

## Modeling the distribution of settlements on slope gradients based on GIS in Manado city

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ARTICLE INFO	ABSTRACT
<p><i>Article history:</i> Received June 05, 2025 Received in revised form Oct. 08, 2025 Accepted December 31, 2025 Available online March 01, 2026</p> <p><i>Keywords:</i> GIS Modeling Settlement distribution Slope gradient</p> <p>*Corresponding author: Rieneke Lusya Evani Sela Doctoral Program in Architecture, Postgraduate School, Universitas Sam Ratulangi, Indonesia Email: <a href="mailto:riekesela@unsrat.ac.id">riekesela@unsrat.ac.id</a> ORCID: <a href="https://orcid.org/0009-0002-5966-9326">https://orcid.org/0009-0002-5966-9326</a></p>	<p>Manado City is experiencing rapid population growth, with an annual increase of 1.48% and a population density reaching 2,948 people/km<sup>2</sup> as of 2024. Due to the city's predominantly hilly topography, residential expansion has increasingly shifted toward sloped areas. This study aims to analyze the spatial distribution of residential settlements on sloped terrain using the Average Nearest Neighbor (ANN) method and to evaluate land suitability through Weighted Overlay Analysis (WOA) within a Geographic Information System (GIS) framework. Parameters for WOA include topography, slope gradient, disaster risk, and land-use zoning based on the 2023–2042 Regional Spatial Plan (RTRW) of Manado. The GIS-based analysis, conducted using ArcGIS 10.8 and ArcScene, reveals that settlements are concentrated on slopes with gradients of 25–40% and &gt;40%, covering 163.78 hectares. The densest clusters occur in Wanea and Malalayang Districts. WOA results indicate that Wanea has a larger landslide-prone area (39.53 ha) compared to Malalayang, necessitating risk-sensitive planning. Spatial conformity analysis highlights misalignment between current residential land use and the official RTRW. A spatial planning model was proposed for Karombasan Selatan Subdistrict, integrating terraced housing design, optimal building orientation, and conservation zoning for slopes above 40%. This study contributes to sustainable urban development strategies in hilly urban environments through GIS-based decision support.</p>

### Introduction

The growth of population numbers influences the increasing use of land because humans require residential areas for dwelling (Fitri et al. 2025). Residential areas function as living environments or settlement spaces and as locations for activities that support livelihoods, as stipulated in Law No. 1 of 2011 concerning Housing and Settlement Areas (Pemerintah Republik Indonesia 2011). Settlements represent the most dominant and

dynamic type of land use because they encompass all forms of human activity (Sarker et al. 2024).

Similarly, the City of Manado, as the capital of North Sulawesi Province, has experienced rapid population growth, thereby driving the expansion of settlements into various regions, including hilly areas. Based on data from the Central Bureau of Statistics (BPS) of Manado City, the total population in 2023 was recorded at 451,916 inhabitants, with a growth trend that continues to increase annually (Manado 2024).



The rise in population numbers directly correlates with the demand for residential land, so development is no longer limited to lowland areas but also extends to hilly slopes (Kamran et al. 2023). The characteristics of Manado City are predominantly hilly, with a settlement area of 163.78 hectares located on slope gradients of 25–45% and even exceeding 40%. This phenomenon requires special attention because it is associated with aspects of soil stability, disaster risk, and environmental management (Manabung, Tilaar, and Gosal 2021).

In the Spatial Planning Document (RTRW) of Manado City for 2023–2042, it is emphasized that development locations must follow the stated guidelines. This means that construction is not allowed in protected areas, conservation zones, or disaster-prone regions. If situated in areas with slope gradients exceeding 25%, development requires special permits and technical recommendations, including for residential spaces (Manado 2023).

A data-driven approach in spatial planning can assist in identifying land suitable for development by considering environmental factors (McHarg 2016). Technology-based planning emerges as an approach to ensure sustainable settlements on the slopes of Manado City. The Geographic Information System (GIS) is highly effective in managing spatial data to support spatial planning decisions, particularly in analyzing settlement distribution (Ramasubramanian, Albrecht, and Rojas De Leon 2023).

