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Evaluation of Regional Spatial Development on Landslide and Flood Prone with Actual Site Conditions in Kendari City

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Abstract: Kendari City is an area that has a high level of vulnerability to landslides and floods. The high intensity of rainfall and the geomorphological form of the area make Kendari City almost every year landslides and floods occur. This study aims to analyze the distribution of landslide and flood susceptibility and its suitability to the actual situation and evaluate the spatial pattern plan, especially in settlement areas. The method used is survey-based scoring and weighting. Overlay technique used in this study on physical variables including geological conditions, slope, rainfall, land use, soil type, and distance from the river. The results show that areas in Kendari City are prone to landslides and floods respectively 79.33% and 81.75% with variations in the level of moderate and high vulnerability. Moderate vulnerability dominates in both disasters with an area of 165.80 km² and 165.70 km². The suitability between the map and the actual situation reached 80.63% and 91.30%. Most of the spatial pattern plans, especially settlements that have been made and determined by the government, are appropriate for regional development in Kendari City. Evaluation of spatial patterns of landslide and flood-prone zones shows that a small proportion of high vulnerability zones are in the delineation of settlement areas with suitability levels reaching 93.05% and 76.45%.

Keywords: evaluation of regional development; flood prone; landslide; spatial planning; suitability

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Introduction

Kendari City is one of the areas prone to natural disasters, this area has a high potential for landslides and floods to occur (BNPB, 2020). Studies and research contributions are needed to strengthen information and inventory of landslide and flood hazards in this area, especially in smaller areas so that the information obtained becomes more detailed, as demand for land increases in the context of population growth and rapid regional development. Kendari City as the provincial capital is supported by other sectors such as agriculture, service industry, animal husbandry, fisheries, tourism, and culture which always grow. This phenomenon is increasingly supported by the development of centers of economic activity that create population migration and has implications for the amount of land built in Kendari City (Amiruddin, 2014) and is expected to increase more (Alwan et al., 2020).

The provincial capital is known for its hilly to steep hilly geomorphological forms, such as in Kendari, West Kendari, Mandonga, Abeli, and Poasia Sub-Districts (Aldiansyah et al., 2021). Spatial planning based on the vulnerability to landslides and floods is very important considering the geomorphological form of this area. The development of residential areas in Kendari City is influenced by the presence of a main road (Rahmi et al., 2022) and geomorphological forms (Aldiansyah et al., 2021). This phenomenon demands that development of settlement areas must be limited and carried out in areas that are safe from the dangers of landslides and floods.

The 2010-2030 City Spatial Plan (RTRW) of Kendari City aims to create a spatial structure and spatial use pattern to accommodate all current activities, as well as activities that will grow as a result of urban development while maintaining balance and environmental sustainability. The increase in development due to population growth will certainly affect the sustainability of the function conservation area that must be protected, therefore the creation and evaluation of spatial planning is the right solution (Pribadi, 2021). However, the spatial pattern plan carried out in Kendari City is not in accordance with current conditions (Aldiansyah, 2021; Alwan et al., 2020; Pribadi, 2021).

The results of the evaluation related to disaster vulnerability mostly focus on the zone inventory. The research of Dewi et al. (2017) found that landslide susceptibility was carried out by narrowing the analysis on the driving factor variables and the impact of disasters on the region. So far, the zoning of the area has used almost all variables that are directly related to the triggers of ground movement in landslide disasters (Susanti et al., 2017) and slopes in flood disasters (Utama & Naumar, 2015). Currently, the direction of research is starting to move towards spatial policy planning by prioritizing security against landslides and floods in terms of the extent of delineation, especially in settlement areas. This area has a higher life activity compared to non-settlement areas such as forests, rice fields, and plantations.

This study aims to evaluate the spatial plan for areas prone to landslides and floods in Kendari City. Evaluation is carried out on the existing condition of the spatial planning compared to the landslide and flood susceptibility zone. It is known that disasters have a significant and massive impact on the welfare of humans living in the area (Fahmi et al., 2016). This condition may be influenced by inconsistent regulatory deviations in realizing the planned spatial layout or the use of variables that are still not appropriate.

Method

Study Area

Kendari City has an absolute location of 03°54'40"S - 04°5'05"S and 122°26'33"E - 122°39'14"E with a total area based on the projection of UTM 51 S Zone covering an area of 274.91 km^2 which is divided into 10 Sub-Districts. Kendari City is an area with potential for economic growth. Kendari City as the provincial capital intends to make regional plans to create a city that is comfortable to live in. In this area, land use in the form of settlements occurs on flat to sloping slopes and follows a linear pattern. The north and south sides are hill areas with sloping to steep geomorphology which are feared to trigger landslides. While the city center is flat which is the point of accumulation of water towards the bay. An overview of the study area can be seen in Figure 1, while the area of each sub-district can be seen in Table 1.

