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A FLOOD SUSCEPTIBILITY ANALYSIS OF THE DAVAO RIVER WATERSHED, DAVAO CITY, PHILIPPINES

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Abstract
This study aimed to assess the susceptibility to flood of Davao River Watershed by analyzing geospatial and hydrological characteristics. It employs Geographic Information System (GIS) and Remote Sensing (RS) techniques to quantify flood susceptibilities based on the parameters evaluated. Data has revealed 63.40% of the watershed is classified as very low drainage density resulting in slower water movement. In terms of elevation, 37.79% is considered highly elevated with estimated elevation of 1080-1440 means above sea level indicating lower susceptibility. The watershed areas dominated by forest with 75.93% with rainfall distribution patterns of 34.80% receiving an estimated rainfall of 3000 mm classified as highly susceptible. The area has lower computed TWI which covers the 51.91% indicating that water is less likely to accumulate, most likely to related to its gentle slopes classified as 3-8% which facilitates good drainage. Although, vegetation cover is classified as low which increases the susceptibility to flood, which potentially accelerated due to its soil type which is Camasan Clay accounts the 63.52% of the watershed. Its proximity to streams can influence the likelihood of flood risks covering 31% of the watershed located 800-1000 away from the nearby stream. AHP results have determined slope with weight of 20.87 as the most influential variable among geomorphological and hydrological parameters examined. Even with these parameters, the Davao River Watershed is categorized as moderately susceptibly to flood indicating vulnerabilities considering extreme rainfall events and land use change dynamics.

Keywords: flood susceptibility, GIS, watershed, remote sensing, Philippines.

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INTRODUCTION

Floods are among the most destructive natural disasters, causing significant damage to life, property, and the environment (Aslantas et al. 2024). Many cities face significant flooding-related challenges attributed to the changing climate (Kim et al. 2024). Flood forecasting is crucial, particularly on a watershed scale, as it allows for predicting and mitigating potential flood impacts (Mehta et al. 2023). Understanding flood dynamics and characteristics is crucial in developing preventive and protective engineering and similar structures (Maria et al. 2024). The heightened climatic-related extremes, especially extreme rainfall events, have been related to land cover change and urbanization (Aryee et al. 2024), and the understanding of meteorological aspects is the first step in the challenge of dealing with floods (Breugem et al. 2020). Hydrological models may provide critical and technical support for regional flood management and damage assessment (Li et al. 2023). Geographic Information Systems (GIS) and Remote Sensing (RS) are fundamental in catastrophe analysis and management of flood disasters, and real-time flood, early warning systems, and damage assessment are all aided by GIS and RS (Burayu et al. 2023). Currently, there is limited data on flood vulnerability at the watershed scale. Moreover, minimal literature that explores geomorphological characteristics to study and understand the flood dynamics within the Davao River watershed is available. This study aims to (a) map and analyze areas susceptible to flooding based on drainage density, elevation classification, land use land classes, rainfall class, topographic wetness index, slope classification, vegetation cover, soil type, distance to stream, and stream power index (b) to determine the spatial position of areas susceptible to flooding within the Davao River watershed.

MATERIAL AND METHODS

A descriptive and quantitative design employing a Geographic Information System (GIS) to identify flood risk areas along the Davao River Watershed in Davao City. Davao River watershed is one (1) of the eight (8) watersheds in Davao City. Geospatial and ecological data from various global, national, and local databases are critical for flood susceptibility mapping. This data undergoes management, transformation, and processing for weighted sum overlay analysis, with weights assigned through multi-criteria decision analysis, explicitly using the Analytical Hierarchy Process (AHP). The Digital Elevation Model (DEM) used in the study is a LiDAR dataset with 10-meter accuracy, obtained from the Department of Environment and Natural Resources (DENR) – Region XI Office. The DEM data was used to derive raw elevation and slope ranges using geographic information system (GIS) software. The data undergoes a reclassification process to transform into five flood mapping susceptibility levels. The Land Use/Land Cover (LULC) 2020 data were extracted from geoportal.gov.ph through the National Mapping and Resource Information Authority (NAMRIA). The soil type data were extracted from geoportal.gov.ph through the Bureau of Soils and Water Management (BSWM) as vector data and were rasterized and resampled to 10–meter accuracy. The TWI was analyzed using Digital Elevation Model (DEM) data. The DEM was processed by filling empty cells or sinks using the "fill" function in ArcGIS or QGIS. This ensures that the DEM is hydrologically corrected and ready for analysis. The flow accumulation was calculated using the filled DEM, representing the total amount of water flowing into a specific cell from the surrounding terrain. Once the flow accumulation was obtained, it is being scaled using the formula:

$$\text{Flow Accumulation Scaled} = (\text{Flow Accumulation} + 1) \times \text{Cell Size}$$

After flow accumulation is scaled, another variable for the Topographic Wetness Index (TWI) is the tangent of the slope, where the default unit for slope analysis in QGIS is in degrees. In converting the slope, the following formula was used:

$$\text{Slope (Radians)} = [\text{Slope (Degrees)} \times 1.570797] / 90$$

After converting the slope in radians, the computation for the tangent of the slope was converted using the following condition:

$$\text{Tangent of Slope} = \{[\text{Condition}]\ [(\text{Slope in Radians} > 0,\ \text{Tan (Slope in Radians)}),\ 0.001]\}$$

With the flow accumulation and slope values being processed, the calculation for the TWI was calculated using the formula:

TWI = ln (Flow Accumulation Scaled/Slope in Tangent)

In addition, vegetation cover was analyzed using the Normalized Difference Vegetation Index (NDVI), utilizes satellite imagery with embedded spectral signature data. Typically, NDVI values range from -1 to +1, while in the local study area, they vary between -0.15 and 0.53 (Khosravi et al. 2016). The satellite imagery was extracted from USGS.gov, provided by the Landsat 8 satellite with a Level-2 surface reflectance product. The downloaded data was already atmospherically corrected to provide surface reflectance values. The satellite image was captured on March 31, 2020, and processed on August 22, 2020, using Collection 2, Tier 1 standards. This ensures that the data is of the highest quality and meets geometric and radiometric accuracy standards. In creating the NDVI map, the following equation was used: NDVI = (NIR – VIS) / (NIR + VIS), where VIS and NIR represent the spectral reflectance measurements in the visible (red) and near-infrared regions, respectively (Khosravi et al., 2016). For fainfall data, it utilized a 10-year rainfall data extracted from worldclim.org and resampled and reclassified to create a rainfall susceptibility map. For the Stream Power Index (SPI) it analyzes SPI using the Interferometric Synthetic Aperture Radar (IFSAR) Digital Elevation Model (DEM). It involves filling the sinks of the raw DEM to ensure continuous flow. Furthermore, flow accumulation is computed using hydrological tools available in the SAGA or GRASS toolbox. Simultaneously, the slope of the terrain is derived also from IFSAR DEM. The calculated and analyzed flow accumulation and slope were then combined using raster calculation using the defined formula of SPI = ln (flow accumulation * slope). The proximity to watercourses, such as rivers and streams, significantly influences flood risk. Streams serve as the primary conduits for floodwaters, and their spatial proximity to a specific location can significantly impact and amplify vulnerability, risk, and the intensity of flooding events (Shah & Ai 2024).

