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GIS-Based Multi-Criteria Decision Analysis (MCDA-AHP) for Flood and Landslide Susceptibility Mapping and Urban Sprawl Assessment in the Mati City, Davao Oriental, Philippines

Ramil L. Ramos[1,2*], **Jonathan S. Cabrera**[1,3,4]

[1] *Master of Science in Environmental Science Program, Faculty of Advanced and International Studies, Davao Oriental State University, Mati City, Davao Oriental, 8200 Philippines, ORCID No. Ramil L. Ramos: https://orcid.org/0009-0009-1623-6273, Jonathan S. Cabrera: https://orcid.org/0000-0001-7575-4251*
[2] *Department of Environment and Natural Resources Office (DENR), Mati City, Davao Oriental, 8200 Philippines, ORCID No. Ramil L. Ramos: https://orcid.org/0009-0009-1623-6273,*
[3] *Bachelor of Science in Information Technology Program, Faculty of Computing, Engineering, and Technology, Davao Oriental State University, Mati City, Davao Oriental, 8200 Philippines, ORCID No. Jonathan S. Cabrera: https://orcid.org/0000-0001-7575-4251*
[4] *Computational Analytics for a Resilient Earth and Advanced Complex Computing for Environmental and Life Systems (CARE-ACCESS) Laboratory, Davao Oriental State University, ORCID No. Jonathan S. Cabrera: https://orcid.org/0000-0001-7575-4251*

*Corresponding author: *ramilramos500@gmail.com*

ABSTRACT

Flooding and landslides pose persistent and compounding risks in the City of Mati, Davao Oriental, Philippines, where rapid urban expansion increasingly intersects with hazard-prone landscapes. This study applied a Geographic Information System (GIS)-based Multi-Criteria Decision Analysis integrated with the Analytical Hierarchy Process (MCDA-AHP) to generate spatially explicit flood and landslide susceptibility maps and examine their interaction with urban sprawl from 2017 to 2024. Flood susceptibility was modelled using slope, elevation, rainfall, land use/land cover, and topographic wetness index, while landslide susceptibility incorporated slope, rainfall, soil type, erodibility, clay content, and land cover. Weighted overlay analysis produced composite hazard maps that were subsequently integrated with urban growth data. Results indicate that approximately 2,458.66 ha are highly susceptible to flooding, primarily in low-lying coastal barangays, while 10,267.15 ha are highly prone to landslides in steep upland areas. Urban expansion increased from 1,864.21 ha in 2017 to 3,181.88 ha in 2024, with significant encroachment into high-risk zones. This spatial convergence of hazards and development intensifies exposure, particularly in densely populated and rapidly developing communities. The study demonstrates the effectiveness of GIS-based MCDA-AHP as a decision-support tool for multi-hazardassessment and highlights the urgent need for risk-informed land-use planning. Integrating hazard-susceptibility maps into local policies, zoning regulations, and infrastructure planning is critical to minimizing disaster impacts and guiding sustainable urban development. These findings provide a robust scientific basis for enhancing resilience and adaptive capacity in hazard-prone coastal and upland environments.

Keywords: *Flood susceptibility, GIS-based MCDA-AHP, landslide susceptibility, urban sprawl, weighted overlay analysis*

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INTRODUCTION

The Philippines has been recognized as one of the most disaster-prone countries in the world due to its geographic location and physical environment, particularly along its eastern seaboard facing the Pacific Ocean, where intense tropical cyclones frequently originate (FLUP Mati City). These climatic conditions, combined with the country's location within the Pacific Ring of Fire, exposed many regions to multiple and interacting hazards, including flooding and landslides. The impacts of these hazards have often been severe and cascading, as demonstrated during the 2017 tropical cyclones "Urduja" (Kai-tak) and "Vinta" (Tembin), which triggered widespread flooding and landslides across Eastern Visayas and Northern Mindanao, resulting in over 200 fatalities and large-scale displacement (Lagmay and Racoma, 2019).

In the Mati City, Davao Oriental, flooding has been a recurrent and persistent hazard, particularly in low-lying and coastal barangays, where surface water accumulation is intensified by terrain and hydrological conditions (Cabrera and Lee, 2020). At the same time, landslide susceptibility had been significant in upland and mountainous areas, where slopes exceeding 18% dominated the landscape (Kinde et al., 2024). These geomorphological characteristics, combined with intense rainfall, created conditions conducive to slope instability, particularly in areas affected by land disturbances such as road exwpansion and vegetation removal. Landslide occurrence was governed by a complex interplay of factors, including unstable areas increased the potential for damage and loss (Danumah et al., 2016). This pattern reflected broader trends of urban sprawl, characterized by unplanned, dispersed, low-density expansion into previously non-urban areas (Mohd Noor et al., 2018). Urban sprawl had become a global phenomenon driven by population growth, economic development, and increased reliance on private transportation (Burchell et al., 2002; Masancay and Jimenez, 2024; Chen et al., 2025). Such expansion altered natural landscapes by reducing vegetation cover, increasing surface impermeability, and disrupting hydrological processes, thereby intensifying both flood and landslide susceptibility (Wang et al., 2020; Yang et al., 2022). Previous studies had quantified urban sprawl using indicators such as expansion rate, accessibility, compactness, and land-use mix (Chen et al., 2021; Sarzynski et al., 2014; Yu et al., 2023); however, the integration of urban growth dynamics with hazard susceptibility mapping remained limited, particularly at the city scale (Masancay et al., 2025).

Given these challenges, there was a critical need for spatially explicit, integrative approaches that could simultaneously assess multiple hazard factors and their interactions with urban expansion. Geographic Information Systems (GIS), coupled with Multi-Criteria Decision Analysis (MCDA) and the Analytical Hierarchy Process (AHP), provided a robust framework for evaluating complex environmental systems and generating hazard susceptibility maps. These methods enabled the systematic integration of diverse datasets, including terrain, hydrological, and land-cover variables, into a unified analytical framework, thereby allowing the identification and prioritization of high-risk areas.

In this context, the present study applied a GIS-based MCDA-AHP approach to assess flood and landslide susceptibility and analyze urban sprawl patterns in the Mati City, Davao Oriental. Specifically, it aimed to: (1) map flood susceptibility in low-lying and coastal barangays using parameters such as slope, elevation, rainfall intensity, land use/land cover, and topographic wetness index; (2) identify landslide-prone areas based on slope, rainfall, soil properties, and land cover; and (3) evaluate the spatial extent of urban expansion and its overlap with identified hazard-prone zones. The results revealed that approximately 2,458.65 ha were highly susceptible to flooding, while about 10,267.15 ha were highly prone to landslides, with expanding settlements increasingly encroaching into these high-risk areas.

The findings contributed to the growing body of GIS-based hazard assessment research and provided practical, evidence-based guidance for local government units, planners, and policymakers. Integrating these spatial insights into land-use planning, zoning regulations, and infrastructure development was essential to reducing disaster risk, optimizing resource allocation, and enhancing long-term community resilience in hazard-prone environments.

MATERIALS AND METHODS

Description of the study area

The study was conducted in the Mati City, located in the southeastern part of Mindanao, Philippines (6°57'07.4" N, 126°12'50.0" E). The Pacific Ocean bounds the city to the east and by mountainous terrains, including the Municipality of Governor Generoso, to the west. Mati City has a total land area of approximately 79,316 ha and is administratively divided into 26 barangays, of which 16 are coastal and 10 are inland. Forestlands cover about 30,912 ha of the total area (DENR-CENRO Mati data). The geographic and topographic characteristics of the area make it highly susceptible to flooding and landslides (Figure 1).

