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Spatial Analysis Of Disaster-Resilient Multifunctional Landscape In Informal Settlements, Indonesia

Roosna MO Adjam[1], Imam Buchori[2], Wakhidah Kurniawati[3]

(1) Doctoral Program of Architecture and Urban Science, Diponegoro University, Semarang Indonesia

(2) Department of Urban and Regional Planning, Diponegoro University, Prof. Soedarto SH Street, Tembalang, Semarang, Indonesia. 50271.
Email : i.buchori@live.undip.ac.id

(3) Department of Urban and Regional Planning, Diponegoro University, Semarang, Indonesia. Prof. Soedarto SH Street, Tembalang, Semarang, Indonesia. 50271.
Email : wakhidahkurniawati@lecturer.undip.ac.id

*Corresponding Author: Prof. Soedarto SH Street, Tembalang, Semarang, Indonesia. 50271.
Email : roosnaa@gmail.com
https://orcid.org/0000-0002-8860-2676

Abstract.

Urban landscapes with significant plant habitats become multifunctional when linked to climate disaster resilience, such as floods and strong winds. Multifunctional is spatially heterogeneous in that it provides many landscape services. This suitability depends on the biophysical area that is favorable to the conditions and interactions between landscape functions. This study aims to spatially analyze disaster-resilient multifunctional landscapes in informal settlements. Using quantitative methods, classification was carried out by applying the method of normalized difference vegetation index (NDVI) and interpolation to analyze resilient areas of floods and windstorms that are recognized as landscape functions. We mapped and analyzed the capacities to provide services of five landscape functions (flood and windstorm control, water availability, habitat; social activities) of three sub-districts in Kupang, Indonesia. The result of the study showed that the functions of flood and windstorm control synergized in several areas, while humans had a significant need for the water supply function in the area. The multifunctional landscape covered 3.51% of the study area. It is in low-lying areas with high slopes, a high level of vegetation cover, and a good level of water availability. Also, the study area had several social activities and is close to rivers and main roads. Community perceptions of landscape functions as an approach to assess the effectiveness of multifunctional landscapes as a medium for disaster resilience and avoiding environmental degradation. This calls for more appropriate policy interventions to support community disaster resilience and landscape conservation.

Keywords: Multifunctional landscape, Spatial analysis, Landscape functions, Disaster resilient landscape, Informal settlement.

Introduction

Extreme weather events are the most common cause that accounts for a large economic loss impacting on post-disaster recovery (Gautam et al., 2020; Chaiechi, 2014; Friedt & Toner-Rodgers, 2022). The Center for Regional Economic Development (CRED, 2019) notes that in 2018, climate-related disasters affected an estimated 68 million people and caused $131.7 billion worth of damage worldwide. Urban residents at lower economic levels tend to live in non-ideal housing conditions known as “informal settlements” (Pojani, 2019; Celhay & Gil, 2020). Mostly, those who reside in informal settlements lack access to durable housing, clean water, proper sanitation, adequate living space, and secure tenure (Vaccari et al., 2020).

Discussions about informal spaces and their resilience to disasters have been a worldwide concern since 2005 (Millennium Ecosystem Assessment (MEA), 2005). Informal spaces often have two important aspects that go hand in hand, where vulnerability and resilience are perceived by people's beliefs and perceptions (Usamah et al., 2014). Therefore, social relations and communication networks between citizens, the connection between residents and their vicinity, and institution activeness are the keys to resilience against climate disasters (Uddin et al., 2020; Pauwelussen, 2016; Faulkner et al., 2018; Mia et al., 2019). Household capitals are important to shape preparedness for disaster recovery (Gaisie et al., 2021; Sou et al., 2021).

Due to progressing urbanization processes, the demand for high-quality urban landscapes that ecologically provide multiple functions in urban areas is continuously rising (D’Ambrogi & Guccione, 2021). Sustainable landscape management requires paying more attention to the notion of connecting ecological processes and their relation to landscape functions (Duarte et al., 2020; Sarah T. Lovell et al., 2021) that determine the landscape's capability to provide goods and services for human needs (Czyżewski et al., 2021). Within landscape multi-functionality, the basic types of landscape functions are divided into four major groups, namely: production functions, regulation functions, ecological functions, and cultural functions (Bolliger et al., 2011). Several articles developed a conceptual framework from the perspectives of production, social, and ecological functions (Peng et al., 2016; Liu et al., 2018; Sarah Taylor Lovell et al., 2010). Some other research examines productivity, soil retention, water yield, crop production, and residential support components (Peng et al., 2019) and social values (Rastandeh et al., 2021; Godtman Kling et al., 2019), but articles analyzes multifunctional landscapes supported by community perceptions in the informal area are few and far between.

The interplay between landscape services has been further recognized, especially in different landscape forms. Related research has studied different kinds of landscapes, such as agricultural landscapes (Lovell et al., 2021; Rallings et al., 2019), forest landscapes (Navalho et al., 2019), rural landscapes (Ricart et al., 2019), urban landscapes (D'Ambrogi & Guccione, 2021; Peng et al., 2016), riparian landscapes (Semmens & Ancona, 2019), and mountainous landscapes (Peng et al., 2019). They often utilize the method of spatially quantifying functions, but not much has been discussed about multifunctional landscapes in informal urban areas.

Climate-smart landscape themes that focus on climate change adaptation and mitigation functions, such as a resilience strategy in vulnerable landscapes, have become more popular (Cerreta et al., 2021). More specifically, several articles on landscape functions related to flooding (Zhang et al., 2020; Morimoto, 2019; Paolinelli et al., 2022), and windstorms (Podhrázská et al., 2021; Uddin et al., 2020) have been in discussion for quite some time, but they are not focused on multifunctional landscape analysis. The resilience of landscape functions to climate disasters can be described as landscape features that provide multi-functionality that can simultaneously control climate change in a location. In relevance to this concept, many studies assess the relationship between the ecological and the community's social aspects, which serve as a service delivery component of the landscape. However, less attention has been focused on the disaster-resilient landscape's regulatory function.

The regulatory function relates closely to production, habitat, and cultural function. It plays a vital role as a supporter of the urban landscape balance in facing climate disasters such as floods and winds. Multifunctional open space systems supported by regular land use are able to significantly lower river water levels, reduce inundated areas, and respond more resiliently to flooding (Lourenço et al., 2020). Wind disasters vary in size and strength, but it can affect forest structure, species diversity, and spatial form (Xi et al., 2008). Landscape services against windstorms benefit communities by increasing soil organic matter content (reducing the need for fertilizer), accumulating wind farms, and allowing residents to sell collected debris for extra income (Vink & Ahsan, 2018). Reduced tree clusters after windstorms can stimulate the growth of the remaining trees (Čada et al., 2013). Landscape services are equated with the use of landscapes and biodiversity as part of a strategy for adaptation and disaster risk reduction due to climate change (CBD, 2009) closely related to the role of local society. Various community-based interventions to landscape function such as the forest care movement, education, community capacity support, and community-based ecotourism were studied (Sherpa et al., 2022; Koju et al., 2023). Community perception helps to reduce susceptibility and strengthens disaster resilience in complex informal settlements (Usamah et al., (2014); Mitra et al., (2017)) and local communities that consider the existence of supporting landscape function (an ecological function) as important also prioritize the function of climate control (Young et al., 2019). Cultural landscape function must be approached politically, socially, and economically in order to reduce disaster risk (Shirvani Dastgerdi & Kheyroddin, 2022).