The application of GIS in urban planning has been widely implemented in various regions to improve efficiency in spatial management and disaster mitigation. In this study, the Average Nearest Neighbor (ANN) method is employed to identify settlement distribution patterns because it can analyze the spatial patterns of existing buildings as well as predict future settlement development trends (A'idah, Susiloningtyas, and Shidiq 2021; Sari, Jumadi, and Anton 2024). GIS technology is also utilized to evaluate land suitability through Weighted Overlay Analysis (WOA), which integrates various factors such as topography, slope gradients, disaster risk, and spatial conformity (Shit, Bhunia, and Maiti 2016; Basharat, Shah, and Hameed 2016). Through this approach, appropriate recommendations are expected to be obtained regarding safe and suitable zones for settlement development in Manado City.

One of the features of GIS, ArcScene, is used to visualize the three-dimensional distribution of settlements on slopes, thereby facilitating stakeholders in making decisions regarding land management (Bratt and Booth 2002; Emamgholian, Taleai, and Shojaei 2021). With this method, the research results can provide tangible contributions to spatial planning that is more adaptive, sustainable, and disaster-risk based in the City of Manado.

## Methods

### A. General description of the area

The general description of the research location is situated in Manado City, with an area of 157.26 km<sup>2</sup>. Administratively, the boundaries of Manado City are as follows: to the north, the Sulawesi Sea; to the east, North Minahasa Regency; to the south, Minahasa Regency; and to the west, Minahasa Regency and Manado Bay. The geographical coordinates of Manado City are located between 1° 29' N - 1° 40' N and 124° 47' E - 124° 58' E. The topographic characteristics of the area are predominantly hilly, with boundaries along the northern and western coastal areas (Manado 2024).



**Figure 1.** WOA map of settlement distribution on slope gradients

Source: Spatial Planning Document (RTRW) of Manado City 2023–2042 (Manado 2023)

### B. Research approach

The research adopts a quantitative descriptive approach to measure the spatial distribution of settlements (Zhang, Zhou, and Zhou 2025; Mackiewicz 2018; Sela et al. 2024). GIS-based research using ArcGIS software version 10.8 allows the integration of multiple spatial datasets

to analyze settlement patterns on slope gradients (Devara, Sutoyo, and Rau 2023).

The novelty of this research lies in the application of a more comprehensive combination of GIS methods, namely the Average Nearest Neighbor (ANN) and Weighted Overlay Analysis (WOA), to achieve a more in-depth analysis. Previous studies generally employed only one approach in analyzing slope settlements, such as NNA for spatial distribution patterns or WOA for assessing land suitability (Sari, Jumadi, and Anton 2024; Riadhi, Aidid, and Ahmar 2020; Basharat, Shah, and Hameed 2016).

The specific focus on Manado City as a study area is important, as previous GIS-based studies were limited to identifying settlements or conducting land suitability analyses only for certain locations (Syafri 2015; Utubulang, Kumurur, and Moniaga 2015; Manabung, Tilaar, and Gosal 2021). The uniqueness of Manado City lies in its topographic character, which is dominated by hills and highly susceptible to landslide risks, thereby requiring analysis using updated and location-specific data (Malik et al. 2023).

Earlier studies have rarely employed references to Manado City's spatial planning documents, focusing instead on evaluating land suitability primarily through physical factors, without directly linking them to prevailing spatial planning regulations (Paiman, Kindangen, and Prijadi 2024; Natan, Kumurur, and Gosal 2021). This study integrates modeling results with the Manado City RTRW 2023–2042, thereby serving directly as an evaluation of existing settlement suitability while also identifying areas inconsistent with the spatial planning framework.

Furthermore, GIS-based settlement zoning modeling has previously been limited to mapping existing settlement zones without providing recommendations or applying other methods such as Cellular Automata (Tarumingkeng, Kapantow, and Pakasi 2023). This modeling process integrates ArcScene 3D modeling to provide spatial visualization plans for settlement distribution on slope gradients as the final stage of this research.

#### C. Data collection method

The data collection method for settlement distribution on slope gradients consists of primary data collection through direct field observation. Secondary data were obtained from relevant

institutions, including land use maps, as summarized in table 1.

