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Spatiotemporal Distribution Pattern and Spatial Grouping of Landslide and Flood Prone Areas in Metropolitan Palapa, Indonesia

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ABSTRACT

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The rapid development of urban areas is one of the driving factors for hazard exposure which causes vulnerability and environmental degradation. Environmental degradation causes vulnerability to disasters which will have implications for a decrease in economic benefits and an increase in community poverty. Landslides and floods are frequent natural disasters that cause environmental degradation. To reduce the risk of landslides and floods and formulate development policies and strategies in disaster-prone areas is necessary to identify landslides and flood areas. This study aims to identify and detect areas prone to landslides and flooding in Metropolitan Palapa using GIS analysis and Moran's Local Index based on LISA statistics. The analysis results show that the northern to northeastern areas of Metropolitan Palapa (Pariaman regency and Pariaman municipal) are areas with high vulnerability to landslides, with high positive spatial associations of landslide occurrence and intensity. The area has an altitude between 350 to > 1100 above sea level and a slope between 15 to > 45%. Meanwhile, Padang and Pariaman municipal are areas that are vulnerable to flood hazards, and this is because these areas are

lowlands/coastal areas. We can be applied Strategies and policies to the Palapa Metropolitan area, including a) strengthening environmental management institutions, b) establishing cooperation between regions, c) increasing public awareness to care for and protect the environment;

Keywords:

Regional development, regional economy, spatial analysis, LISA statistics, environmental degradation

INTRODUCTION

Rapid development in urban areas is one of the factors causing damage and environmental degradation. Urban economic development is one of the engines of danger worldwide that causes urban vulnerability(Eakin et al., 2022) (McHale et al., 2015). Vulnerability will occur because urban areas are the centre of complex economic, socio-cultural, political, institutional and environmental interactions.

Urban environmental degradation occurs due to industrial growth, increased energy consumption(Kahouli et al., 2022), economic growth(Pandey & Rastogi, 2019), population growth and utilisation of natural resources that cause a decrease in environmental quality(U. Burki & Tahir, 2022) (Capps et al., 2016). Environmental degradation causes vulnerability to disasters(Ananda & Herath,

2003). Environmental degradation has implications for a decrease in economic benefits (Hoagland et al., 2013) and increasing poverty, especially in developing countries (MAK Burki et al., 2021). Urban environmental problems are a threat to people's welfare and hinder the realisation of sustainable development (Majeed & Mazhar, 2021).

Metropolitan Palapa is a strategic economic area with three administrative areas: Padang Pariaman regency, Padang municipal and Pariaman municipal. The Palapa Metropolitan administrative area consists of 32 sub-districts and 235 urban villages/nagari with the potential to be developed for trade and services, industry and tourism. A strategic area is an economic area with the potential to have a significant dual effect across sectors, regions and actors (Bappenas, 2014). Strategic economic areas are prioritised for development (Sosnovskikh, 2017) and have characteristics that distinguish them from other regions (Komarovskiy & Bondaruk, 2013).

The urban area in Metropolitan Palapa has developed mainly by converting land use from agricultural land to urban use, especially in urban areas. Metropolitan Palapa will continue developing with various activities as a functional area. The diversity of development activities and economic interests impacts the decline in the environment's carrying capacity (Eakin et al., 2022) (Rustiadi et al., 2015).

² | According to the National Disaster Management Agency (BNPB), for the past 10 years (2011-2021), floods and landslides have been disasters that have frequently occurred in Indonesia. Landslides and floods represent 47% to 67% of the total disasters. The average incidence of floods reaches 30%, and landslides are 25% of the total disasters. Data for 2022 shows that the incidence of floods and landslides in Indonesia from January to August is 39% for floods and 18% for landslides.

A landslide is the movement of masses of rock, debris or soil down a slope due to the influence of gravity (Arsyad, 2009) (Cruden & Varnes, 1996). According to Cruden and Varnes (1996), the trigger for landslides is external stimuli such as high rainfall, earthquakes, changes in water levels, storms, or river erosion which causes a decrease in the strength of the slope-forming material. In addition, other factors that trigger landslides are increased human activity, population increase, urbanisation, and development in areas with high soil vulnerability.