Landscape functions are the capacity of landscape that have different biophysical and social conditions to control floods or strong winds and the integration of functions within them as multifunctional landscapes. We identified significant functions of flood control, wind resistance, water availability, plant habitat, and social functions in the three research areas which helped us define the five functions. Previous studies have used geographical information system-based suitability analysis and the landscape function approach (Martínez-Martínez et al., 2022; Busayo et al., 2022; Malecha et al., 2018) to minimize conflict and provide spatial information that supports the management of areas with disaster-resistant landscape functions.

Multifunctional landscape analysis is important because it relates closely to the survival of the community from disaster and the balance of landscape functions in the coastal area. When green space is reduced, it will be followed by reduced landscape functions, including provisioning, regulating, and supporting functions which are very important for human welfare such as flood and climate control, water supply, and forest products (Villarreal-Rosas et al., 2022; Abildtrup et al., 2013; Krause et al., 2017). Efforts are needed to support sustainable landscapes and a better understanding of how people around the landscape perceive and react to minimizing the impact of disasters. This study aims to spatially analyze disaster-resilient multifunctional landscapes and their perceived contribution to local communities in informal urban areas.

This study uses remote sensing for land surface analysis on a large scale using two spectral indexes – NDVI (normalized Difference Vegetation Index) and NDWI (normalized Difference Water Index). The choice of the NDVI is due to its feasibility to assess land cover classification by mapping the greenness index of the soil surface (Sihag & Sihag, 2021; Barbosa et al., 2019), whereas the NDWI is suitable for mapping the presence index of water bodies. We use these indices to determine areas that have the potential to control floods and windstorms in the study area. NDVI and NDWI spectral indices are considered powerful tools to assess vegetation cover and surface water cover in high spatial resolution (Ahmed & Akter, 2017; Xie & Fan, 2021). In detail, this area analysis will focus on the spatial pattern of landscape multifunctionality. Landscape function analysis is very useful in helping to visualize multifunctional areas with high resilience, supporting the strategic plans to optimize areas with landscape functions, and encouraging the participation of community members and other stakeholders in sustainable landscape management.

Airmata, Mantasi, and Manutapen are three urban villages in Kota Lama District, located on the outskirts of Kupang, Indonesia. The areas have a form of settlement located in the center of Kupang city (also part of the Kota Lama District), have local customary characteristics, and residents still have rural life behaviors that include close family ties. Various building conditions, high population density, an irregular environment, and a lack of basic service facilities are the characteristics of informal settlements in this area. The settlement pattern is also characterized by land ownership which is difficult to standardize. The understandings and life habits of villagers often clash, but they can live side by side in the villages.

They were chosen as the study area because they are considered to have relevant landscape services that help residents of informal settlements survive climate disasters. The area had an average urban population growth rate of 2.64% from 2000 to 2012. It has a distinct geographical setting with an ecological function of the watershed toward the sea estuary, where floods and windstorms are common. With the increasing demand for residential space and basic living facilities such as water, multifunctional landscapes are considered an effective approach for sustainable urban landscape management and planning.

Methodology

Study Area

This paper analyzes the area of three urban villages located in an ecological river basin (Fig. 1), namely: Airmata, Mantasi, and Manutapen in Kota Lama District, Kupang, Indonesia. The total area is approximately 138.18 ha, consisting of a total of 55.53 ha (40%) of green open spaces and 79.2 ha (57.3%) of residential areas that totally accommodate 9362 population. The Dendeng watershed, which flows through the area and functions as the ecological corridor, is a suburban area with a history of annual floods and windstorms. Additionally, the ever-increasing population has caused the emergence of informal settlements, with unlicensed housing (squatter settlements and slums) dominating this area. The study areas are in the densely populated urban center of Kupang, with an average household size of about 4.9 inhabitans.

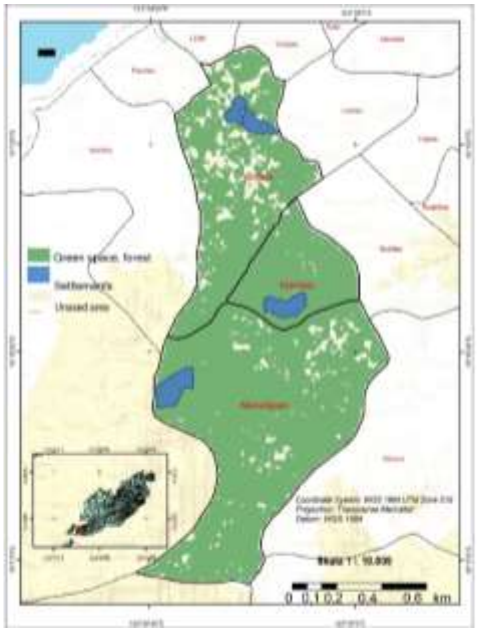


Figure 1. The study area consists of three informal areas in the subdistricts of East Nusa Tenggara, Indonesia.

Following the current focus of the study area, we include five landscape functions in our analyses; the landscape's capacity to provide: (1) flood control, (2) wind control, (3) water availability, (4) plant habitat, and (5) social activities. Land cover indicators were obtained by analyzing images acquired through Sentinel-2, a satellite developed and operated by European Spatial Agency for accurate and accessible ground level mapping (Misra et al., 2020). The NDVI value was taken on July 12, 2021, in the summertime with high biomass. It was calculated using reflectance data bands 8 (Near Infrared 0.842 micrometers) and band 4 (red, 0.665 micrometers) reflected by plants, where this method was able to identify plant cover through image computing processes (Ashok et al., 2021; Filippa et al., 2018). All remote sensing images are assumed to have the amount of cloud cover and the highest quality satellite imagery. Following the initial process, the NDVI value was calculated using the formula below (Riihimäki et al., 2017).

$$\mathrm{NDVI} = \frac{\mathrm{NIR-Red}}{\mathrm{NIR+Red}} \qquad \text{……………………(1)}$$

In Equation (1), band 8 NIR and band 4 Red are based on the reflected waves in the NIR Band and Red Band.

Assessment of the hydrological index was performed by using the Normalized Difference Wetness Index (NDWI) method to detect small changes in water content in water bodies. The NDWI value was calculated using the following formula.

$$\mathrm{NDVI} = \frac{\mathrm{Green-NIR}}{\mathrm{Green+NIR}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

In Equation (2), green is the reflectance value of the green channel (Band 3), and NIR is the reflectance value of the infrared channel (Band 5). The next step is to interpolate with the resulting Inverse Distance Weighted (IDW) by giving weights based on distance, where the closer the distance from the target location, the heavier it weighs (Emmendorfer & Dimuro, 2021). The weight used for the average is the derivative of the distance function between the sample point and the interpolated point (Achilleos, 2011).