In analyzing flood susceptibility, it extracted the streams and rivers, then created a 1,000-meter buffer zone divided into five distance categories: 0–200 meters, 200–400 meters, 400–600 meters, 600–800 meters, and 800–1,000 meters. In calculaing the drainage density, it analyzed stream orders from the IFSAR digital elevation model (DEM) using the Channel Network and Drainage Basins analysis through the SAGA toolbox in QGIS. A grid with a resolution of 100 m x 100 m was generated to determine the overall drainage density of the watershed. The analyzed stream order was then embedded into the generated grid using the intersecting tool, and drainage density was analyzed using the following formula: Dd = $\sum_1^n L$ / A. Where *Dd*, the length of waterways, denotes drainage density, is signified by *L*, and the basin's total area is signified with symbol *A*. This study applies GIS and RS techniques to process, analyze, and visualize geospatial and environmental data to create a flood susceptibility map for the Davao River Watershed. This includes resampling all data layers to ensure a uniform spatial resolution of 10m by 10m. A reclassification process is then applied to each geospatial and environmental dataset, assigning values on a five-point susceptibility scale: 1 for very low susceptibility, 2 for low, 3 for moderate, 4 for high, and 5 for very high susceptibility. Finally, all geospatial and environmental layers are combined using the raster calculator to produce the flood susceptibility model. Furthermore, MCDA-AHP was applied as a qualitative tool, leveraging expert input to determine weightings. The analysis proceeded through four stages, as outlined by Convertino et al. (2013), guided by experts and stakeholders. These stages included (a) identifying potential decision alternatives; (b) establishing the value tree's criteria, which would serve as the basis for evaluating these alternatives; (c) assigning importance to each criterion relative to others and then independently standardizing these weights for each criterion hierarchy; and (d) assessing the value of each alternative concerning each criterion (Chaulagain et al. 2023). Three experts selected geospatial and environmental layers to achieve the study's objective of assessing and quantifying flood susceptibility areas in the Davao River Watershed using a five-level susceptibility scale. The analysis incorporated field observations and group discussions with residents affected by flooding in the Davao River Watershed. The pairwise comparison method in AHP was employed to calculate the sub-criteria weights, with input from the three experts. Each expert's weights were calculated separately, and the consistency ratio (CR) was checked to ensure reliability.

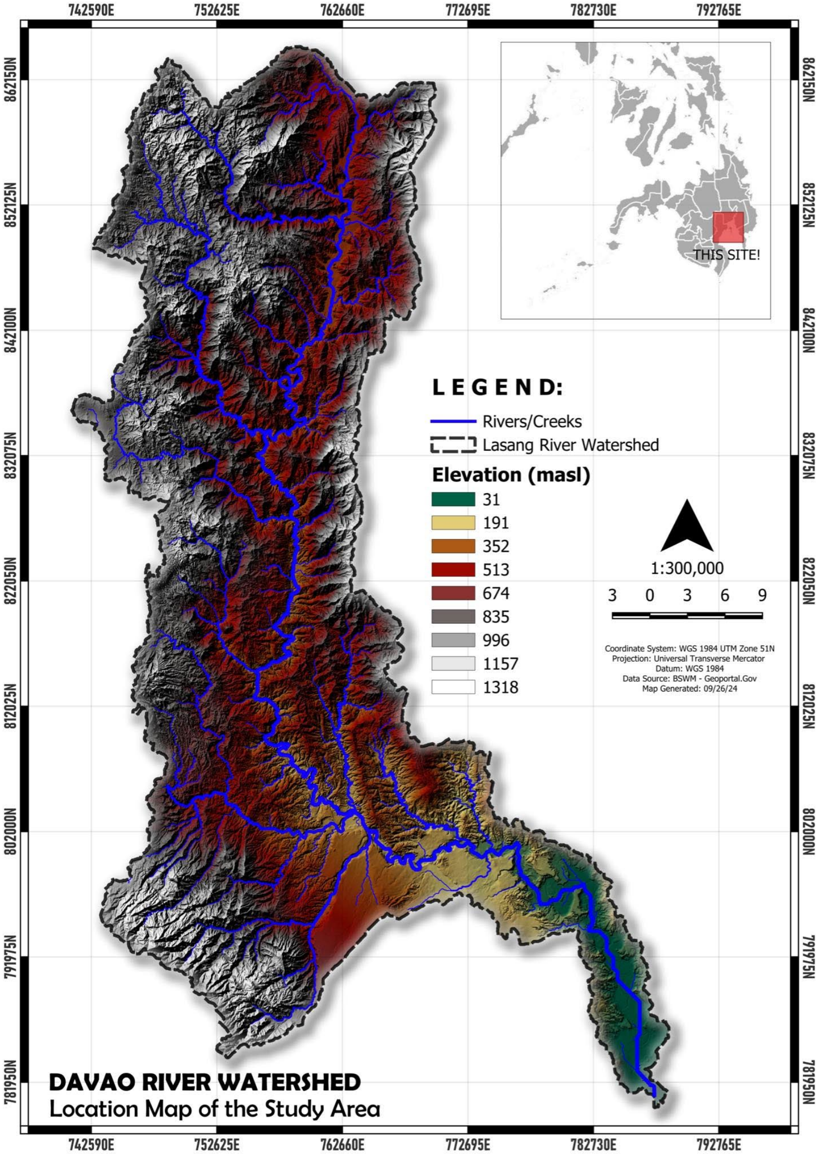

Figure 1. Map showing the location of the Davao River Watershed.

RESULTS AND DISCUSSION

Table 1 and Figure 2 present the analyzed data and map of the drainage density of the Davao River Watershed. Results have revealed a very low drainage density class with a total area of 109927.89 ha or 63.40% of the total area, while a very high-density area covers 76.07 ha or 0.04% of the total area. This implies that most of the area is less likely to develop a drainage network, and water takes longer to travel through the basin, which can reduce the risk of flooding and result in groundwater recharge. On the other hand, the lower density range of the Davao River watershed implies that significant portions of rainfall infiltrate the ground, indicating less surface runoff and reducing soil erosion and sediment transport. Also, factors such as soil permeability are considered essential elements that cause a very low drainage density range. Results from the study of (Carlston 1996) have found out that base flow is affected by precipitation or recharge while varying inversely with drainage density and the change in drainage density depends not only on the direction of the change in climate but also on the prevailing climate regime (Moglen et al. 1998).

Table 1. The drainage density of Davao River Watershed.

Susceptibility value	Susceptibility class	Drainage density range (m/ha)	Drainage density class	Area (ha)
1	Very low	<19	Very low	109,927.89
2	Low	19 - 38	Low	60,848.60
3	Moderate	38 - 57	Moderate	2,281.81
4	High	57 - 76	High	241.61
5	Very high	>76	Very high	76.07
		Total		17,3376.00

In terms of elevation gradient, as shown in Table 2. Results have shown that most of the land areas are classified as high elevation with 65,515.41 ha, which comprises 37.79% of the total land area and is classified under low susceptibility class. On the other hand, 2.07% of the total land area is classified as low elevation, which comprises 3,594.77 ha of the total land area, which is categorized as very high susceptibility. This implies that the area is less susceptible to flooding, although intense rainfall can overwhelm the drainage capacity of an area, leading to flash floods even in high-elevation regions. Nonetheless, some areas in the Davao River watershed are very highly susceptible to flood, particularly those located in low-lying areas wherein flat terrain cannot facilitate quick runoff of water, leading to pooling and potential flooding associated with heavy and frequent rainfall, especially those in proximity to rivers and large water bodies. Results from study of (Vojtek & Vojtekova 2019) revealed that elevation most affects flooding in an inverse way highlighted which highlights flood frequency increases with decreasing elevation making lower areas susceptible to flooding.

Table 2. The elevation classification of Davao River Watershed.

