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ArcGIS-Based Identification of Rainwater Harvesting System Sites for Communal Irrigation for Rice Farmers in Tabuk City, Kalinga

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Abstract

Fresh water from natural resources serves as a valuable source for irrigation, helping to meet the water demands of people. Given the region's diverse topography and rainfall patterns, it is considered necessary to develop a rainwater harvesting system. This research employs spatial modeling and multi-criteria analysis using the ArcGIS tool to evaluate various factors such as rainfall data, slope, stream order, drainage density, land uses/land cover, soil type, and distance to roads. The main goal of the research is to identify suitable sites for a rainwater harvesting system. The criteria were classified according to their suitability. The results show that 23.26% of the study area is classified as very high suitability, followed by 20.83%, 17.13%, 15.34%, and 14.38% as medium suitability, low suitability, high suitability, unsuitable, and others, respectively. The findings of the research can be a useful tool for concerned authorities and other agencies in identifying areas prone to flooding or erosion, guiding farmers to refrain from cultivation in such vulnerable zones, and implementing farm management strategies as well. Maps can highlight the soil properties, which farmers can use to identify crops best suited for specific fields. The rainfall condition of the study area can also be a basis for applying irrigation according to the water requirements of the crops to be planted, thereby preventing water waste and sedimentation.

Introduction

The world's water resources are currently depleted. Finding effective solutions to solve water shortages through different strategies is important. In line with sustainable development, water scarcity has become a major problem not only in the agricultural industry but also in meeting domestic water needs in other sectors of society that are relevant to water usage (Saccoccia & Kuzma, 2024). Optimizing our natural resources, like collecting rainwater through precipitation, is one solution to address the environmental challenges today. Using the available sources and data, through navigating GIS-based software, will determine potential topography and the best locations for rainwater harvesting systems (RWHS).

Tabuk is widely considered the rice granary of the Cordillera, due to its large agricultural area, producing large quantities of rice that are supplied to other places. The city has also produced outstanding farmers at the national level for the last two decades. Tabuk City and some parts of Kalinga have the availability of more than 10,000 hectares of rice farms, which have sustained the region's rice self-sufficiency over the past several years (Hent, 2022).

Water irrigation is a significant challenge for agricultural communities all over the world (Ingrao *et al.*, 2023). According to the National Irrigation Administration data, the Cordillera Administrative Region's six provinces have 185,406 hectares of potential irrigable areas. In the province of Kalinga, 30,486.91 ha out of 44,190 ha (68.99%) has been irrigated (Agoot, 2024), leaving 13,703 ha dependent on rainfall or temporary water sources. In the City of Tabuk, the Office for City Agricultural Services revealed that 192.5 hectares of the 4,178.6 hectares of rice planted between March and April 2024 were damaged by drought, resulting in losses estimated at P6,033,638.60. The province's topography also affects the distribution of water in terms of farm irrigation. There are sloppy areas that become a challenge in delivering water uniformly to all scattered farmlands throughout the city.

While numerous studies applied ArcGIS for rainwater harvesting, most have focused on general watershed or urban catchment applications. Limited research has explored RWHS site identification specifically for communal irrigation systems.

Geographic Information System (GIS) software provides great assistance to scientists, government agencies, and individuals in identifying rainwater harvesting systems. This can also include the exploration and expansion capabilities to build dams, ditch plugs, percolation ponds, and derived lakes (Alrawi *et. al.*, 2023). The widespread adoption of GIS software has made it easier to find basic information on the water characteristics of a particular region.

Multi-Criteria Analysis (MCA) is a systematic decision-making tool used to identify optimal sites for rainwater harvesting (RWH) systems by evaluating multiple criteria. Common criteria include rainfall patterns, soil texture, slope, drainage density, and land use/land cover (Sayl *et al.*, 2020). Various methodologies, such as the Analytic Hierarchy Process (AHP) and Fuzzy AHP, often combined with Geographic Information Systems (GIS), are employed to assign weights to criteria, allowing for a comparative analysis of potential sites (Ahmed *et al.*, 2022). Several studies shows efficiency of AHP-GIS integration, including RWH site mapping in Davao City (Masancay *et al.*, 2025), groundwater recharge zone identification in Mount Makiling (Sandoval & Tiburan, 2019), and agrometeorological station placement in Pampanga (Dawis *et al.*, 2025).