Spatial analysis and mapping of wind control locations in the research area uses ArcMap 10.8 software, with a scoring method based on the value of the scoring variable for potential floods and wind disasters (Hossain & Meng, 2020 We use the scoring as it is located in a flood-prone area of the city, has a high population density, and takes into account several factors such as elevation, slope, land use, geology, rainfall, and distance from rivers. A rainfall map was obtained by analyzing rainfall data at the research location for ten years, from 2011 to 2020. Landscape observation techniques are often focused primarily on land cover, which, in this case, does not provide significant information about the spatial character of the landscape function in the area. Mapping landscape functions requires different methods and approaches (Haines-Young et al., 2006). One of the most appropriate methodological frameworks to describe the function of the landscape is by using landscape indicators (Willemen et al., 2010) that represent the ecological, economic, and social identities (Rastandeh et al., 2021). The determining factor in this methodological framework is the availability of spatial information about the location, relationship, and capabilities of each landscape function. The precise location of some landscape function characters can be easily identified (for example, residential areas, or water bodies). Meanwhile, the location of social activities for the cultural function must be assessed using GPS within a 250-500 m radius to obtain a significant spot and measured in percentage (Willemen et al., 2010). In this study, when landscape function is mentioned, it follows the appropriate parameters in the unit related to community or policy aspects. Table 1 lists the names of the landscape functions and their indicators as measurable variables needed for this paper. Methodological flowcharts are needed to describe the function of a landscape spatially, along with indicators representing some of the selected landscape components.

Table 1 Landscape functions and indicators

Landscape Function	Landscape indicator	Criteria
Production function 1. Water supply	Water springs, River	(1) high wetness 0.33 –1; (2) Moderate 0-0,33; (3) Non wetness -1,0 - 0;
Regulatory Function 1. Flood control (Hossain & Meng, 2020)	Soil types	(1) Low run-off; (2) moderate run-off; (3) high run off
	Land use	(1) Forest, shrubs; (2) Cultivated plants, few buildings; (3) Settlement
	Slope	(1)>38,38; (2)10,90 – 38,38 (3)0 – 10,89
	Rainfall	(1) <1000 mm; (2)1000-2500 mm; (3)>2500 mm
	Distance from river	(1)>2000 m; (2)200-2000; (3)0-200 m
	Flood Frequency	(1)>10 years; (2)5-10 years; (3)0-5 years
2. Wind control (Tercan, 2021); (Singh et al., 2022)	Topography	(1)>3000 asl, (2)1500-3000 asl (3)<1500 asl
	Rainfall	(1) <1000 mm , (2)1000-2500 mm (3) >2500 mm
	Land use	(1) Forest, shrubs; (2) Cultivated plants, few buildings; (3) Settlement
	Wind speed	(1) < 4.4 m/sec, (2) 4.4-10 m/sec; (3) >10 m/sec
	Slope	(1)>25%; (2)10 – 25%; (3)0 – 10%
	Distance from wetland	(1)>1000 m; (2) 200-1000 m; (3)0-200 m
Habitat Function 4. Plant Habitat	Vegetation density (NDVI)	(1) High (0,35-1); (2) Moderate (0,25-0,35); (3) Low (0,15-0,25); (4) very low (-0.03- 0.15); (5) unvegetated (-0,79 - -0,03)
Cultural Function	--community activities	- % within 250m radius
5. Social *	--agriculture spot	- % within 500m radius - % within 500m radius

(Willemen et al., 2010)	--social events --historical sites --economic value	- % within 250m radius - % within 500m radius
	*semi-structured interviews with community members and village managers. *Social were assessed using the global positioning system (GPS) in the areas	

2.2 Analyzing Landscape Functions

Landscape functions are equated with the use of landscapes and biodiversity as part of a strategy for adaptation and disaster risk reduction due to climate change (CBD, 2009). We identify landscape services for climate disaster reduction, especially flood and wind control for regulatory functions. For example, the biophysical conditions of the landscape affect the quantity of run off, peak flow, and the volume of water stored. Runoff is related to the overall level of surface water flow, while peak flow is more relevant to the risk of flooding and landslides as well as the presence of water bodies related to soil retention which has an impact on increasing groundwater absorption where all three of them contribute to reducing climate disasters (McVittie et al., 2018). We recorded several aspects of landscape functions with descriptions, indicators, and roles of resilience to informal settlements in our field survey (Table 2) and Figure 2 shows the schematic chart of the research approach.

Table 2 Descriptions, indicators, and roles of landscape function to informal settlements.

Category	**Landscape functions**	**Importance**	**Indicators**	**Roles of functions for community**
Provisioning Function	Water accessibility	Drinking and washing water for basic needs	Number and discharge of clean rivers and springs	Availability of clean water during a disaster
Regulating Function	Flood control	- The river is stable as a barrier to water flow - Green space as a soil erosion prevention	Trees and forest density	Environmental conservation; Increasing soil retention and landscape resilience against flood

		-Settlements with drainage		
	Wind control	Green spaces and treelines act as wind corridors and windbreaks; Plains surrounded by trees; Areas of tall trees, Areas >1000 m from the coast.	Tree density	Landscape management, protecting settlements from strong winds
Supporting Function	Plant Habitat	Green area for plant and wildlife habitat; Effective water catchment areas increase soil absorption, shorten the duration of inundation, and minimize the impact of flood	Number of plants and wildlife	-Decrease the impact of flood and strong wind
Cultural Function	Social activities	Cultural sites, social activities, and traditions identified as a function of the cultural landscape	The existence of historical and cultural sites, ecotourism, cultivation, and local economy	Tradition, local values, and community participation as support for disaster resilience

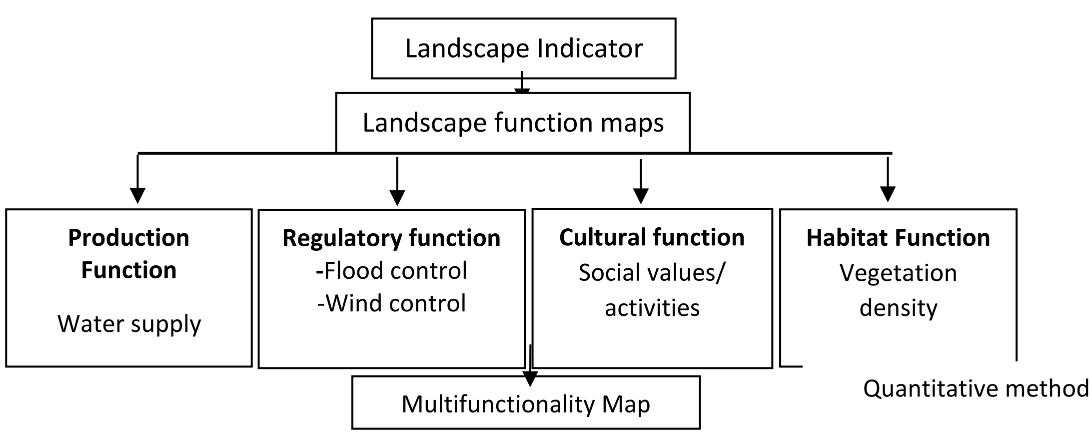


Figure 2. Chart of the research approach

Various types of landscapes in urban areas have some informal settlements that can produce several landscape functions in the face of pressure on vegetation, flood events, wind disturbances, tropical windstorms, water shortages, and decreased social ties among city communities. As a result, the following landscape functions were selected in this study. They are production functions (water availability), regulatory functions (flood and wind control), habitat functions (plant habitat), and cultural functions (social activities). These functions are directly mapped based on indicators derived from land cover and field surveys that explain the actual situation.