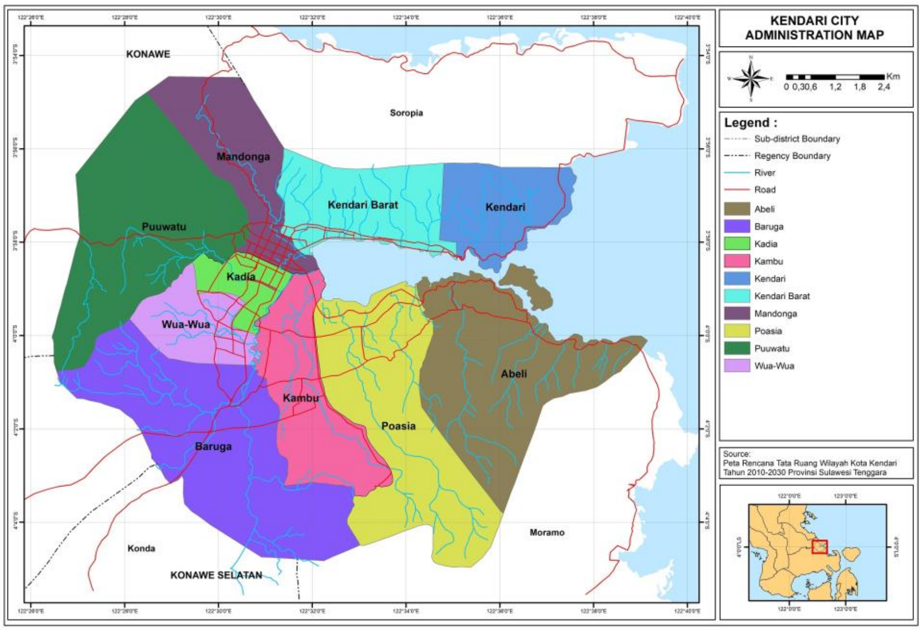

Figure 1. Study Area in Kendari City, Southeast Sulawesi

Table 1. Sub-Districts based on Area in Kendari City

No.	Sub-District	Area (km^2)	Percentage (%)
1	Abeli	41.70	15.17
2	Poasia	41.89	15.24
3	Kendari	16.29	5.92
4	Kendari Barat	20.64	7.51
5	Mandonga	20.72	7.54
6	Kambu	22.43	8.16
7	Baruga	49.12	17.87
8	Puuwatu	43.51	15.83
9	Kadia	6.68	2.43
10	Wua-Wua	11.93	4.34
	Total	274.91	100

Source: Kendari City Spatial Plan 2010-2030

Types and Methods of Research

This research was conducted in June-July 2022. The type of research used is quantitative research by utilizing survey-based geographic information system technology. The method applied in this research is descriptive research with scoring and weighting which is done by overlaying analysis of the variables used. The software used is ArcMap 10.4.1. Intersect feature in the software is used to combine attributes of each variable with other variables. A Map of landslides and flood prone in Kendari City was obtained after this step was taken. Evaluation of the Regional Spatial Plan (RTRW) is also carried out using the Overlay method on maps of landslide and flood prone areas.

Data collection, processing, and analysis methods

The data used in this study consisted of primary data and secondary data. Primary data in the form of field surveys. Data collection in the field was carried out using direct interviews with agencies related to landslide and flood-affected areas in Kendari City and then surveyed to validate landslide and flood prone maps. Secondary data is accessed from literature studies from recording and statistical institutions, relevant journals and official websites of related agencies, both tabular and spatial in nature to be analyzed using geographic information systems. The use of secondary data can provide further information on the phenomenon to be studied in addition to data obtained directly from the field (Omukuti et al., 2021).

Table 2. Secondary Data

No	Data	Type	Source
1	Rupa Bumi Indonesia Map	Vector	Geospatial Information Agency (BIG)
2	Rainfall 2021 Southeast Sulawesi	Raster	https://gis.bmkg.go.id/arcgis/home/
3	Slope	Raster	https://earthexplorer.usgs.gov/
4	Geology Southeast Sulawesi	Vector	Southeast Sulawesi Agricultural Technology Study Center, Agricultural Research and Development Agency, Ministry of Agriculture.
5	Soil Type Kendari City	Vector	Center for Research and Development of Agricultural Land Resources (BBSDLP)
6	RTRW Southeast Sulawesi Province	Vector	Public Works and Spatial Planning Department of Kendari City

Table 3. Variable

No	Data	Description	Unit
1	Rainfall	Measurement of the amount of water that falls to the ground surface from the precipitation process during a certain period, used annual rainfall in 2021 in Southeast Sulawesi Province	mm/year
2	Slope	Relief shape of the earth's surface is determined by topographic characteristics that form the angle of inclination	%
3	Geology	The rock type that forms and occurs over a long period of time	km^2
4	Soil Type	The type of subsoil and occurs over a long period of time	km^2
5	Land Use	Land with allotment for social and physical aspects	km^2
6	Distance from River	The distance of the river to the nearest area	m

Source: Modification Results from Sulistio et al. (2020).

Making a landslide and flood prone map in Kendari City requires variables as well as scores and weights to determine the level of influence of the elements used on map results. Scores, weights, and classifications for landslides consist of rainfall which is the result of modifications from SNI (Pangaribuan et al., 2019), scores, weights, and classification of the slope, geology, soil type, and land use are modified from PUSLITTANAK 2004 (Hardianto et al., 2020). Scores, weights, and classifications for flooding of rainfall which is a modified result of the SNI (Pangaribuan et al., 2019). Scores, weights, and classification of slope and soil type are modified by Darmawan et al. (2017), distance from the river from Lumban Batu & Fibriani (2017), and modified land use by Damamik & Restu (2012); Faizana et al. (2015); and Darmawan et al. (2017).

Each score is summed and multiplied by a predetermined weight. The results obtained were reclassified into three classes, namely low, moderate, and high (Sihotang, 2016). The scoring and weighting with the classification of each variable are shown in Table 4 and Table 5. Analysis of the vulnerability of an area to landslides and floods uses the Equation (1).

$$V = \sum_{i-1}^{n} (Wi \; x \; Si) \quad (1)$$

Description: V = vulnerability value; Wi = weight of the i-th parameter; Si = score of each class on the i-th parameter.