Floods are natural disasters when overflowing rivers, lakes, and oceans inundate land caused by high rainfall. A flood is an overflow of water that submerges land and is a catastrophe for life and property that affects the environment around the world (Maskong, 2019). Flood is one a natural disaster that is quite dangerous because it causes negative moral and material consequences (Araújo et al., 2019) for human health and life, the environment, cultural heritage, economic activity and infrastructure (Perz et al., 2022) (Rutgersson et al., 2022).

Rapid development and increasing environmental damage will cause disasters like landslides and floods. These natural disasters will become an important issue in sustainable urban environmental management. As a result, it is very necessary to identify locations prone to landslides and floods to plan appropriate disaster prevention (Edamo et al., 2022) (Tazmul Islam & Meng, 2022) (Xiao et al., 2022). This study aims to identify the spatiotemporal distribution pattern and spatial grouping of areas prone to landslides and floods in Metropolitan Palapa using Moran's Index based on Local Indicators of Spatial Association (LISA) statistics.

METHODOLOGY

2.1 Study Areas

c)

The Study Area is located in the Palapa Metropolitan Area of West Sumatra Province, Indonesia, which consists of three regencies/cities (Figure 1). The height of the Palapa Metropolitan area varies from 0-1,650 meters above sea level. Most of the area is at an altitude of 0-200 meters above sea level (Figure 2). The land use of most of the Palapa Metropolitan area is agricultural land, with a population of between 303-34,825 people in 2021, with rainfall ranging from 228,000-398,000 millimetres per year.

INDONESIA

Metropolitan

Palapa

Figure1. Palapa Metropolitan Location Map

The Palapa metropolitan area, which consists of three regency/municipal, 32 sub-districts and 235 urban villages and nagari, had a population of 1,437,354 people in 2021 (Figure 2a). Nagari is the division of administrative areas after sub-districts in the province of West Sumatra. The highest population is in Kuranji urban village, Padang municipal, at 34,825 people, and the area with the lowest population is in Pasir Sanur, Pariaman municipal, at 303 people. The land use of most of the Palapa Metropolitan area is agricultural land consisting of dry land agriculture and rice fields, followed by forest consisting of primary dry land forest and secondary dry land forest (Figure 2b). The slope of the Palapa Metropolitan area varies from 0 to > 45%. Areas with a slope of 0 – 15% are in the coastal area, and areas with a slope of 25 to greater than 45% are in the northeast and southeast (Figure 2c). The area's altitude varies widely between 0 – 1392 above sea level (Figure 2d). Annual rainfall in the Palapa Metropolitan area is quite high. Areas with very high rainfall are north and northeast (Figure 2e).

d)

b)

a)

Figure2. Metropolitan Palapa thematic map a) population, b) land use, c) slope, d) elevation, e) rainfall

2.2 Data and Method

The data is on the number of landslides and floods in each village. Data were obtained from PODES (Village Potential Statistics) from 2011 to 2018 and data from the Central Bureau of Statistics (BPS) for 2021. We made the map for the distribution of landslides and floods based on the number of landslides and floods in 2011, 2015, 2017 and 2021. The unit of analysis in this study is the village level.

We used GIS analysis and Moran's Local Index based on LISA statistics to see the spatiotemporal distribution pattern and identify the spatial grouping of landslide and flood-prone areas. Local Moran Index analysis based on LISA statistics using Geographic Data Analysis (Geoda) software

The approach used in Moran's Index is a spatial autocorrelation approach (Gelaw et al., 2019) (Wang et al., 2018). A positive autocorrelation will indicate that adjacent locations have similar values and tend to cluster.

