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# GIS-Based site selection for Rainwater Harvesting (RWH) systems in Davao City Philippines

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## ABSTRACT

The looming water crisis and environmental problems aggravated by climate change, such as flooding, the implementation of RWH systems for different applications is deemed an effective solution, especially for areas with abundant rainfall, such as Davao City. This study utilized QGIS to map suitable site for open area rainwater harvesting (RWH) systems in Davao City, Philippines. This study aimed to identify potential location sites for RWH systems in Davao City by producing suitability maps using weighted overlay analysis. The Weighted Overlay Analysis was implemented to produce a suitability map based on the assigned weights of datasets to influence the overall RWH suitability. The datasets employed include slope, rainfall, land use, soil type, and lineament density. Findings show that the very highly suitable areas for RWH systems are located mostly in the districts of Marilog, Baguio, Calinan, Paquibato and some parts of Tugbok. In addition to the same districts, Calinan, and Tugbok have highly suitable areas for the RWH system. Unsuitable areas, or areas that were not recommended to implement RWH systems were concentrated in the district of Agdao, Buhangin, Bunawan, and Poblacion, where urban areas are located. The resulting suitability map can benefit the local authorities and planners in implementing RWH systems for the development of city's agriculture in water resource conservation, and flood management, supporting sustainable development and climate resilience in Davao City.

*Keywords:* Inverse Distance Weighting (IDW) interpolation, rainfall, remote sensing, weighted overlay analysis

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## INTRODUCTION

Water is the most essential element for human life. Due to population growth and the high demand for water in various places for more purposes, the world's water resources are currently under increasing pressure (Government of Newfoundland and Labrador, 2019). This rapid use of natural resources leads to poor quality and scarcity of groundwater ecology, and severe intrusion of seawater in coastal areas seawater in coastal areas (D'Silva et al., 2021). Further, there is a possibility of water scarcity that is expected to worsen during the dry seasons. With this, the Intergovernmental Panel on Climate Change or IPCC (2007) emphasized that one of the possible effects of an increase of 1°C in temperature is the declining water availability. This amplifies the demand for alternative and sporadic water sources, like rainwater harvesting (Lumbera et al., 2023).

Philippines with an average annual rainfall of 1835.5 mm representing a 30-year period from 1991-2020, rainwater harvesting systems have the potential to be implemented for various applications in areas with abundant rainfall (Kapli et al., 2023). Recently, some countries have used rainwater harvesting systems to provide alternative water supply sources for various purposes such as in the United Kingdom, Portugal, Malaysia, and cities in Indonesia. Rainwater harvesting systems in Semarang, Indonesia, are used as a supplementary source of clean water rather than a main source (Mukaromah, 2020). Given the long history, many frameworks have been used over the last few decades, each with its own criteria to identify and rank sites of rain harvesting, a process which is critical in order to improve and maintain water resources, especially in arid and semiarid regions where (Ahmed et al., 2023). Separate RWH investigations in Cebu and in Manila have established that RWH systems, in general, may help to find solutions for urban flooding, as well as to the imminent water crisis, and may be used for groundwater recharge (Bañados and Quijano, 2022; Necesito, 2013).

Davao City recognized the need to promote proper harvesting, utilization, and storage of rainwater by establishing the Davao City Ordinance No. 0298-09 also known as the Davao City Rainwater Ordinance of 2009, which sought to mainstream the use of RWH systems throughout the city considering the impending water crisis and the abundant rainfall of Davao City. It is among the proposed climate-adaptive interventions for climate hazards in Davao City, which is within the scope of the rainwater harvesting Ordinance by Davao City LGU as one of its current initiatives toward ecological environmental stability (Institute for Global Environmental Strategies, 2020).

The Water Summit hosted by Hydrology for Environment, Life, and Policy Davao Network (HELP Davao Network), the International Center for Water Hazard and Risk Management Japan (ICHARM Japan), and the Department of Science and Technology XI raised the issues of water challenges posed by the climate change and urbanization of Davao City. One of the major issues raised is the problem of agricultural wastes that runoff and contaminate the water sources (Rebuelta, 2023). The increasing danger of further climate change, especially following the persistent destruction of water recharge sites in upland areas, considers RWH for its potential to deliver water supply and stormwater management, soil and water conservation, reduction of the high inflows and flood potential, and replenishment of aquifers (IPCC, 2007; Patel et al., 2021; Quinn et al., 2021).

The study of Lumbera et al. (2023) has recognized the need for further investigations on RWH systems in the country. On top of this, the country harvests only 6% of its rainfall (Department of Agriculture, 2019), and there hasn't been any substantial research on RWH in Davao City despite the call for investment towards

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sustainability regarding the city's water resources. This calls for more research endeavors and more green technologies to be used, such as rainwater harvesting, as declared by D'silva et al. (2021).

In recent decades, many countries have supported updated implementation of this practice due to new technological possibilities to address the rise in water demand pressures caused by climatic, environmental, and societal changes. With today's technological development, such a challenge in water resources necessitates the use of Geographic Information Systems (GIS) to identify suitable locations of rainwater harvesting systems due to its excellent tools in water management studies for more accurate and effective analysis (Elewa et al., 2012; Buraihi and Shariff, 2015).

In this regard, the study intends to demonstrate a weighted overlay analysis as an application of GIS-based utilization in generating suitable site for RWH systems. The outcome of this research seeks to produce a map showing suitable sites for on-land RWH systems in Davao City. More importantly, the lack of comprehensive research on RWH in Davao City drives the present study to contribute to the research field regarding water resources management as a partial solution to the looming water crisis. Likewise, considering effective, influential parameters and appropriate methodology, this study will guide decision-makers, local officials, and other concerned individuals in water resources management efforts.

## MATERIALS AND METHODS

### Study area

Davao City is located on the southeast coast of Mindanao which is extended by mountain ranges having unequal distribution of lowlands and plateaus in most parts. It is divided into eleven administrative districts namely, Poblacion, Talomo, Agdao, Buhangin, Bunawan, Paquibato, Toril, Tugbok, Calinan, Marilog, and Baguio. The adjoining lowland of the city consists of coastal lowlands and gently rising valleys with a slope varies from zero to three percent (0-3%), with a predominant composition of silt and clay, and some areas are composed of sand and gravel (OCPDC, 2021). Its climate is categorized by PAGASA (2021) as mild tropical, where in it is mostly sunny compared to other parts of the Philippines.