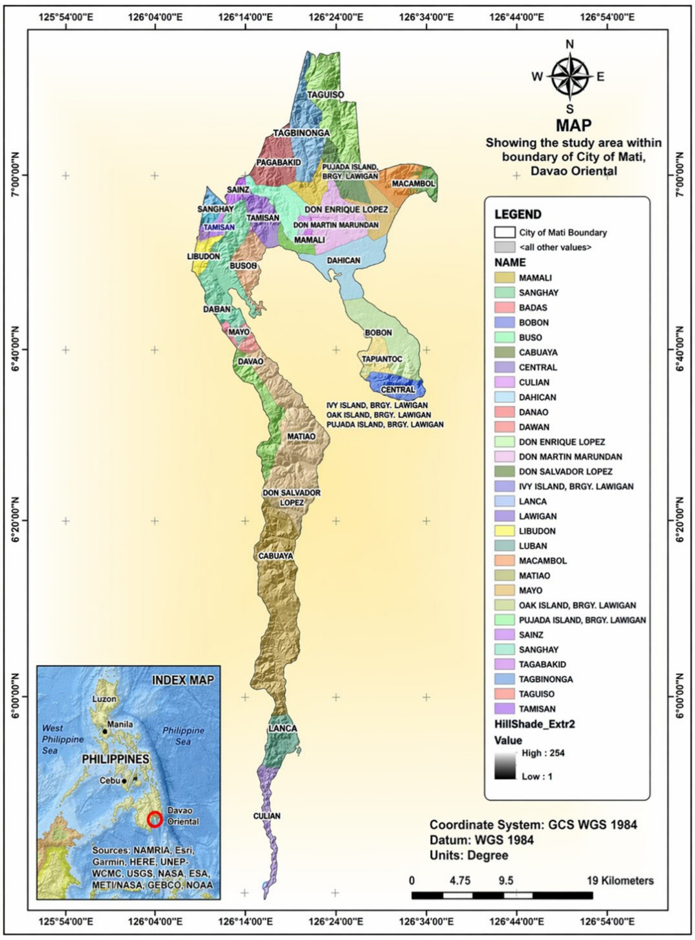


Figure 1. Barangay boundary map of the Mati City, Davao Oriental, illustrating the full spatial extent of the study area.

Data sources and processing

Spatial datasets were obtained from various sources, including Interferometric Synthetic Aperture Radar (IFSAR) data from the National Mapping and Resource Information Authority (NAMRIA), rainfall data from WorldClim, and soil and land cover data from DENR and other geospatial databases. The IFSAR-derived Digital Elevation Model (DEM) with 10 × 10 m resolution was used to generate key terrain parameters, including slope, elevation, and the topographic wetness index (TWI), which are critical factors influencing both flood and landslide susceptibility.

These derived layers provided spatially detailed, high-resolution topographic information, enabling accurate classification of areas by their susceptibility to hazards. By converting the DEM-derived layers to standardized raster scales, they could be directly incorporated into the MCDA-weighted overlay analysis, ensuring that terrain characteristics were quantitatively integrated with other environmental factors, such as rainfall, soil properties, and land cover.

Slope, derived from the IFSAR DEM, was calculated to assess terrain inclination and its influence on flood susceptibility. Using ArcGIS, slope values were computed and reclassified into categories reflecting relative flood risk. Steeper slopes facilitate runoff and reduce flood potential, whereas flatter areas tend to accumulate water, making them more flood-prone (Kinde et al., 2024).

An inverse relationship approach was applied during reclassification: lower slope values were assigned higher flood susceptibility, while higher slope values corresponded to lower flood susceptibility. The slope ranges and their corresponding flood susceptibility classifications are summarized in Table 1. Specifically, slopes ranging from 0–4.7° were considered to indicate very high susceptibility, whereas slopes of 44.34–66.24° were considered to indicate very low susceptibility. Spatially, areas within Barangays Dawan, Central, Bobon, Don Salvador, Matiao, Mayo, Macambol, Mamali, Don Enrique, and Cabuaya were identified as potentially flood-prone.

Table 1. Slope classification and corresponding flood susceptibility.

Slope range (°)	Flood susceptibility	Color code	Reference
0 – 4.7	Very High	Yellow	Kinde et al. (2024)
4.71 – 14	High	Orange	Kinde et al. (2024)
14.01 – 24	Moderate	Light Green	Kinde et al. (2024)
24.01 – 44.33	Low	Dark Green	Kinde et al. (2024)
44.34 – 66.24	Very Low	Light Blue	Kinde et al. (2024)

All datasets were processed and analyzed using ArcGIS. Raster layers were standardized, reclassified, and converted into a common scale to allow systematic integration within the MCDA framework. The spatial datasets used in this study are summarized in Table 2, including their sources, temporal coverage, and data formats.

Table 2. Summary of spatial and environmental datasets used for flood and landslide susceptibility mapping in the Mati City, Davao Oriental.

Data type	Location	Description	Year	Source	Data format
Digital Elevation Model (DEM)	Mati City	Interferometric Synthetic Aperture Radar (IFSAR), 10 × 10 m resolution	2015	National Mapping and Resource Information Authority (NAMRIA)	GeoTIFF
Rainfall	Mati City/ Global	Historical daily rainfall and annual average data	2024	WorldClim	GeoTIFF
Administrative map	Mati City	Barangay and municipal boundaries	2015	NAMRIA	Shapefiles
Soil Type	Mati City	Soil classification within city boundary	2020	NAMRIA	Shapefiles
Soil Erodibility	Mati City	Soil erodibility within city boundary	2020	DENR Region XI survey mapping Division	Shapefiles
Soil Clay Content	Mati City	Percentage clay content derived from global soil gridded data	2020	ISRIC – World Soil Information	GeoTIFF
Building Footprint	Mati City	Latest building footprints extracted from Sentinel-2 / Landsat 8 imagery	2025	Sentinel-2 / Landsat 8	GeoTIFF
Vegetative Cover	Mati City	NDVI images and reclassified land cover	2020–2024	Sentinel-2 / Landsat 8, NAMRIA	GeoTIFF / Shapefiles

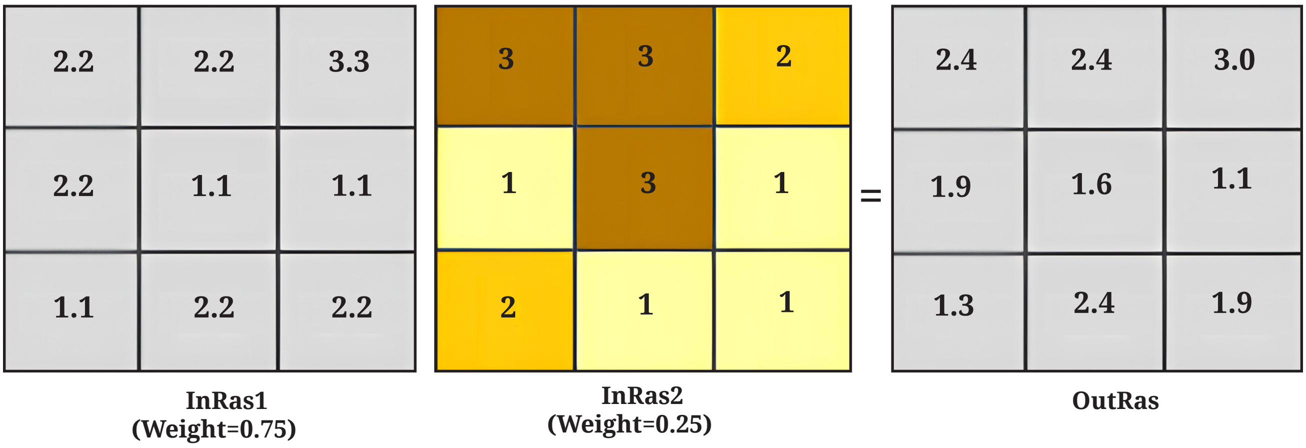
Criteria selection and weighted overlay analysis

This study employed a quantitative spatial analysis approach integrating Geographic Information Systems (GIS) with Multi-Criteria Decision Analysis (MCDA) and the Analytical Hierarchy Process (AHP) to analyze spatial datasets on flood and landslide susceptibility and urban sprawl patterns. This approach enabled the systematic evaluation of multiple environmental and terrain-related factors influencing hazard occurrence. The AHP method was used to assign weights to each criterion based on their relative importance through pairwise comparison, ensuring consistency and reliability of the weighting process. The criteria were structured according to key components such as exposure, susceptibility, and environmental conditions (Lee et al., 2013; Mourato et al., 2023). Weighted-sum analysis was then applied to generate hazard susceptibility maps.

The analysis incorporated several thematic layers known to influence flood and landslide occurrence. For landslide susceptibility mapping, six parameters were used: slope, rainfall, soil type, soil erodibility, clay content, and land use/land cover (LULC). These parameters were selected based on their documented relevance in previous GIS-based hazard studies (Kazakis et al., 2015; Sarkar and Kanungo, 2004; Pourghasemi et al., 2012).