2.3 Mapping and Analyzing Multifunctionality

Assessment of the multifunctionality of the landscape involved overlaying mapping on five landscape functions with different maps, namely flood control, windstorm control, vegetation density, water availability, and social activities maps. This overlay generates a map quantification that depicts the landscape's multilevel function. The total potential for water supply, habitat, and disaster control at multifunctional sites was measured by normalizing and summing up the capacities of all landscape functions. The map shows numbers 1 to 5, which means that in an area, there is only one landscape function or five landscape functions at once (Peng et al., 2019; Willemen et al., 2010).

2.4 Community perception of the role of landscape functions

We implemented quantitative methods to assess the role of each landscape function based on the perceptions of residents in informal settlements. This approach is applied to analyze landscape indicators and community activities, their presence around the study area, and their perceptions of the role of the five landscape functions in helping them survive disasters. Several literature studies have been conducted on local community perceptions of forest ecosystem services and conservation management (Hassen et al., 2023), mangrove ecosystems (Afonso et al., 2022), and more specifically, spatial perceptions of ecosystem services and biodiversity (Pingarroni et al., 2022). We conducted interviews and distributed questionnaires to 91 respondents of the local population in informal areas, including staff from urban planning and implementation departments, as well as district and sub-district area management (273 residents in total). However, to develop a questionnaire, research narrative explained conceptually regarding the role of landscape functions regarding their spatial perception of each landscape service. We also discussed landscape indicators, landscape functions, and community activities in each function area, where we assisted participants by forming associations on factual issues of floods, winds, water access, and social activities in landscapes that could help their understanding. This method uses a proportional random sampling technique where the sample taken has the same opportunity to be selected as a sample (Salkind, 2010). The sample is determined using the Slovin formula with an error tolerance of 0.1, where the sample is taken from a population that also considers the level of confidence and the margin of error, which are as follows,

N

$$= \frac{N}{1 + N.r^2}$$

where, n is the number of individuals in the villages and r is the confidence interval, N is the total population.

Respondents were asked to rate the level of importance (low to high) of the five landscape functions using a Likert scale ranging from 1 (very low importance) to 5 (very high importance). Descriptive analysis was carried out to see the description of the respondents' perceptions of the function of the landscape in their area. This analysis was carried out by calculating the mean score of respondents' answers on each research variable (Sidel et al., 2018). The average score of these answers is then categorized into 3 categories, namely the low category if the mean value is between 1,000 – 2,330; medium category if the mean value is between 2,330 – 3,670 and high category if the mean value is between 3,670 – 5,000.

We also conducted interviews to obtain community perceptions about the role of landscape function and its relation to disaster resilience. Interviews are also intended to clarify the results obtained from the questionnaire. Due to the different education levels of the participants, an explanation of the function of the landscape was introduced before. The interviews were conducted for 30-60 minutes, depending on the respondent's interest and time. Then, we managed a total of 175 interviews in the three informal areas. Finally, community perceptions of landscape functions are used to assess the effectiveness of multifunctional landscapes in specific areas as medium for disaster resilience and avoiding environmental degradation.

3 Results

3.1 Characteristics of the Subdistricts

Of the three subdistricts in the study area, the largest was Manutapen (55.70%), followed by Airmata (30.82%), and the smallest was Mantasi (13.43%). The characteristics of each subdistrict and some of its landscape services can be seen in Table 3.

Table 3 Characteristics of the Subdistricts in the Study Area

	Airmata	Mantasi	Manutapen
Subdistrict profile	The oldest area with historical and cultural values; a total area of 42.64 ha; 695 of populations in informal areas	Development area (1930); riparian settlement; a total area of 18,56 ha; 476 of populations in informal areas	Newer and bigger area with immigrants and, high topography, and a total area of 76,98 ha; 851 of populations in informal areas
	Strong religious respect where decisions are made by the imam of the mosque and obeyed by the community	Decisions are made by the village head but with the approval of religious elders	Decisions are made by the village head but with the approval of religious elders
	20 springs in several residential areas	2 springs in several residential areas	2 natural dams' site
Livelihood activities	-Growing and selling vegetable farming for subsistence	-Vegetable farming for subsistence	Coconut and palmyra fruits farming for sale
	Snack and homemade food industry	Snack and homemade food industry	Pig husbandry
	-Fishing in the sea for subsistence	Fishing in the sea for subsistence	--

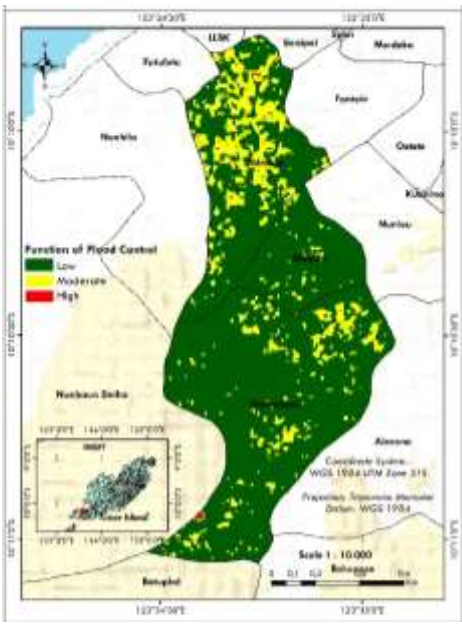
	Working in town as a carpenter/ temporary laborer	Working in town as a carpenter/ temporary laborer	Working in town as a carpenter/ temporary laborer
Hazard	River flooding and surface erotion	Few areas of landslide	Areas affected by strong winds
Impacts	Risk to residential and local business properties, decreasing of fishing source and livelihood.	Risk to residential properties and recreational area, damage to settlement access	Risk to residential and agricultural properties, decreasing of livelihood.

3.2 Analyzing Landscape Functions

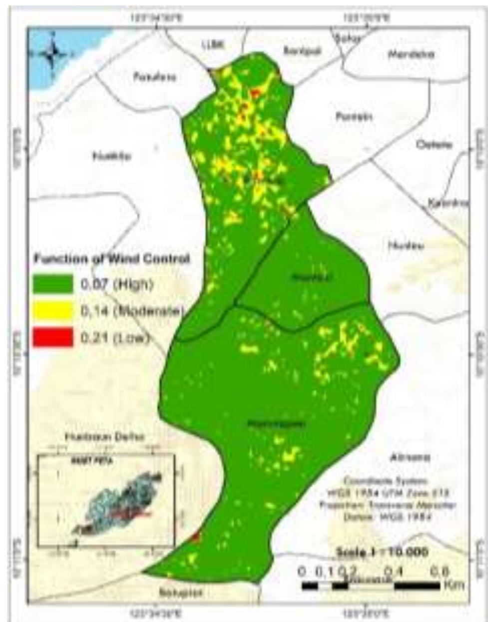
Five landscape functions were quantified using GIS analysis. They are flood control, wind control, plant habitat, and water availability. However, the cultural function (social activities) needs to be mapped using GPS and then displayed on the GIS to determine the radius of the activity. Figure 3 shows the spatial characteristics of landscape functions in the study area.