The study aims to identify and map suitable areas for rainwater harvesting (RWH) in Tabuk City, Kalinga, through the integration of Geographic Information System (GIS) using topographic, hydrologic, and land use criteria. The results of this study will help relevant units plan and implement effective water management plans, reduce dependence on groundwater, and ensure long-term water supply in the study area.

Materials and Methods

Study Location

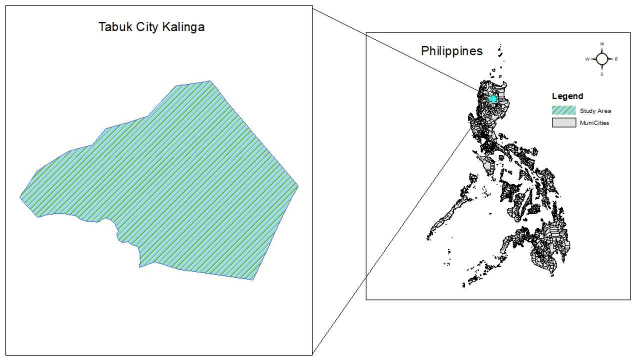


Figure 1. Map of the study area

The study area focused on Tabuk City, Kalinga. Due to its geography and topographic location, it can facilitate the collection and directed flow of rainwater and is described as a developing city where the population is continuously increasing, and water demand will proportionally increase. The study area lies at a latitude of 17° 24 '42.25"N and a longitude of 121° 26' 18.42"E, with a geographical area of approximately 774.25 square kilometers, which constitutes 21.34% of Kalinga's total area. Balbalan, Pinukpuk, Pasil, and Tanudan are western municipalities with diverse high-altitude mountain terrains.

Data Source and Collection

Table 1. Sources of data used in the study

Data description	Source	Year
Rainfall	Center for Hydrometeorology and Remote Sensing(CHRS)	2021
Stream order, Drainage density	University of Glasgow (National-scale geodatabase of catchment characteristics in the Philippines for river management applications	2023
LULC, Soil type, Slope, Distance road	Geoportal Philippines	2023

The sources of the data were freely available online. Utilizing these resources makes it possible and accurate to meet the research objectives. All of the data is in a vector dataset, which consists of individual points stored as coordinate pairs that denote geographical location. All the criteria were georeferenced from the datum of the World Geodetic System (WGS) of 1984.

Schematic Diagram/Procedures in Locating RWHS

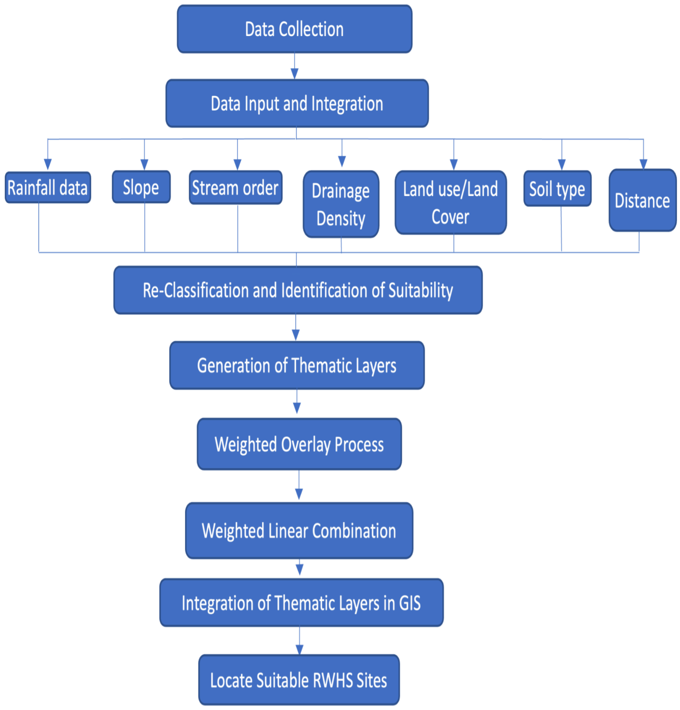


Figure 2. Schematic diagram of identifying RWHS.