**Table 1.** Data sources and types

Data Source	Data Type	Use
Central Bureau of Statistics (BPS) of Manado City 2024	Population numbers and density data	Determining settlement growth trends
RTRW of Manado City 2023–2042	Spatial planning maps and zoning policies	Evaluating settlement suitability with spatial planning policies
Satellite Imagery	High-resolution imagery	Detecting land use

#### D. Data analysis method

The analysis method for modeling settlement areas on slope gradients using GIS applies the Average Nearest Neighbor (ANN), also known as the Nearest Neighbor Ratio (NNR), to calculate the average distance between each point in a dataset and its nearest neighbor.

$$NNR = \frac{\text{Observed Mean Distance}(d_o)}{\text{Expected Mean Distance}(d_e)}$$

The ANN or Nearest Neighbor Ratio (NNR) is interpreted as follows: if  $NNR < 1$ , the pattern is clustered, meaning residential or building points tend to concentrate in particular areas, indicating social or economic factors that drive clustering. If  $NNR = 1$ , the pattern is random, meaning the distribution of points shows no specific tendency, caused by natural factors or the absence of spatial regulations governing building distribution. Meanwhile, if  $NNR > 1$ , the pattern is dispersed (regular distribution), signifying that points are evenly spread, influenced by strict spatial regulations or geographical constraints limiting density (Riadhi, Aidid, and Ahmar 2020).

The subsequent stage employs Weighted Overlay Analysis (WOA), a multi-criteria analysis technique in GIS that integrates various data layers and assigns weights to each factor according to its importance level. The fundamental principle of WOA involves converting all data to a standardized scale, assigning weights to each factor that reflect its influence on the analysis, and then overlaying the data layers with their respective weights to generate a land suitability map. WOA in GIS

typically incorporates influential factors such as slope gradient, disaster risk, and spatial conformity, while converting datasets into raster format (Hassan et al. 2020). Data are then classified by assigning scale values, as illustrated in table 2 for slope gradients.

**Table 2.** Characteristics and scoring of slope gradients

Slope range (%)	Characteristics	Skoring
0–8%	Highly Suitable	5
8–15%	Suitable	4
15–25%	Less Suitable	3
25–40%	Unsuitable	2
>40%	Highly Unsuitable	1

Source: Technical criteria guidelines for cultivation areas: regulation of the Minister of Public Works No. 41/PRT/M/2007 (Ditjen Penataan Ruang 2007)

The weighting is determined by the relative importance of each factor: topography (40%), accessibility (30%), disaster risk (20%), and spatial conformity (10%). These layers are then overlaid with their respective weights (Ruang 2007). The classified data are subsequently integrated using the Weighted Overlay Tool in ArcGIS. The final stage involves visualization using ArcScene, a feature of ArcGIS 3D Analyst, which enables three-dimensional spatial data analysis. The research variables are summarized in table 3.

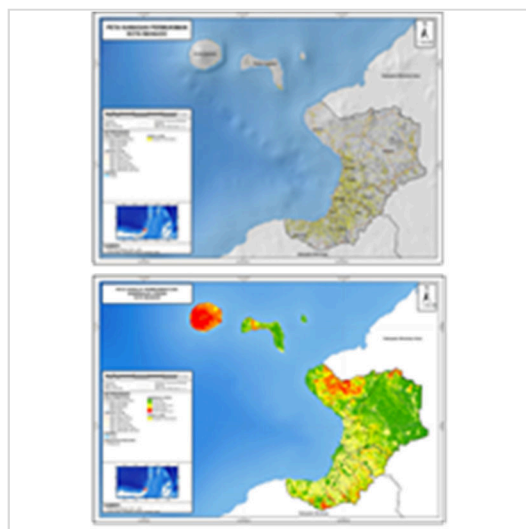
**Table 3.** Analysis method

Variable	Indicator	Method of analysis
<b>Independent variables</b>		
Slope Gradient	Percentage of slope gradients (25–40%, >40%)	Slope Analysis (ArcGIS)
Spatial Planning	Settlement zoning in the RTRW of Manado City 2023–2042	Overlay (GIS)
Disaster Risk	Landslide-prone areas	Weighted Overlay Analysis
<b>Dependent variables</b>		
Settlement Distribution	Settlement distribution patterns (clustered, random, dispersed)	Average Nearest Neighbor (ANN)
Land Suitability	Categories of land suitability or unsuitability	Weighted Overlay Analysis
3D Model	Visual representation of settlements on slopes	3D Modeling ArcScene