1 Flood Control.

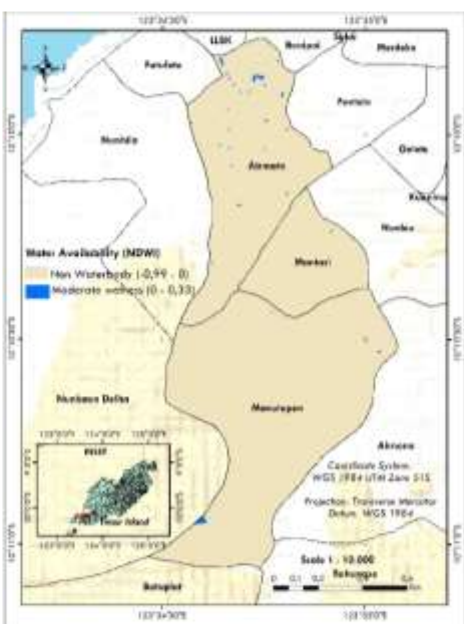
Figure 3a shows how the landscape functions as flood control. The flood control function is mapped in low-risk flood zones with high topography and vegetation density (Figure 3e). Most areas of the three villages are areas with low flood risk (85.2%), which can be considered areas with high flood control function. However, Airmata (elevation of 30-60m AMSL) and Manutapen (elevation of 60-120m AMSL) also have several densely populated areas with moderate flood risk. These densely populated areas experience annual flooding originating from the Dendeng River. The Dendeng watershed, which flows through these three villages, has a second class of water quality standards that the community uses for water recreation facilities, freshwater fish cultivation, animal husbandry, and agriculture (Solo, 2020) . Turbidity and water quality in September to November are usually worse than in other months. The water level around Dendeng River varies with the seasons. In the rainy season, the river's water level rises significantly. Flood records in Airmata village show that major floods are mostly caused by the Dendeng River runoff, causing severe damage to public facilities and residential areas around the border. This happens every ten years, in 1991, 2001, and 2021. In addition to that, annual flood occurrences are mostly in the form of an increasing water level to the maximum capacity of the river. Floods also struck some densely populated areas with moderate flood potential.



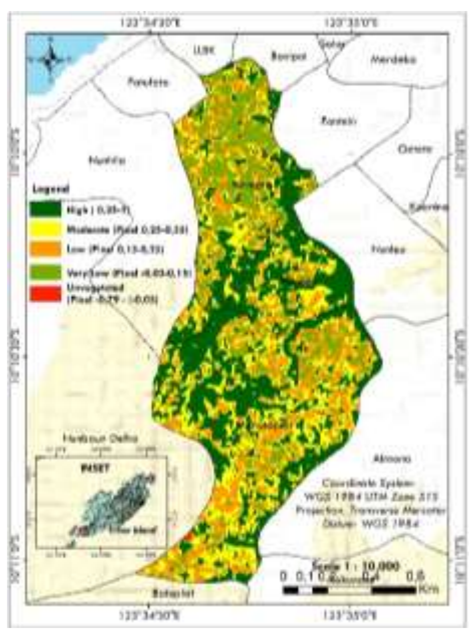
3a Flood control



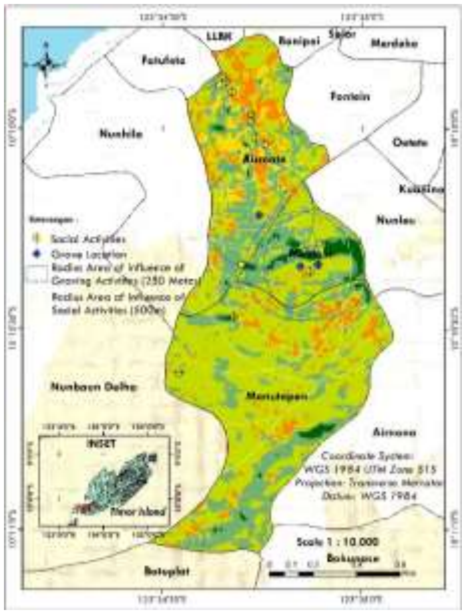
3b Wind control



3c Water Availability



3d Plant Habitat



3e Social activities

Figure 3 Spatial Characteristics of Landscape Functions in the Study Area

Based on the interview with the community, they defined Mantasi, Airmata, and Matupen as movable lands. On the slope map, the landscape function area in Mantasi has a steepness level of 30-40 % in a chain of rock hills located in a high vegetation density area within the Dendeng River tourist area. Most areas have eutric latosol soil types formed by ferralization and latosolization processes involving continuous intensive weathering and silica hydrolysis processes (Siddiqui, 1971). This area also consists of alluvial rock formed from river and lake sediments, which makes it suitable for agricultural land.

2 Wind Control

Figure 3b illustrates the entire study area as an area with a high (good) wind control landscape function or an area of low wind susceptibility. This analysis used parameters such as topography, rainfall, land use, wind speed, slope, and distance from the sea (wetland). The result is affected by moderate annual rainfall (1442.15 mm/year) and the presence of forests with high vegetation densities. The three sub-districts located in coastal areas have a reasonably close distance to the sea, namely Airmata (400-1200 m), Mantasi (1000-1500 m), and Manutapen (1300-2000 m). The annual average wind speed in the study area was 21.17 knots. The annual average wind speed in the study area was 21.17 knots. In annual windstorm conditions, we could describe the area of wind control landscape function, but not in specific events such as a tropical cyclone in April 2021. The cyclone caused considerable damage. It started with high-intensity rain accompanied by strong winds with a speed of 45-50 knots or 75-80 km/hour for three days in Kupang city, which resulted in flash floods in the highway area and public facilities area. It damaged 102 houses in Airmata, 76 houses in Mantasi, and 132 houses in Manutapen. A safe residential location is far from the beach/sea estuary and has wind protection vegetation that can form a rough surface to prevent the formation of wind corridors.

3 Water Availability

The NDWI map in Figure 3c shows that 0.6 ha (0.4%) of the area has moderate wetness due to the presence of twenty-four springs in the three study areas, which are twenty in Airmata and one in Mantasi, and the other three in Manutapen. The springs are artesian flows or occur due to hydraulic pressure and the appearance of water on the ground surface in a scattered manner in low-lying settlements (Airmata and Mantasi), compounded by a moderate rainfall and the presence of forest, grassland, and agricultural lands along the watershed and upland areas.

4 Plant Habitat

Figure 3d is the result of landscape identification to provide plant habitat. The calculated NDVI value in landscapes with high-density vegetation is between 0.35 and 1, with an area of 50.46 ha, or 36.52 %. The empty or built landscape with no vegetation area has an area of 0.13 ha, or 0.092 percent of the total study area. The survey results show that areas with low vegetation density are residential landscapes with small amounts of tree vegetation. Table 4 describes vegetation density level in the study areas.