Susceptibility value	Susceptibility class	Elevation ranges (m.a.s.l.)	Elevation class	Area (ha)
5	Very high	0 - 360	Very low	3,594.77
4	High	360 - 720	Low	19,738.93
3	Moderate	720 - 1080	Moderate	51,728.70
2	Low	1080 - 1440	High	65,515.41
1	Very low	1440 - 1840	Very high	32,798.19
		Total		173,376.00

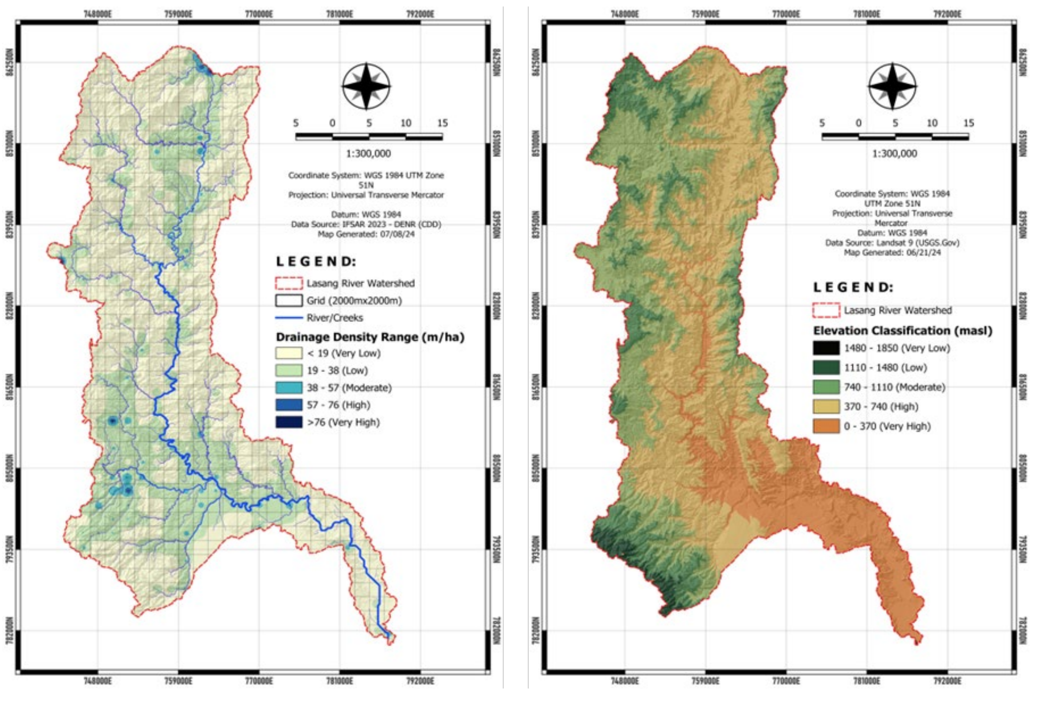

Figure 2. The drainage density and elevation classification.

Presented in Table 3 is the land use and land classification of the Davao River watershed. Results revealed forest as the most dominant land classification with 131,651 ha, which covers 75.93% of the total land area and is classified as very low susceptibility. In addition, water bodies are the least with a total area of 1,556.61 ha or encompass 0.90% of the total land area that falls under very high susceptibility. However, prolonged and intense rainfall can lead to flooding even in forested areas. In general, forests are less susceptible to flooding than other land types associated with their ability to absorb and manage water. On the other hand, water bodies are often the sources or conduits of flood water that affect surrounding areas, leading to significant changes in water levels and causing flooding to adjacent lands. It was cited in the literature that LULC is considered one of the most remarkable factor affecting the flood susceptibility in watersheds (Rashidiyan & Rahimzadegan 2023).

Table 3. The land use and land classification of Davao River Watershed.

Susceptibility value	Susceptibility class	LULC value	LULC class	Area (ha)
1	Very high	1	Water bodies	1,556.61
2	High	7	Built-up	6,378.56
3	Moderate	5	Barren	8,187.40
4	Low	11	Agricultural	25,602.33
5	Very low	2	Forest	131,651.10
		Total		173,376.00

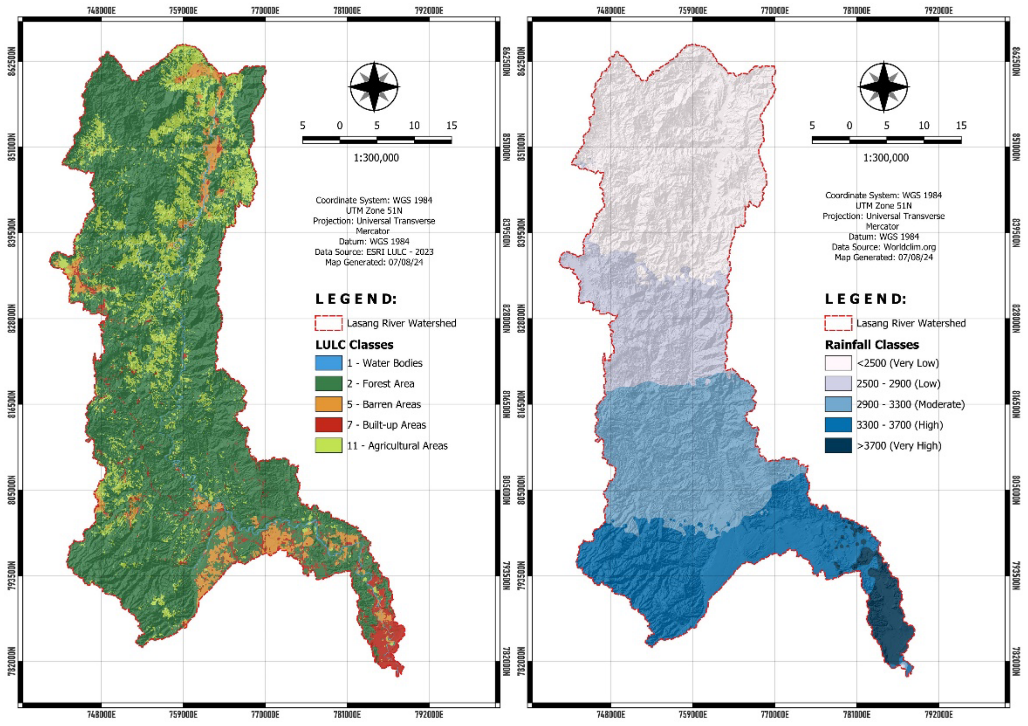

Figure 3. The land use and land classes and rainfall classification.

Table 4 shows the rainfall classification of the study area. Data have revealed that most of the area received rainfall >3000 mm of rainfall covering 60,328.68 ha or 34.80% of the total land area, considered as very high rainfall and classified as very high susceptibility. On the other hand, 3.625% of the total land area receiving rainfall of <2500 mm is considered low rainfall class and classified as very low susceptibility. In an area with very high susceptibility to flooding, a very high rainfall rate significantly increases the likelihood of flooding. High rainfall rates can quickly saturate the soil in susceptible areas, reducing its capacity to absorb additional water and leading to increased runoff and higher chances of flooding. On the other hand, very high rainfall rates of the Davao River watershed can overwhelm the existing drainage, which might need to be improved due to its high susceptibility conditions. A study in Markahm river catchment have revealed that the exposure to flood was attributed to rainfall, peak discharge and physiographic conditions (Samanta et al. 2018)

Table 4. The rainfall classification of Davao River Watershed.