## Results and discussion

### A. Identification of settlement distribution on slopes

Manado City has rapidly developed as a coastal city with settlement centers concentrated in lowland areas and along the coast. The distribution of settlements across the eleven districts of Manado can be seen in Figure 1, where the yellow-shaded zone covers most of the coastal and lowland areas. Settlements are concentrated in the central part of Manado City, namely in the districts of Sario, Wenang, Tikala, Wanea, and Paal Dua, which are areas with dense road networks. In the eastern part of Manado City, namely Mapanget District, the distribution of settlements has begun to expand but remains less dense compared to the city center.



**Figure 2.** WOA map of settlement distribution on slope gradients

Source: RTRW Manado City 2023–2042

The identification of settlement distribution on slope gradients in Manado City using WOA was conducted to analyze the spatial relationship between settlement distribution and slope gradients by assigning weights to each slope category.

**Table 4.** Characteristics and suitability weights

Slope gradient	Characteristics	Suitability weight
0–8% (Light green)	Flat–gently sloping, suitable for settlements	5 (highly suitable)
8–15% (Light yellow)	Slightly sloping, can still be	4 (moderately suitable)

Slope gradient	Characteristics	Suitability weight
	developed with reinforcement	
15–25% (Yellow–orange)	Sloping, mitigation strategies required	3 (less suitable)
25–40% (Orange–pink)	Steep, landslide risk increases	2 (not suitable)
>40% (Dark red)	Very steep, best allocated for conservation	1 (highly unsuitable)

Source: Guidelines for spatial planning in disaster-prone areas (Ditjen Penataan Ruang 2007)

Table 4 explains that settlements located in slope gradients of 25–40% are assigned a weight of 2 (not suitable) because of the very high risk of landslides, while settlements in slope gradients of >40% are given a weight of 1 (highly unsuitable), which should be prioritized for conservation (Ditjen Penataan Ruang 2007).

The distribution of settlements in each district of Manado City on slopes of 25–40% and >40% is shown in Table 5. The total area of settlement distribution located on slope gradients is 163.782012 hectares, which is classified based on the percentages of 25–40% and >40% across all districts.

**Table 5.** Distribution of settlements on slope gradients in Manado City

Slope	District	Area (Ha)
>40%	Bunaken Kepulauan	1.414966
>40%	Malalayang	0.225066
25–40%	Bunaken	7.536134
25–40%	Bunaken Kepulauan	28.098164
25–40%	Malalayang	30.000937
25–40%	Mapanget	2.894856
25–40%	Paal Dua	20.2041
25–40%	Sario	0.519225
25–40%	Singkil	2.84362
25–40%	Tikala	24.215121
25–40%	Tuminting	3.766121
25–40%	Wanea	41.746826
25–40%	Wenang	0.316876
Total		163.782012

Source: GIS analysis, 2025

Wanea District on slope gradients of 25–40% has the largest land area of 41.75 hectares, followed by Malalayang District and Bunaken Kepulauan District. Bunaken Kepulauan District has the largest land area on slopes of >40% at 1.41 hectares, followed by Malalayang District at 0.23 hectares. The total land area on slopes >40% is relatively small compared to the 25–40% category.



**Figure 3.** Settlements on slope gradients in Wanea District, Manado City

Based on table 6, the distribution of settlements located on slope gradients of 25–40% and >40% are found in Wanea District with an area of 39.71491 hectares and in Malalayang District with an area of 27.274062 hectares, making these two districts the delineated research areas with a total area of 66.988972 hectares. Wanea District was identified with 1,180 housing units, while Karombasan Selatan Sub-district contained 332 housing units covering an area of 11.21 hectares. This condition indicates high building density, where most areas have a ratio of land area to the number of buildings that demonstrates concentrated development.