To assign relative importance, the Analytic Hierarchy Process (AHP) was applied, which involves pairwise comparison of criteria and calculation of consistency ratios to ensure reliability. In this study, all six landslide parameters were initially assigned equal weights of 16.67%, reflecting the assumption of equal contribution in the absence of strong evidence favoring any particular parameter. This approach aligns with prior studies that adopt equal weighting as a baseline before sensitivity or validation analyses (Kazakis et al., 2015; Mourato et al., 2023).

For flood susceptibility mapping, five parameters were considered: slope, elevation, rainfall intensity, land use/land cover, and topographic wetness index (TWI). The Topographic Wetness Index (TWI) was derived from the DEM using the Open Courseware GIS (OCWGIS) method, enabling the identification of areas prone to surface water accumulation. The resulting raster layer was standardized and incorporated into the MCDA-weighted overlay analysis for flood-susceptibility mapping. Each was assigned a weight of 20%, following the same principle of initial equal contribution. The parameters were reclassified into suitability classes, and the weights were applied using the GIS weighted overlay tool. Each criterion was multiplied by its assigned weight and summed to generate composite hazard maps. These outputs were subsequently overlaid with urban sprawl data to identify hazard-prone communities and areas at risk (Figure 2).



2.2	2.2	3.3
2.2	1.1	1.1
1.1	2.2	2.2

3	3	2
1	3	1
2	1	1

=

2.4	2.4	3.0
1.9	1.6	1.1
1.3	2.4	1.9

Figure 2. Mathematical framework and equations illustrating the weighted-sum analysis used in the GIS-based multi-criteria decision analysis (MCDA).

Integration with urban sprawl analysis

The resulting flood and landslide susceptibility maps were overlaid with urban sprawl data derived from satellite imagery to assess the spatial interaction between expanding built-up areas and hazard-prone zones. This integration enabled the identification of vulnerable communities and provided a basis for risk-informed land-use planning. The overall methodological framework is illustrated in Figure 3, which highlights the integration of GIS, MCDA, and AHP to generate hazard and urban expansion maps. The overall methodological framework, integrating GIS, MCDA, and AHP for flood and landslide susceptibility mapping and urban sprawl analysis, is illustrated in the conceptual framework (Figure 3).

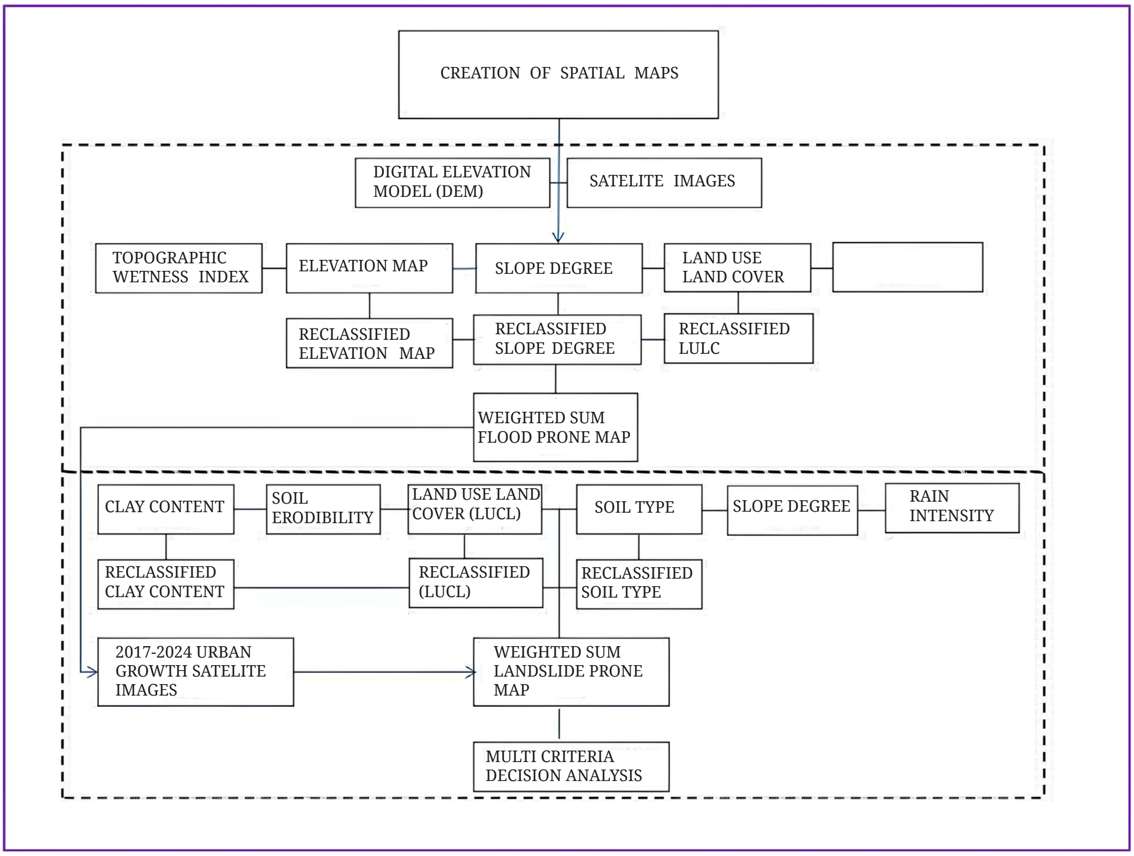


Figure 3. Conceptual framework illustrating the integration of GIS, MCDA, and AHP for flood and landslide susceptibility mapping and urban sprawl analysis in the Mati City, Davao Oriental.

RESULTS

Flood risk susceptibility mapping

The flood risk susceptibility of the Mati City was assessed using a weighted-sum spatial analysis integrating five equally weighted criteria (20% each), as determined by the Analytic Hierarchy Process (AHP), following the approach of Jayaswal et al. (2023). The Topographic Wetness Index (TWI) map (Figure 4A) derived from the Digital Elevation Model (DEM) using the OCWGIS method identifies spatial variations in water accumulation potential. Areas classified as very susceptible (light blue) are concentrated in portions of Barangays Bobon, Dahican, Don Enrique, and Sanghay (Figure 4B), highlighting locations where surface runoff is most likely to accumulate. Meanwhile, elevation mapping further identifies low-lying areas (−1 to 3 meters), particularly in Sitio Guang-Guang (Barangay Dahican), Bobon, and portions of Barangay Mayo, as highly susceptible to flooding and potential saltwater intrusion (Figure 4C).