Negative autocorrelation indicates that adjacent locations have different values and tend to spread. The Moran Index (global index) clustering method will provide a single statistic that summarises the spatial pattern of the research area. Moran's index is used to determine whether there is a spatial

relationship in an event(Gelaw et al., 2019) (Wang et al., 2018)(Kurnia et al., 2019).

The local clustering technique is carried out by examining a particular sub-region or environment in the study to determine whether the area represents a group of high values (hot spots) or low values (cold spots) (Oliver, 2010), using the Local Indicator of Spatial Autocorrelation (LISA) (Saputro et al., 2017).

This study uses the local Moran Index approach, a local spatial autocorrelation measurement based on Moran's I developed byAnselin (1995)as LISA statistics(Pravitasari et al., 2014). LISA statistics have two characteristics: 1) each observation indicates the extent to which the spatial grouping has a significant value, and 2) the number of LISA for all observations is proportional to the global indicator of spatial association. Global spatial association shows the presence or absence of a relationship in a single event. Local spatial associations indicate the location of local clusters and spatial outliers.

$$I = \frac{1}{S} \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad i \neq j$$

where

$$S = \sum_{i=1}^n \sum_{j=1}^n W_{ij}$$

$$I = \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2}$$

$$= \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_j - \bar{x})(x_i - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2}$$

$$= \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_j - \bar{x}) W_{ij} (x_i - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2}$$

Where:

I = Moran's Global Index

i = Moran's Local Index

x_i = value of interest of variable x for point i

x_j = value of interest of variable x for point j

\bar{x} = average value of x

W_{ij} = continuity matrix, representing the proximity of point i 's and point j 's locations, with $W_{ii} = 0$ for all points

n = total number of points

S_x^2 = variance of the observed values

Analysis of Moran's Local Index will identify the spatial grouping of areas prone to landslides and floods. Spatial grouping of flood-prone areas will appear if the spatial association (SA) is positive with high-high (HH) or low-low (LL) types and negative values (spatial outliers) with high-low (HL) or low-high types. (LH). A positive spatial association (SA) will appear if a high value is correlated with a high-value neighbour or a low value is correlated with a low-value neighbour. Conversely, a negative spatial association (SA) will appear when a high value correlates with a low neighbour value or a low value correlates with a high-value neighbour (Oliver, 2010) (Anselin, 1995). In this study, queen contiguity will be used as a spatial weighting method to detect the spatial association of landslides and floods in Metropolitan Palapa. Queen contiguity weighting is the touch of both sides and vertex points of one region to another (Oliver, 2010).

RESULTS AND DISCUSSION

According to Law number 26 of 2007 concerning spatial planning, an area is a geographical unit and all related elements whose boundaries and systems are determined based on administrative and/or functional aspects. Based on typology and regional classification consisting of homogeneous areas, nodal areas, planning areas, metropolitan regions, development axes, frontier regions and depressed regions (Rustiadi et al., 2018) (Adisasmita, 2018). We developed Metropolitan Palapa as a planning area into a metropolitan area. It is very important to look at the definition of the region, typology, and regional classification to see development strategies, policies and programs related to regional development (Rustiadi et al., 2018) (Amelia et al., 2022).

The geographical position of West Sumatra Province, especially the Palapa Metropolitan area, and community activities will lead to environmental degradation, creating vulnerability to disasters, especially landslides and floods. Areas with high vulnerability to disasters will hinder sustainable development goals (Majeed & Mazhar, 2021). The overexploitation of natural resources can also cause environmental degradation and vulnerability to landslides and floods. Results of research conducted Shahbaz et al. (2016) and Bai et al. (2018) show that the inefficient use of energy resources harms environmental quality. The development of energy-efficient technologies at production and consumption levels will greatly help reduce environmental degradation and increase productivity in the long term. In addition, the cooperation of the banking sector is also needed to provide credit relief to the energy sector and allocate funding for environmentally friendly business activities.

Çakar et al. (2021) researched the relationship between human resources to environmental degradation in the European Union. The results show that human resources can reduce carbon emission levels in low-growth activities

but increase carbon emissions in high-growth activities. Reducing environmental degradation is necessary to increase human resources to innovate to protect the environment.