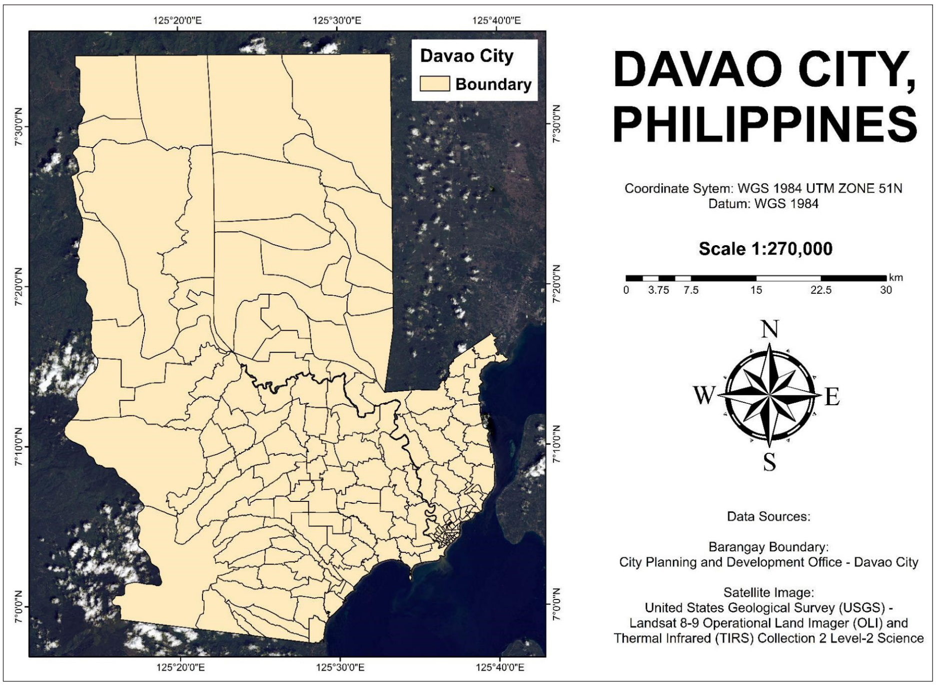

**Figure 1.** Map of the study area.

## Data requirement

In this study, the researchers made use of secondary data in the process to identify suitable sites for rainwater harvesting systems. Secondary data, in this context, consist of spatial data acquired from concerned government agencies through formal letters of request, and other datasets such as the digital elevation model (DEM) and rainfall data were obtained through publicly accessed online portals of the government and other agencies outside the Philippines.

The spatial datasets used in this study include the Comprehensive Land Use Plan and the fault map from the Office of the City Planning and Development Coordinator (OCPDC) through their GIS Section, soil type from the Department of Environment and Natural Resources through the Mines and Geosciences Bureau (DENR-MGB), and climatological normals (rainfall) of sixteen different weather stations from the PAGASA. The DEM is acquired online from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) of the National Aeronautics and Space Administration (NASA). ASTER DEMs are produced with 30m postings and have Z accuracies generally between 10 m and 25 m root mean square error (RMSE) (ASTER GDEM, 2009). Table 1 enumerates the list of data and the respective data sources.

**Table 1.** List of datasets and data sources.

| Data | Data source | Data format |
|---|---|---|
| Comprehensive land use plan (2019-2028) | Office of the City Planning and Development Coordinator (OCPDC) - GIS section | Shape file |
| Rainfall data | Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) | Tabular data |
| Barangay boundary of Davao City | Office of the City Planning and Development Coordinator (OCPDC) - GIS section | Shape file |
| Digital Elevation Model (DEM) | National Aeronautics and Space Administration (NASA) - Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) | Raster |
| Soil type | Department of Environment and Natural Resources - Mines and Geosciences Bureau (DENR-MGB) | Shape file |
| Fault map | Office of the City Planning and Development Coordinator (OCPDC) - GIS section | Shape file |

## Criteria selection and GIS processing data

The sites for RWH systems should ideally be in open areas with low infiltration capacities (Bañados and Quijano, 2022) hence, incorporating the most important factors for this site suitability study. A total of five (5) parameters were considered, namely, rainfall, slope, soil type, land use, and lineament density, all of which have corresponding levels of influence, which were adopted from the study of Jayswal et al. (2023) conducted in India. Jayswal et al. (2023) justified the consideration of these parameters in accordance with the guidelines of the Food and Agriculture Organization (FAO) for RWH site selection. Rainfall was chosen as a parameter for climate, slope as a parameter for topography, land use as a parameter for agronomy, soil type as a parameter for soils, and lineament density as a parameter for hydrology. The weightage for each parameter in the current study was adopted from the results of AHP performed by Jayswal et al. (2023). While the methods align with the established criteria for RWH system site suitability, its direct application introduces limitations due to differences in local conditions such as climate and land use patterns. The outline of this study to generate the suitability maps is demonstrated in Figure 2.

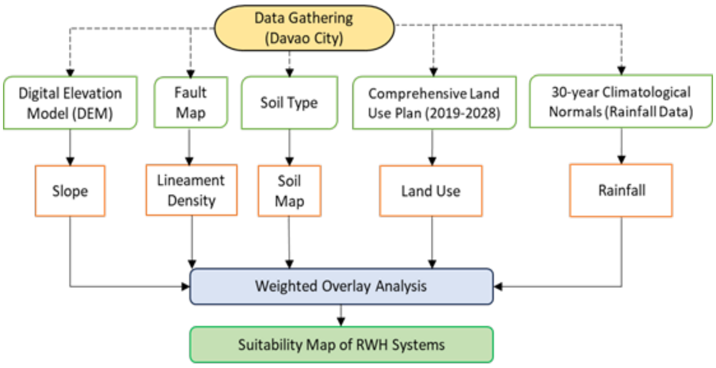

**Figure 2.** The methodological framework for the site suitability mapping for RWH systems in Davao City.

In the process of site suitability using GIS techniques, the steps involve selecting specific criteria, determining the degree to which each criterion is justified, selecting appropriate locations for rainwater harvesting, and developing suitability maps. With GIS processing, the decision-making process is seamless with the representations of such data integrated (Preeti et al., 2023). It is considered how each criterion affects the identification of suitable areas for on-land rainwater harvesting in Davao City. The description, justification, and identification of the parameters used for the suitability study are laid out below. His study utilized the Weighted Overlay Analysis by GIS in order to generate the suitability map and show the suitable locations for RWH Systems in Davao City, the outline of which is demonstrated in Figure 2.

***Criteria 1. Rainfall.*** The assessment of reliable precipitation parameters has been an important challenge in all water resource management studies, besides the different temporal and spatial accuracy of data. The selection of RWH sites is influenced by the amount of rainfall. In view of the fact that it can help tackle water scarcity in large quantities, a geological potential site with an abundance of rainfall is economically and technically feasible (Taher et al., 2022). As explained by Al-Adamat (2008), the main component of all water harvesting systems is rainfall. In any particular area, abundant rainfall indicates higher possibilities of harvesting part of it.

In this study, the Climatological Normals of rainfall from sixteen (16) weather stations gathered from the PAGASA, representing the long-term averages over a 30-year period from 1991-2020, were utilized. As explained by ClimateData.ca (2023), it is recommended to use data spanning at least 30 years in making decisions that take into account future climate change. The same source stated that the World Meteorological Organization updates its climate normals at the end of each decade, and believes that a 30-year period is the minimum needed to calculate the average climate. In generating the rainfall map, fifteen more weather stations outside the study area were taken into account, totaling sixteen (16) stations, including the station in Davao City. The latitude and longitude, the annual rainfall data from 1991-2020, and the number of rainy days of each station were in tabular form, added as points in the QGIS software. The IDW interpolation was performed with the processing extent following the boundary of Davao City from the OCPDC-GIS-Section. This resulted in a rainfall map of the study area divided into five different feature classes for the said parameter.