The first stage involves gathering significant information, which includes data elevation, historical rainfall patterns, soil characteristics, land use/land cover details, and existing water infrastructure. Georeferencing is then performed to ensure the spatial accuracy of the collected data. Afterward, incorporate the data into the table of contents and proceed with the integration process by navigating the tool. From the Arc Toolbox, go to spatial analyst tools and choose reclassify in order to map the suitability level of the added data. The next step is the generation of thematic layers, which involves creating separate map layers that display different data inputs such as rainfall data, slope, stream order, drainage density, land use/land cover, and soil type. The weighted overlay process is a technique used to merge these layers by giving a weight to each layer and assigning each one a weight based on its importance to the analysis. The process involves a weighted linear combination, in which the values of each thematic layer are multiplied by their respective weights and then summed to produce a single composite suitability map. By integrating thematic layers through this process, it enables complex spatial analysis and decision-making. It allows for simultaneous consideration and quantitative evaluation of multiple factors that facilitate tasks, such as suitability modeling and assessment. This model assists in determining the best locations for the rainwater harvesting system, which is to be visualized in the end.

Criteria for Site Selection

a. Rainfall

Precipitation is the principal criterion in choosing a suitable location for a rainwater harvesting system. It should always be based on the availability of rainfall that is gathered in a particular area. Precipitation characteristics such as patterns, intensity, duration, and spatial distribution have a significant impact on the watershed's hydrologic systems. In this study, the inverse distance weight spatial interpolation method was used to create the map of yearly rainfall distribution. Generally, Tabuk City typically receives about 136.65 millimeters (5.38 inches) of precipitation and has 207.29 rainy days (56.79% of the time) annually\. Regions with low evaporation can have a strong potential for developing rainwater harvesting system sites, which also include locations with a high number of trees.

b. Slope

The slope is one parameter that must be considered when planning the rainwater harvesting system. Watersheds with a diverse range of elevations and a fan shape can be more effective at storing runoff. Moreover, the degree of slope directly influences the runoff rate—flat terrain produces low runoff, while areas with steeper slopes experience rapid water flow, especially along longer slopes. The downloaded elevation data were uploaded to ArcGIS and processed using the spatial analyst tool to generate a slope map of the area. The slope map of the study area was distinguished by the slope percentage. When constructing the RWHS, always consider the slope characteristics, as sites with higher slope percentages are not recommended due to the increased excavation and other earthworks costs they demand.

c. Stream order

The concept of stream order is one of the most important in fluvial geomorphology. It helps us understand how river networks are organized in watersheds. Streams are grouped according to their position within this structure. First-order streams are the smallest. They come from springs or runoff and don't have any branches. Two first-order streams combine to form a second-order stream. The same thing happens when two second-order streams join, a third-order stream is made, and so on. When lower-order streams meet, they form higher-order streams. This creates a network of branches that determines how the watershed drains.

d. Drainage density

Understanding the drainage region is important in water planning and control. Considering the transportation, storage, and distribution of water within a certain geographic region. Drainage density is a key measure that shows the complexity of the stream or river network in an area.

e. Land use/Land cover

Land use/land cover of the watershed is a key factor that corresponds to the changes in the hydrological system of the watershed. It has a vital impact on the management of water resources in the watershed. Cultivated lands and urbanization can lower the water-holding capacity of an area. Natural vegetation can maintain biodiversity mechanisms of water resources and can balance the water volume produced in the watershed.

The land use/land cover maps of the area will be categorized under five levels of suitability: very high suitability, high suitability, medium suitability, low suitability, and unsuitable classes.

f. Soil Type

Mapping the classification of the soil of the study area for locating RWHS is an essential consideration for understanding the geography of the area. The soil permeability will become a key factor in determining the infiltration rate and the amount of water stored in soil layers. The textural categorization of the soil can be determined by comparing the quantities of sand, silt, and clay. Fine and medium-grained soils, recognized for their high water retention capacity, are ideal for rainwater collecting. To characterize the classification of soil in the area, these 4 levels of suitability were considered: very suitable, suitable, moderate, and unsuitable classes.

g. Distance to roads

Spatial data analysis, such as georeferencing in the Arc Toolbox and vector classification were implemented to evaluate the distance of roads and settlements.

Understanding and incorporating the distance to highways and towns using spatial data analysis improves the design and execution of technical works.