Table 4 Area Classification based on Vegetation Density Level

No.	Description	Total Area (Ha)	%
1	Unvegetated land	0.13	0.09
2	Very low vegetation	19.67	14.23
3	Low vegetation	32.70	23.67
4	Moderate vegetation	35.22	25.49

5	High vegetation	50.46	36.52
	Total	138.182	

Vegetation in riparian areas or floodplains is an ecological counterbalance to climate problems. Based on the tree density survey conducted in the riparian area, there was a total tree population of 565 trees. We discovered that Musa paradisiaca and Cocos nucifera were the most dominant plants around the river, while Senna seamea and Bambusa sp. were also in abundance. We found that Senna seamea and Artocarpus elastica had higher resistance than other vegetation because of their quantities, even though they were close to the water flow. The least found plants were Ficus benjamina, Delonix regia, Borassus sp, Ceiba pentandra, and Samanea saman (Fig. 4). In terms of windstorm resistance, the most resistant plants were Polyalthia longifolia, Borassus sp., Cocos nucifera, and Samanea saman. These plants were found to remain stable during windstorms and were able to recover faster than other plant groups.

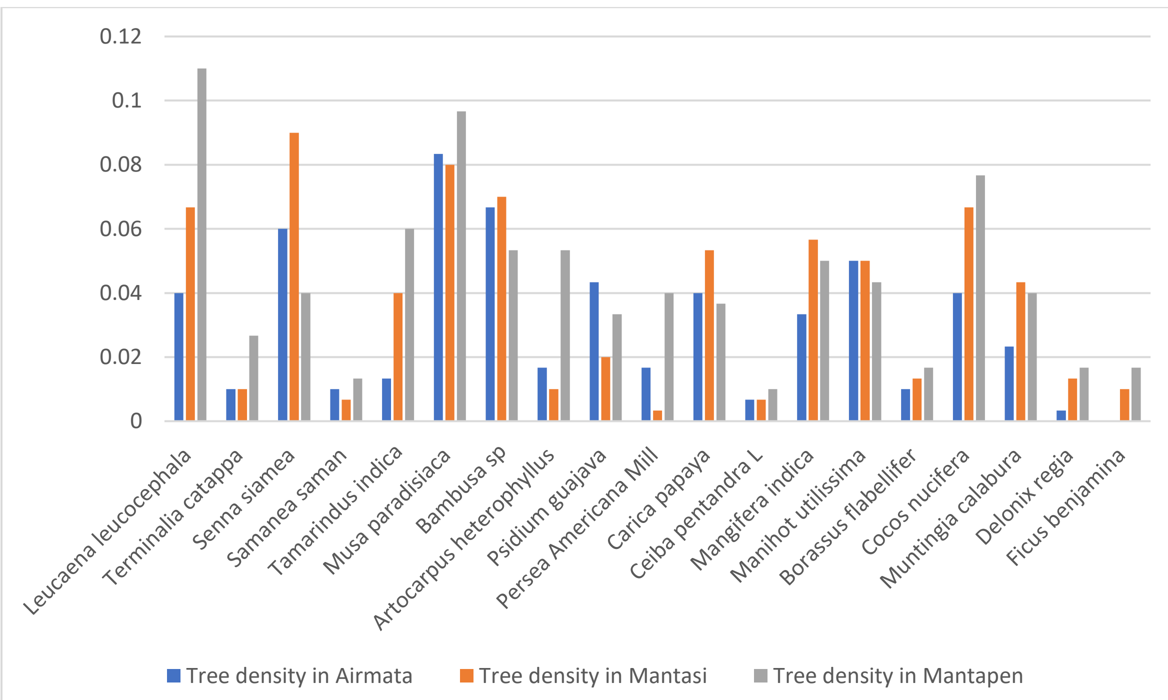


Figure 4 Plant Characteristics in the Landscape

5 Social activities

Figure 3e illustrates the spatial characteristics of social activities in the study area. Airmata's culinary and cultural heritage businesses enhance the local economy and social activities (Table 5). The local economy is quite developed in Manutapen (7.27%) and Airmata (8.28%). Historical sites (12.34%) are the most visited areas in Airmata. Ecotourism (2.52%) in Mantasi, on the other hand, has grown quite well, with a consistent number of visitors (15-30 people per day) based on observations. The three villages have a vibrant local economy, but only Mantasi residents are directly involved in ecotourism management. Agricultural land is found in Manutapen (27.34%), while in Airmata it is only 1.33%.

Table 5 Characteristics of the cultural function

No	Social	Subdistrict	Length (m)	Size (m2)	%	Radius of influence (Ha)
1	Ecotourism	Mantasi	167.21	5016.3	2.52	52.51
2	Social activities	Airmata	139.32	6966	3.5	43.75
3	Agriculture	Airmata	132.51	2650.2	1.33	41.62
4	Local economy	Airmata	329.3	16465	8.28	103.44
5	Local economy	Mantasi	81.2	1218	0.61	25.52
6	Local economy	Manutapen	288.82	14441.4	7.27	90.69
7	Social activities	Manutapen	189.25	70000	35.24	59.42
8	Historical sites	Manutapen	117.34	1760.1	0.88	18.42
9	Historical sites	Airmata	122.62	24524	12.34	19.25
10	Agriculture	Manutapen	468.7	54307	27.34	73.6
	Total area			198638	100	528.22

The five social values that the cultural landscape serves are social activities, ecotourism, historical sites, local economy, and cultivation. Social activities and ecotourism have the highest number of disaster resilient aspects (Table 6). Residents build retaining walls, evacuation points, and shortcuts way to higher areas to minimize the impact of floods as well as planted annual plants along the windbreak tree corridor to control winds.

Table 6 Disaster resilient aspects in the cultural landscape function of the Informal settlements

Social	Location	Activities	Community-built disaster resilience
Social activities	Settlement (Airmata, Mantasi, Manutapen)	Worship, Society events, Community activities	(1) Information sharing (2) Evacuation area, (3) Boat shelter spot, (4) Collecting aids spot, (5) Retaining walls (6) Water catchment area, (7) Cleaning water body
Ecotourism	Riparian forest, Upland area (Airmata, Mantasi)	Sightseeing, relaxing, boating.	(1) Water catchment area, (2) Flood-resistant vegetations, (3) Retaining walls (4) Evacuation area (5) A shortcut way to other region when flooding (7) Windbreak trees corridor
Historical	Public grave (Airmata) King's grave (Manutapen)	Family pilgrimage, Historical pilgrimage	(1) Water catchment area, (2) Windbreak trees corridor, (3) Water availability
Local economy	Along the main street (Airmata, Mantasi, Manutapen)	Culinary business	(1) Food availability (2) Collecting aids spot (3) Windbreak trees corridor
Cultivation	Narrow yard and vacant land (Airmata, Mantasi, Manutapen)	Crops planting, Community discussion,	(1) Food availability, (2) Information sharing (3) Water catchment area

(Interviews and Field Surveys, 2023)

3.3 Landscape Multifunctionality

Spatial landscape multifunctionality is identified as a combination of several landscape functions. Figure 5 shows that the wind control function includes 74.85 ha (54.2% of the total area) in these three villages. Settlements and green space areas are the primary land uses. Then, 38.28 ha had two landscape functions: residential areas and urban parks, which covered 27.7% of the total area. This map also shows that 13.17 ha, or 9.5%, provides three types of landscape functions, namely wind control, flood control, and water availability, located in the middle of Airmata and lower Manutapen with their dense forest vegetation. However, only 3.51% of the area could provide four or five landscape functions simultaneously. This area is considered a multifunctional landscape with its capability of proficiently utilizing five types of landscape functions that include water availability, flood and wind control, plant habitat, and social activities.