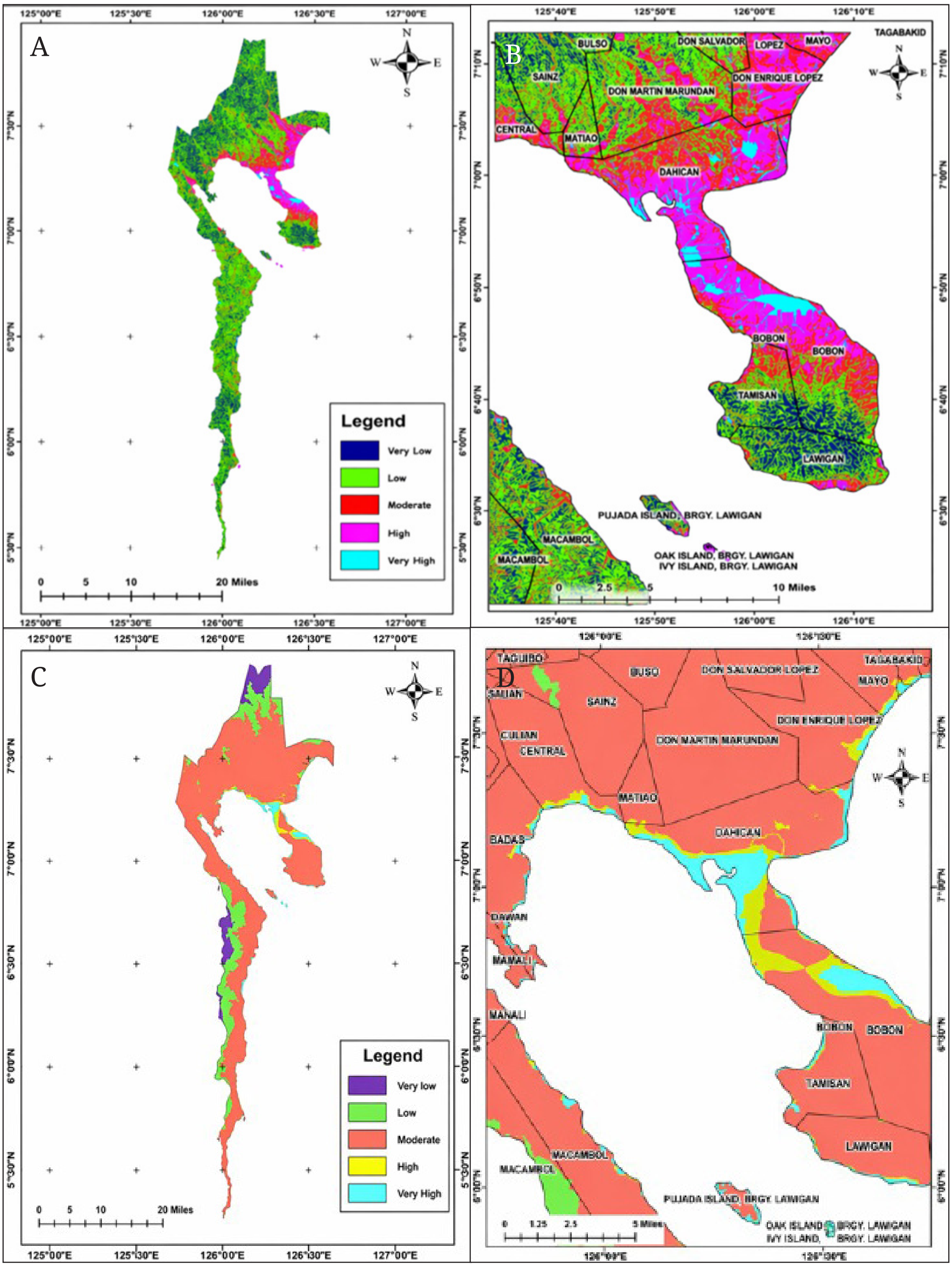


Figure 4. Flood susceptibility and elevation maps of the Mati City using GIS-based MCDA-AHP. (A) Topographic Wetness Index (TWI) map showing water accumulation potential. (B) Flood susceptibility map from weighted-sum analysis (20% per criterion). (C) Elevation map of the Mati City. Low-lying areas (−1 to 3 m), particularly in Sitio Guang-Guang, Dahican, Bobon, and portions of Barangay Mayo.

Rainfall intensity, reclassified into five categories based on WorldClim data, shows that areas receiving the highest precipitation (red zones) are most vulnerable, with Barangay Taguibo identified as particularly at risk (Figure 5A). Slope degree analysis using Interferometric Synthetic Aperture Radar (IFSAR) DEM data from NAMRIA (Figure 5B) reveals that gentle slopes (0–4.7°) correspond to areas of high flood susceptibility (yellow), whereas steeper slopes (44–66°) are less prone to flooding (light green), demonstrating the inverse relationship between slope steepness and flood risk (Kinde et al., 2024). Land Use and Land Cover (LULC) analysis, based on ESRI Sentinel-2 imagery and expert guidance from the DENR Regional Office, further indicates that sparsely vegetated areas exhibit high flood susceptibility. At the same time, closed canopy regions are relatively protected (Figure 5C). Areas with cloud cover in imagery were excluded from analysis. The weighted-sum analysis integrating TWI, slope, elevation, LULC, and rainfall intensity produced the overall flood susceptibility map (Figure 5D), categorizing areas into five risk levels from very low (dark green) to very high (red).

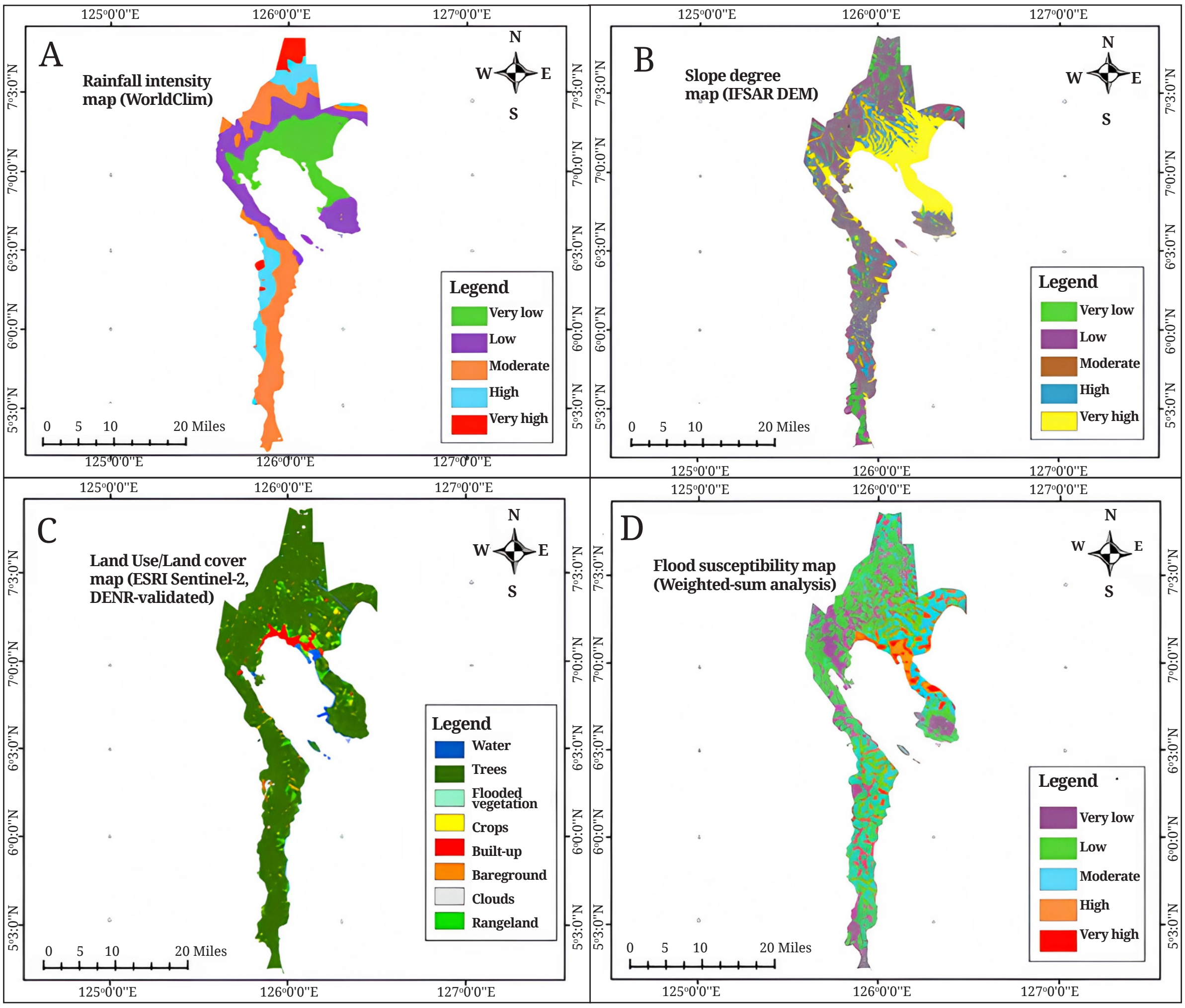


Figure 5. (A) Rainfall intensity map of the Mati City derived from WorldClim data and reclassified into five categories, highlighting areas of high precipitation (red), with Barangay Taguibo identified as particularly vulnerable. (B) Slope map generated from IFSAR-derived Digital Elevation Model (DEM) data from NAMRIA. (C) Land use/land cover (LULC) map derived from Sentinel-2 imagery and validated by DENR, indicating higher flood susceptibility in sparsely vegetated areas and lower susceptibility in dense vegetation; cloud-covered areas were excluded. (D) Flood susceptibility map produced through weighted-sum analysis integrating topographic wetness index (TWI), slope, elevation, LULC, and rainfall, classified into five levels ranging from very low (dark green) to very high (red).