The results of previous studies show a two-way relationship between regional growth and the environment. The results show that the level of environmental degradation and economic growth has a U-shaped relationship known as the Kuznets Curve in the long run (Vo et al., 2021) (Shahbaz et al., 2016).

Development is associated with reduced environmental degradation to some extent. After this threshold, increased development will increase environmental degradation.

In this study, we observe the relationship between development and environmental degradation in the Palapa Metropolitan area. Landslides and floods were chosen as representatives of natural disaster hazards and are proxies for environmental degradation. The Palapa Metropolitan Area is a planning area that has been developed into a metropolitan area in West Sumatra Province. In preparing the development plan for the area, the government and the community should pay attention to reducing environmental degradation.

Regarding regional topography, the Palapa Metropolitan Area is at various altitudes and slopes, so the area is prone to landslides and floods. Population growth and rapid development are also the causes of degradation in the Palapa Metropolitan area. So it is very necessary to identify areas vulnerable to landslides and floods (Tazmul Islam & Meng, 2022) (Xiao et al., 2022).

Identification of landslide and flood areas will assist the government in making appropriate policies and strategies to reduce environmental degradation (Vo et al., 2021) (Sarkodie et al., 2020).

3.1 Spatiotemporal distribution patterns of landslides and floods

Natural disasters are complex events and pose risks to landscape changes that cause harm to the environment, economic activities and public health(Perz et al., 2022) (UNDRR, 2020). Landslides and floods are frequent natural disasters that cause great losses to human life and livelihoods. Increased human activities and development further exacerbate the factors that cause landslides and floods. Landslides and floods will cause environmental degradation in the long term.

The making of landslide and flood maps needs to be done to see the extent of the landslide and flood phenomena in an area and to know the spatial distribution pattern of landslide and flood events. The landslide and flood map will be able to be developed to determine the landslide and flood zone areas and the vulnerability and risk of landslides and floods. Landslide and flood zone maps will be very useful in spatial planning by local governments to formulate development policies and strategies.

2015

2011

2021

2017

Figure3. Landslide distribution pattern in 2011, 2015, 2017 and 2021

Figure 3 shows the distribution pattern of landslides in Metropolitan Palapa in 2022, 2015, 2017 and 2021. The landslide disasters show that the number of urban villages/nagari and the area of landslides has increased and spread widely from 2011 to 2021. In 2021 most of the landslides occurred in the eastern part of the Palapa Metropolitan area. The eastern part of Metropolitan Palapa is a highland region. This area is an area with an altitude of between 350 to > 1100 above sea level (Figure 2d) and is on a slope of between 15 to > 45% (Figure 2c), with rainfall between 227.085 to 397.806 millimetres per year (Figure 2e). The number of urban villages/nagari experiencing landslides has increased,

The complex morphology of the area causes landslides(Li et al., 2021)at Metropolitan Palapa. The slope and altitude of the area are factors that cause landslides(Panchal & Shrivastava, 2022) (Qi et al., 2021). The diverse topography of the Palapa Metropolitan area is exacerbated by high enough rainfall, causing landslides(Pradhan et al., 2022) (Alvioli et al., 2018). High rainfall will cause softening of strength and reduce slope stability, causing weakened soil cohesion(Zhou et al., 2019). Population and population density, as well as human activities, are also the causes of landslides(Kamal et al., 2022). The construction of the road network and the cutting of hilly areas are also the causes of landslides(Pradhan et al., 2022).

The landslide disaster in the Palapa Metropolitan area has caused a great loss of property and life. Landslides have buried many people's houses and cut off road access. As has happened in the Sungai Sirah Kuranji Hulu urban village, Sungai Geringging sub-district, Padang Pariaman Regency, which has isolated 78 heads of families because of the material blocking the road as high as 2 meters. The landslide in Nagari Pasie Laweh, Lubuk Alung sub-district, Padang Pariaman Regency, also claimed 7 lives. Losses reduce landslides; it is

necessary to zone landslide-prone areas and evaluate landslide hazards(Asmare, 2022). The zoning of landslide-prone areas can practically be applied to regional and infrastructure development planning in the Palapa Metropolitan area.