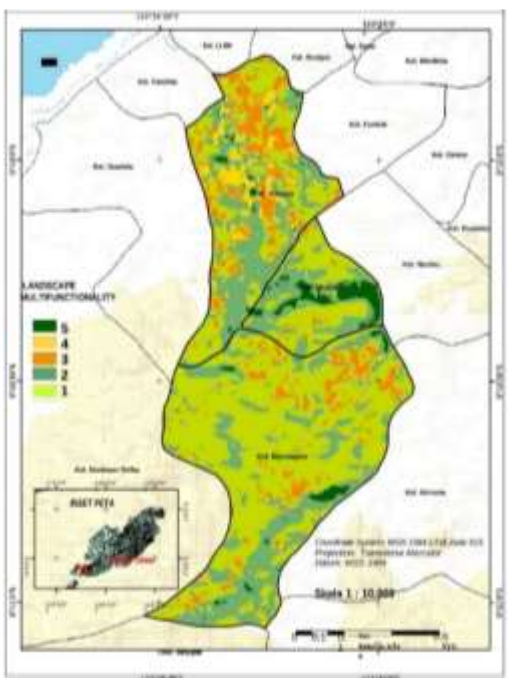


Figure 5 Landscape Multifunctionality

This study found that the three villages in the study area have landscape functions, but almost all areas have the characteristics of one or more distinctive landscape functions. Figure 5 shows that 3.51% of the landscape area with five functions is in Mantasi and a few part of Manutapen. This area has high density vegetation, rainfall of 1442 mm/year, a slope of 30–45%, contains corraline limestone (alluvial) rock types and latosol soil, has 30–60 m of topography, and has river bodies and springs available for the basic needs of residents. Based on the results of questionnaires, the form of social activities in the informal areas includes activities to maintain the rivers, plant flood-resistant vegetation, build retaining walls, establish alternative areas for evacuation, and establish shortcuts to other areas during floods. The identification of this multifunctional area is expected to become a focus area for city managers in disaster impact reduction activities. It is important to know and defend the area of multifunctionality because, in the future, these five landscape functions may experience an increase or decrease in the multifunctional areas as land use changes.

3.2. Community perceptions of the role of the landscape function

Respondents in Airmata perceived that the water availability function (provisioning function) was quite high in this region (3,899) compared to Mantasi (3,263) and Manutapen (3,596) (Figure 6). The role of the flood control function (regulatory function) was moderate (3,202), almost the same as in Mantasi (3,192). But the highest flood control function was in Manutapen (3.788), in contrast to the lowest wind control function in the region (2,757). The community agreed that the role of the plant habitat function (ecological function) was quite balanced in Mantasi (3,859) and Manutapen (3,909), and the lowest was in Airmata due to settlement density and the concentration of plant habitat only in the riparian forest. Finally, the value of social activities (cultural function) was quite high in the three regions, in order from the highest: Manutapen (4,202), then Airmata (3,889), and Mantasi (3,798). Overall, the respondent's score for each value was in the range of 2,737–4,293.

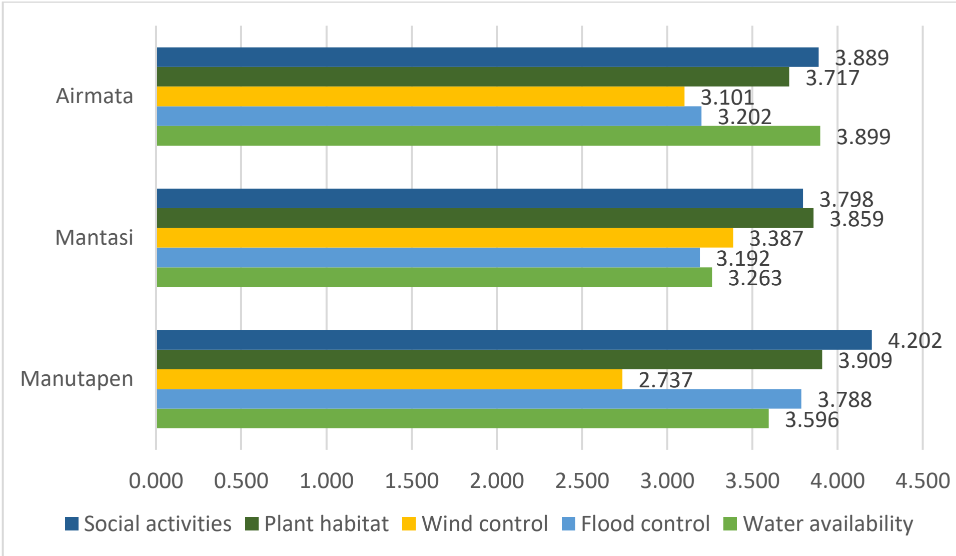


Figure 6 Community perceptions in the three study areas of the five landscape functions roles.

According to the results of the questionnaire, Figure 7 shows that springs and rivers play an important role in meeting the water needs of the residents, but several springs in settlements are simply left unmanaged. The value of the river maintenance aspect is higher than in the forests and hills where residents have a community that cares about the Dendeng River and actively cleans the river and pays attention to the river's water discharge. The highest value was found in the features of places of worship located in settlements. In terms of maintaining road vegetations, residents have regular time to plant vegetation on the main road of the settlement. According to respondents, this should be followed by improved management of the city's drainage facilities, which currently represent around 26% of the city's actions in programs to improve the rainwater system in the region. Another action that should be carried out more frequently is the maintenance of riparian forests and riverbanks, which have stagnated with the change into residential areas because one eighth of residents have left these areas and moved to other subdistricts. In general, the municipality lacks significant control over construction in the floodplains, which seems to be the contradiction that residents need. Figure 8 shows several disaster-resilient aspects of informal settlements.

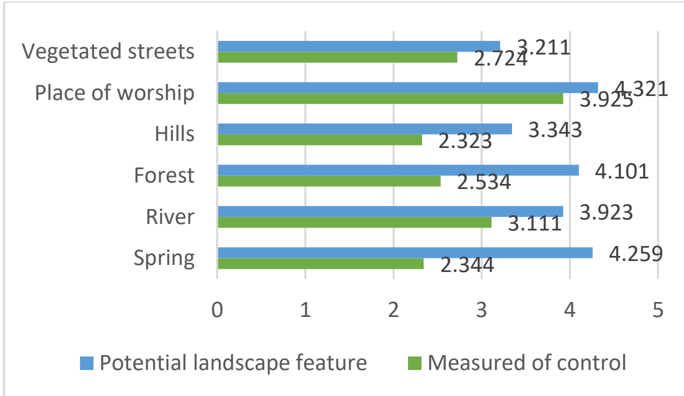


Figure 7 Potential landscape feature on multifunctional landscape and controlled measures.