Table 4. Scoring, weighting, and determining the classification of each landslide variable

No	Variable					Score
	Rainfall (mm/year)	Slope (%)	Geology	Soil Type	Land Use	
1	<2000	0-8	Alluvial (Qa)	Alluvial, Gleisol	Water Body, Pond	1
2	2000-3000	8-15	Sediment (Ql, Tml1, Tmpb3)	-	Settlement	2
3	>3000	15-25	Vulcanic (TRJm)	Mediterranean, Kambisol	Forest and Plantation (Secondary Dryland Forest, Secondary Mangrove Forest, Dryland Farming, and Mixed Dryland Farming)	3
4	-	25-45	-	Podsolik	Scrub	4
5	-	>45	-	Litosol	Ricefield, Open Land	5
Weight	30	20	20	10	20	

Table 5. Scoring, weighting, and determining the classification of each flood variable

No	Variable					Score
	Rainfall (mm/year)	Slope (%)	Distance from River (m)	Soil Type	Land Use	
1	<2000	>45	0-50	Litosol	Forest (Secondary Dryland Forest, Secondary Mangrove Forest)	1
2	2000-3000	25-45	50-100	Podsolik	Plantation (Dryland Farming, and Mixed Dryland Farming), Scrub	2
3	>3000	15-25	150-250	Mediterranean, Kambisol	-	3
4	-	8-15	250-500	-	Pond, Ricefield	4
5	-	0-8	-	Alluvial, Gleisol	Settlement, Water Body, Open Land	5
Weight	10	30	20	30	10	

The classification of the level of suitability of the RTRW against landslides (Table 4) and floods (Table 5) each is grouped into 5 classes based on the percentage of area in the total land use. Very unsuitable (0-20%), not suitable (20-40%), quite suitable (40-60%), suitable (60-80%), and very suitable (80-100%).

Results and Discussions

Vulnerability Variable

Kendari City has 4 rainfall areas, namely 1800 mm/year – 3200 mm/year. Most areas have a rainfall of 1800 mm/year with a low category that extends from the east to the west of the region. Areas with a high category of rainfall of 3200 mm/year occupy only a small part of the area (Figure 2a). There are five categories of slopes, ranging from (1) flat of 114.58 km^2 (41.68%); (2) gentle of 66.88 km^2 (24.33%); (3) slightly steep areas of 50.76 km^2 (18.47%), (4) steep covering an area of 37.29 km^2 (13.56%), and (5) a small portion is categorized as very steep with an area of 5.40 km^2 (1.96%) (Figure 2b).

The geological condition of Kendari City is composed of volcanic rocks, namely *TRJm* in most areas with an area of 172.23 km^2 (62.65%), Alluvial rocks, namely *Qa*, covering an area of 47.53 km^2 (17.29%), and Sedimentary rocks consisting of *Ql* covering an area of 42.31 km^2 (15.39%), *Tml1* covering 7.2 km^2 (2.62%), and *Tmpb3* covering 5.64 km^2 (2.05%). The geological structure in this area is formed as a result of sedimentation and metamorphosis processes in pre-existing rocks. This geological process is thought to have occurred in Triassic Jurassic to Holocene (Figure 2c). The soil type found in this area consists of six soil types, namely Gleisol covering an area of 1.93 km^2 (0.70%), Kambisol covering an area of 8.53 km^2 (3.10%), Alluvial covering an area of 26.17 km^2 (9.52%), Mediterranean area of 54.36 km^2 (19.77%), Litosol area of 80.36 km^2 (29.23%), and Podsolic which dominates area of 103.56 km^2 (37.67%) (Figure 2d).

There are 10 types of land use such as water bodies with an area of 1.10 km^2 (0.40%), open land covering an area of 1.12 km^2 (0.41%), rice fields covering an area of 1.98 km^2 (0.72%), secondary mangrove forest covering an area of 2.59 km^2 (0.94%), ponds covering an area of 6.08 km^2 (2.21%), mixed dryland farming covering an area of 29.18 km^2 (10.61%), secondary dryland forest covering an area of 29.30 km^2 (10.66%), settlements area of 51.15 km^2 (18.61%), dryland farming 58.65 km^2 (21.33%), and shrubs that still dominate in this area are 93.77 km^2 (34.11%). The distance from the river that dominates in this area is >250 m with an area of 156.74 km^2 (57.02%), followed by a distance of 100-250 m covering an area of 66.46 km^2 (24.18%), 50-100 m covering an area of 25, 42 km^2 (9.24%), and 0-50 km^2 of 26.29 km^2 (9.56%)The variables above are considered parameters that affect the level of vulnerability to landslides and flooding in an area. According to Sturges (1926) that the slope, geological conditions, soil texture and permeability, plasticity index, climate, and water management, affect the occurrence of landslides.