2015

2011

2021

2017

Figure4. The pattern of flood distribution in 2011, 2015, 2017 and 2021

Figure 4 shows the distribution pattern of flooding in Metropolitan Palapa in 2011, 2015, 2017 and 2021. Flood disasters also show that the number of villages and areas affected by floods has increased from 2011 to 2021. Flood areas in 2011 and 2015 generally occurred in plain areas low in 2017 and 2021, spreading to the highlands. Flood events have increased; in 2011, the flooded areas were 29 urban villages/nagari increasing to 52 urban villages/nagari in 2015, increasing to 94 urban villages/nagari in 2017, and becoming 196 urban villages/nagari in 2021.

The floods in the Palapa Metropolitan area caused losses to property and lives. Floods and landslides in October 2021 in Padang resulted in 8 sub-districts being affected, with water levels reaching 150 cm. The floods submerged 350

houses, 418 residents were evacuated, and 2 road points were affected by landslide materials. Floods in the Koto Tengah sub-district, Padang municipal, resulted in 1 person's died and 2 people being declared missing. Floods in Banda Gadang and Gurun Laweh urban villages, Nanggalo sub-district, Padang municipal, with a height of 200 cm. The flood that hit the Sungai Limau Subdistrict damaged the Belimbing River Dam. In September 2021, floods and landslides killed 4 people in Padang Pariaman Regency. Floods in Padang Pariaman Regency impact 10 sub-districts with water levels between 75 to 200 cm. In addition to the fatalities damaged, 338 housing units, 80 hectares of agricultural land, one unit of public facilities, and one unit of educational facilities. Floods in Ulakan Tapakis sub-district, with water levels reaching 100 to 150 cm, damaged 70 houses and 17 hectares of rice fields.

Floods that occurred in the Palapa Metropolitan area were caused by high rainfall intensity. In addition to the intensity of rainfall, flooding can also be caused by land use and land cover(Pabi et al., 2021), population growth and development activities(Mayo & Lin, 2022), elevation and slope of the area, as well as drainage density(Ogato et al., 2020). The high intensity of rainfall and climate change are causing rivers to overflow and sea levels to rise, especially in coastal areas(Townend et al., 2021). Parts of the southwest to northwest Palapa Metropolitan area are low-lying coastal areas prone to flooding(Uddin & Matin, 2021). Climate change causes the generation and distribution of storm waves, which has implications for the danger of flooding in coastal areas(Mayo & Lin, 2022). The human factor and lack of human concern for the environment further exacerbate the flooding that occurs(Oulahen, 2021).

Floods are natural disasters that often occur in the Palapa Metropolitan area and the world, so it is necessary to identify and map flood-prone areas(Thapa et al., 2020)to determine mitigation measures to prevent flood hazards

(Xafoulis et al., 2022). Mapping flood-prone areas are needed to plan safety measures for both property and lives when a flood occurs. In addition, to carry out evacuation and planning shelter areas(Uddin & Matin, 2021). Mapping the flood area in the Palapa Metropolitan area will help the local government plan a development strategy and a strategy for building shelters. The government can implement strategies to reduce the risk of flooding, including maintaining many perennials and grassland vegetation and providing early flood warnings(Pabi et al., 2021). It is no less important to increase public awareness of the environment. Local governments incentivise communities or groups of people who care about the environment(Entorf & Jensen, 2020).

Spatial grouping of areas prone to landslides and floods

The spatial grouping of areas prone to landslides and flooding in Metropolitan Palapa was carried out using the LISA method using the Local Moran Index. LISA statistical method, according to Asselin (1995), serves two purposes. The first objective is to indicate the extent to which spatial areas have significant value as local indicators or hot spots. The second goal of LISA statistics is to see the effect of individual locations on global statistics and identify outliers. LISA statistics are very useful for viewing spatial scrambling and identifying local hotspots. We used a randomisation approach to generate references for statistical significance values.