Cultivation area in river side (Mantasi)

Urban village along the river (Airmata)

A shortcut way to other region when flooding (Mantasi)

A community's retaining wall (Airmata, Mantasi)

Boat shelter spot (Airmata)

A Spring in a settlement (Airmata)

Figure 8 Disaster-resilient sspects in informal settlements

4 Discussion

This study presents an assessment to investigate the landscape multifunctionality of informal settlements in three urban villages in the study area. This study focuses on mapping the functions of a disaster-resistant landscape, such as flood control, wind control, plant habitat, water availability, and social activities. The landscape was unique because it was in a flood control function area in densely populated urban areas with strong cultural characters. The local community has an agreement to manage land use (upstream area maintenance, reforestation, drainage cleaning) to obtain a sustainable landscape function, which was able to lower river water levels and reduce inundated areas. A study of flood mitigation in the urban landscape was also carried out by Lourenço et al. (2020), which used land use, land occupation, ground cover, topography, and urban drainage parameters. On the other hand, to obtain more detailed mapping results, this study integrated more parameters, namely land use, slope, rainfall, soil type, distance from rivers, and flood frequency.

Wind disaster varies in size, and its strength changes forest structure, species diversity, and spatial form (Xi et al., 2008). The forest structure in the study area, both in the hills and valleys, was damaged after a windstorm in 2021. We found that several forest vegetation communities, such as Polyalthia longifolia, Borassus sp., Cocos nucifera, and Samanea saman, were the most resistant to storms. They were found to remain stable during and after storms and recover faster than other plant groups. Also, we discovered that Senna siamea and Artocarpus elastica had higher resistance than other vegetation because they were located closer to watercourses and were not affected by significant drought conditions across landscape positions. Figure 4 shows a comparison of the annual forest structure of the Dendeng watershed landscape, consisting of large trees, herbs, and shrubs, and the forest structure that suffered significant damage after windstorms. The most dominant changes in vegetation structure also occur along the edges of road infrastructure and settlements. Apart from their destructive impact, the strong winds in this region may have a positive effect too. Observations showed that 60 days after the strong wind, there was a lot of plant succession with abundant plant growth in areas that previously had no vegetation. This fact was in line with Vink & Ahsan (2018), who state that there was an increase in soil organic matter content after a windstorm, reducing the residents' need for fertilizer. It also supports the study of (Čada et al., 2013) on the aspect of plant habitat function, which noted that tree groups damaged and reduced after windstorm can stimulate subsequent growth of the remaining trees.

Figure 6 shows that fresh water from springs and rivers are the two most important provisioning landscape functions in this region, followed by cultural functions (social activities) and then regulatory (floods and wind control) and supporting functions (plant habitat). Springs became active in the settlement area of Airmata during the rainy season, while Mantasi and Manutapen did not have active springs and only depended on rivers, wells, or regional drinking water companies. Interestingly, in this study, respondents considered the supporting and cultural functions to be more important than the provisioning functions (Figure 7), which explains the findings in the aspects of the riparian forest ecosystem. We also found that respondents who support the existence of a plant habitat support function tend to consider the function of climate regulation more important, and it is in line with Young et al., (2019). Cultural services are consistently considered very important because these three areas are urban villages that have strong social values and ties and often carry out activities together. This result is in line with Levy & Marans, (2012) finding that social bonds between residents are built even though they have differences in ethnicity, culture, or economy, but residents feel that having lived together in the area for years allows them to work together as a cohesive unit in dealing with disasters.

The largest agricultural land area was in Manutapen (57.34%), while Airmata had only 1.33%, and the ecotourism area in Mantasi was only 2.52% of the total area. These results differ from the study by Rastandeh et al. (2021), which found that that agriculture, recreation, and conservation were the activities that people valued most in the landscapes of the river basin. The differences were since informal residents in the study area were dependent on jobs in the city center.

The Mantasi and Airmata communities have paid significant attention to the Dendeng River in the last ten years. They regularly observed river conditions and carried out several river maintenance activities, such as planting flood-resistant and windbreaker plants, cleaning rivers, and building retaining walls. Residents' social activities in the multifunctional landscape area also includes establishing alternative evacuation areas, collecting aid during flooding or windstorms, and initiating shortcuts to other regions when floods occurs. Following Usamah et al., (2014) and Mitra et al., (2017) that social activities helps to reduce vulnerability and strengthens disaster resilience in dense informal settlements. Increased community awareness in the Mantasi area is in line with various community-based interventions such as forest care programs, education, capacity building and support, and community-based ecotourism (Sherpa et al., 2022; Koju et al., 2023). However, it should also be noted that not all Mantasi residents benefit from the multifunctional landscape, because residents in the three neighborhood units still live in dangerous locations such as riverbanks and steep slopes, for example neighborhood units of 03, 05, and 06 and neighborhood units of 18 and 19 on Manutapen subdistricts. The forest is the largest ecosystem in this area, covering 36.52% of the total area of the three areas. This value is quite high considering that the three are still included in the city of Kupang. The people's livelihoods do not depend directly on the forest materials such as wild food or medicinal plants, which can hardly be found in the forest anymore. A growing population that requires a certain amount of food has led to an increase in cultivation of land, especially in the Manutapen area. Taken together, this leads to a lower forest value than previously, which is in line with (Krause et al., 2017).

The findings in Table 5 explain the existence of social ties with the components of ecotourism, agriculture, and the local economy. This illustrates the community's awareness of the surrounding river and hill ecosystems that help them reduce the impact of disasters. It is in accord with Shirvani Dastgerdi & Kheyroddin, (2022), cultural landscape functions as a way in reducing disaster risk must be supported socially, ecologically, and economically in order to remain resilient. The provision of an understanding of flood resilience that depends on natural ecosystems and is carried out through community cultural media (religious or social events) as well as the provision of small business loans for residents to have economic resilience is important to do.

In recent years, local communities in the area have undertaken resilience efforts by optimizing existing landscape conditions to reduce the impact of floods and wind disasters. The findings of this multifunctional landscape are expected to be important information for city managers in developing this area to strengthen resilience to disasters.

Subsequent research can focus on the function of the landscape for tropical cyclone resistance, which is starting to occur frequently in the east of Indonesia, by measuring the spatial variation of the impact of typhoon risk in all administrative zones of the tropics using the criteria by Mansour (2019).

5 Conclusion

Disaster-resilient multifunctional landscapes are an approach in this study that is considered effective in assisting landscape management. This study observed the overlap between the landscape functions for the first time. These functions are strongly related to the primary services provided by the ecosystems of the landscape. Multifunctional landscapes, which are a combination of the functions of water availability, flood control, wind control, plant habitat, and cultural functions, are 3.51% of the total research area. The landscape is a lowland area with a moderate slope, high vegetation cover, adequate water availability, dominant social characteristics, and is close to rivers and roads. The study facilitates our better interpretation of how resilience is explained from the perspective of multifunctional landscapes that have the potential to support urban systems even under very limited conditions. It is important to put in place a mechanism that utilizes ecosystem services to enhance the city's ability to restore its functions.

Availability of data and materials

Data will be made available on reasonable request.

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Conflict of interest

The authors declare no competing interests in this paper.

Declaration of interests

The authors declare no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions:

Roosna MOA were responsible to compose, design, and conduct the experiments; Imam Buchori and Wakhidah Kurniawati analyzed the data; Roosna MOA, Imam Buchori, and Wakhidah Kurniawati reviewed the paper.

Ethical approval

All authors have read, understood, and have complied with all applicable aspects of the statement regarding "Author's ethical responsibility" as required in the Instructions for Authors and are aware that absolutely no changes can be made to authorship after the paper is submitted.

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