Susceptibility value	Susceptibility class	Rainfall (mm)	Rainfall class	Area (ha)
1	Very low	< 2500	Very low	6,268.69
2	Low	2500 - 2900	Low	36,980.82
3	Moderate	2900 - 3300	Moderate	41,692.88
4	High	3300 - 3700	High	28,103.92
5	Very high	>3700	Very high	60,329.68
		Total		173,376.00

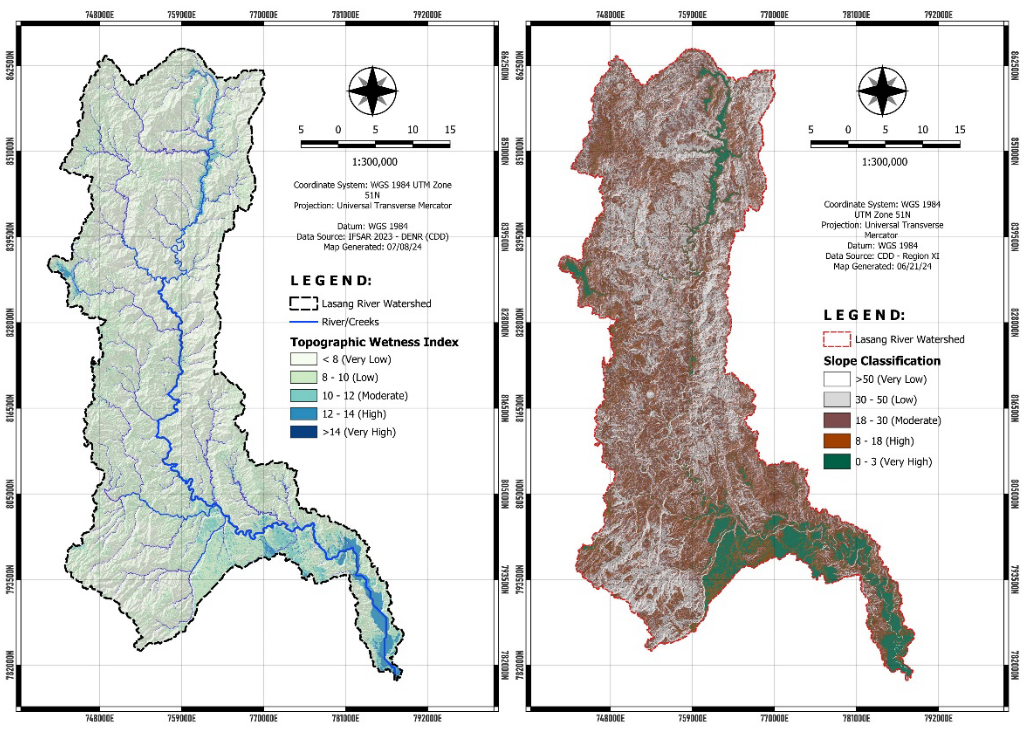

Figure 4. The topographic wetness index and slope classification.

Described in Table 5 is the computed Topographic Wetness Index (TWI) of Davao River watershed. Results have revealed a TWI classification of very low among the 51.91% of the study area which cover 89,994.38 ha and was classified as very low susceptibility with TWI range of <8. Likewise, 0.12% of the total land area is considered very highly susceptible with TWI of >14 which covers 201.72 ha. Lower TWI indicates lower potential for water accumulation or saturation and implies that the terrain features do not support significant water pooling or accumulation in the area, and these areas are less likely to retain and typically drier. However, some areas in the Davao River watershed have a very high TWI indicating the likelihood of accumulating and retaining more moisture compared to surrounding areas. Although it covers a small portion of the land area, these areas have potential to become waterlogged and more susceptible to flooding, especially during periods of heavy rainfall due to the inability of terrain features to absorb and drain water. The study of (Latue & Rakuasa 2023) of states that a higher TWI is an indicative of higher humidity level while lower TWI indicates a drier area which was helpful in identifying flood prone areas.

Table 6 presents the slope classification; most of the area is classified as gently sloping to undulating with a slope range of 3-8%, classified as low susceptibility with a total land area of 57,708.24, covering 33.29% of the total land area. Meanwhile, 8.64% of the total land has a slope classification of rolling to moderate steep with a slope range of 18-30%, with a high susceptibility class covering 8.64% of the total land area. Although most of the land area is classified as highly susceptible due to its potential to collect water rather than flow away. Nevertheless, the study area's gently sloping and undulating slope features can promote adequate water drainage. The slope gradient of the Davao River watershed is within the range of 3-8% potential to facilitate the gradual flow of waterway from the land, reducing the likelihood of accumulating and flooding. On the other hand, the least was classified as low susceptibility, those areas with steeper slopes within the watershed because the fast-moving water does not have time to accumulate significantly. Results from the study of determined slope as moderating variable tested in linear regression analysis demonstrate viability and reliability for defining precisely the flood-susceptible zones especially in reducing flood risks (Al-Juaidi 2023).

Table 5. The topographic wetness index of Davao River Watershed.

Susceptibility value	Susceptibility class	TWI data range	TWI class	Area (ha)
1	Very low	< 8	Very low	89,994.38
2	Low	8 - 10	Low	67,235.76
3	Moderate	10 - 12	Moderate	11,341.50
4	High	12 - 14	High	46,02.63
5	Very high	> 14	Very high	201.72
		Total		173,376.00

Table 6. The slope classification of Davao River Watershed.

Susceptibility value	Susceptibility class	Slope range (%)	Slope class	Area (ha)
5	Very high	0 - 3	Level to nearly level	43,656.97
4	High	3 - 8	Gently sloping to undulating	57,708.24
3	Moderate	8 - 18	Undulating to rolling	41,954.31
2	Low	18 - 30	Rolling to moderately Steep	14,984.21
1	Very low	30 – 50	Steep	15,064.09
		Total		173,376.82

Regarding vegetation cover, Table 7 presents data on the prevailing vegetation cover of the Davao River watershed. It shows that most of the land area is classified as low vegetation with 57,709.88 ha, which covers 36.29% of the total land area, which is also categorized as highly susceptible to flood. On the other hand, the least land covered with vegetation is classified as high, only covering 8.64%, covering 14,985 ha of the total land area categorized as low susceptibility. Low vegetation increases the likelihood of flood susceptibility, especially in watershed areas, as vegetation, especially deep-rooted plants, helps stabilize soil and prevent erosion. When vegetation is low, soil is more likely to be eroded by water, reducing the ground's ability to absorb rainfall. Without vegetation to hold the soil together, erosion can lead to increased sediment in waterways, reducing their capacity to carry water and increasing the risks of floods. On the other hand, dense vegetation stabilizes the soil, and roots bind together the soil, making it less prone to being washed by rainwater. It also increases permeability, allowing more water into the ground. Vegetation, particularly in riparian zones and floodplains, acts as a natural buffer, slows down water movement, and reduces the force and extent of flooding. According to (Viezzer et al. 2022) vegetation increases evapo-transpiration, rainwater interception, and water infiltration whole decreasing peak discharge, runoff speed, and the frequency of flood.

Table 7. The vegetation cover of Davao River Watershed.