***Criteria 2. Slope.*** The suitable sites for rainwater harvesting are significantly influenced by slope on runoff and hydrological losses. Therefore, slope is also one of the critical factors of criteria for site selection. Khan et al. (2022) stated that surface runoff occurs more slowly in areas with gentle slopes than in higher slopes due

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to more time allowance for rainwater to percolate. Areas with a medium or low slope are more practical than those with a high slope because a sizeable amount of storage can be easily accommodated in smaller RWH structures (Critchley et al., 2013).

In this study, the researchers made use of the ASTER DEM that covers the study area, which was acquired from NASA Earthdata. It is noted that the datasets used contained vertical biases due to errors such as cloud masking, and huge leap of slope percentage due to large resolution (Abrams et al., 2020). To fill the gaps, the 30m pixel size ASTER DEM of the study area underwent cloud masking in QGIS. The two images were mosaicked and extracted by mask following the boundary of the area of interest, creating a unified and cohesive representation of the whole study area. Accordingly, the DEM undergoes Raster Terrain Analysis Slope in QGIS to derive the slope, the parameter of interest, of Davao City.

***Criteria 3. Soil type.*** It is an important parameter for a rainwater harvesting system suitable site since it influences infiltration and surface runoff behaviors (Setiawan and Nandini, 2022). According to Jha et al. (2014), clay soils that are naturally poorly drained produce more runoff than sandy soils. The soil map of the study area was derived from the map acquired from the DENR-MGB. Every soil type was in shapefile data format, which was then clipped to the boundary of the study area to produce the map.

***Criteria 4. Land use.*** The land use pattern affects the runoff and evapotranspiration of the study area and is a critical indicator when selecting suitable locations for rainwater harvesting (Kadam et al., 2012). The suitability of the land for water harvesting is influenced by the amount of vegetation. The LULC pattern has a significant impact on the water's hydrological response. Areas with higher vegetation coverage densities tend to have higher infiltration and abstraction rates (Setiawan and Nandini, 2022). In a prediction study on land use/land cover changein Davao City, the findings showed that in 2030, there will be a 0.34% decrease in water and a 3.25% decrease in crops. By 2050, their decrease will reach up to 0.53% and 3.32%, respectively (Dumdumaya and Cabrera, 2023). The same observation was noted by Mugo and Odera (2019) in their RWH study, that there has been a change in land use and cover of Kiambu County from agricultural use to residential/commercial use as a result of its growing population. Taking into account such a scenario in Kiambu County, diversifying water sources in order to address the rising water demand was deemed necessary in the area.

The land use map under this study was based on the Comprehensive Land Use Plan (2019-2028) provided by the OCPDC GIS Section. It was then manually reclassified by the researchers into three classes and given values. The Agriculture class is designated as low Suitable, comprises the Agricultural zone; the Forest class as unsuitable, which consists of Forest and Forestland Zone, and Water and Built-up as restricted, which includes the Buffer/Greenbelt Zone, Cemetery/Memorial Park Zone, Critical Watershed Zone, General Commercial Zone, General Industrial Zone, General Institutional Zone, General Residential Zone, Open Space/Easement Zone, Parks and Recreation Zone, Production Water Sub-Zone, Protected Water Sub-Zone, Tourism Development Zone, Utilities, Transportation, and Services Zone, and Waste Management, Treatment, Utilization, Disposal Zone.

***Criteria 5. Lineament density***. Lineaments are linear features in a landscape that represent underlying geological formations, like faults. Due to the weaker bedrock zones created by earth movement, surface runoff penetrates into the subsurface and forms lineaments. Tonal differences concerning other terrain surfaces allow for the identification of lineaments as linear, curvilinear, or rectilinear features from satellite imagery. An essential consideration when locating RWH sites is the lineament density.

Using the Fault Map provided by the OCPDC GIS Section, fault lines of the study area were traced. The Line Density Spatial Analyst tool is required to generate a lineament density map, which is done through GIS techniques (Mageshkumar et al., 2019). The generated map was reclassified lineament density into five classes, where the lowest class indicates a low concentration of lineaments, while the highest class signified areas with lineaments of high concentration. A region's high lineament density indicates numerous faults and significant changes in the direction of the lines, making the area unsuitable for storing water. This is due to the water being expected to either locate different drainage along the line direction or drain through the faults (Mugo and Odera, 2019). The formation of the rock strata, which is free of cracks, makes low lineament density good for storage and prolongs the time that water is kept in place (Yegizaw et al., 2022). As a result, areas with low lineament density were identified as highly suitable, while those with high lineament density were identified as unsuitable.

## Weighted overlay analysis

Prior to generating a suitability map for RWH systems, the obtained datasets underwent conversion into raster format, which enabled the data to become valid parameters for using the Weighted Overlay tool in the QGIS software. Using such a tool ascertained the overall impact of the parameters on identifying suitable locations of RWH systems. In doing so, all five (5) reclassified maps were added, each with a corresponding percentage level of influence. Site suitability is among the issues addressed by the use of the weighted overlay tool (Bañados and Quijano, 2022), which, when applied, overlays raster layers using a common measurement scale and weights each according to its significance. The outcome of the study conducted by Rahman et al. (2021) corroborates the method used as the various functions and tools made available by GIS software coupled with the weighted overlay analysis approach proved to be a practical means for selecting a new water reservoir site.

Corresponding weights are applied to each criterion as established by a previous study conducted by Jayswal et al. (2023). Similarly, Bañados and Quijano (2022) assigned different weights were assigned to each of the parameters in order to select suitable rainwater retention sites, since not all of the parameters had the same level of significance. Table 2 illustrates the distribution of levels of influence in percentage of each criterion.

**Table 2.** Weighted overlay analysis and % influence of parameters description by Jayswal et al. (2023).

| Criteria | Feature class | % Influence | Scale value |
|---|---|---|---|
| Rainfall | Less than 1800 mm; 1801-1900 mm; 1901-2000 mm; 2001 - 2100 mm; greater than 2100mm | 36 | 1;2;3;4;5 |
| Land use | Agriculture; Forest; Water and Built-up | 21 | 3;2;Restricted |
| Soil type | Clay; Clay Loam; Silty Clay Loam; Sandy Clay Loam; Mountain soil | 18 | 5;4;3;2;1 |
| Lineament density | 0-0.25; 0.26-0.45; 0.46-0.65; 0.66-0.85; > 0.85 | 13 | 5;4;3;2;1 |
| Slope | Less than 5%; 5–10%; 10-15%; 15-30%; Over 30% | 12 | 5;4;3;2;1 |

## RESULTS

Rainfall. In this study, the rainfall parameter bears a 36% weight. For the average annual distribution of Davao City, as seen in Figure 3, the northern area has higher values of rainfall which receives a greater than 2,100 mm amount of rainfall in the 30-year period while the lower region receives less than 1800 mm. The reclassified map, as seen in Figure 4, depicts the priority levels in each class. Notably, areas

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with the highest rainfall were accorded the highest priority, while those with the lowest rainfall received the lowest priority. The parts of the study region given with the highest priority, covering 10.37% of the total area, cover almost similar percentage of area as that of the lowest priority areas, with 10.63% cover. The areas designated as low priority have a substantial coverage area of 33.44%, or a third of the study area.