Criteria Weighting

The weight was determined through a literature review based on its relative influence on rainwater harvesting site suitability. Following the approach of Preeti *et al.* (2022), Aklan *et al.* (2022), and Ibrahim *et al.* (2019), they used a similar GIS-based model for rainwater harvesting site selection. The following weight values were used in the study: Rainfall: 20; Slope: 10, Stream order: 5, Drainage Density: 20, Land use/Land cover: 20; Soil type: 20, and Distance to roads: 5. Based on the findings of these previous studies, this weighting scheme was found effective in producing suitability maps for rainwater harvesting systems.

Results and Discussion

Rainfall

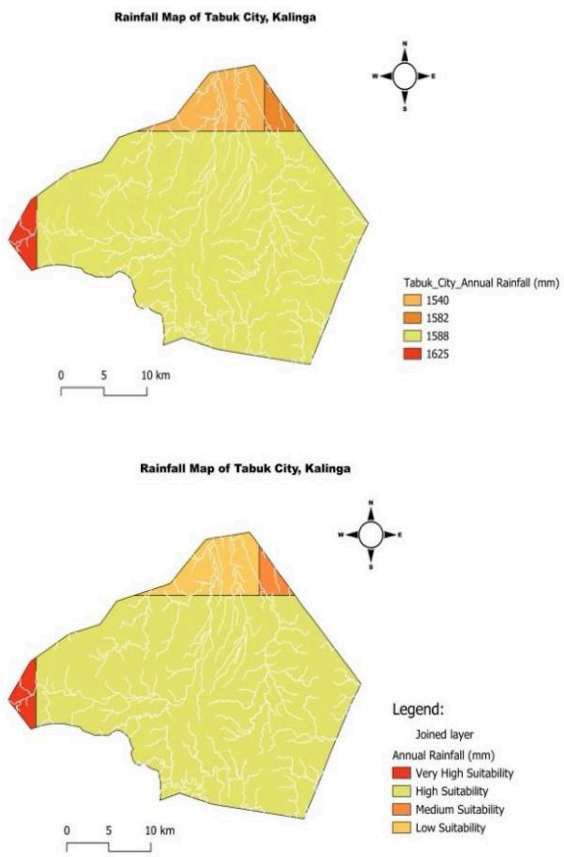


Figure 3. Annual rainfall map (up) and the reclassified rainfall map (down) of the study area

Figure 3 displays the distribution of rainfall in the study area and reclassifies it based on its suitability. Based on rainfall data obtained from the Center for Hydrometeorology and Remote Sensing (CHRS, 2021), the results indicate that the study area primarily falls within the high suitability level. Areas with higher rainfall suitability can be prioritized for constructing communal rainwater harvesting systems.