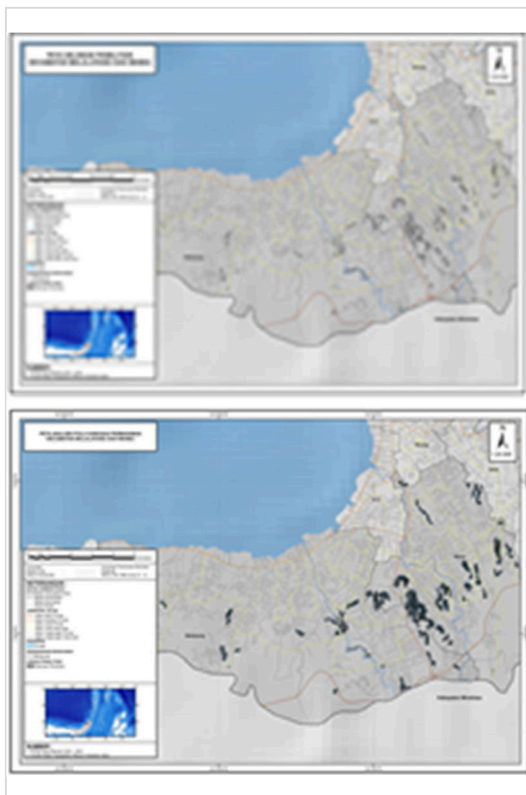
**Table 6.** Land area and number of buildings on slope gradients in Wanea and Malalayang districts

District / Sub-district	Area (ha)	Number of buildings
Wanea		
Bumi Nyiur	5.527126	127
Karombasan Selatan	11.207624	332
Karombasan Utara	6.563896	269
Pakowa	0.454625	3
Ranotana Weru	5.76686	170
Tanjung Batu	2.062702	47
Teling Atas	2.029716	54

District / Sub-district Wanea	Area (ha)	Number of buildings
Tingkulu	6.102361	178
Total Wanea	39.71491	1,180

Source: GIS Analysis 2025

Malalayang District has a total of 628 housing units, with the largest land area located in Winangun 1 Sub-district at 8.71 hectares and 136 buildings. Meanwhile, the sub-district with the highest number of buildings is Winangun 2 with 193 housing units covering 7.60 hectares. The map below illustrates the largest settlement areas in these two districts, namely Wanea and Malalayang.

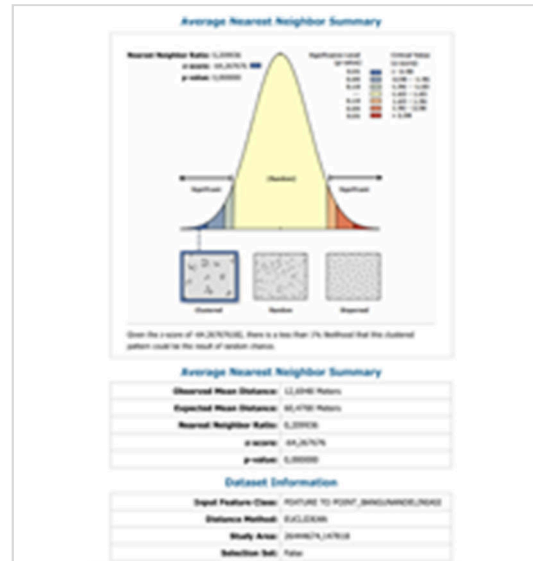


**Figure 4.** Delineation map and analysis of research area in Wanea and Malalayang districts  
 Source: GIS Analysis 2025

**B. Settlement distribution patterns**

Based on the previous analysis, the delineation of settlement research on slope gradients of 25–40% and >40% was focused on Wanea and Malalayang Districts. The GIS analysis of the Average Nearest Neighbor (ANN) results, as shown in figure 4, indicates that for the dataset FEATURE TO

POINT\_BANGUNANDELINIASI, the observed mean distance = 12.6948 meters. This means that the average distance between the observed settlement points is 12.69 meters.



**Figure 5.** Results of Average Nearest Neighbor (ANN)  
 Source: GIS analysis 2025

The expected mean distance = 60.4700 meters. If the point distribution were random, the average distance between points should be 60.47 meters. The Nearest Neighbor Ratio (NNR) = 0.209936, indicating that the distribution of residential buildings is highly clustered. The z-score = -64.267676 shows a very large negative value, indicating a very strong clustering pattern compared to a random distribution. Meanwhile, the p-value = 0.000000 indicates an extremely small probability (<0.01), meaning that this pattern does not occur randomly or by chance. The analysis suggests that the near-zero p-value indicates that the clustering pattern is not random but influenced by factors such as accessibility, spatial planning, or geographic conditions.