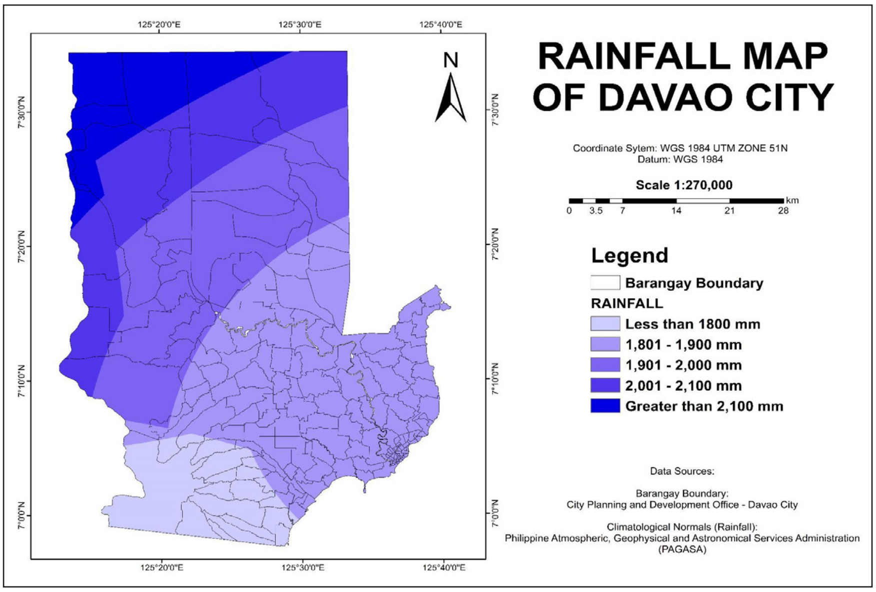

**Figure 3**. Rainfall map of Davao City.

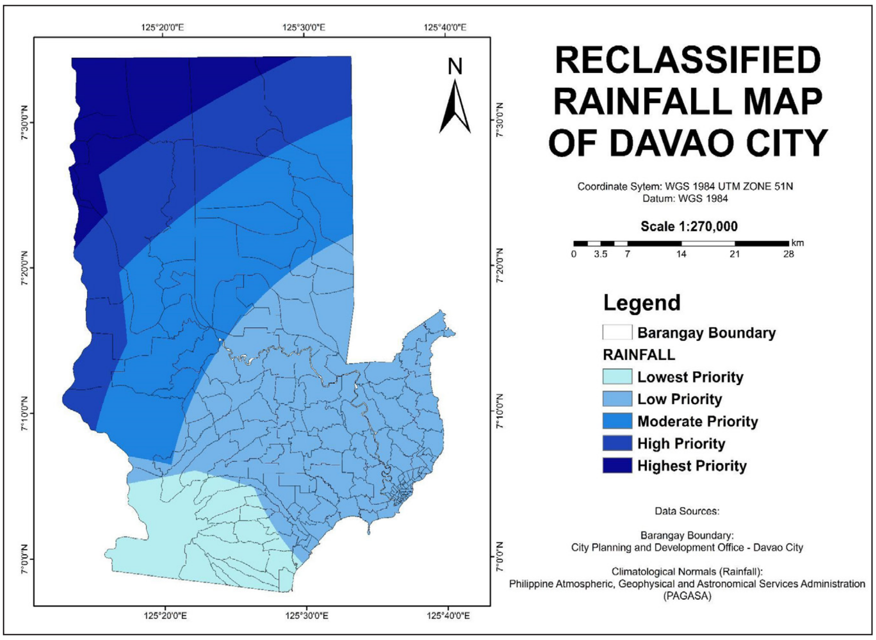

**Figure 4**. Reclassified rainfall map of Davao City.

**Table 3.** Distribution of rainfall into priority levels.

| Factor | Interval (mm) | Rate | Suitability | Coverage (ha) | Coverage (%) |
|---|---|---|---|---|---|
| Rainfall | > 1,800 | 1 | Lowest Priority | 25898 | 10.63 |
| | 1,801 - 1,900 | 2 | Low Priority | 81458 | 33.44 |
| | 1,901 - 2,000 | 3 | Moderate Priority | 63475 | 26.05 |
| | 2,001 - 2,100 | 4 | High Priority | 47546 | 19.52 |
| | < 2,100 | 5 | Highest Priority | 25253 | 10.37 |

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***Land use.*** The Land Use Map of Davao City is shown in Figure 5. The distribution of land use within Davao City covers 22.75% of Agricultural zone, 0.51% of Buffer/Greenbelt Zone, 0.09% of Cemetery/Memorial Park Zone, 2.47% of Critical Watershed Zone, 52.58% of Forest and Forestland Zone, 2.05% of General Commercial Zone, 1.39% of General Industrial Zone, 0.67% of General Institutional Zone, 6.52% of General Residential Zone, 4.55% of Open Space/Easement Zone, 0.17% of Parks and Recreation Zone, 0.06% of Production Water Sub-Zone, 1.07% of Protected Water Sub-Zone, 0.74% of Tourism Development Zone, 1.92% of Urban Ecological Enhancement Zone, 2.46% of Utilities, Transportation, and Services Zone, and 0.02% of Waste Management, Treatment, Utilization, Disposal Zone of the total area. From the reclassified map, it can be seen that restricted areas for RWH system concentrated in the southeast coastline areas where it is tickly populated and built-ups are present. Unsuitable areas were expected to crowd in the northern region where the forestlands were classified. Meanwhile low suitable areas were in between the unsuitable and restricted areas for RWH system establishment.