Slope

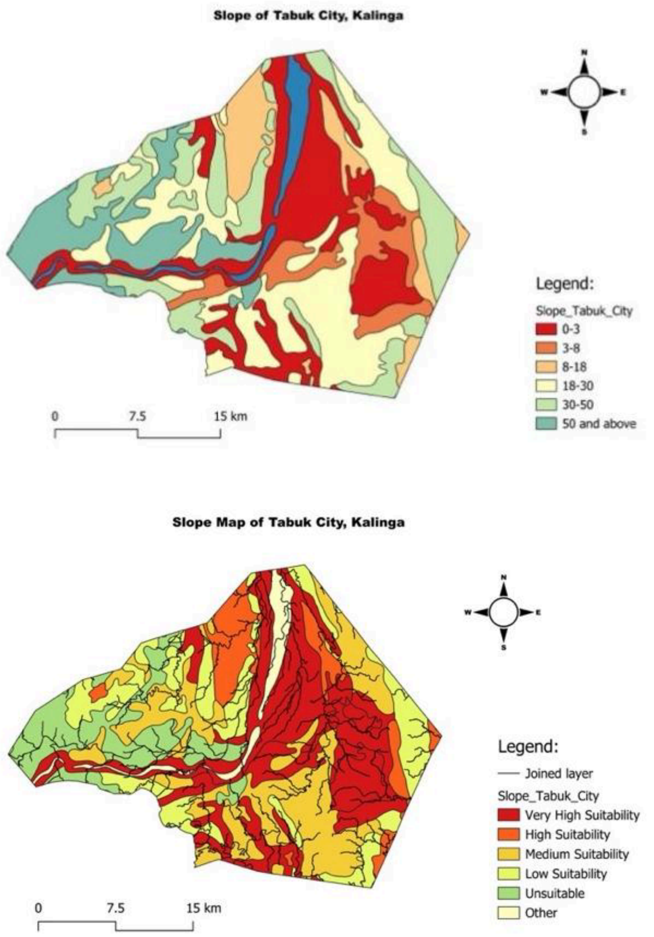


Figure 4. Slope (up) and the reclassified slope (down) map of the study area

Table 2. Covered area of the slope suitability classes

Rate	Suitability	Coverage (km^2)	Coverage (%)
1	Very High Suitability	127.43	17.82
2	High Suitability	110.15	15.4
3	Medium Suitability	124.72	17.44
4	Low Suitability	123.19	17.22
5	Unsuitable	116.78	16.33
6	Other	113.02	15.8

Figure 4 displays the study area's slope and the reclassified slope map. Six categories were determined, ranging from a minimum slope of 0-3% to a maximum slope gradient of 50% and above. The minimum slope area was classified as flat terrain, while the maximum slope has the steepest gradient. The percentage result for each suitability indicates that the distribution is contiguous.

Stream order

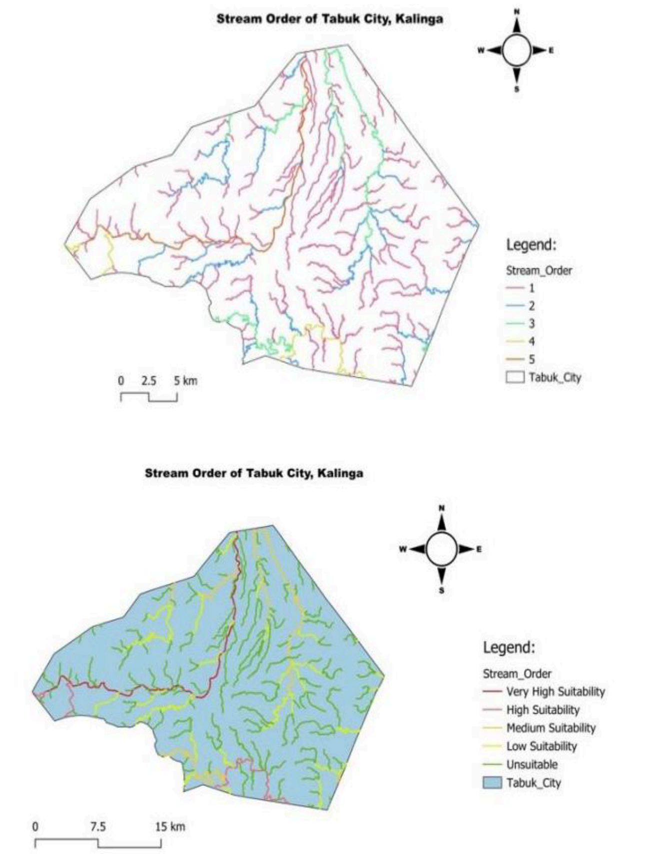
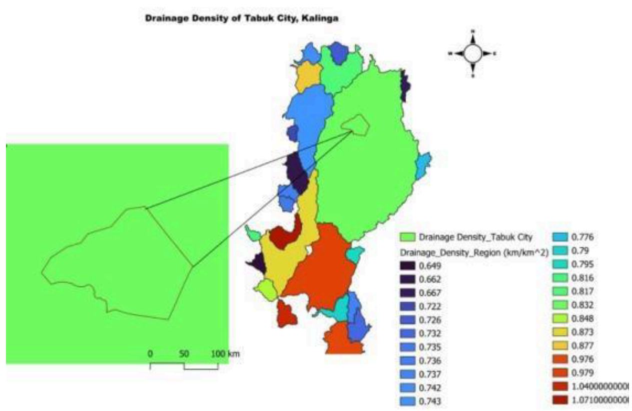


Figure 5. Stream order (up) and reclassified stream order (down) map of the study area

Figure 5 shows the vector data results for the stream order. The stream order ranges from 1 to 5, with 1 being the lowest and 5 being the highest. According to Ammar *et al.* (2016), stream orders lower than 3 are not suitable for rainwater harvesting systems, and on the other hand, higher stream orders are appropriate for rainwater harvesters. Most of the study area falls in the higher stream order, which highlights areas where the natural flow of water occurs.