Architectural strategies for settlements forming clustered patterns should prioritize building arrangement. The spacing between buildings must allow for cross-ventilation, natural lighting, and evacuation access. Additionally, clear building setback regulations are required to avoid concentrated loading on a single slope point (Lestari 2022).

C. Land suitability of settlements according to spatial planning directions

The subsequent spatial analysis assessed settlement land suitability using Weighted Overlay Analysis (WOA) to evaluate disaster risk levels based on slope gradient, hazard potential,

and land use. The standard criteria for safe settlements include: avoidance of flood- or landslide-prone zones, access to roads for evacuation, construction on stable soil, and provision of adequate drainage systems (Ditjen Penataan Ruang 2007).



**Figure 6.** Slope gradient and Hazard-Prone areas in Manado City  
Source: GIS analysis 2025

Settlements on steep slopes (landslide-prone), located in the southern hilly areas of Wanea and Malalayang Districts, are situated on slopes of 25–40% and >40%, which are highly susceptible to landslides, particularly during the rainy season. However, not all areas have adequate slope reinforcement systems, indicating non-compliance with safe settlement standards.

**Table 7.** Disaster area extent in Wanea and Malalayang districts

District / Sub-district	Flood area (Ha)	Landslide area (Ha)
Wanea	0.127337	39.533673
Bumi Nyiur	0	5.527126
Karombasan Selatan	0.127337	10.581171
Karombasan Utara	0	6.563896
Pakowa	0	0.454625
Ranotana Weru	0	5.76686
Malalayang	0	27.057726
Batu Kota	0	5.023849
Malalayang 1	0	0.547094
Malalayang 1 Barat	0	3.259912
Malalayang 1 Timur	0	1.91138
Winangun 2	0	7.605292
Winangun 1	0	8.710199
Tanjung Batu	0	2.062702
Teling Atas	0	2.029716
Tingkulu	0	6.102361
<b>Grand Total</b>	<b>0.127337</b>	<b>66.146185</b>

Source: GIS analysis 2025

Table 7 demonstrates WOA raster processing in ArcGIS, overlaying multiple spatial layers to evaluate each district and sub-district against disaster criteria. Existing conditions in Wanea indicate a very high landslide-affected area of 39.533673 Ha. Flooding is also a minor threat at 0.127337 Ha.

In contrast, the disaster-affected area in Malalayang District is approximately 27 hectares. In several sub-districts with landslide-affected areas, Winangun 1 covers 8.710199 hectares, while no flood-affected areas exist in Malalayang. High landslide potential in these two districts is particularly identified in Karombasan Selatan at 10.58 hectares and Winangun 1 at 8.71 hectares. This indicates that settlements in these areas are located on steep slopes, requiring disaster mitigation-based planning.

Architectural strategies for residential buildings should incorporate stepped foundations that follow the terrain contours. Lightweight construction materials, such as precast panels and light steel, are recommended to reduce load on the slopes. Subsurface drainage systems (sub-drains) and rainwater harvesting are also necessary. Slope-retaining vegetation and micro-gardens can be added to reinforce the soil (Irehie, Imaah, and Youdeowei 2018).

WOA analysis was conducted to evaluate conformity with the Manado City Spatial Plan (RTRW 2023–2043), particularly the spatial

pattern plan. The analysis shows that most of Wanea District is allocated for urban settlements, office areas, and social facilities, whereas

Malalayang District features a combination of urban settlements and protected areas.



**Figure 7.** WOA map of spatial plan results in Wanea and Malalayang districts  
 Source: GIS analysis 2025

Figure 6 also illustrates high building density in Wanea, located on slopes of 25–40% and >40% in the central and southern areas. In contrast,

Malalayang has >40% slope areas in the southwestern region, bordering Minahasa Regency.