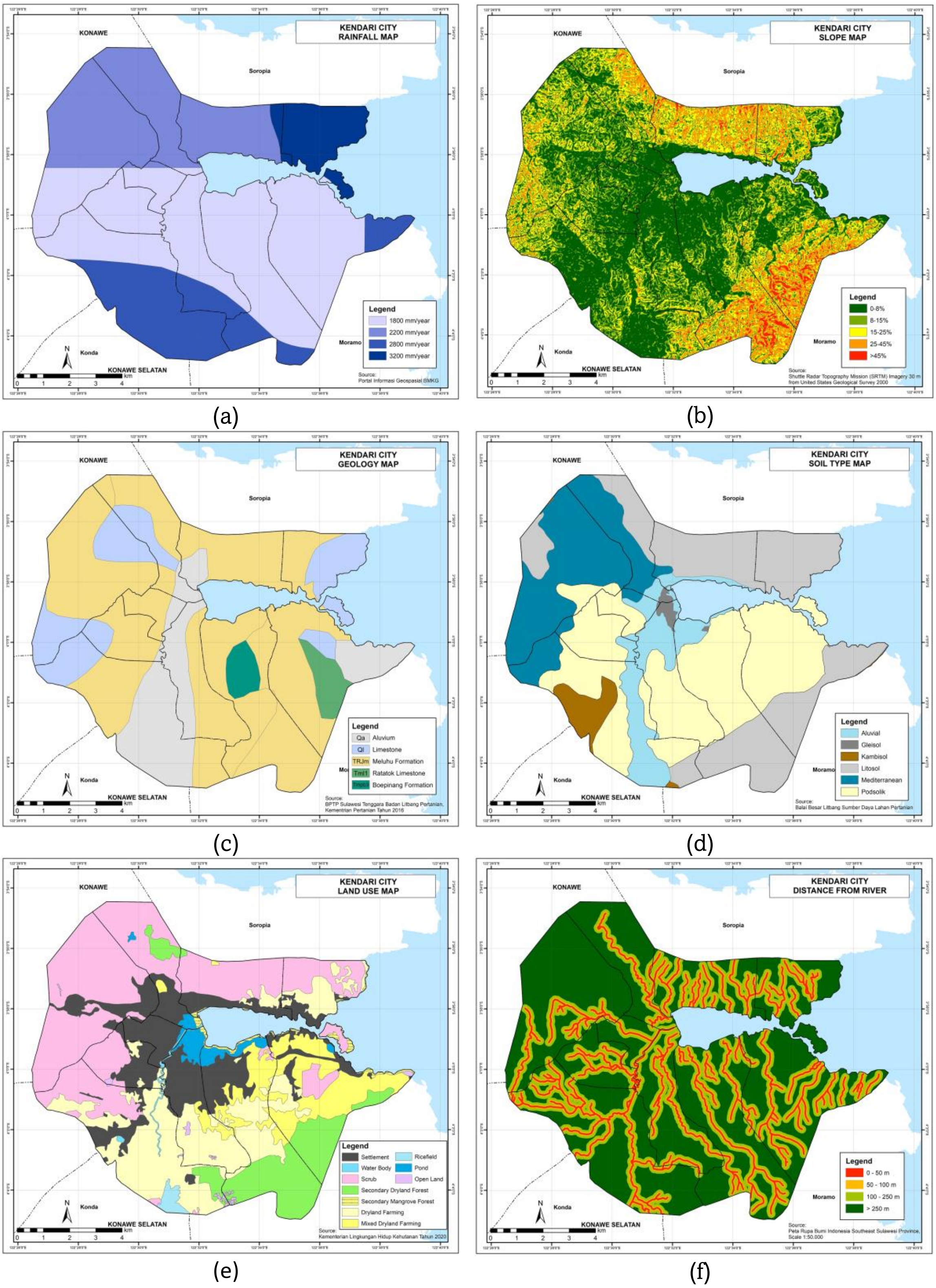

Figure 2. Landslide and Flood Prone Variables: (a) rainfall; (b) slopes; (c) geology; (d) soil type; (e) land use; (f) distance from river

Landslide and Flood Prone

Landslide and flood vulnerabilities are obtained after overlaying the vulnerability determinant variables. The landslide susceptibility map produces three classifications, namely low (0.93-1.86) covering 56.80 km^2 (20.66%), moderate (1.87-2.79) covering 165.8 km^2 (60.31%), and high (2.8-3.73) covering an area of 52.32 km^2 (19.03%) (Table 6). The landslide susceptibility map also produces three classifications, namely low (1-2.2) covering an area of 50.19 km^2 (18.26%), moderate (2.2-3.4) covering an area of 165.70 km^2 (60.28%), and high (3.4-4.6) covering an area of 59.02 km^2 (21.47%).

High landslide susceptibility occurs on the north, south, and northwest sides of Kendari City. According to Restele et al. (2023) that the structural hills in the north and south of Kendari City are areas that have a high level of vulnerability to landslides. The area is an area with a rather steep to steep slope. The pattern of flood susceptibility is centered in the city center and follows the flow of the Wanggu river towards Kendari Bay. The area is an area with a flat to gentle slope so that it accumulates the entire amount of water into this area. According to Aldiansyah & Wardani (2023) that the highest flood vulnerability is in the middle of the area in Kendari City, which is downstream of the Wanggu watershed. This area has a flat lowland morphology (Aldiansyah et al., 2021), although most of the soil types are alluvial with a high level of permeability. However, the area has developed into a built-up area that is dense with a layer of concrete or cement so that it interferes with the absorption capacity of the soil. The model also highlights the Wanggu River as the main river with a high level of flooding compared to other tributaries. Sedimentation in this area is also the cause of flooding. Kendari City's flood vulnerability is strongly influenced by the vegetation density index and the Terrain Roughness Index (Aldiansyah & Wardani, 2023). The extent of vulnerability to landslides and floods by sub-district can be seen in Table 6 and Table 7.