Drainage Density



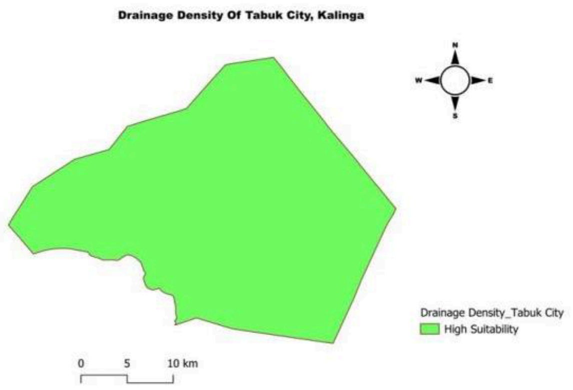


Figure 6. Drainage density (up) and the reclassified density (down) map of the study area

Figure 6 below shows the drainage density and the reclassified drainage density map of the study area. Based on the results of the vector data sets, it shows that 100% of the study area lies in high suitability with a drainage density of 0.832 km/km^2. This indicates that the area has a higher concentration of stream density, and a high drainage density indicates the presence of a compact system of streams and channels.

Land Use/Land Cover

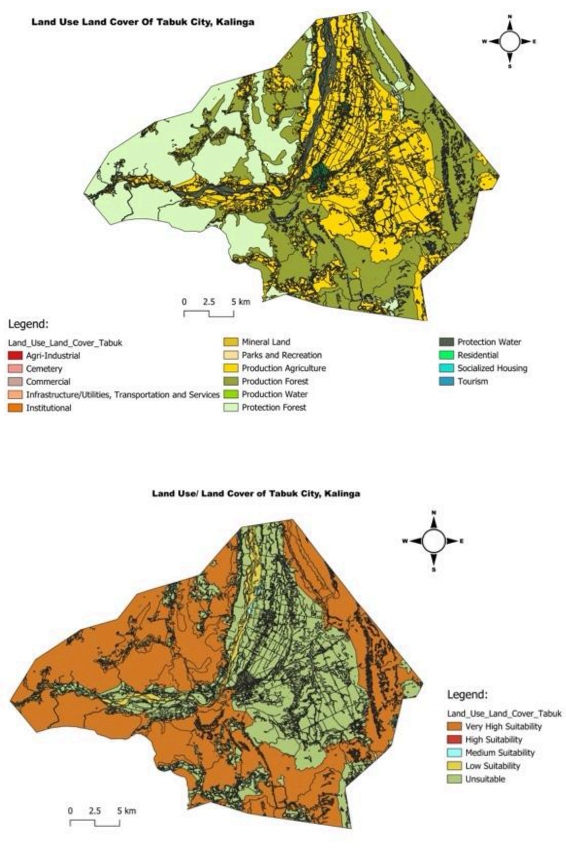


Figure 7. Use/ Land Cover (up) and the reclassified Land Use/ Land Cover (right) map of the study area

The results of the analysis below show that the largest part is the production forest, which occupies 565.29 square kilometers, and vegetation is very important to the area's infiltration capacity. The reclassified map of land use and land cover indicates that 78.31 percent of the area is very highly suitable, followed by 17.77 percent that is unsuitable and 3.16 percent that is low suitability.

Table 3. Covered area of land use/land cover suitability classes

Rate	Suitability	Coverage (km^2)	Coverage (%)
1	Very High Suitability	565.29	78.31
2	High Suitability	0.12	0.017
3	Medium Suitability	1.19	0.17
4	Low Suitability	22.65	3.16
5	Unsuitable	127.36	17.77

Soil Type

Figure 8 shows the soil type and a reclassified soil type map of the study area. This consists of different types of soil, like clay, clay loam, loam, sandy clay, sandy clay loam, and sandy loam. The results classified the soil types into four categories: very high suitability, medium suitability, low suitability, and unsuitability. Table 3 shows that 18.64% of the study area has very high suitability, and 17.32%, 23.82%, 23.09%, and 17.13% have medium suitability, low suitability, unsuitability, and others, respectively. Mapping areas with clay and loam soils indicates zones where infiltration ponds can be developed to increase groundwater recharge and sustain soil moisture for rice cultivation.