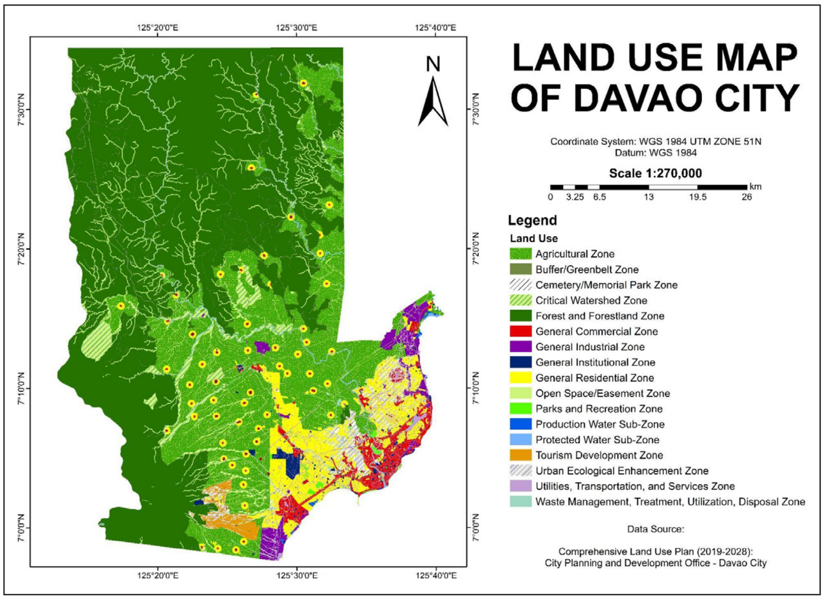

**Figure 5.** Land use map.

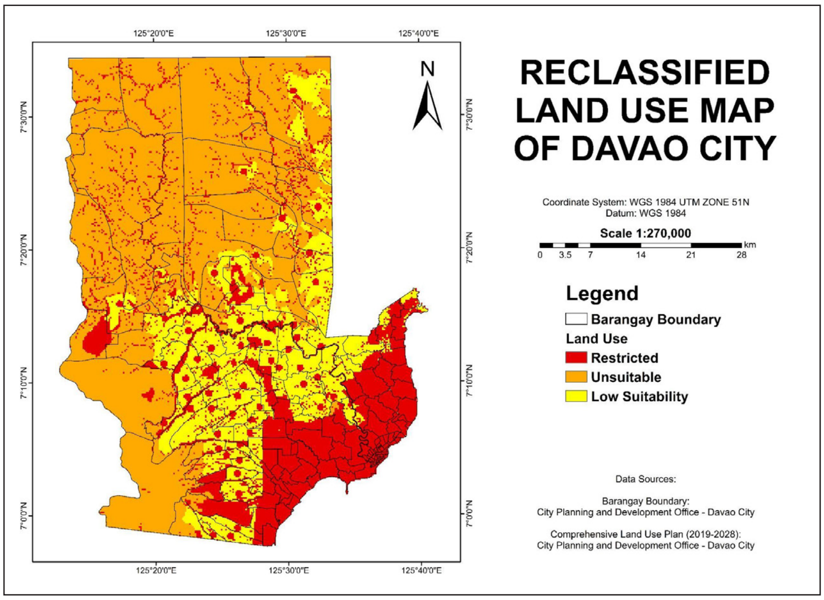

**Figure 6.** Reclassified land use map.

**Table 4.** Distribution of land use suitability classes.

| Factor | Feature class | Rate | Suitability | Coverage (ha) | Coverage (%) |
|---|---|---|---|---|---|
| Land use | Water and Built-up | 1 | Restricted | 57130 | 23.38 |
| | Forest | 2 | Unsuitable | 130741 | 53.50 |
| | Agriculture | 3 | Low Suitability | 56509 | 23.12 |

***Soil type.*** The soil type present in the study area is represented in Figure 7. The soil map displays the study area's variation of soil types, such as mountain soil, sandy clay loam, silty clay loam, clay, and clay loam. The dominant portion of the study area is clay (41.54%), followed by mountain soil (31.75%) and sandy clay loam (21.63%). A small portion of the study area is composed of clay loam (3.91%) and silty clay loam with the smallest coverage (1.18%). In Figure 8, the data were reclassified into five ranks based from their permeability. The reclassified map shown in Figure 8 was in accordance with the Soil Texture Triangle of the United States Department of Agriculture (USDA) that illustrates the percentage of clay, silt, and sand in soil, as referenced by Mechell and Lesikar (2008), that in the soil composed of significant amounts of clay or silt, the movement of water is restricted, hence more suitable for RWH.

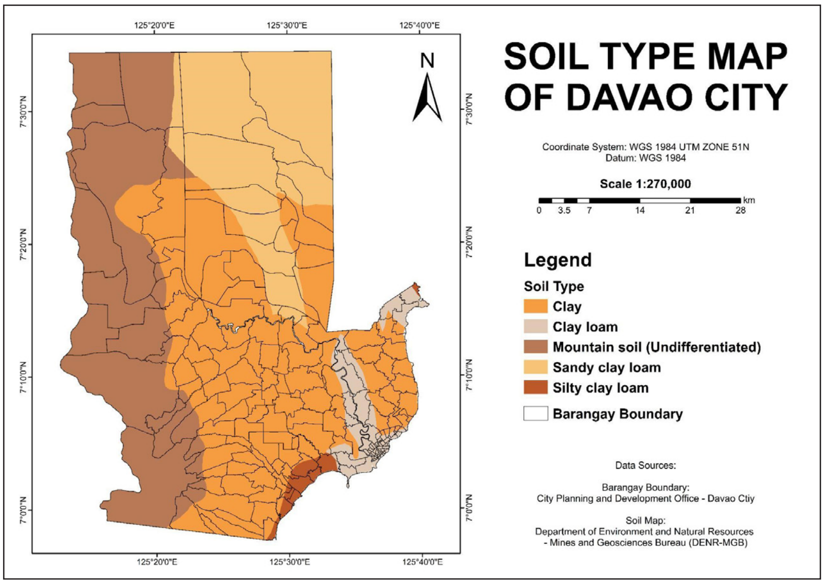

**Figure 7.** Soil type map.

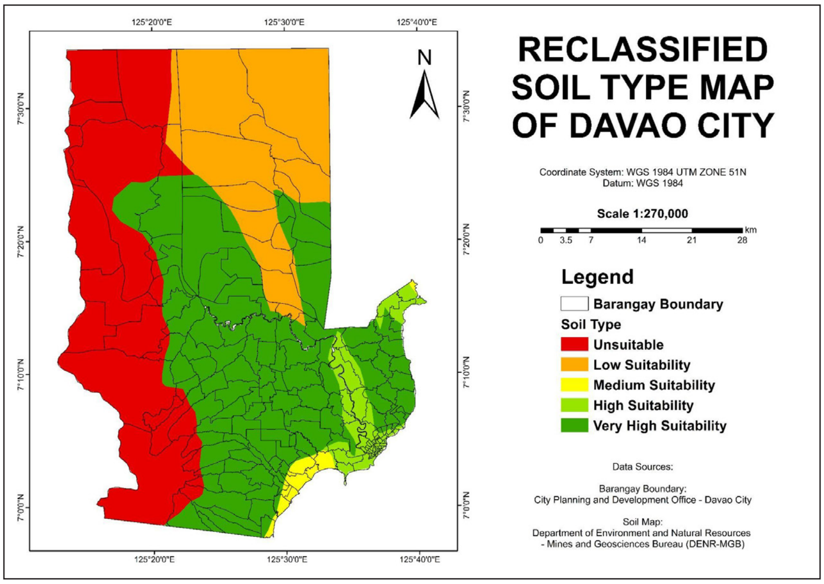

**Figure 8.** Reclassified soil type map.

**Table 5.** Distribution of soil types into suitability classes.

| Factor | Feature class | Rate | Suitability | Coverage (ha) | Coverage (%) |
|---|---|---|---|---|---|
| Soil type | Mountain soil | 1 | Unsuitable | 77321 | 31.75 |
| | Sandy clay loam | 2 | Low Suitability | 52676 | 21.63 |
| | Silty clay loam | 3 | Medium Suitability | 2886 | 1.18 |
| | Clay loam | 4 | High Suitability | 9511 | 3.91 |
| | Clay | 5 | Very High Suitability | 101162 | 41.54 |

***Lineament density.*** Figures 9 and Figure 10 show the Lineament Density and Reclassified Lineament Density Map of Davao City, respectively. In the Southwestern area, the density of lineaments is extremely high (>0.85). In the northern and southwestern region of the city accumulates 0-0.25 density values which is the lowest lineament density. It is later reclassified to differentiate the most suitable to unsuitable areas.