The results of interviews with BPBD, Camat, and Lurah in selected locations were matched with the results of field surveys for landslides and floods. The results of the landslide disaster show: 6 points for low vulnerability levels, 20 points for moderate vulnerability levels, and 5 points for high vulnerability levels. The results of the validation of the suitability between the landslide map and the results of the field survey were (25/31) x 100 or 80.63%. The results of the flood disaster show that: 2 points for low vulnerability levels, 10 points for moderate vulnerability levels, and 11 points for high vulnerability levels. The results of the validation of the suitability between the flood map and the results of the field survey are (21/23) x 100 or 91.30%. This means that the results of the spatial analysis of vulnerability to landslides and floods can be used in mapping the level of vulnerability to landslides and flooding in Kendari City (Figure 3 & Figure 4).

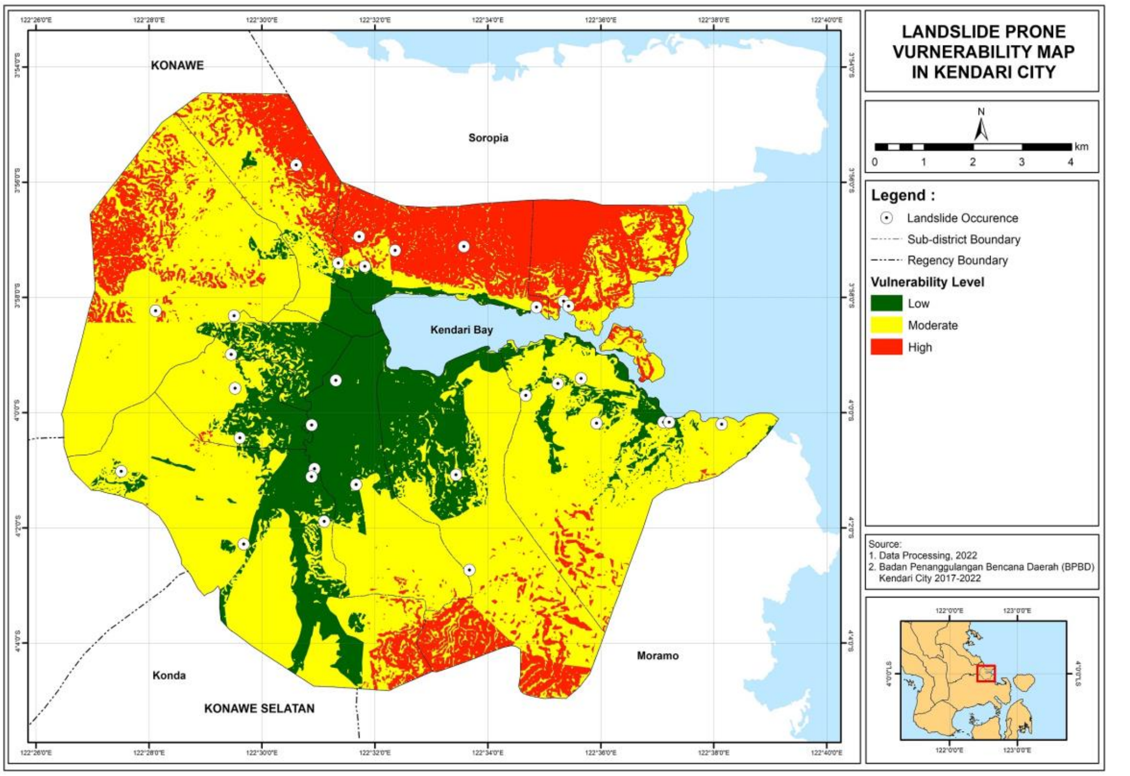

Figure 3. Landslide Prone Map, Kendari City

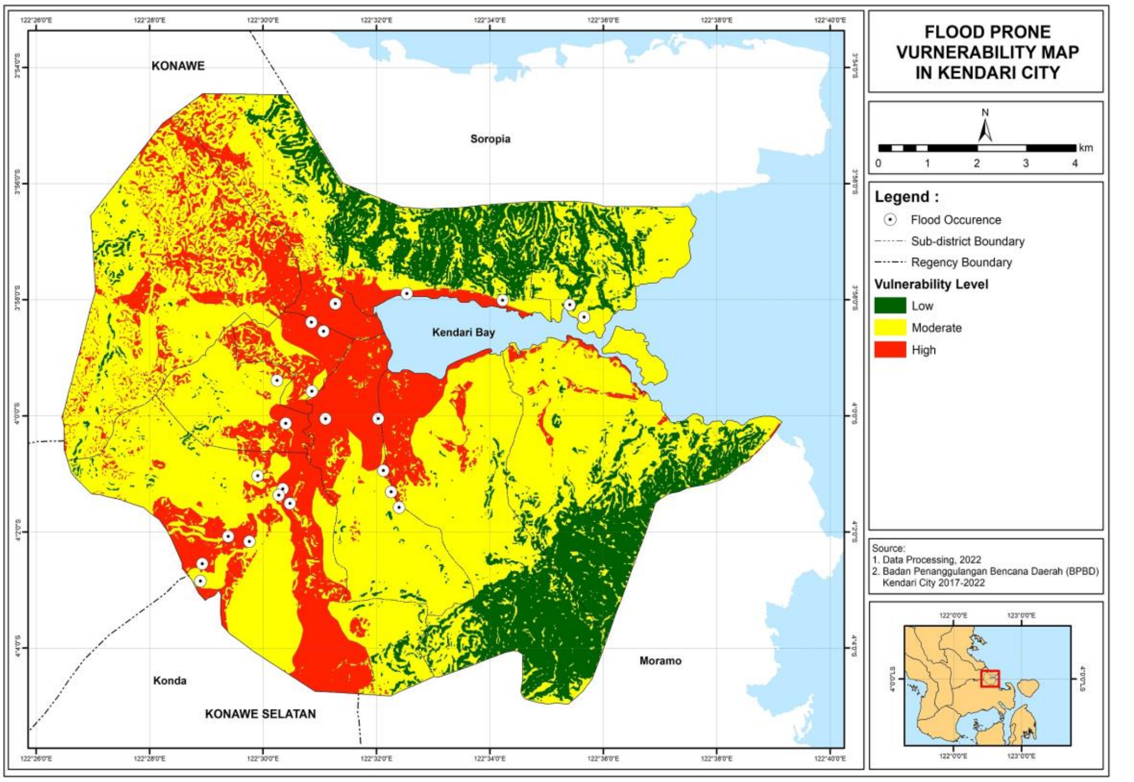

Figure 4. Flood Prone Map, Kendari City

Evaluation of Regional Spatial Plan for Landslide and Flood Prone in Settlement Land Use