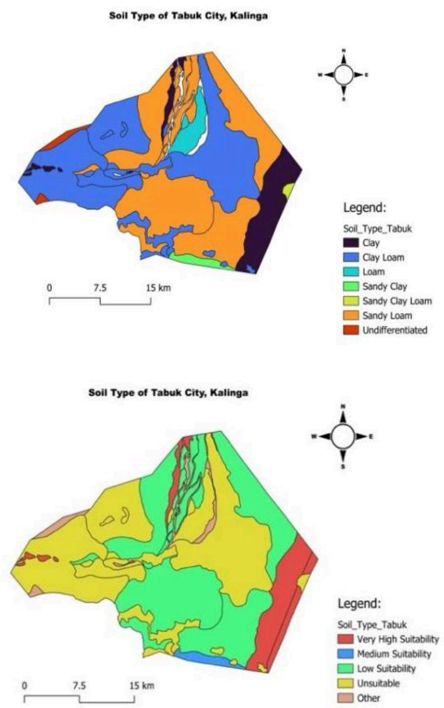


Figure 8. Soil type (up) and the reclassified soil type (down) map of the study area

Table 4. Coverage area of soil types and suitability classes.

Rate	Suitability	Coverage (km^2)	Coverage (%)
1	Very High Suitability	133.98	18.64
2	Medium Suitability	124.45	17.32
3	Low Suitability	171.16	23.82
4	Unsuitable	165.89	23.09
5	Other	123.11	17.13

Distance to Roads

Figure 9 shows the various types of materials used in road construction in the study area. Here, we can rely on the accessibility of the roads to the location of the rainwater harvesting system. Concrete and asphalt can be more accessible, particularly in material transportation and project monitoring. The roads provide reliable and quick access for repair and maintenance in case of any emerging emergencies within the project, ensuring the system's smooth operation. Gravel roads can also be advantageous, particularly in regions with intense rainfall, as their high permeability and regular groundwater replenishment benefit the areas surrounding the rainwater harvester.

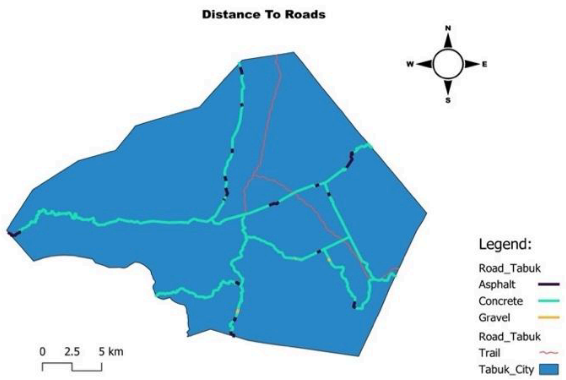


Figure 9. Road Map of the Study Area.

Final Suitability Map

Figure 10 shows the final suitability map of the study area. Classified into very high suitability, high suitability, medium suitability, low suitability, and unsuitable. From the results, figure 11 shows that 23.26% of the study area lies in the very high suitability classes, with an area of 166.68 km^2, followed by 20.83% (149.27 km^2) classified as medium suitability, 17.13% (122.76 km^2) as low suitability, 15.34% (109.93 km^2) as high suitability, and 14.39% (103.12 km^2) as unsuitable. An additional 9.05% (64.84 km^2) falls into the “other” category. The other category indicates that the area is not suitable for the intended land use and does not need further assessment. Some locations are simply not applicable for certain uses, such as areas beyond available irrigation water. Although these areas are not relevant, they will be retained in the total land coverage computation to maintain the spatial integrity of the study area.

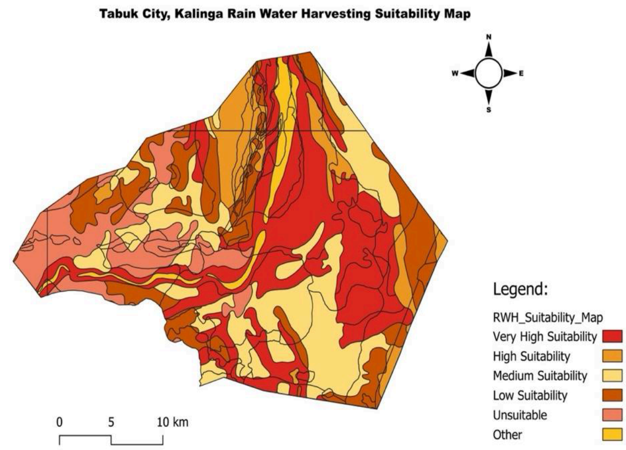


Figure 10. Final suitability map for identifying rainwater harvesting system sites in the study area.