Table 3 summarizes the area coverage for each class, with the very high-risk category covering 2,458.66 ha, primarily affecting portions of Barangays Bobon, Macambol, Central, Matiao, Dahican, Cabuaya, Don Enrique, Badas, and Don Salvador. Overlaying NAMRIA settlement shapefiles on this map identifies the number of settlements at risk within each barangay, summarized in Table 4.

Table 3. Area coverage (ha) of flood susceptibility classes, highlighting the extent of very high-risk zones across selected barangays in Mati City.

Grid code	Color code	Area (ha)
1	Dark green (Very Low)	19, 279.46
2	Light green (Low)	22, 091.47
3	Yellow (Moderate)	13, 821.17
4	Orange (High)	5, 072.58
5	Red (Very high)	2, 458.66

Table 4. Number of settlements at risk per barangay based on overlay of NAMRIA settlement shapefiles with the flood susceptibility map.

Barangay	Susceptible areas (ha)	Settlements affected
Badas	52.84	307
Bobon	368.66	356
Cabuaya	230.79	22
Central	88.93	1,114
Don Martin Marundan	118.23	252
Dahican	563.92	2,890
Dawan	8.45	0
Don Enrique	95.73	79
Lawigan	29.01	155
Libudon	9.51	133
Luban	89.26	40
Macambol	286.54	283
Mamali	7.19	53
Matiao	22.68	175
Mayo	25.65	119
Sainz	38.52	142
Tagabakid	21.27	59

Landslide risk susceptibility mapping

Landslide susceptibility was evaluated using six conditioning factors: slope degree, clay content, rainfall intensity, soil type/permeability, soil erodibility, and LULC. Slope analysis (Figure 6A) indicates that very steep slopes (>36°) are associated with higher landslide risk, affecting portions of Barangays Lawigan, Taguibo, Dawan, Macambol, Lanca, Luban, Cabuaya, and Tagabakid (Kinde et al., 2024). Areas with higher clay content, notably in Taguibo, Dawan, and Bobon, are associated with reduced susceptibility due to cohesive soil properties (Figure 6B) (Soilgrids 250m). Rainfall intensity, as shown in Figure 6C, exacerbates landslide potential by increasing pore-water pressure and promoting slope instability during heavy precipitation events (Kinde et al., 2024). Soil type and permeability significantly influence slope stability, with highly permeable soils such as Camansa sandy clay loam, Bolinao clay, Matina clay loam, and Malalag loam exhibiting higher landslide susceptibility (Figure 6D). Soil erodibility, derived from MGB data (Figure 6E), identifies areas prone to the detachment and transport of soil particles, with higher erodibility soils more susceptible to slope failure. LULC analysis (Figure 6F) demonstrates that sparsely vegetated areas are more vulnerable to landslides due to reduced surface protection and increased runoff, consistent with expert geologist assessments.

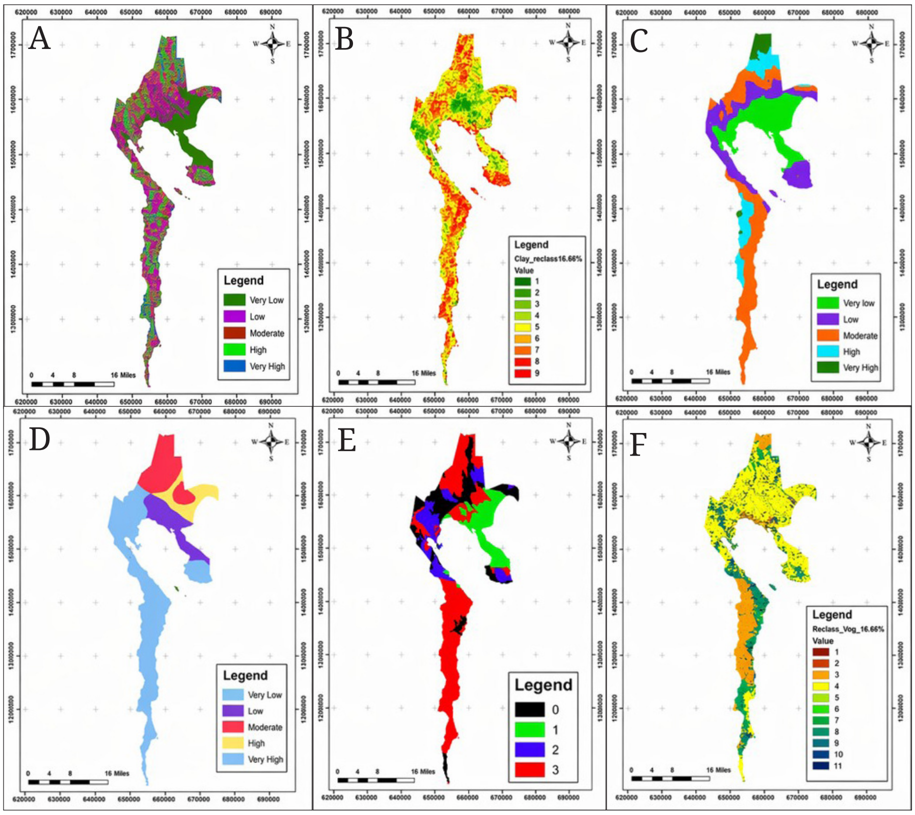
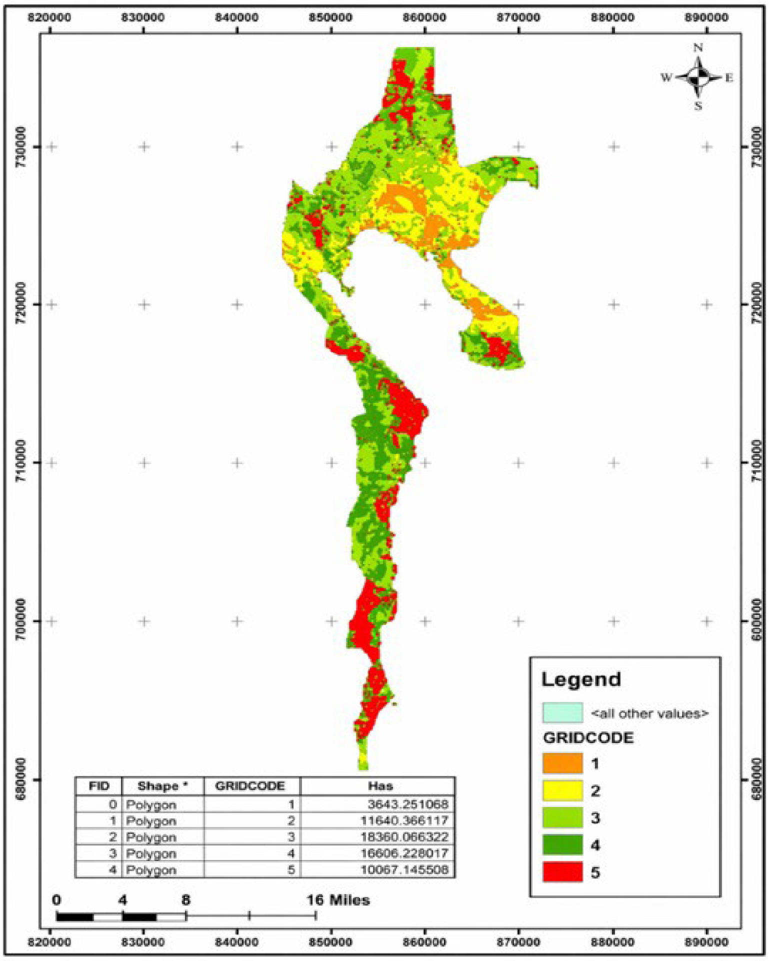


Figure 6. Multi-factor spatial analysis of landslide susceptibility across selected barangays based on key geophysical and environmental controls. (A) Slope gradient map showing that very steep terrain (>36°) is strongly associated with increased landslide susceptibility (Kinde et al., 2024). (B) Clay content distribution (SoilGrids250m), indicating generally reduced susceptibility in high-clay areas due to enhanced soil cohesion. (C) Rainfall intensity map highlighting increased susceptibility driven by elevated pore-water pressure and slope instability during heavy precipitation events (Kinde et al., 2024). (D) Soil type and permeability map showing higher susceptibility in highly permeable soils that facilitate rapid infiltration and slope weakening. (E) Soil erodibility (MGB dataset): identifying areas prone to slope failure due to increased soil particle detachment and transport. (F) Land use/land cover (LULC) map indicating elevated susceptibility in sparsely vegetated areas due to reduced root reinforcement, lower surface protection, and increased surface runoff.