To see the spatial grouping of the Palapa Metropolitan area is the number of landslides and floods in 2021 (Figure 5). The landslide and flood grouping maps resulting from the LISA analysis can be seen in Figures 6 and 7. Observations were made of 235 urban villages and nagari in Metropolitan Palapa.

The LISA clustering map is a map that identifies significant spatial relationships and their outliers. At the same time, the LISA significance map is

a map of the significance level for each object that is interconnected with a p-value of 0.05, 0.01 and 0.001. An outlier is an area that has the opposite value to the surrounding area. The spatial relationship on the LISA grouping map consists of 1) not significant, which is an area that is not significant at the 0.05 standard quasi-significance level); 2) aloft hot spots are areas of high value surrounded by high and significant values; 3) low-low cold spots are areas that have low values surrounded by low and significant values; 4) low-high outliers are areas that have low values surrounded by high and significant values; The results of LISA analysis using the Local Moran Index can be used to identify the spatial classification of landslides and floods in Metropolitan Palapa. Each index has a statistical test, so we can map areas with a statistically significant relationship with their neighbours and see the type of relationship.

Figure5. Spatial distribution of landslides and floods in 2021

Significance Maps

LISA Cluster Maps

Figure6. LISA cluster map and landslide significance map for 2021

Significance Maps

LISA Cluster Maps

Figure7. LISA cluster map and flood significance map for 2021

Figure 5 shows the distribution of landslide and flood events in 2021 based on the number of flood events in each urban village and nagari. Figures 6 and 7 show the LISA grouping map and the landslide and flood significance map for 2021. The areas in red are hot spots representing the height-height group (HH); we can call it a positive spatial association of HH. That means that urban villages/nagari with a high incidence of landslides and floods are adjacent to areas with a high incidence of landslides and floods. The analysis results show that areas with a positive HH association with landslides are in the north and northeast of Metropolitan Palapa. Most of these areas are located in Padang Pariaman Regency and Pariaman municipal, significantly in 18 urban villages/nagari (Figure 6).

The areas in blue are cold spots representing the low-low (LL) group, and we can call it the LL positive spatial association. That means urban villages/nagari with a low incidence of landslides and floods are surrounded by areas with low incidence. The analysis results show that the landslide areas with positive spatial associations LL are located in the western and southern parts of Metropolitan Palapa (Pariaman municipal and Padang municipal) and are significant in 50 urban villages/nagari (Figure 6). Meanwhile, the positive association of LL in flood-prone areas from the west to the south of Metropolitan Palapa (Padang Pariaman regency, Pariaman municipal and Padang municipal) is significant in 9 urban villages/nagari.

Regions in purple are outliers representing the low-high (LH) group, which we call the LH negative association. Areas with negative associations (outliers) mean that the value representing the number of landslides and floods differs

from the value representing the number of landslides and/or flooding from neighbouring areas. The negative association of LH means that areas surround areas with low landslide and flood events with high incidence. The analysis results show that the negative association areas for landslides are in the north, northeast, southwest, the south of Metropolitan Palapa (Padang Pariaman regency, Pariaman municipal and Padang municipal) and are significant in 12 urban villages/nagari (Figure 6). Negative associations for flood LH are in the western and southern parts of Metropolitan Palapa (Pariaman municipal and Padang municipal),

Regions in pink are outliers representing high-low (HL) clusters which we refer to as HL-negative associations. The negative association of HL means that an area surrounds an area with a high number of landslides and floods with a low incidence of landslides and flooding. The analysis results show that the negative association of LH landslides is in the southern part of Metropolitan Palapa (Padang municipal) and is significant in 3 urban villages (Figure 6). The negative association of flood HL was also found in the southern part of Metropolitan Palapa (Padang municipal) and was significant in 2 urban villages (Figure 7).