Evaluation of settlement areas has a major impact on landslides and floods such as loss of life and material losses compared to forest, plantation, and agricultural areas because they have an intensive level of human activity. It can be seen that a small part of the settlement area is in the high category delineation of landslide susceptibility level. Approximately 8.61 km^2 (6.95%) of the area with a high level of vulnerability to landslides is included in the delineation of settlement areas (Table 6). This shows that the regional development in the spatial plan has been categorized as safe from landslides with a suitability level of 93.05% or equivalent to 115.26 km^2 (Figure 7).

In ¼ settlement areas is a high delineation of flood susceptibility. Approximately 29.22 km^2 (23.59%) of areas with a high level of flood vulnerability are included in the delineation of settlement areas (Table 7). Regional development in the spatial plan from the flood aspect has been categorized as safe from flood prone with a suitability level of 76.45% or equivalent to 94.86 km^2 (Figure 7).

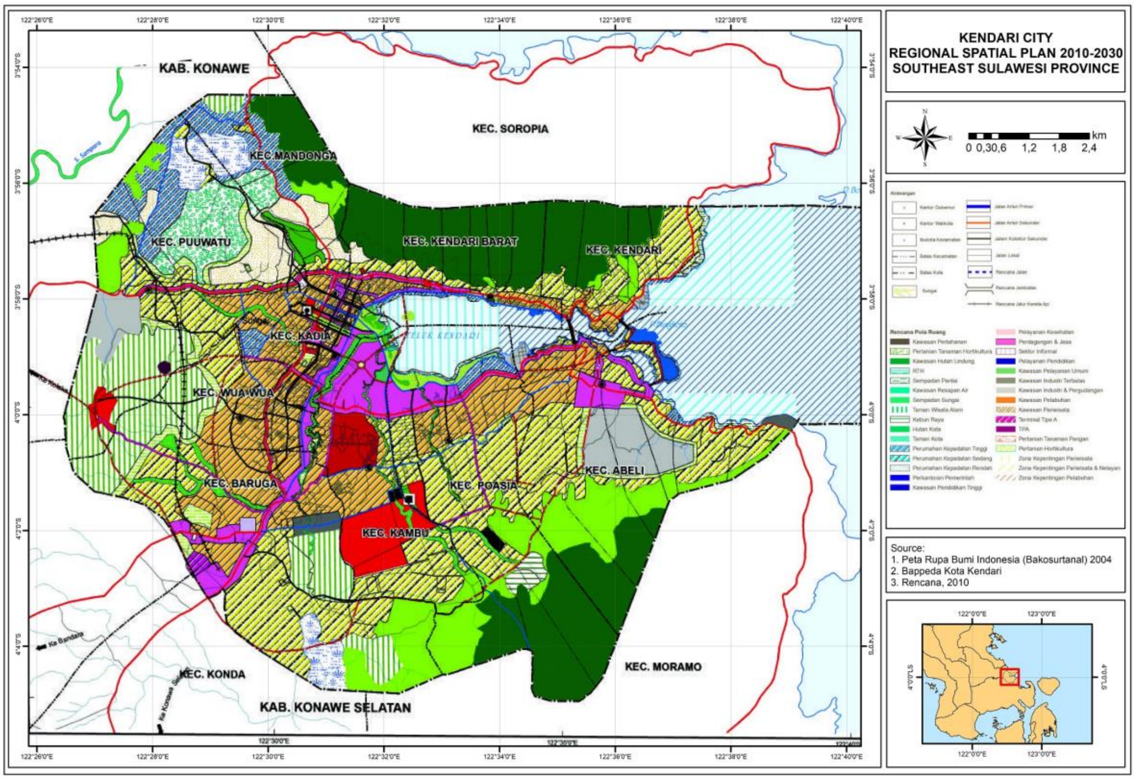

Figure 5. Regional Spatial Plan 2010-2030, Kendari City

The scores and weights used show that the rainfall variable has a greater influence on the results of the landslide prone map. This indicates that the intensity of rainfall is a trigger for landslides (Hasnawir, 2012) because it will affect slope stability and soil absorption ability related to the density in soil shift (Sarya et al., 2014).