Integrating these six factors through Multi-Criteria Decision Analysis (MCDA) with weighted overlay in ArcGIS generated the landslide susceptibility map (Figure 7). Areas classified as very high susceptibility (red) cover approximately 10,267.15 ha, where unfavorable terrain, soil properties, and high rainfall coincide, affecting barangays including Macambol, Luban, Cabuaya, Lanca, Lawigan, Sanghay, Taguibo, Tagbinonga, and Tagabakid. Conversely, areas of very low susceptibility (orange) cover 3,943.25 ha, reflecting gentler slopes, stable soil properties, lower rainfall, and protective vegetation cover. Table 5 summarizes area coverage per susceptibility class, while Table 6 identifies settlements at risk in each barangay.



FID	Shape *	GRIDCODE	Has
0	Polygon	1	3643.251068
1	Polygon	2	11640.366117
2	Polygon	3	18360.066322
3	Polygon	4	16606.228017
4	Polygon	5	10067.145508

Figure 7. Landslide susceptibility map generated via MCDA weighted-overlay in ArcGIS, showing areas from very low (orange) to very high (red) susceptibility across selected barangays.

Table 5. Area coverage (ha) of landslide susceptibility classes based on MCDA weighted-overlay analysis.

Grid code	Color code	Area (ha)
1	Orange (Very low)	3,940.25
2	Yellow (Low)	11,45831
3	Light green (Moderate)	18,360.67
4	Dark green (High)	16,606.23
5	Red (Very high)	10,267.15

Table 6. Number of settlements at risk per barangay according to landslide susceptibility map.

Barangay	Susceptible areas (ha)	Settlements affected
Badas	73.17	37
Bobon	195.07	6
Cabuaya	2,619.59	6
Central	52.14	4
Culian	554.93	20
Don Salvador	29.13	1
Lanca	246.10	1
Lawigan	355.70	8
Macambol	2,708.47	47
Mayo	49.97	13
Sanghay	167.59	6
Tagabakid	101.52	8
Tagbinonga	1,916.72	89
Taguibo	97.49	6

Urban sprawl mapping

Urban expansion in the Mati City has been continuous, increasing from 1,864.21 ha in 2017 to 3,181.88 ha in 2024 (Figure 8). The expansion from 2017 to 2020 accounted for a 28.96% increase, while growth from 2020 to 2024 added 17.53% to the urban area. This growth includes settlements, infrastructure, roads, bridges, commercial areas, and the conversion of forestlands to agricultural use, often overlapping with flood- and landslide-prone zones. Table 6 summarizes the average annual rate of urban sprawl.

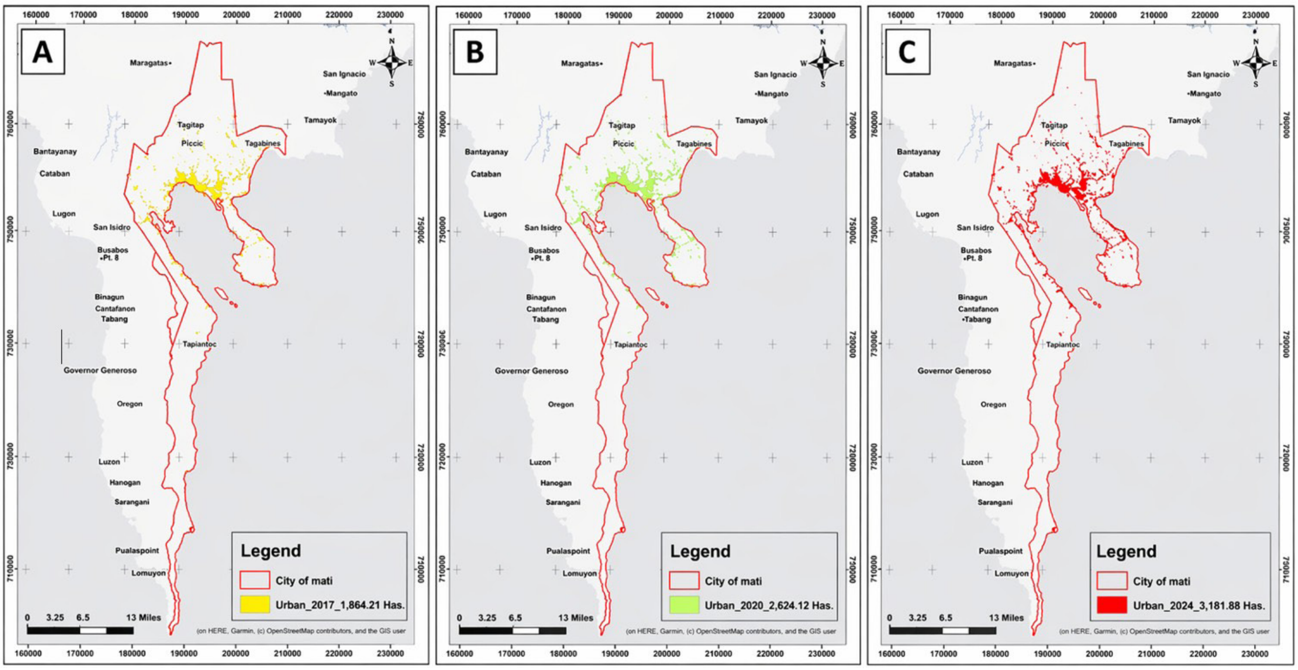


Figure 8. Urban sprawl map showing the expansion of urban areas over time: (A) 2017, (B) 2020, and (C) 2024.

Table 7. The average expansion of urban sprawl.

Year	Urban sprawl area (ha)	Average growth of area
2017	1,864.21	0
2020	2,624.13	28.96%
2024	3,181.88	17.53%

Total area sprawl-baseline Total area=/Total area sprawl X 100=Average growth percentage of area

DISCUSSION

Integration of GIS-Based MCDA-AHP for Multi-Hazard Assessment

This study successfully applied a GIS-based Multi-Criteria Decision Analysis (MCDA) integrated with the Analytical Hierarchy Process (AHP) to achieve its primary objectives: mapping flood and landslide susceptibility and examining their interactions with urban sprawl in the Mati City. The use of weighted overlay analysis, supported by standardized spatial datasets such as IFSAR DEMs, WorldClim rainfall, SoilGrids, and Sentinel-derived land use/land cover (LULC), enabled a systematic, spatially explicit evaluation of hazard susceptibility. The adoption of equal weighting (20% for flood parameters and 16.67% for landslide parameters) provided a balanced baseline consistent with similar studies (Kazakis et al., 2015; Mourato et al., 2023), particularly in contexts where localized calibration data are limited. This approach ensured that all key environmental drivers, topography, hydrology, soil characteristics, and land cover, were incorporated into the decision framework, aligning with the methodological structure of the study and reinforcing the robustness of GIS-based MCDA-AHP in multi-hazard assessment.

Flood susceptibility in low-lying and coastal barangays

In direct response to the first objective, the flood susceptibility mapping revealed that approximately 2,458.66 ha of Mati City fall under very high flood risk, primarily located in low-lying and coastal barangays such as Dahican, Bobon, Central, Don Enrique, and Matiao. These findings reflect the combined influence of low elevation (−1 to 3 m), high Topographic Wetness Index (TWI), gentle slopes, and high rainfall intensity, all of which are critical determinants of flood occurrence. The TWI layer effectively identified hydrological accumulation zones, demonstrating how surface runoff converges in flat and poorly drained areas, consistent with the hydrological principles outlined by Kazakis et al. (2015) and Mourato et al. (2023). The observed inverse relationship between slope and flood susceptibility further supports the findings of Kinde et al. (2024), confirming that flatter terrains promote water stagnation.