Based on the significance map, we can see that the positive association of landslides was significant in 42 urban villages/nagari with a p-value of 0.05, significant in 33 urban villages /nagari with a p-value of 0.01, and significant in 8 urban villages/nagari with a p-value of 0.001 (Figure 6). Based on the significance map, we can see that there is a positive association of significant flood HH in 21 urban villages with a p-value of 0.05, significant in 6 urban villages with a p-value of 0.01, and significant in 1 urban village with a p-value of 0.001 (Figure 7).

In this study, apart from looking at the LISA statistics using the Local Moran Index, we can also look at the Global Moran Index to determine the spatial autocorrelation of landslide and flood-prone areas (Figures 8 and 9). Global Moran Index to see if the landslide and flood-prone areas are clustered, random or spread out.

Moran's Index:

0.144723

Z-score:

9.414579

P-value:

0.000000

Figure8. Spatial autocorrelation of landslide-prone areas

Moran's Index:

0.070426

Z-score:

4.556883

P-value:

0.000005

Figure9. Spatial autocorrelation of flood-prone areas

Figures 8 and 9 show the spatial autocorrelation of landslide and flood-prone areas in Metropolitan Palapa. The spatial autocorrelation of landslide-prone areas shows a Moran Index value of 0.1447 and a z-score of 9.4146, while for flood-prone areas, the Moran Index is 0.704 and a z-score of 4.5568. That means the spatial associations of landslide and flood-prone areas are clustered based on the number of landslides and floods. The existence of clustered landslide and flood-prone areas will make it easier for local governments to make development plans to realise sustainable development and establish strategies to reduce the risk of landslides and floods.(Majeed & Mazhar, 2021) (Qi et al., 2021) at Metropolitan Palapa.

CONCLUSIONS

The rapid development of the urban economy is one of the driving factors for hazard exposure worldwide which causes vulnerability and environmental degradation (Eakin et al., 2022). Environmental degradation in an area causes disaster vulnerability, which will have implications for reducing economic benefits and increasing poverty. Landslides and floods are the most frequent natural disasters in Indonesia and throughout the world, which cause

6 | environmental degradation. To minimise the risks of floods and landslides; it is necessary to identify areas prone to landslides and floods. Maps of landslide and flood areas will greatly assist the government in implementing project policies and strategies to minimise hazard risks (Kahal et al., 2021).

Using LISA statistics, we identified local spatial associations of landslides and floods in Metropolitan Palapa. The analysis results show that the area north to northeast of Metropolitan Palapa (Padang Pariaman regency and Pariaman municipal) is a high vulnerability to landslides, with a high positive spatial association of landslide occurrence and intensity. Meanwhile, Padang and Pariaman are areas that are vulnerable to flooding; this is because these areas are lowland/coastal areas. The LISA landslide and flood grouping map can be used as zoning for landslide and flood areas used for spatial planning in Metropolitan Palapa.

Strategies and policies are needed in integrated environmental planning and management to reduce the decline in social and economic benefits due to environmental degradation. Some of these things include: a) strengthening strategies for the use of natural resources that are effective and efficient; b) increasing community participation in environmental management (Thanh Thi Pham et al., 2020); c) increasing public awareness to care for the environment (Oulahen, 2021); d) establishing inter-regional cooperation (Majeed

& Mazhar, 2021); e) increasing community innovation(Çakar et al., 2021); f) strengthening environmental management institutions and implementing an integrated watershed approach for flood management(Ogato et al., 2020); g) maintaining the presence of woody vegetation and grasslands as well as disaster early warning(Pabi et al., 2021); h) provide incentives to communities and community groups concerned with the environment(Entorf & Jensen, 2020).

Strategies and policies that apply to the Palapa Metropolitan area include: a) strengthening environmental management institutions; b) establishing cooperation between regions; c) increasing public awareness to care for and protect the environment; d) providing incentives to people who care about the environment.

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