps and landforms were layered and added with weights of the AHP results. The results of the analysis are presented in Figure 3. The overlapping results showed that the land conditions in the central part of Kendari tended to be vulnerable to multi-disaster hazards compared to the northern and southern regions. Areas with a green symbol (high resilience) are covered with high and dense vegetation, while settlements and open land dominate areas with a reddish color (low resilience).

In addition, the results of tabular data indicated that Kendari was dominated by a low resilience class with a total area of 8,259.98 ha (30.01%). Inland units TWH-B, TWH-S, TWH-ST, and TWH-W had low resilience, with the lowest score being 0.2259259. These areas were mostly observed in the Districts of Wua-Wua and Kadia. The land unit with the lowest total score was observed in KHY-ST, with an area of 0.097222. The settlement factor (ST) can hardly be manipulated to increase the land's resilience so that it is possible to modify land cover in non-ST buffer areas with high-weight land covers such as forests or plantations. Forests and plantations have wide canopies that can withstand the impact of rainwater on the ground, reducing the possibility of splash, sheet, and groove erosion.

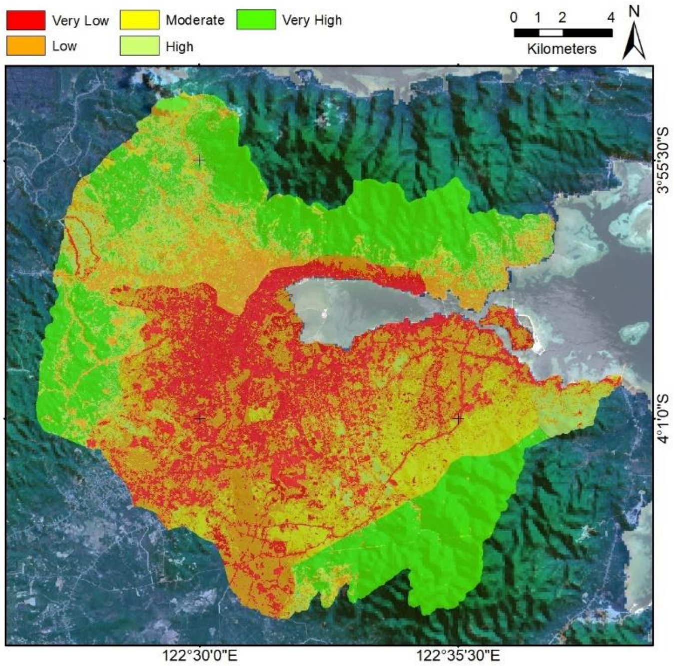

Figure 3. Land Resilience Towards the Disaster Hazard Map of Kendari

SFO-F was observed to be the land unit with the highest value located over the northern and southern parts of Kendari. This area holds a very significant role in regulating the surface hydrological cycle, which can prevent landslides and inundation floods. Furthermore, the sustainability of this land unit should be maintained because the satellite image data suggest the presence of human activities possibly interfering in the area. The details of Kendari's resilience area can be seen in Table 5.

Ground checking was carried out at several points from December-April 2020 to 2021. The results showed that areas with low resilience tended to have high multi-disaster hazards. Figure 4 shows that inundation occurs in residential areas due to prolonged rains, while the rivers cannot accommodate the overflowing water (Riyanto, Rizkinia, Arief, & Sudiana, 2022; Shige-Eda, Akiyama, Duran, Kanaya, & Katsura, 2022). The puddle's dark brown color indicates that the upstream area's erosion process is intensive, so various forms of prevention, such as reforestation or the construction and checking dams, need to be carried out as soon as possible (Dunn & Minderhoud, 2022; Singh et al., 2022; Y. Wang et al., 2022).

This study used an ecosystem services approach in assessing the resilience of land to multi-disaster hazards. However, this study still disregarded the parameters of soil form analysis commonly used to evaluate the resilience of the land. Laboratory soil analysis concerning the physical, biological, and chemical aspects needs to be carried out to improve the accuracy of this study and be used as a validation model (Nouri et al., 2021; Wang & Li, 2019). Future studies are suggested to adopt the laboratory soil analysis to produce more precise results.

Table 5. Percentage of Kendari Land Resilience

No	Category	Area (acre)	Percentage (%)	Land unit combination	Type of disaster
1	Very Low	5,168.16	18.77	GBJ-S, KHY-B, KHY-S, KHY-ST, KHY-W, KLG-B, KLG-ST, LBS-B, LBS-ST, LWW-B, LWW-ST, SBG-S, TWH-B, TWH-S, TWH-ST, TWH-W	Landslide
2	Low	8,259.98	30.01	BPD-B, BPD-S, BPD-ST, BPD-W, GBJ-M, GBJ-P, GBJ-PF, KHY-F, KHY-M, KHY-P, KHY-PF, KLG-M, KLG-PF, KLG-S, KLG-W, LBS-M, LBS-PF, LBS-S, LBS-W, LWW-M, LWW-PF, LWW-S, LWW-W, SBG-M, SBG-P, SBG-PF, SFO-B, SFO-S, SFO-ST, SFO-W, TWH-M, TWH-P, TWH-PF	Landslide and flash flood
3	Moderate	4,185.90	15.21	BPD-M, BPD-PF, GBJ-F, KLG-P, LBS-P, LWW-P, SBG-F, SFO-M, SFO-PF, TWH-F	Landslide and inundation
4	High	2,272.81	8.26	BPD-P, KLG-F, LBS-F, LWW-F, SFO-P	Inundation
5	Very High	7,641.06	27.76	BPD-F, SFO-F	Inundation
Total		27,527.91	100.00	-	

Figure 4. Inundation During the Rainy Season

4. Conclusion

This study presents a simple analysis in evaluating land resilience against the hazard of multiple disasters, especially floods, and landslides. The analysis results demonstrated the role of land use and landforms in assessing the resilience of the land. The findings also showed that land use had a dominant role in influencing land resilience, especially in relation to the presence of vegetation. Also, the results showed that land with dense vegetation had better resilience than bare land and settlement. The existence of a settlement near Kendari Bay increases the risk element since the area is the estuary of the Wanggu River. All surface water flow is concentrated towards the estuary due to the hills to the north and south of Kendari. Thus, it may cause significant flooding in the future. The surface runoff energy should be broken down through systematic modification of surface hydrology so that the water flow is not centralized. Systematic Waterflow modification is essential, considering that land management is almost impossible to carry out because of built up land. In addition, the results of the resilience analysis can be used as a reference for regional planning, especially in areas with low resilience. Apart from some limitations in this study, this model can be used as a rapid assessment of resilience because it used only a few easily obtained parameters. Further studies can investigate accuracy testing and soil sampling so that they produce a model that is more convincing, trustworthy, and reliable. Further, this study can be a temporal prediction facilitating stakeholders to predict the land's resilience in the future as an anticipatory effort.

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