The slope and soil type are factors that contribute greatly to the level of flood susceptibility. Biophysical factors such as slopes can cause water to accumulate into puddles in lowlands to erode watersheds (Hutapea, 2020). Soil type also affects water absorption followed by the form of land use (Maranguit et al., 2017).

The research of Fariza et al. (2017) and Mandal & Mandal (2018) use the Analytic Hierarchy Process (AHP) method which is more popular because it is more representative in temporal aspects and the existing conditions of the area and can simplify the analysis of complex problems. The selection of the overlay method is considered appropriate in describing the raw data in spatial in a wide area. This method does not ignore every detail part of the polygon of the variable. Each part of the polygon has a unit value and will affect the final result. Each historical landslide and flood event can be combined with this method, considering that each historical contains additional information that will affect and determine the landslide and flood prone zone (Nurdin et al., 2019; Kahal et al., 2021).

The overlay method has a weakness, where this method cannot describe the effect of influence on variables in describing landslides and floods. In future research, a regression model can be used based on variables that influence the landslide event data because it can show the relationship between variables and variables with landslide occurrence through correlation tests (Chen et al., 2017; Javidan et al., 2021). The classification used also cannot explain the effect of landslide prone level, in further research, especially in-depth soil classification studies, landslides should be described from the type of landslide, the depth of the landslide, the direction of the landslide movement, and the speed of the landslide (Unisri, 2015). Although the overlay method has used spatial approaches and data. However, this type of method is the simplest for complex problems with a wide scale (Srinivas et al., 2018).

Table 6. Area of Landslide Vulnerability and Suitability of Settlement Areas to Regional Spatial Plan

No.	Sub-District	Landslide Vulnerability (km^2)			Suitability of Settlements in Regional Spatial Plan (RTRW) to Landslide Vulnerability	
		Low	Moderate	High	Suitable	Unsuitable
1	Abeli	5.07	30.24	1.74	15.76	0.26
2	Poasia	11.70	23.85	6.95	17.81	0.01
3	Kendari	-	5.33	10.88	3.55	3.55
4	Kendari Barat	2.25	3.70	14.72	3.76	1.62
5	Mandonga	2.47	11.96	7.49	5.53	0.77
6	Kambu	11.55	15.53	0.18	14.07	0.14
7	Baruga	13.46	34.51	2.13	29.44	0.05
8	Puuwatu	0.59	31.13	8.17	11.92	2.14
9	Kadia	5.40	1.99	-	5.10	-
10	Wua-Wua	4.30	7.56	0.06	8.31	0.06
Amount		56.80	165.80	52.32	115.26	8.61
Percentage		20.66	60.31	19.03	93.05	6.95
Total			274.91		123.87	

Source: Data Processing, 2022

Table 7. Area of Flood Vulnerability and Suitability of Settlement Areas to Regional Spatial Plan

No.	Sub-District	Flood Vulnerability (km^2)			Suitability of Settlements in Regional Spatial Plan (RTRW) to Flood Vulnerability	
		Low	Moderate	High	Suitable	Unsuitable
1	Abeli	14.46	26.06	1.26	15.53	0.50
2	Poasia	13.20	22.76	5.92	14.92	2.91
3	Kendari	5.18	11.11	-	7.18	-
4	Kendari Barat	11.74	6.58	2.38	3.82	1.59
5	Mandonga	2.98	11.94	5.80	3.61	2.69
6	Kambu	0.36	13.79	8.29	12.26	1.95
7	Baruga	1.09	31.63	16.17	20.67	8.67
8	Puuwatu	1.01	31.00	11.55	8.83	5.27
9	Kadia	-	2.13	4.56	1.80	3.30
10	Wua-Wua	0.16	8.69	3.08	6.03	2.34
Amount		50.19	165.70	59.02	94.65	29.22
Percentage		18.26	60.28	21.47	76.41	23.59
Total			274.91		123.87	