Susceptibility value	Susceptibility class	Surface reflectance range	Vegetation cover class	Area (ha)
5	Very high	< 0	Very low/no	43,658.61
4	High	0 - 0.2	Low	57,709.88
3	Moderate	0.2 - 0.4	Moderate	41,955.95
2	Low	0.4 - 0.6	High vegetation	14,985.84
1	Very low	> 0.6	Very high	15,065.73
		Total		173,376.00

Table 8 presents the soil type and classification of the Davao River watershed. Data have shown 63.43% of the total land area of the Davao River watershed is classified as Camasan Sandy Clay Loam which covers 109,964.88 ha and is categorized as very low susceptibility followed by Tugbok Clay with 22.38% or 38,806.76 ha considered as very high susceptibility to flood, Matina Clay with 4.90% or 8,498.61 ha classified as high susceptibility, Matina Clay Loam identified as low susceptibility with 3.21% or 5,564.65% ha, Bago Clay and Matina Clay loa, both considered as very high susceptibility with 2.91% and 2.10% which covers 5,037.39 and 3,648.53 ha respectively and the least is categorized as moderate susceptibility is La Castellana Clay Loam which covers the 0.04% of the total land area or 72.36 ha. Since most of the land area is considered low susceptible to flood, the soil has a high potential for infiltration, allowing water to move quickly in the soil and having a greater chance of infiltration. Moreover, such soils are often sandy or well-draining loamy soil that resists saturation, reducing the likelihood of flooding during extreme weather events. It was cited in the literature that soil type contributes 70% in developing maps for stormwater management and surface runoff is closely linked to flood occurrences (Mahmoud & Gan 2018). According to (Basri et al. 2022) different soil types have different abilities in passing water into the ground and taking into account various uses and types in a watershed.

Table 8. The soil type classification of Davao River Watershed.

Susceptibility value	Susceptibility class	Soil description	Soil type class	Area (ha)
1	Very low	Camasan sandy Clay loam	Very low	109964.88
2	Low	Matina clay loam	Low	5564.65
3	Moderate	La Castellana Clay Loam	Moderate	72.36
4	High	Matina clay	High	8498.61
5	Very high	Antipolo clay	Very high	1782.82
5	Very high	Bago clay	Very high	5037.39
5	Very high	Matina clay loam	Very high	3648.53
5	Very high	Tugbok clay	Very high	38806.76
		Total		173,376.00

Table 9 shows the data on the distance to the stream of the Davao River watershed. Data have shown a very low susceptibility of the Davao River watershed to flooding in terms of its distance to stream, which comprises 31% of the total area accounting 53,742.97 ha, followed very high susceptibility with 35,194.86 or 20.30% of the total land area, low and high susceptibility with 29,385.97 or 16.95% and the least is classified as moderately susceptible with 25,666.23 ha or 14.80% of the total land area. This implies that direct flooding from a stream or river channel is less likely to affect the substantial distance to a stream. This class within the Davao River watershed represents the most prominent area, indicating that a significant portion is at least 800 meters away from the stream and has a minimal flood risk under normal conditions. Although it contributes less to direct runoff, it can still influence overall watershed hydrology through surface runoff during intense rainfall events. Results from the study of (Miranda et al. 2023) of that the distance from the major drainage network reflects the threat represented by overflows and that it is reasonable to consider that flat areas adjacent to rivers typically flood prone.

Table 9. The distance to stream of Davao River Watershed.

Susceptibility value	Susceptibility class	Distance to stream range	Range class	Area (ha)
1	Very low	800m - 1000m	Very low DS	53742.97
2	Low	600m - 800m	Low DS	29385.97
3	Moderate	400m - 600m	Moderate DS	25666.23
4	High	200m - 400m	High DS	29385.97
5	Very high	0 - 200m	Very DS	35194.86
		Total		173,376.00

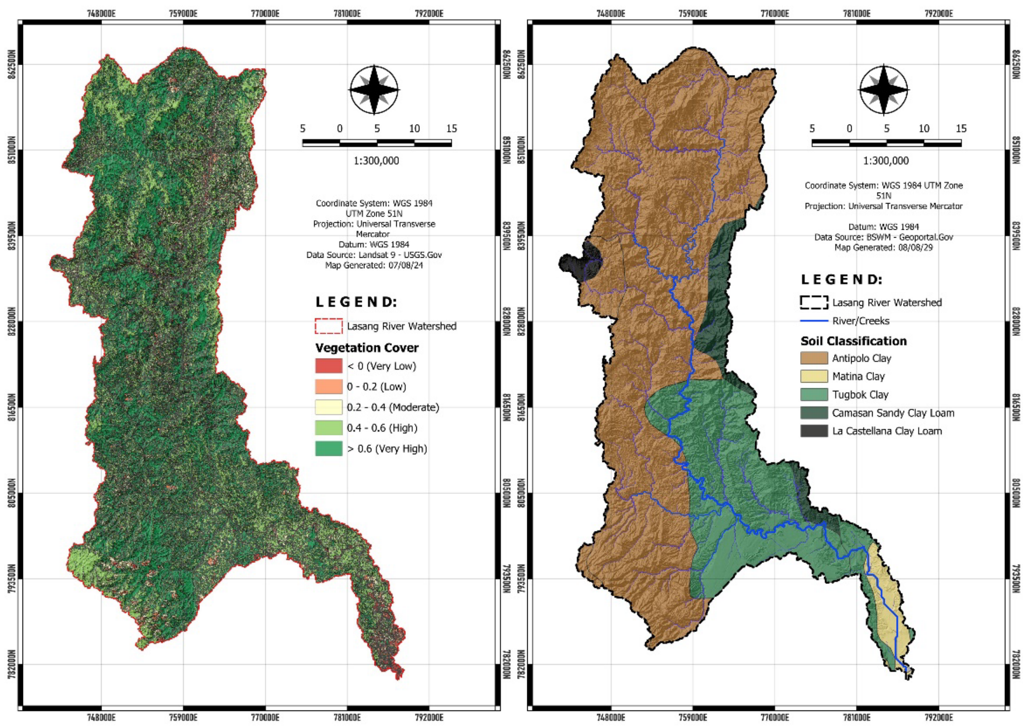

Figure 5. The vegetation cover and soil type classification.

Table 10 presents the Davao River watershed's Stream Power Index (SPI). Data have shown that the majority of the study area has an SPI of 0-3, classified as very low which covers 92.03% of the total area equivalent to 159,562.42 ha, followed by 3-6 categorized as low with 6.47% with 11,218.97 ha, 6-9 considered as moderate SPI with 1.15% equivalent to 2001.64 ha, 9-12 with classified as high with 461.03 ha or .27% of the total land area and the least is 12-16 classified as very high with 131.89 ha or .08% of the total land area. This indicates that the Davao River watershed has little potential for erosion due to low water energy flow and is often associated with a gentle slope, resulting in slower movement of water and the reduction of the ability to erode soil or transport sediments. On the other hand, zones with low SPI signify sediment deposition as sediments tend to accumulate, and these areas are considered more stable for agriculture and construction as they are less prone to erosion. The study of (De Rosa et al. 2019) has revealed that a standard screening of stream power variability along a stream can be utilized as a preliminary diagnostic element to identify the most sensitive points of the stream especially in developing mitigating measures aimed to reduced flood risks associated with dynamics of the riverbed.

Table 10. The stream power index of Davao River Watershed.