In the context of Mati City, these flood-prone zones are further influenced by coastal proximity, making areas such as Sitio Guang-Guang in Dahican and parts of Mayo and Bobon vulnerable not only to pluvial flooding but also to coastal inundation and saltwater intrusion (Macusi et al., 2020). This highlights the compounding effects of geomorphology and climatic exposure, consistent with Bañados and

Quijano (2022). The overlay of settlement data adds a critical socio-spatial dimension to the analysis, revealing that barangays such as Dahican (2,890 settlements) and Central (1,114 settlements) have the highest exposure. This indicates that flood risk is intensified by population concentration and land-use patterns, supporting previous findings that urban expansion into flood-prone areas significantly increases vulnerability (Danumah et al., 2016). Overall, flood risk in Mati City is shaped by both natural susceptibility and anthropogenic pressures, emphasizing the importance of integrating hazard maps into drainage planning, zoning regulations, and coastal management strategies.

Landslide susceptibility in upland and mountainous areas

Addressing the second objective, the landslide susceptibility analysis identified approximately 10,267.15 ha as very highly susceptible, predominantly in upland and mountainous barangays such as Macambol, Cabuaya, Lanca, Lawigan, Taguibo, and Tagbinonga. These areas are characterized by steep slopes (>36°), high rainfall intensity, erodible soils, and reduced vegetation cover, all of which contribute to slope instability. Slope emerged as the most influential factor, consistent with established landslide studies (Guzzetti et al., 2008; Highland and Bobrowsky, 2008), where gravitational forces increase with terrain steepness. Rainfall further exacerbates this condition by increasing pore-water pressure, reducing soil shear strength, and triggering slope failure (Kinde et al., 2024; Masancay, and Balilahon, 2024).

Soil-related parameters also played a significant role in determining landslide susceptibility. Areas with high permeability and erodibility, particularly those with sandy clay loam and loam textures, showed increased susceptibility due to rapid infiltration and soil weakening. In contrast, regions with higher clay content exhibited relatively lower susceptibility due to increased cohesion, as observed in parts of Taguibo, Dawan, and Bobon. This aligns with the understanding of soil mechanical behavior in landslide processes (Heidari et al., 2011; Kinde et al., 2024). The spatial distribution of landslide-prone areas reflects the geomorphological structure of Mati City, where upland zones act as source areas for sediment and runoff that may further influence downstream flood-prone communities, demonstrating the interconnected nature of hazards. Although fewer settlements are exposed compared to flood-prone areas, barangays such as Tagbinonga (89 settlements) and Macambol (47 settlements) still face considerable risk, particularly due to their proximity to unstable slopes and limited accessibility during extreme events.

Urban sprawl and increasing hazard exposure

In line with the third objective, the urban sprawl analysis revealed a substantial increase in built-up areas, expanding from 1,864.21 ha in 2017 to 3,181.88 ha in 2024. This rapid expansion reflects ongoing socio-economic development in Mati City, but also introduces significant environmental challenges. The spatial overlay of urban growth with hazard maps indicates that expansion is occurring within both flood-prone lowlands and landslide-prone uplands, reinforcing concerns raised in previous studies on unregulated urbanization (Mohd Noor et al., 2018; Chen et al., 2025). This pattern exemplifies urban sprawl, characterized by dispersed, unplanned development that alters natural landscapes and increases vulnerability to hazards (Burchell et al., 2002; Wang et al., 2020; Yang et al., 2022).

From a hydrological perspective, increasing impervious surfaces reduces infiltration and enhances surface runoff, thereby intensifying flood risks. Simultaneously, land conversion in upland areas reduces vegetation cover, weakening slope stability and increasing landslide susceptibility. These processes highlight the dual impact of urbanization on both flood and landslide hazards, as noted by Chen et al. (2021), Sarzynski et al. (2014), and Yu et al. (2023). The findings reveal a critical gap in risk-sensitive land-use planning, as current urban expansion trends do not adequately account for underlying hazard conditions. Without appropriate intervention, continued development in high-risk zones may significantly increase disaster losses and undermine the Mati City long-term sustainability.

Implications for planning and disaster risk reduction in Mati City

The integration of flood and landslide susceptibility maps with urban sprawl analysis provides a comprehensive decision-support framework for local governance and planning in Mati City. The results underscore the importance of incorporating GIS-based hazard assessments into the Comprehensive Land Use Plan (CLUP) and disaster risk reduction strategies. High-risk barangays such as Dahican, Central, Macambol, and Tagbinonga should be prioritized for targeted interventions, including stricter zoning regulations, infrastructure improvements, and community-based preparedness programs. Enforcing no-build zones in floodplains and steep slopes, combined with promoting nature-based solutions such as reforestation and watershed management, can significantly reduce hazard exposure. Additionally, investments in drainage systems, coastal protection measures, and early warning systems are essential to enhance resilience. These strategies align with broader disaster risk reduction frameworks and emphasize the role of science-based planning in minimizing disaster impacts.

CONCLUSION

This study provides compelling evidence that the convergence of natural hazards and unregulated urban expansion is rapidly intensifying disaster risk in the Mati City. By integrating GIS with MCDA-AHP, the research not only mapped flood and landslide susceptibility with high spatial precision but also revealed a critical and escalating pattern: urban growth is systematically encroaching into high-risk zones. This spatial overlap transforms natural hazards into imminent socio-economic threats, particularly in densely populated coastal and upland communities.

The identification of 2,458.66 ha as highly flood-prone and 10,267.15 ha as highly susceptible to landslides underscores the scale and urgency of the challenge. More importantly, the documented expansion of built-up areas intothese zones signals a trajectory of increasing vulnerability if current land-use practices persist. The findings elevate hazard mapping from a purely analytical exercise to a strategic planning imperative, demonstrating that risk is no longer a future possibility but a present and growing reality embedded in the city's development patterns.

Hence, this study advances GIS-based MCDA-AHP as a powerful decision-support framework that bridges science and policy. It highlights that sustainable urban development in hazard-prone regions like Mati City depends not only on understanding where risks exist, but on decisively integrating that knowledge into governance, planning, and investment decisions. Without immediate, risk-informed interventions, the gains of urban growth may be outweighed by escalating disaster losses.

The following priority actions are essential to translate the study's findings into effective policy and practice:

- Institutionalize risk-informed land-use planning: Integrate flood and landslide susceptibility maps into the CLUP and zoning ordinances, and enforce no-build and controlled development zones in high-risk coastal and upland areas.
- Prioritize targeted mitigation investments: Allocate resources to high-exposure barangays (e.g., Dahican, Central, Macambol, Tagbinonga) for resilient infrastructure, including drainage improvements, slope stabilization, coastal protection, and reforestation.
- Establish a dynamic geospatial monitoring system: Develop a city-level GIS platform that regularly updates hazard and urban growth data to support real-time planning, early warning, and adaptive decision-making.

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AUTHOR CONTRIBUTIONS

R. L. R: Designed the methodology, conducted data processing and GIS analysis, and drafted the manuscript. J. S. C: conceptualized the study, supervised the research, contributed to the methodological framework, validated the analytical approach, and critically reviewed and revised the manuscript for intellectual content. Both authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

DECLARATIONS

Informed consent statement

This study complied with standard ethical guidelines for research and publication. All geospatial datasets (e.g., NAMRIA IFSAR DEM, WorldClim rainfall data, DENR and ISRIC soil data, and Sentinel-2/Landsat imagery) were obtained from authorized, publicly available, or institutional sources and were properly cited. The research did not involve human participants, personal data, or animal subjects; therefore, ethical clearance was not required. All analyses were conducted with transparency and methodological rigor, and no data were fabricated, manipulated, or misrepresented. The generated flood and landslide susceptibility maps are intended for academic and decision-support purposes only. They should be interpreted with appropriate caution, as they are model-based outputs that may require field validation for site-specific applications. The authors declare adherence to principles of research integrity, proper attribution, and responsible reporting throughout the conduct of this study.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

AI Desclosure

The authors declare that no Artificial Intelligence (AI) or AI-assisted technologies were used in the preparatin of this manuscript.