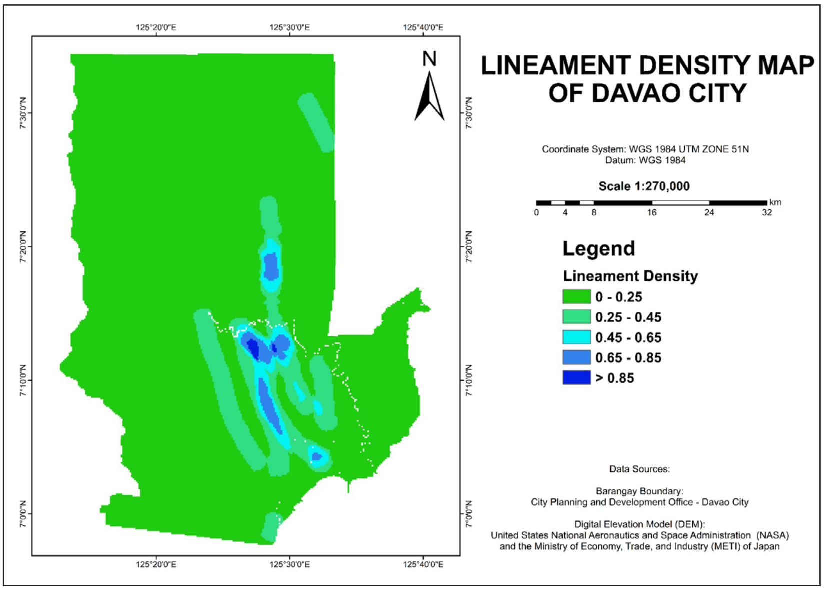

**Figure 9.** Lineament density map.

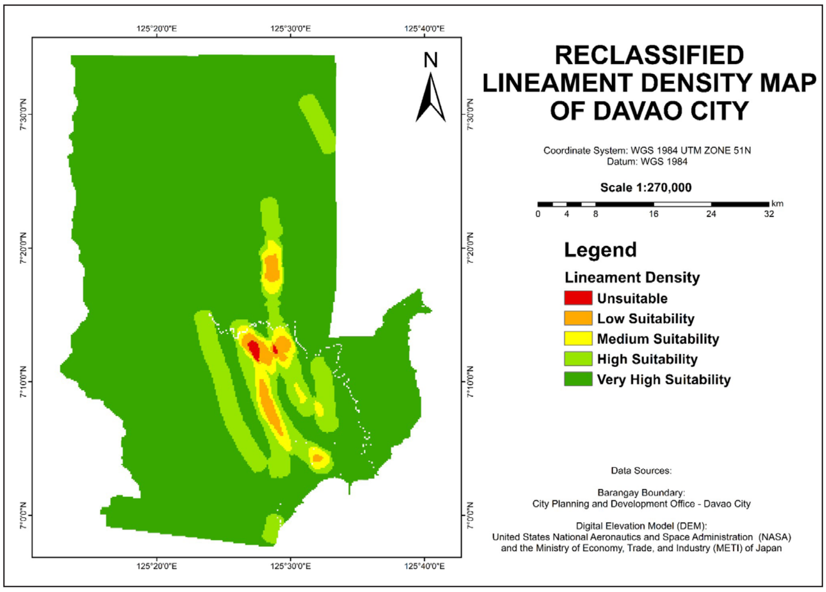

**Figure 10.** Reclassified lineament density map.

***Slope.*** The ASTER DEM produced a slope map with a GIS environment. As shown in Figure 11, slope variations in Davao City are presented in the slope map. The study area is categorized with 5 different slope percentages based on the study of Preeti et al. (2022). The five categories are distinguished with different percentage ranges: less than 5%, 5% to 10%, 10% to 15%, 15% to 30%, and over 30%.

Reclassification was carried out, and the five categories provided raster values of 1, 2, 3, 4, and 5, which were labeled as Unsuitable, Low Suitability, Medium Suitability, High Suitability, and Very High Suitability, respectively. Shown in Table 6 are the coverage areas that are unsuitable to very high suitability in placement for rainwater harvesting systems.