Susceptibility value	Susceptibility class	Stream power index	Range class	Area (ha)
1	Very low	0 - 3	Very low SPI	159562.45
2	Low	3 - 6	Low SPI	11218.97
3	Moderate	6 - 9	Moderate SPI	2001.64
4	High	9 - 12	High SPI	461.03
5	Very high	12 - 16	Very high SPI	131.89
		Total		173,376.00

Table 11 presents the pairwise comparisons of parameters used to analyze the flood susceptibility of the Davao River Watershed. Data has shown that elevation strongly influences the slope, and it is logical since slope is derived from elevation while TWI greatly influences the slope, rainfall, and drainage density as these parameters directly affect water accumulation. For its distance to rivers, it is strongly influenced by elevation, slope, rainfall and SPI as river location, and its flow patterns are terrain dependent. In terms of SPI, it is revealed that it is highly related to slope, rainfall, drainage density considering that SPI is a product of discharge and slope while the slope strongly influences TWI, SPI, drainage density, NDVI, and soil. On the other hand, rainfall strongly influences TWI, drainage density, and SPI as these parameters are all affected by water input while the LULC moderately influences the SPI, NDVI, drainage density, and TWI wherein LULC reflects human-environment interaction and is moderately dependent on the topographic and hydrological factors. Moreover, NDVI is strongly associated with LULC, TWI, and SPI where vegetation patterns flow land use and moisture which indirectly shows effects on terrain and water availability while the drainage density is influenced by rainfall, TWI, SPI, and LULC indicating its critical role and effects on erosion especially where drainage development is dynamic. Lastly, soil is moderately influenced by elevation, distance to river, LULC, NDVI and SPI wherein soil properties are tied both natural and anthropogenic factors. Results from the study of (Nile 2018) have indicated hydrological parameters like rainfall and indicated that the increase in discharge values which may occur through a higher rainfall intensity. On the other hand, a range of parameters influenced the geomorphic role of the flood, and a series of selected morphological and hydraulic controlling factors showed robust correlations with changes in the channel width and were stronger in alluvial sub-reaches (Righini et al. 2017)

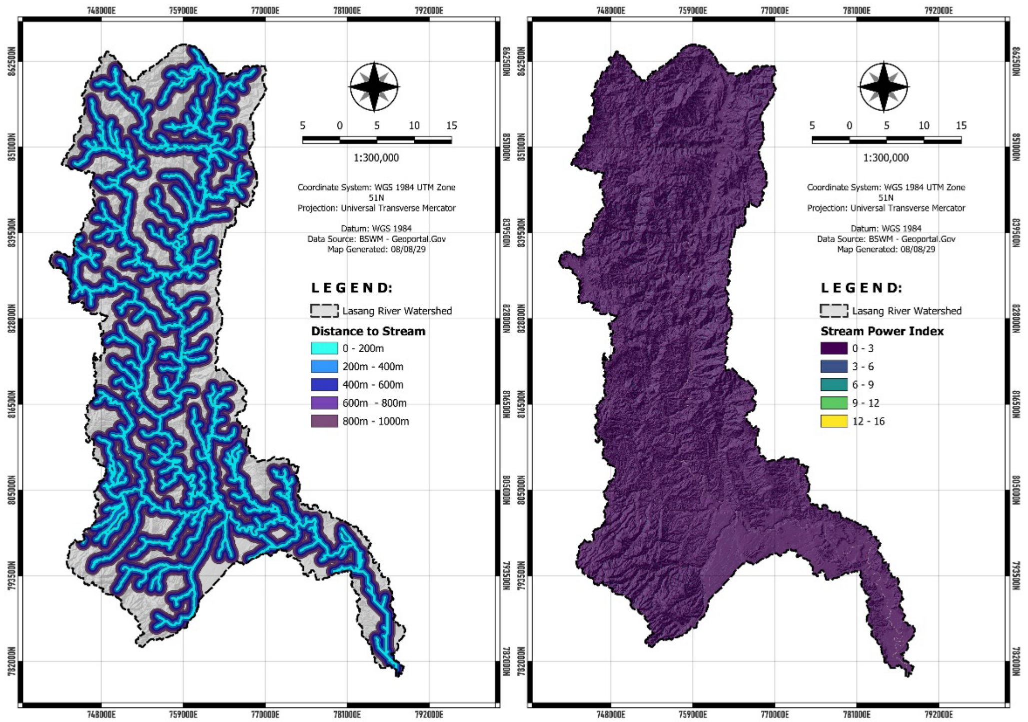

Figure 6. The distance to stream and stream power index.

Table 11. The pairwise comparison matrix of relationships between variables.

Parameters	Elevation	TWI	Distance to river	SPI	Slope	Rainfall	LULC	NDVI	Drainage density	Soil
Elevation	1	3	3	3	1	3	3	3	3	3
TWI	.33	1	.5	1	.20	.20	.33	.33	.20	.33
Distance to river	.33	2	1	3	.33	.33	3	3	1	2
SPI	.33	1	.33	1	.33	.20	.33	.33	.33	3
Slope	1	5	3	3	1	5	3	3	3	3
Rainfall	.33	5	3	5	0	1	3	3	5	3
LULC	0	3	.33	3	.33	.33	1	.33	.33	1
NDVI	0	3	0	3	0	.33	3	1	1	1
Drainage Density	0	5	1	3	0	.20	3	1	1	3
Soil	0	3	1	.33	.33	.33	1	1	.33	1
	4.67	31	13.00	25.33	4.40	10.93	20.67	16.00	15.20	20.33

Table 12 presents the normalized pairwise matrix and the ranks and weights of variables used to assess flood susceptibility of Davao River Watershed as shown Figure 7. Results have slope with weights of 20.87 rank as the most influential variable where steeper slopes can enhance runoff velocity, followed elevation with 18.39 indicating low lying areas are more prone to flooding, rainfall with 16.07 indicating prolonged rainfall as trigger factor for factor flooding. Moreover, drainage density ranked 4 with 9.43 as areas with higher drainage density have quicker runoff response, followed distance to river 9.34 as proximity to river increases flood risks, NDVI with 7.41 wherein dense vegetation reduces flood risks enhancing infiltration and intercepting rainfall, LULC with 5.59 as land use strongly affects hydrological response triggered by increasing urbanization with high increased impervious surfaces, soil with 5.08 where soil texture and structure influences water retention and infiltration, and SPI with 4.69 in which SPI related to erosive potential and flow energy indicating areas with high SPI can contribute to erosion and sedimentation. Lastly the least influential variable for flood susceptibility in Davao River Watershed is TWI with 3.12. Though ranks the least, it still aids in identifying zones of saturation zone that could become flood prone. According to Ahmed et al (2022) the understanding of flood hydrology and geomorphic changes and develop an accurate flood susceptibility map as a tool to understand and manage flood risks. According to Alam (2020) the geomorphological analysis is crucial on hydrological response of the drainage basins to high rainfall events, and the morphometric attributes of a drainage basin reveal the hydrological and morphological dynamics of an area (Soomro et al. 2022). The result of this study corroborates with the findings of (Aydin & Iban 2022) indicating elevation and slope, and distance to streams as the top contributing factors in determining flood susceptible areas and areas such as lower elevation, lower slopes, areas closer to riverbanks, agricultural areas, and sparsely vegetated areas are more prone to flooding.

Table 12. The normalized pairwise matrix of weights and ranks of variables.

Parameters	Elevation	TWI	Distance to river	SPI	Slope	Rainfall	LULC	NDVI	Drainage density	Soil	Weights	Rank
Elevation	.21	.10	.23	.12	.23	.27	.15	.19	.20	.15	18.39	2
TWI	.07	.03	.04	.04	.05	.02	.02	.02	.01	.02	3.12	10
Distance to River	.07	.06	.08	.12	.08	.03	.15	.19	.07	.10	9.34	5
SPI	.07	.03	.03	.04	.08	.02	.02	.02	.02	.15	4.69	9
Slope	.21	.16	.23	.12	.23	.46	.15	.19	.20	.15	20.87	1
Rainfall	.07	.16	.23	.20	.05	.09	.15	.19	.33	.15	16.07	3
LULC	.07	.10	.03	.12	.08	.03	.05	.02	.02	.05	5.59	7
NDVI	.07	.10	.03	.12	.08	.03	.15	.06	.07	.05	7.41	6
Drainage Density	.07	.16	.08	.12	.08	.02	.15	.06	.07	.15	9.43	4
Soil	.07	.10	.04	.01	.08	.03	.05	.06	.02	.05	5.08	8

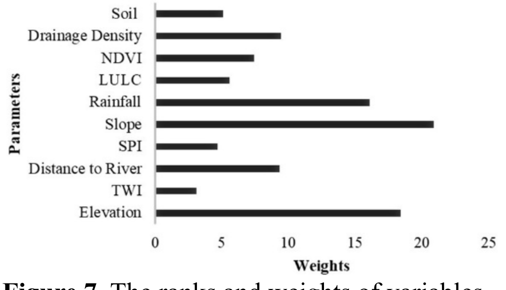

Figure 7. The ranks and weights of variables.