**Table 8.** WOA results of land-use conformity

Area	Roads	Social facilities	Trade and services	Settlements	Plantations
Delineation	0.2574	0.0643	8.3973	54.33882	3.4054
Wanea	0.1972	0.0643	0.7412	38.17582	0.4561
Tanjung Batu	0.0064	0	0.5288	1.52532	0.0021
Tingkulu	0.1908	0	0	5.8013	0.1102
Karombasan Selatan	0	0	0	10.832	0.329
Karombasan Utara	0	0.0643	0.2124	6.2411	0.0124
Bumi Nyiur	0	0	0	5.5248	0.0023
Pakowa	0	0	0	0.4546	0.0001
Ranotana Weru	0	0	0	5.767	0
Teling Atas	0	0	0	2.0297	0
Malalayang	0.0602	0	7.6561	16.163	2.9493
Batu Kota	0.0115	0	0	5.0618	0.0737
Malalayang 1	0.0330	0	0	0.5140	0
Malalayang 1 Barat	0.0008	0	0	3.2971	0.0552
Malalayang 1 Timur	0	0	0	1.8782	0.0332
Winangun 1	0.0149	0	4.0034	1.7212	2.7872
Winangun 2	0	0	3.6527	3.6907	0

Source: GIS analysis 2025

Comparison with the Manado City RTRW shows that settlements in zones with other functions in Wanea occupy 2.5888 hectares, which are not fully designated for residential use. In Malalayang, settlements occupy 16.163 hectares, with parts of these areas designated for trade/services (7.6561 hectares). Karombasan Selatan has 10.832 hectares of settlements in zones that do not entirely support residential functions.

Architectural strategies for settlement planning on slopes of 25–40% require site plan

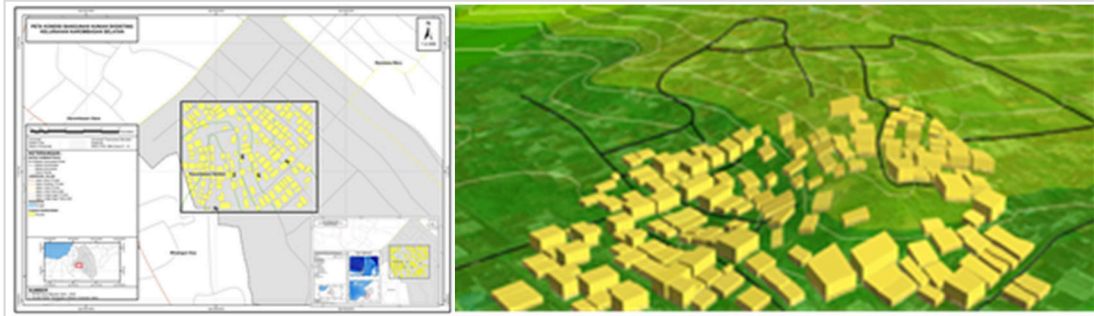
redesigns to avoid construction in unsafe or unauthorized zones, along with the optimization of internal micro-zoning within a single residential lot to provide residential zones, circulation, and open spaces (Domingo, Palka, and Hersperger 2021).

#### D. Modeling settlements on slope gradients

Settlement modeling on slope gradients was carried out using the ArcScene feature of ArcGIS. A 3D visualization sampled Karombasan Selatan in Wanea District because, based on previous

analysis, the settlements are clustered, cover the largest area (11.207624 hectares), and are landslide-prone. The highest number of houses on

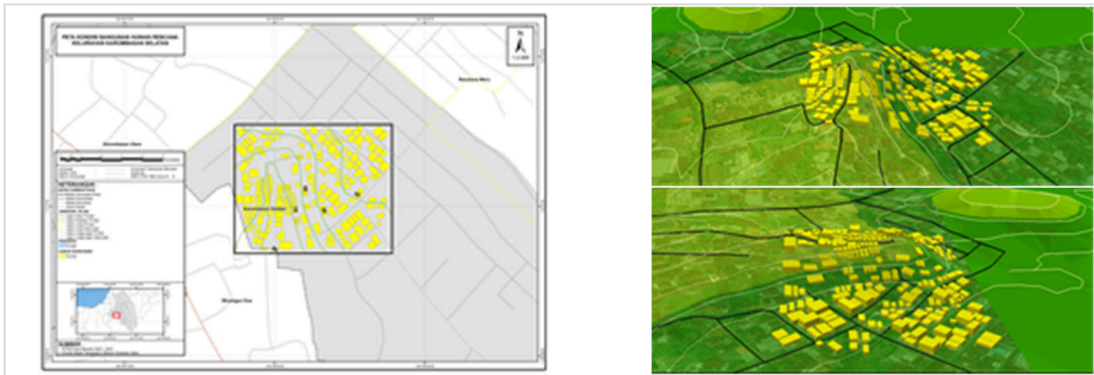
slopes of 25–40% and >40% is 332. The selected cluster in the northern settlement area has irregular existing building patterns.