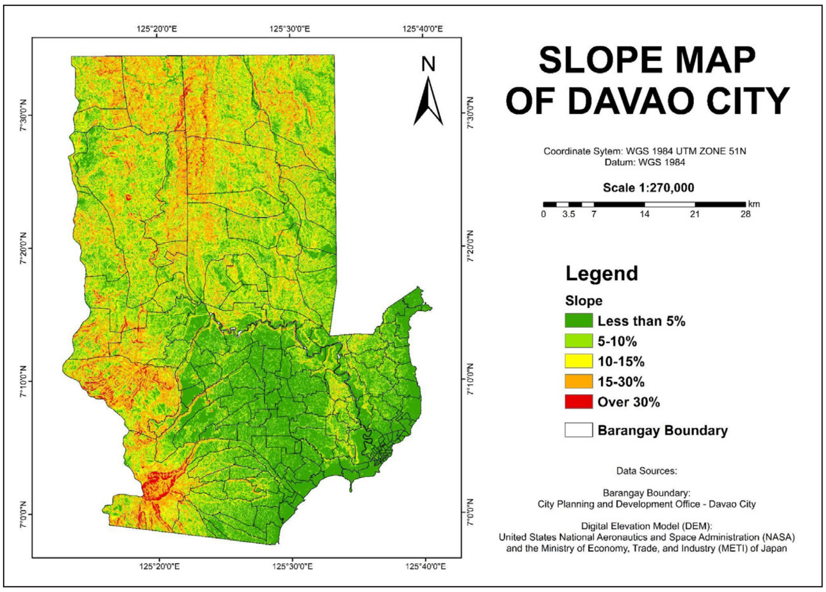

**Figure 11.** Slope map.

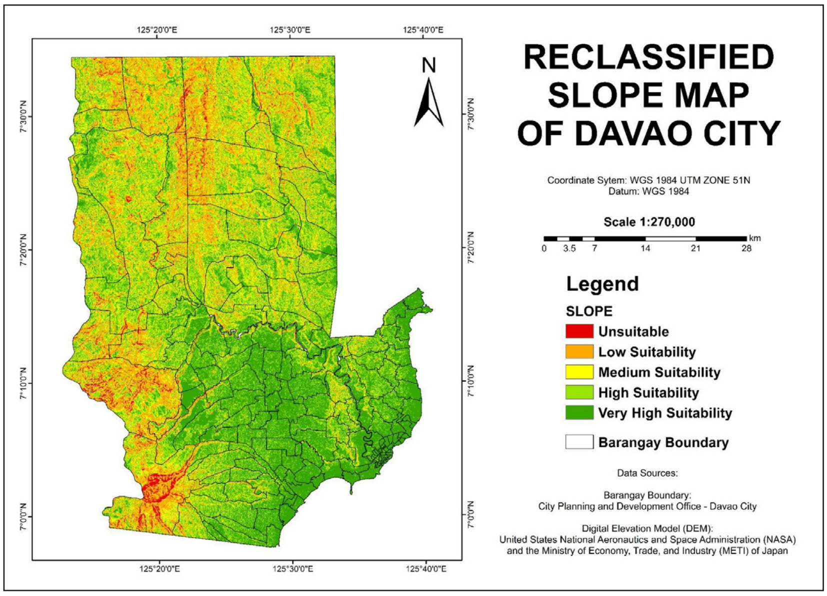

**Figure 12.** Reclassified slope map.

**Table 6.** Distribution of slope into suitability classes.

| Factor | Interval | Rate | Suitability | Coverage (ha) | Coverage (%) |
|---|---|---|---|---|---|
| Slope (%) | >30 | 1 | Unsuitable | 4723 | 1.94 |
| | 15-30 | 2 | Low Suitability | 44373 | 18.21 |
| | 10-15 | 3 | Medium Suitability | 44280 | 18.18 |
| | 05-10 | 4 | High Suitability | 72690 | 29.84 |
| | <5 | 5 | Very High Suitability | 77563 | 31.84 |

***Suitability Map for RWH Systems.*** By integrating the results of individual thematic maps of the five parameters as weighted according to the concept of weighted overlay analysis, an RWH suitability map has been generated. The study area is divided into areas based on suitability for rainwater harvesting systems. This resulted in a suitability map for RWH systems in Davao City, shown in Figure 13, with corresponding coverage for each suitability class illustrated in Table 7. The ranked criteria are classified into five (5) zones for RWH systems which are unsuitable, low suitability, medium suitability, high suitability, and very high suitability. Of the overall study area, the 'very high suitability' portion of the land comprises 15.47% that can be found in the areas of Marilog, Paquibato, Baguio, Calinan, and Tugbok districts. 23.40% of Davao City's area is considered unsuitable for RWH systems that are concentrated in the urban areas in Agdao, Poblacion, Buhangin, Bunawan, and Talomo districts. A portion of the unsuitable area can be also found in the districts of Toril, Tugbok, Calinan, and Baguio. The rest were scattered in the districts of Marilog and Paquibato. Moreover, portions with 'high suitability' dominate the study area with 54.40% coverage that were found in all of the district except Agdao, and Poblacion. Areas with 'medium suitability' have coverage of 6.74%, and no portion of the study area was classified under the 'low suitability' rank for the establishment of rainwater harvesting systems. The vicinity of Mt. Apo National Park was considered as one of the medium suitable areas that can be found in the district mostly in Toril, and some parts in Calinan and Baguio. There is also a concentrated medium suitable area in Paquibato district.

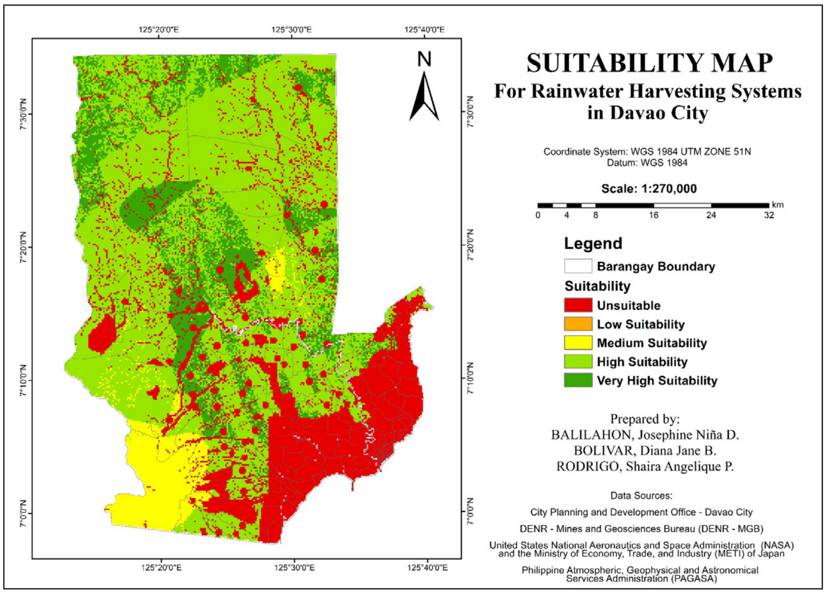

**Figure 13.** Suitability Map for RWH Systems in Davao City.

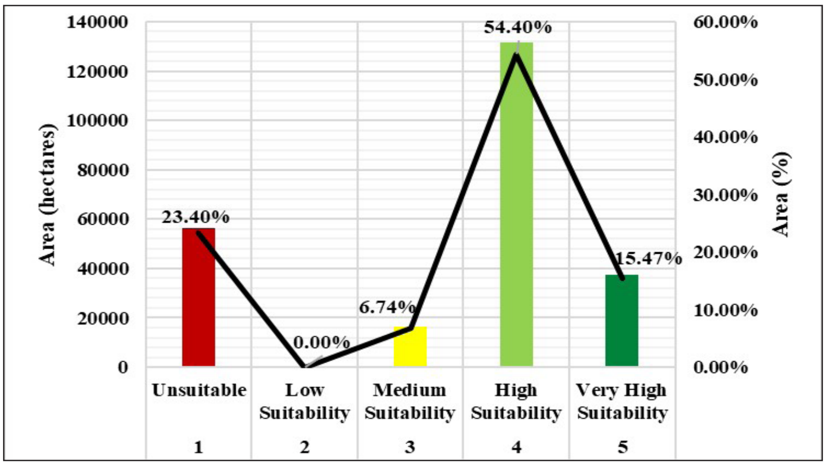

**Figure 14.** Distribution of area coverage of each RWH suitability class.

**Table 7.** Distribution of area coverage of each RWH suitability class.

| Rate | Suitability | Coverage (ha) | Coverage (%) |
|---|---|---|---|
| 1 | Unsuitable | 56536 | 23.40 |
| 2 | Low Suitability | 0 | 0.00 |
| 3 | Medium Suitability | 16278 | 6.74 |
| 4 | High Suitability | 131447 | 54.40 |
| 5 | Very High Suitability | 37389 | 15.47 |

## DISCUSSION

***Rainfall.*** Rainfall significantly influences the RWH suitability assessment, as it determines how much volume of rainwater is available for collection and storage. In the study area, the rainfall ranges from less than 1800 mm to more than 2100 mm, with the greatest amount of rainfall prioritized for RWH suitability. The adaptation of this classification was based on the study of Al-Shabeeb (2016) in using AHP for assessing which parameters influence more in locating potential sites for RWH in Azraq Basin, Jordan. Higher rainfalls are ideal due to increased potential for water storage. In addition, Adham et al. (2016) also claimed rainfall as a major component for the RWH system as it will be only functional if there is a sufficient volume of rainwater collected.