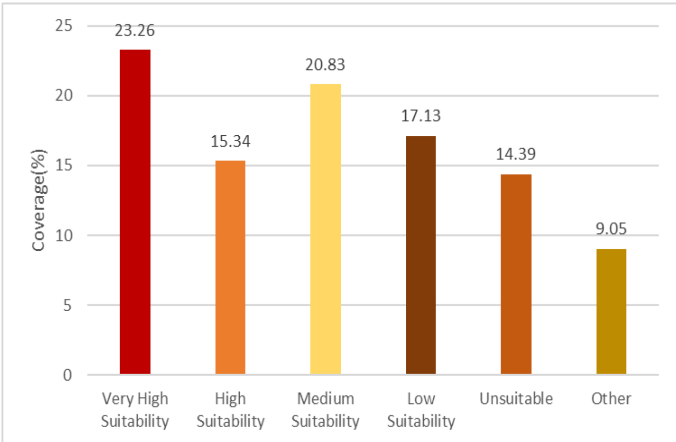


Figure 11. Percentage (%) covered by each suitability class in the study area.

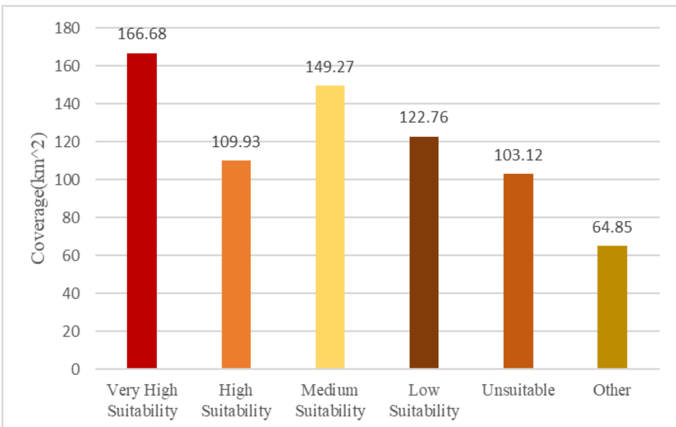


Figure 12. Area(km^2) covered by each suitability class in the study area.

Conclusion

This study utilized an ArcGIS tool to navigate the methodological sets to identify potential sites for the construction of rainwater harvesting systems. The spatial modeling capabilities of ArcGIS were utilized to establish layers and pinpoint suitable locations. To identify suitable sites, a comprehensive source of data is required; accuracy and relevance are important factors in the graphical output. The study used different criteria, including rainfall data, slope stream order, drainage density, land uses/land cover, soil type, and distance to roads, to find the optimal locations. One of the most important factors to consider is the annual rainfall, as it serves as the foundation for the reservoir's water storage capacity. The study was limited to secondary data sources. While the GIS and AHP-based analysis provided a logical assessment of rainwater harvesting (RWH) potential, actual survey and stakeholder verification should be included in future research to increase the reliability of the generated map and to consider also the socio-economic and environmental impacts of the projects in nearby communities.

The generated RWH suitability map serves as a decision support for local government units (LGUs) in policy implementation and planning regarding water resources management. Guided tool in land use zoning to minimize flood-prone development within the city. Training programs and technical support can also be provided to barangay officials and farmer organizations to promote local implementation of RWH projects.

Ethical Statement

This study used secondary data from publicly available and institutional sources. There were no human or animal participants; informed consent was not required. All data were handled with confidentiality, used strictly for academic purposes, and properly cited.

Conflict of Interest Statement

The authors declare no conflict of interest related to the conduct and publication of this research. All procedures followed were in accordance with institutional and ethical standards, and there were no financial or personal relationships that could have influenced the outcomes of this study.

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Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this work, the authors utilized SciSpace and Consensus for literature review and reference identification, QuillBot for grammar checking and language refinement, and ChatGPT for clarification of academic writing. Following the use of this tool/service, the authors conducted a review and made necessary modifications, assuming full responsibility for the content of the publication.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

JGB: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Writing – Review and Editing, and Visualization; **JCS:** Writing – Original Draft, Writing – Review and Editing, Visualization, and Supervision.

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