**Figure 8.** Existing settlement distribution in Karombasan Selatan, Wanea District  
Source: GIS analysis with ArcScene 2025

Settlement distribution on steep slopes is primarily toward the southwest and southeast, with variable elevations. Existing conditions show settlements along roads at 40, 50, 60, 70, and 80 meters above sea level, situated in hilly

areas. High building density indicates a densely populated residential area. Therefore, a planned settlement model for the slope area in Karombasan Selatan was developed as follows:



**Figure 9.** Planned settlement modeling in Karombasan Selatan, Wanea District  
Source: GIS analysis with ArcScene 2025

Building orientation and adaptation to topography in the planned development follow contour lines. Attention to sun orientation and wind direction is essential for energy efficiency. Slope-adaptive design principles recommend a North–South orientation to maximize natural lighting while avoiding overheating. Cross-ventilation systems reduce the need for artificial cooling (Ardiyanto 2024).

Manado City, at coordinates 1°29′–1°40′ N and 124°47′–124°58′ E in the Southern Hemisphere, benefits from north-facing buildings. Roof overhangs or vegetation can mitigate excessive heat during summer (Sharma and Dongre 2024).

Architecturally, zones with slopes of 25–40% can be developed in a limited manner using tiered building layouts, lightweight structures, and gravity-based drainage systems.



**Figure 10.** Example of residential building design on slope gradients

Areas with slopes >40% are not recommended for residential development due to high landslide risk. Architectural recommendations include restricting construction to specific functions, such as green spaces or disaster mitigation infrastructure (retaining walls, slope-reinforcing vegetation). Zones above 45% are unsuitable for settlements and are more appropriate for conservation purposes (Widiantara, Nursanty, and Cauba 2024; Notodipuro and Mandala 2022).

## Conclusions

The identification of settlement distribution on slope gradients was focused on Wanea and Malalayang Districts, considering area, building count, and slope gradient. Based on the total analyzed settlement area, approximately 42.5% is located on slopes of 15–25%, 32% on slopes of 25–40%, and 25.5% on slopes greater than 40%.

The ANN/NNR analysis indicated that residential building distribution follows a clustered pattern. Architectural strategies for building layout should consider spacing, building orientation, and cross-ventilation. Meanwhile, the WOA analysis of disaster risk shows that Wanea District has very high landslide-affected areas, covering 39.533673 hectares, compared to approximately 27 hectares in Malalayang. This necessitates disaster mitigation-based planning. Architecturally, residential buildings should be designed with stepped foundations following the terrain contours. Lightweight construction materials, such as precast panels and light steel, are recommended to reduce load on the slopes. Subsurface drainage systems (sub-drains) and rainwater harvesting must be carefully planned. Slope-retaining vegetation and micro-gardens can be incorporated to reinforce the soil.

Based on the RTRW spatial pattern analysis, most settlements on slopes of 25–45% and >45% show deviations, with portions located in roadways, social and public facilities, and plantation areas. Architectural strategies include redesigning the site plan to avoid construction in unsafe or unauthorized zones. Internal micro-zoning within a single residential lot should be implemented to differentiate residential areas, circulation, and open spaces.

ArcScene modeling shows that in Karombasan Selatan, Wanea District, the planned house distribution follows slope contours and

adjusts building orientation. Expansion into slopes >40% increases disaster risk and requires architectural mitigation. Residential buildings on steep slopes should use stilt structures, while areas with slopes >40% should only be developed using specialized techniques or repurposed for conservation functions.

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**Rieneke Lusya Evani Sela** contributed to the research concepts preparation, methodologies, investigations, data analysis, visualizations, articles drafting and revisions.

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