Furthermore, high rainfall also improves efficiency of RWH systems. Kapli et al. (2023) stated in their study that the potential benefit of installing an RWH system is highlighted by the high average annual rainfall, which generally indicates higher potential water savings from its implementation.

***Land use.*** It is noted that the Critical Watershed Zone is included as a restricted area for RWH site suitability in this context, in accordance with the Comprehensive Land Use Plan (2019-2028). As defined by the DENR Administrative Order No. 2021-41, a critical watershed is “a drainage area of a river system” supporting various works and facilities of different purposes needing “immediate protection.” According to the City Planning and Development Office of Davao City in its CLUP (2019-2028), critical watershed zones are “areas of land which show critical degradation as to threaten their natural feature on which rainwater drains from a river system to a common outlet such as a dam, lake or sea” and the only allowable uses/activities in the recognized critical watershed zones are reforestation and non-permanent early warning facilities/ structures. Thus, it receives classification as restricted for the RWH system. Built-up areas in the city were also classified as restricted for RWH systems due to the consideration that these areas constricted water harvesting sites (Jayswal et al., 2023). The Forestland/Forest areas of the study area are classified as unsuitable for RWH due to its hydrological and ecological functions. Forestlands exhibit high infiltration and abstraction rates due to dense vegetation and organic matter in the soil, which reduce surface runoff (Setiawan and Nandini, 2022). Kadam et al. (2013) emphasized in their study that dense vegetation in forest areas leads also to high evapotranspiration, along with lower surface runoff. This lowers its potential for suitable areas for the RWH system since this characteristic is critical for groundwater recharge and prevention for soil erosion. Thus, the researchers classified the forestland as unsuitable for preservation of ecological functions.

***Soil Type.*** As illustrated in Table 5, the soil types of the study area are reclassified into five ranks: with clay under the very high suitability class, clay loam under the high suitability class, silty clay loam under the medium suitability class, sandy clay loam under the low suitability class, and mountain soil (undifferentiated) under the unsuitable class. The reclassified map shown in Figure 8 was in accordance with the Soil Texture Triangle of the United States Department of Agriculture (USDA) that illustrates the percentage of clay, silt, and sand in soil, as referenced by Mechell and Lesikar (2008) that in the soil composed of significant amounts of clay or silt, the movement of water is restricted, hence more suitable for RWH.

Due to the low permeability of clay, allowing it to hold harvested water well, clay soils are the best for storing water. With the third largest coverage, the silty clay loam is considered suitable for RWH systems (Mbilinyi et al., 2007). Fine soils with a high water-holding capacity include silt and clay. A soil's surface area increases when the size of its particles, such as silt and clay, decreases. Consequently, soils with a larger surface area can hold more water, thus appropriate for RWH systems (Ball, 2001).

***Lineament density.*** An area's high lineament density indicates that there are numerous faults and sudden changes in linear alignment, which make the area unsuitable for storing water. This occurs as it is expected that water will either find a connected drainage channel along the line direction or drain through the faults (Jayswal et al., 2023). Most of the northern part of the city and the southwestern portion is where areas of the lowest lineament density, making it very highly suitable for water harvesting due to the rock strata structure formation that is free of cracks and allows for extended periods of storing water. Aligned with this, the results show that with the consideration of lineament density, high-density areas are the least suitable, and low-density areas are the most suitable (Mugo and Odera, 2019). A combination of high, moderate, and low lineament density concentrations can be found in the northern and mostly in southwestern parts of the study area. Jayswal et al. (2023) selected similar criteria for site selection for rainwater harvesting structures in the Dhatarwadi river basin in the Amreli district of the Saurashtra region of Gujarat, India. Al-Shabeeb (2016) also adopted a harvested water storage structure with low lineament density as the highest priority and high lineament density as the lowest priority.

***Slope.*** Davao City is surrounded extensively by vast mountain ranges with an uneven distribution of plateaus and flat terrains. The region's highest elevation, Mount Apo, has slopes exceeding 30%. The slope is a crucial factor in the evaluation of the surface RWH technique since it affects the intended area's water storage due to runoff (Critchley et al., 2013). In the identification of suitable locations for RWH, a slope with less than 5% is ideal, according to a study by Adham et al. (2022). Major parcels of land are very highly suitable (31.84%) sites, while only a small portion of unsuitable (1.94%) sites have been identified.

***Suitability Map for RWH Systems.*** The final suitability map for RWH systems shown in Figure 13 indicates that the southeastern part of the study area comprises largely of unsuitable areas for RWH systems, where most built-up/settlement areas are found, classified as restricted areas for RWH. Portions of the unsuitable class are found in the central south for those that are built-up areas, and the remaining can be found in the western part of the city, which is a critical watershed as such land use classification is a conservation area under the Comprehensive Land Use Plan hence, a restricted area for this purpose.

The mountainous area in the southwest of the study area comprises the portion with medium suitability for RWH systems. Areas with medium suitability are dominant in the southwest part, which covers the portion surrounding Mt. Apo. These districts include Marilog, Calinan and Toril districts. Areas that are of high suitability for RWH systems cover the majority of Davao City, under which the class is in low-mid elevation with a slope from 5-30%, dominated by the very highly suitable soil type which is clay, and a rainfall range given with low to highest priority. Lastly, it is visible in the figure that the areas of ‘very high suitability’ cover only a fifteenth of overall study area in comparison with other suitability classes, which, as shown in the map, are distributed in patches across the study area, mostly in the central portion, while also dominating the northwestern part.

## CONCLUSION

Most of the study areas were classified to be highly suitable are for the construction of RWH systems. The rainfall and land use parameters greatly affect the outcomes of the suitability map in locating very highly suitable areas that were within Marilog, Calinan, and Toril districts. This study and comparable ones exhibit the advantage of utilizing geospatial techniques to identify potential/suitable rainwater harvesting locations, especially in areas where the need for strategic planning at water resources projects is growing, like in developing nations such as the Philippines.

Research gaps of this research include the adaptation of parameters and classifications from different area could affect the outcomes of the study. For increased reliability, it is recommended to perform a validation of the generated suitability map whether through an actual survey or verification of the establishment of existing RWH systems in the study area, if there are, using data on their locations.

The generated suitability map for RWH systems under this study will be beneficial for the local government and authorities as well as the decision-makers regarding water resource management in Davao City, which may be used in the early steps towards the development of RWH systems for applications such as agricultural productivity and climate change mitigation efforts. Additionally, this study will help the Local Government Unit by providing insights on how to reduce flooding within the city with the identified locations for redirecting and retaining floodwater, aiding in the effective mitigation of flood-related challenges in the city.

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