Table 13 presents the flood susceptibility of the Davao River watershed. Data have shown 59.98% of the total land area within the Davao River watershed is classified as moderately susceptible to flood, which covers a total land area of 103,983 ha, followed by very low susceptibility with 24.77% or 42,950.38 ha, low susceptibility with 13,620.89 or 7.86% of the total land area, high with 7.39% or 12,804.72 ha and the least is categorized as very high susceptible which accounts the .01%

or 16.21 ha of the total land area. This implies that most of the area of the Davao River watershed is not highly vulnerable to flood but could be affected if conditions change, such as events of extreme rainfall, deforestation, and land use changes. Moreover, high and very high susceptibility zones concentrated along the main river channels, and their immediate surroundings indicate the likelihood of bank overflow and the potential for significant flood impacts on adjacent areas. Data from the study of (Zhu et al. 2024) have revealed that the rising intensity and frequency of extreme precipitation as well as increase in the impervious surface areas were identified as a critical factor that heightened flood susceptibility. On the other hand, current study demonstrates the capability of sub-watershed drainage morphometric investigations in the flood susceptibility analysis (Jothimani et al. 2021), and geomorphometric characteristics can be utilized to determine watersheds hydrological characteristics and behavior (Narendra et al. 2024)

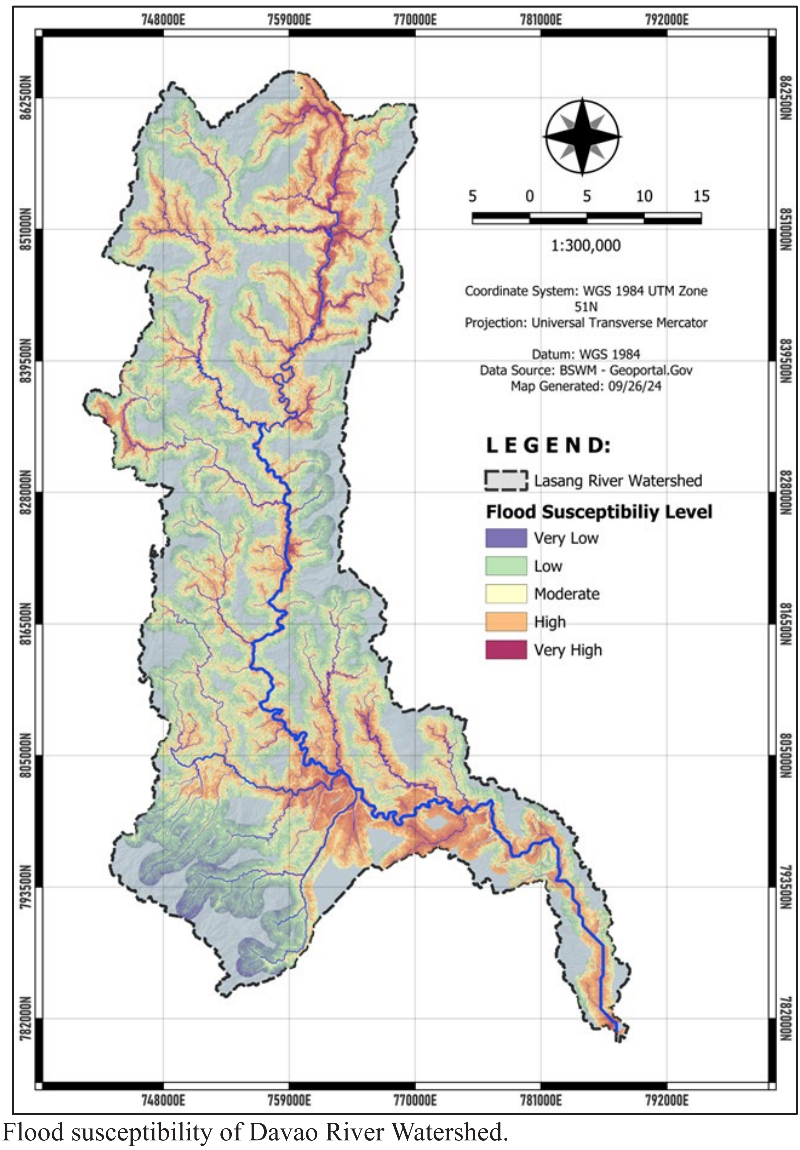

Figure 8. Flood susceptibility of Davao River Watershed.

Table 13. The flood susceptibility of Davao River Watershed.

Susceptibility Value	Susceptibility Class	Area (*ha*)	Area in (%)
1	Very Low	42950.38	24.77
2	Low	13620.89	7.86
3	Moderate	103983.78	59.98
4	High	12804.72	7.39
5	Very High	16.21	.01
	Total	173,376.00	100.00

CONCLUSIONS

Based on the results of the analysis of various parameter to examine the susceptibility of the Davao River Watershed. Data has shown that it exhibits diverse hydrological geomorphological features that can potentially contribute to the susceptibility of some areas to flooding. Results have revealed varied influences between and among geomorphological and hydrological parameters being analyzed. It also shows that slope has been the most influential variable with computed weight of 20.87 and the least was TWI with 3.12. Data have identified 59.98 of the areas within the Davao River Watershed are classified moderately susceptible to flood, necessitating preventive measures focusing on land management and conservation efforts to reduce vulnerability while increasing resilience and ecological health within the nearby communities. The flood susceptibility maps play a critical role in environmental and urban planning particularly in the early identification of high-risk areas, guiding development away from vulnerable zones and designing resilient infrastructures.

REFERENCES

Ahmed A., Alrajhi A., Alquwaizany A., Al Maliki A., Hewa G. 2022. Flood susceptibility mapping using watershed geomorphic data in the Onkaparinga Basin, South Australia. *Sustainability* 14(23): 16270. https://doi.org/10.3390/su142316270

Alam A., Ahmed B., Sammonds P. 2021. Flash flood susceptibility assessment using the parameters of drainage basin morphometry in SE Bangladesh. *Quaternary International* 575: 295–307. https://doi.org/10.1016/j.quaint.2020.04.047

Al-Juaidi A.E.M. 2023. The interaction of topographic slope with various geo-environmental flood-causing factors on flood prediction and susceptibility mapping. *Environmental Science and Pollution Research* 30(21): 59327–59348. https://doi.org/10.1007/s11356-023-26616-y

Aryee J.N.A., Afrifa F.O.T., Agyapong K.H., Gyau Frimpong N.A., Quagraine K.T., Davies P. 2024. Quantifying climatic heavy-precipitation-induced floods in West Africa using multiple precipitation indices. *Scientific African* 25. https://doi.org/10.1016/j.sciaf.2024.e02309

Aslantas B., Maleska V., Alvarez L.V., Babalola S.O. 2024. Flood risk assessment for Mulde River Catchment transferring data from an observed meteorological flood event. *Results in Engineering*. https://doi.org/10.1016/j.rineng.2024.103029