REFERENCES

Akıncı, H., Yavuz Özalp, A., and Turgut, B. (2013). Agricultural land use suitability analysis using GIS and AHP technique. *Computers and Electronics in Agriculture*. 97, 71-82. https://doi.org/10.1016/j.compag.2013.07.006

Amini, S., Rohani, A., Aghkhani, M. H., Abbaspour-Fard, M. H., and Asgharipour, M. R. (2020). Assessment of land suitability and agricultural production sustainability using a combined approach (Fuzzy-AHP-GIS): A case study of Mazandaran province, Iran. *Information Processing in Agriculture*, 7(3), 384–402. https://doi.org/10.1016/j.inpa.2019.10.001

Cabrera, J. S., and Lee, H. S. (2020). Flood risk assessment for Davao Oriental in the Philippines using geographic information system-based multi-criteria analysis and the maximum entropy model. *Journal of Flood Risk Management*, 13(2), e12607. https://doi.org/10.1111/jfr3.12607

Chen, D., Lu, X., Hu, W., Zhang, C., and Lin, Y. (2021). How urban sprawl influences eco-environmental quality: Empirical research in China using the spatial Durbin model. *Ecological Indicators*, 131, 108113. https://doi.org/10.1016/j.ecolind.2021.108113

Chen, L., Qi, Q., Wu, H., Feng, D., and Zhu, E. (2023). Will landscape composition and socio-economic development of coastal cities impact the marine cooling effect? *Sustainable Cities and Society*, 89, 104328. https://doi.org/10.1016/j.scs.2022.104328

Chen, Y., La Rosa, D., and Yue, W. (2025). Does urban sprawl lessen green space exposure? Evidence from Chinese cities. *Landscape and Urban Planning*, 257, 105319. https://doi.org/10.1016/j.landurbplan.2025.105319

Dadashpoor, H., and Shahhossein, G. (2024). Defining urban sprawl: A systematic review of 130 definitions. *Habitat International*. https://doi.org/10.1016/j.habitatint.2024.103039

El Baroudy, A. A. (2016). Mapping and evaluating land suitability using a GIS-based model. *Catena*, 140, 96–104. https://doi.org/10.1016/j.catena.2015.12.010

Fenta, A. A., Yasuda, H., Haregeweyn, N., Belay, A. S., Hadush, Z., Gebremedhin, M. A., and Mekonnen, G. (2017). The dynamics of urban expansion and land use/land cover changes using remote sensing and spatial metrics: The case of Mekelle City, northern Ethiopia. *International Journal of Remote Sensing*, 38(14), 4107–4129. https://doi.org/10.1080/01431161.2017.1317936

Horton, R. E. (1945). Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin*, 56(3), 275–370. https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

Kazakis, N., Kougias, I., and Patsialis, T. (2015). Assessment of flood hazard areas at a regional scale using an index-based

Kazakis, N., Kougias, I., and Patsialis, T. (2015). Assessment of flood hazard areas at a regional scale using an index-based approach and analytical hierarchy process: Application in Rhodope–Evros region, Greece. *Science of the Total Environment*, 538, 555–563. https://doi.org/10.1016/j.scitotenv.2015.08.055

Kazemi, H., and Akinci, H. (2018). A land use suitability model for rainfed farming by multi-criteria decision-making analysis (MCDA) and geographic information system (GIS). *Ecological Engineering*, 116, 1–6. https://doi.org/10.1016/j.ecoleng.2018.02.021

Kent, A., and Vujakovic, P. (Eds.). (2017). *The Routledge handbook of mapping and cartography.* Routledge.

Mahmoud, S. H. (2014). Investigation of rainfall–runoff modeling for Egypt using remote sensing and GIS integration. *Catena*, 120, 111–121. https://doi.org/10.1016/j.catena.2014.04.011

Macusi, E. D., Macusi, E. S., Jimenez, L. A., and Catam-isan, J. P. (2020). Climate change vulnerability and perceived impacts on small-scale fisheries in eastern Mindanao. *Ocean and Coastal Management* https://doi.org/10.1016/j.ocecoaman.2020.105143doi.org

Masancay, F. D., and Jimenez, L. A. (2024). Predicting the unseen: A shoreline shift analysis and prediction along Mayo Bay, Davao Oriental. *Davao Research Journal*, 15(4), 19–45. https://doi.org/10.59120/drj.v15i4.269

Masancay, F. D., Arizobal, A. E., Pascua, V. T., and Petalcorin, I. G. D. (2025). Urban sprawl mapping based on land use and land cover (LULC) time-series in District II of Davao City, Philippines. *Davao Research Journal*, 16(1), 81–99.https://doi.org/10.59120/drj.v16i1.305

Masancay, F. D., Balilahon, J. N. D., Bolivar, D. J. B., and Rodrigo, S. A. P. (2024). GIS-based site selection for rainwater harvesting (RWH) suitability mapping in Davao City. *Davao Research Journal*, 15(4), 176–194. https://doi.org/10.59120/drj.v15i4.291

Masancay, F. D., Comendador, Y. J. F., Dizon, J. A. L.,and Jallores, L. P. L. (2024). Geographic information system-based prioritization mapping for urban search and rescue in Poblacion, Davao City. *Davao Research Journal*, 15(3), 111–121. https://doi.org/10.59120/drj.v15i3.254

Mohd Noor, N., Rosni, N. A., Hashim, M., and Abdullah, A. (2018). Developing land use geospatial indices (LUGI) for sprawl measurement in alpha cities: Case study of Kuala Lumpur, Malaysia. *Cities*, 82, 127–140. https://doi.org/10.1016/j.cities.2018.05.012

Parry, J. A., Ganaie, S. A., and Bhat, M. S. (2018). GIS-based land suitability analysis using AHP model for urban services planning in Srinagar and Jammu urban centers of J&K, India. *Journal of Urban Management*, 7(2), 46–56. https://doi.org/10.1016/j.jum.2018.05.002

Pelone, B. C., and Arellano, A. J. P. (2024). Flood preparedness and utilization of early warning systems among households in selected flood-prone areas in Tagum City, Davao del Norte. *Davao Research Journal*, 15(1), 34–47. https://doi.org/10.59120/drj.v15i1.149

Pilevar, A. R., Matinfar, H. R., Sohrabi, A., and Sarmadian, F. (2020). Integrated fuzzy, AHP, and GIS techniques for land suitability assessment in semi-arid regions for wheat and maize farming. *Ecological Indicators*, 110, 105887. https://doi.org/10.1016/j.ecolind.2019.105887

Ritung, S., Wahyunto, Agus, F., and Hidayat, H. (2007). *Land suitability evaluation Guidelines with a Case Map of Aceh Barat District*. World Agroforestry Centre (ICRAF). https://www.cifor-icraf.org/publications/downloads/Publications/PDFS/MN15224.pdf

Russell, A., Li, Z., and Wang, M. (2023). Equalizing urban agriculture access in Glasgow: A spatial optimization approach. *International Journal of Applied Earth Observation and Geoinformation*, 124, 103525. https://doi.org/10.1016/j.jag.2023.103525

Sarkar, S., and Kanungo, D. P. (2004). An integrated approach for landslide susceptibility mapping using remote sensing and GIS. *Photogrammetric Engineering & Remote Sensing*, 70(5), 617–625. https://doi.org/10.14358/PERS.70.5.617

Sarzynski, A., George, G., and Stack, L. (2014). Typologies of sprawl: Investigating United States metropolitan land use patterns. *Urban Geography*, 35(1), 48–70. https://doi.org/10.1080/02723638.2013.826468

Schumm, S. A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geological Society of America Bulletin*, 67(5), 597–646. https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2

Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In V. T. Chow (Ed.), *Handbook of applied hydrology* (pp. 439–476). McGraw-Hill.

Tercan, E., and Dereli, M. A. (2020). Development of a land suitability model for citrus cultivation using GIS and multi-criteria assessment techniques in Antalya province of Turkey. *Ecological Indicators*, 117, 106549. https://doi.org/10.1016/j.ecolind.2020.106549

Yang, S., Li, C., Lou, H., Luo, Y., Wang, P., Zhang, J., Li, X., and Wu, X. (2022). The impact of urban expansion on plant diversity change in karst regions of Southwest China. *Chinese Geographical Science*, 32(3), 493–505.

Zolekar, R. B., and Bhagat, V. S. (2015). Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach. *Computers and Electronics in Agriculture*, 118, 300–321. https://doi.org/10.1016/j.compag.2015.09.016

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