Source: Data Processing, 2022

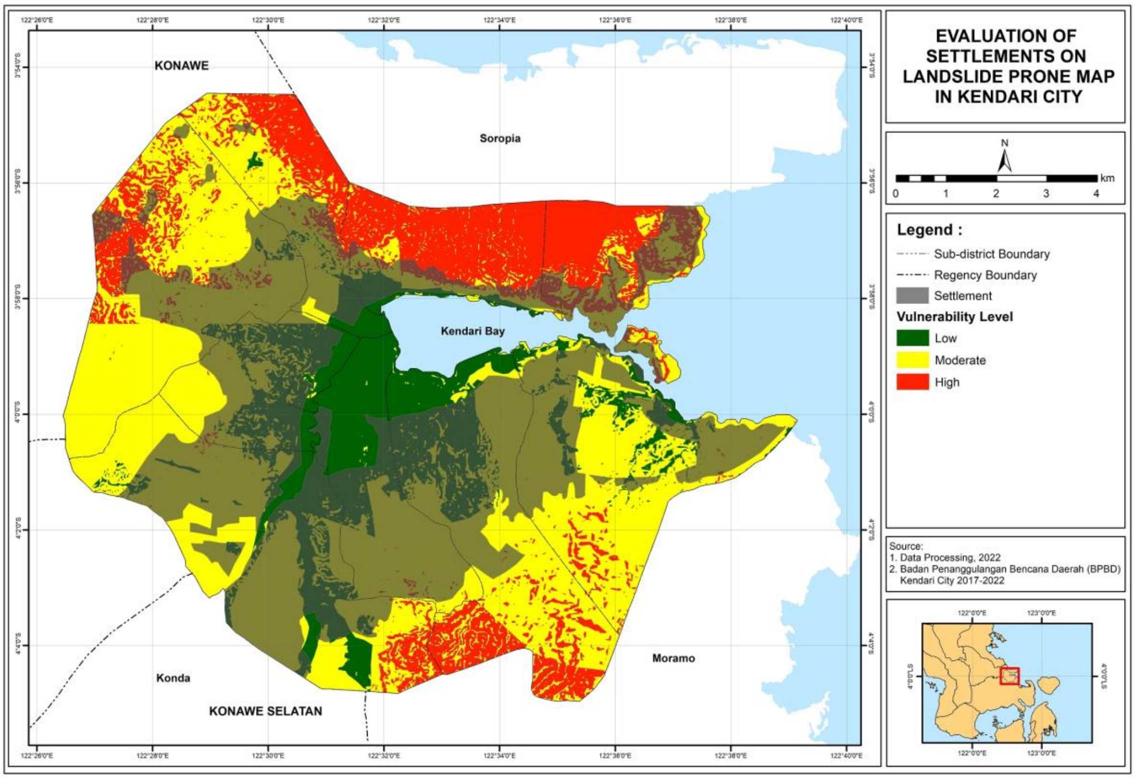

Figure 6. Evaluation Map of Settlements to Landslide Prone, Kendari City

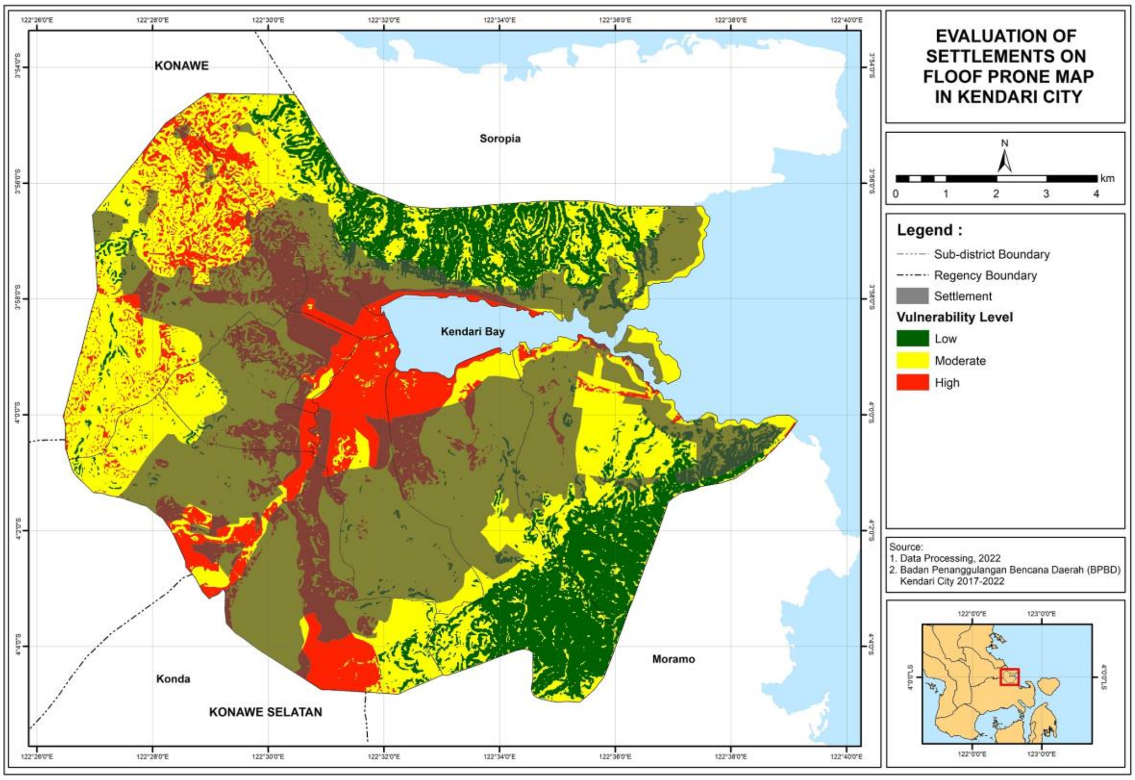

Figure 7. Evaluation Map of Settlements to Flood Prone, Kendari City

Conclusion

Almost all areas in Kendari City are prone to landslides and flooding with an area percentage of 79.33% and 81.75%, respectively. The level of conformity of the map with actual conditions reaches 80.63% and 91.30%, which means that the results of the spatial analysis can be used in mapping the level of landslide vulnerability and flooding in Kendari City.

The planning of residential areas in Kendari City which was evaluated with the 2010-2030 Kendari City RTRW against the vulnerability of landslides and floods has prioritized the disaster aspect with a suitability level of 93.05% and 76.45%, respectively. This progress is one of the preventive measures to build resilience to hydrometeorological disasters such as landslides and floods. This form of disaster mitigation can be the first action for regional development planning to minimize the possible risk of loss of life, destruction of homes, and loss of property.

Regional development that occurs in the future must always be evaluated and consistent with the spatial pattern plan and strong regulations. Future regional development must follow the rules and regulations that have been formulated in the planning stage. This aims to realize the preparation of spatial policies properly.

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