Aydin H.E., Iban M.C. 2023. Predicting and analyzing flood susceptibility using boosting-based ensemble machine learning algorithms with SHapley Additive exPlanations. *Natural Hazards*

116(3): 2957–2991. https://doi.org/10.1007/s11069-022-05793-y

Basri H., Syakur S., Azmeri A., Fatimah E. 2022. Floods and their problems: Land uses and soil types perspectives. In: IOP Conference Series: *Earth and Environmental Science*. 951(1): 012111. IOP Publishing. https://doi.org/10.1088/1755-1315/951/1/012111

Breugem A.J., Wesseling J.G., Oostindie K., Ritsema C.J. 2020. Meteorological aspects of heavy precipitation in relation to floods – An overview. *Earth-Science Reviews* 204: 103171. https://doi.org/10.1016/j.earscirev.2020.103171

Burayu D.G., Karuppannan S., Shuniye G. 2023. Identifying flood vulnerable and risk areas using the integration of analytical hierarchy process (AHP), GIS, and remote sensing: A case study of southern Oromia region. *Urban Climate* 51: 101640. https://doi.org/10.1016/j.uclim.2023.101640

Carlston C.W. 1966. The effect of climate on drainage density and stream flow. *International Association of Scientific Hydrology Bulletin* 11(3): 62–69. https://doi.org/10.1080/02626666609493481

Chaulagain D., Rimal P.R., Ngando S.N., Nsafon B.E.K., Suh D., Huh J.S. 2023. Flood susceptibility mapping of Kathmandu metropolitan city using GIS-based multi-criteria decision analysis. *Ecological Indicators* 154: 110653. https://doi.org/10.1016/j.ecolind.2023.110653

Convertino K.M., Baker J.T., Vogel C., Lu B., Suedel I., Linkov I. 2013. Multi-criteria decision analysis to select metrics for design and monitoring of sustainable ecosystem restorations. *Ecological Indicators* 26: 76–86. https://doi.org/10.1016/j.ecolind.2012.10.005

De Rosa P., Fredduzzi A., Cencetti C. 2019. Stream power determination in GIS: An index to evaluate the most 'Sensitive' points of a river. *Water* 11(6): 1145. https://doi.org/10.3390/w11061145

Jothimani M., Dawit Z., Mulualem W. 2021. Flood susceptibility modeling of Megech river catchment, Lake Tana basin, north western Ethiopia, using morphometric analysis. *Earth Systems and Environment* 5(2): 353–364. https://doi.org/10.1007/s41748-020-00173-7

Khosravi K., Nohani E., Maroufinia E., Pourghasemi H.R. 2016. A GIS-based flood susceptibility assessment and its mapping in Iran: A comparison between frequency ratio and weights-of-evidence bivariate statistical models with multi-criteria decision-making technique. *Natural Hazards* 83: 947–987. https://doi.org/10.1007/s11069-016-2357-2

Kim J., Park J., Park S., Kang J. 2024. Enhancing water management and urban flood resilience using Hazard Capacity Factor Design (HCFD) model: Case study of Eco-Delta city, Busan. *Sustainable Cities and Society* 115: 105851. https://doi.org/10.1016/j.scs.2024.105851

Latue P.C., Rakuasa H. 2023. Identification of flood-prone areas using the topographic wetness index method in Fena Leisela district, Buru Regency. *Journal Basic Science and Technology* 12(2): 20–24. https://doi.org/10.35335/jbst.v12i1.3673

Li J., Yuan D., Liu J., Ma M., Li Y. 2023. Evaluating the effects of water exchange between surface rivers and karst aquifers on surface flood simulations at different watershed scales. *Journal of Hydrology* 623: 129851. https://doi.org/10.1016/j.jhydrol.2023.129851

Mahmoud S.H., Gan T.Y. 2018. Multi-criteria approach to develop flood susceptibility maps in arid regions of Middle East. *Journal of Cleaner Production* 196: 216–229. https://doi.org/10.1016/j.jclepro.2018.06.047

Mehta D., Dhabuwala J., Yadav S.M., Kumar V., Azamathulla H.M. 2023. Improving flood forecasting in Narmada river basin using hierarchical clustering and hydrological modelling. *Results in Engineering* 20: 101571. https://doi.org/10.1016/j.rineng.2023.101571

Miranda F., Franco A.B., Rezende O., da Costa B.B., Najjar M., Haddad A.N., Miguez M. 2023. A GIS-based index of physical susceptibility to flooding as a tool for flood risk management. *Land* 12(7): 1408. https://doi.org/10.3390/land12071408

Moglen G.E., Eltahir E.A., Bras R.L. 1998. On the sensitivity of drainage density to climate change. *Water Resources Research* 34(4): 855–862. https://doi.org/10.1029/97WR02709

Narendra B.H., Setiawan O., Hasan R.A., Siregar C.A., Prativi, Sari N., Sukmana A., Dharmawan I.W.S., Nandini R. 2024. Flood susceptibility mapping based on watershed geomorphometric characteristics and land use/land cover on a small island. *Global Journal of Environmental Science and Management* 10(1): 301–320. https://doi.org/10.22034/gjesm.2024.01.19

Nile B.K. 2018. Effectiveness of hydraulic and hydrologic parameters in assessing storm system flooding. *Advances in Civil Engineering* 2018(1): 4639172. https://doi.org/10.35335/jbst.v12i1.3673

Rashidiyan M., Rahimzadegan M. 2024. Investigation and evaluation of land use–land cover change effects on current and future flood susceptibility. *Natural Hazards Review* 25(1): 04023049. https://doi.org/10.1061/NHREFO.NHENG-1854

Righini M., Surian N., Wohl E., Marchi L., Comiti F., Amponsah W., Borga M. 2017. Geomorphic response to an extreme flood in two Mediterranean rivers (northeastern Sardinia, Italy): Analysis of controlling factors. *Geomorphology* 290: 184–199. https://doi.org/10.1016/j.geomorph.2017.04.014

Samanta S., Pal D.K., Palsamanta B. 2018. Flood susceptibility analysis through remote sensing, GIS and frequency ratio model. *Applied Water Science* 8(2): 66. https://doi.org/10.1007/s13201-018-0710-1

Shah S.A., Ai S. 2024. Flood susceptibility mapping contributes to disaster risk reduction: A case study in Sindh, Pakistan. *International Journal of Disaster Risk Reduction* 108: 104503. https://doi.org/10.1016/j.ijdrr.2024.104503

Soomro S.E.H., Hu C., Boota M.W., Ahmed Z., Chengshuai L., Zhenyue H., Soomro M.H.A.A. 2022. River flood susceptibility and basin maturity analyzed using a coupled approach of geo-morphometric parameters and SWAT model. *Water Resources Management* 36(7): 2131–2160. https://doi.org/10.1007/s11269-022-03127-y

Viezzer J., Schmidt M.A.R., dos Reis A.R.N., Freiman F.P., de Moraes E.N., Biondi D. 2022. Restoration of urban forests to reduce flood susceptibility: A starting point. *International Journal of Disaster Risk Reduction* 74: 102944. https://doi.org/10.1016/j.ijdrr.2022.102944

Vojtek M., Vojteková J. 2019. Flood susceptibility mapping on a national scale in Slovakia using the analytical hierarchy process. *Water* 11(2): 364. https://doi.org/10.3390/w11020364

Zhu K., Wang Z., Lai C., Li S., Zeng Z., Chen X. 2024. Evaluating factors affecting flood susceptibility in the Yangtze River delta using machine learning methods. *International Journal of Disaster Risk Science* 15(5): 738–753. https://doi.org/10.1007/s13753-024-00590-6

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