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Abstract

The engineering planning and design of Small Water Impounding Projects (SWIPs) necessitates proper site selection to ensure technical viability and sustainability. This study developed localized criteria for assessing the site suitability of SWIPs in the whole province of Bukidnon by integrating national engineering standards with local experts' opinions using the Analytic Hierarchy Process (AHP). Pairwise comparison of the formulated criteria was performed by selected local experts to derive their relative weights, with consistency ratios checked against Saaty's thresholds to validate their judgments. The resulting weight set showed that hydrological factors dominated the hierarchy, with annual rainfall (25.2%) and watershed area (13%) contributing the most to the composite suitability index, followed by geotechnical factors (soil texture, land slope, reservoir area) and, to a lesser extent, accessibility and socio-economic factors. A weighted linear combination was used to compute pixel-level suitability, classified into four FAO-based suitability classifications. Results of this study provided an objective, transparent, spatially-explicit, and site-specific framework which can be used by water resources planners and engineers for screening and prioritizing SWIP sites in the upland areas of Bukidnon in support of irrigation development in the country.

Keywords: Small Water Impounding Projects (SWIPs); analytic hierarchy process; multi-criteria formulation; GIS-based suitability analysis; Bukidnon, Philippines.

Introduction

The National Irrigation Master Plan (2020-2030) in the Philippines targets the development of a total of 681,709 ha of new irrigated areas and extends irrigation development to irrigable areas with up to 8% land slope (National Irrigation Administration, 2020). Among the options for small-scale irrigation development in the country is the use of Small Water Impounding Projects (SWIPs), which are handled by both the National Irrigation Administration (NIA) and the Bureau of Soils and Water Management (BSWM) of the Department of Agriculture. A SWIP is a small earth dam structure built across a narrow depression or valley to collect and store rainfall and runoff during the rainy season for immediate and future use (BSWM, 2023b). SWIPs are specifically designed to cross natural valley depressions in these rolling terrains. This, therefore, makes them the only technically and economically viable gravity-fed irrigation option for upland sloping areas like those in the province of Bukidnon in southern Philippines, whose slopes generally exceed the traditional slope limit of 3% for irrigation development set by NIA prior to the implementation of the National Irrigation Master Plan (2020-2030).

SWIPs are also among the recommended technologies for climate change adaptation in the National Irrigation Master Plan (2020-2030). Apart from enhancing irrigation water supply and providing supplemental irrigation especially during the dry season, SWIPs can serve as a flood control measure for the flood-prone low-lying areas during the rainy season. SWIPs can also support livestock and fishery production and help maintain local biodiversity, which are additional benefits and advantages compared to other small-scale irrigation options. SWIPs have also proved to reduce poverty and address local food insecurity in vulnerable upland areas (Technical and Institutional Development Support [TIDS], 2022; Bureau of Soils and Water Management [BSWM], 2023). In view of the aforementioned benefits of SWIPs and their suitability in upland watersheds, SWIP development continues to be among the priority irrigation options in the province of Bukidnon.

To ensure the technical viability and sustainability, the engineering planning and design of SWIPs should start with proper site selection. This in turn would require a set of site-specific criteria instead of using a universal "one-size-fits-all" approach to account for regional variabilities in environmental and socioeconomic conditions. Since the Philippines is an archipelagic country with diverse climates and varied terrain, a universal set of criteria would prove to be inadequate for proper SWIP site selection. Factors such as rainfall, geology, and soil texture in the locality must be properly and adequately considered as they influence hydrologic conditions, which consequently determine the technical viability of SWIPs. Pantano *et al*. (2020) pointed out that these factors help in the identification of potential sites with favorable hydrological and geomorphological conditions beneficial to the locality. Moreover, there may be other factors that influence the site suitability of SWIPs particularly in the province of Bukidnon that only a scientifically-sound analysis could generate.

Among the most widely accepted and sound approaches used to develop selection criteria include the Analytic Hierarchy Process (AHP) (Saaty, 2008). While AHP and other approaches have been used to develop site suitability criteria for SWIPs and similar structures in some regions in the Philippines (Vicente *et al*., 2024; Amongo *et al*., 2020; Pantano *et al*., 2020; Manaopanao, 2018), to date no study exists in published literature on the development of site-specific AHP-based criteria for suitability assessment of SWIPs in the whole province of Bukidnon. This study, therefore, addresses this knowledge gap. Specifically, this study aimed to develop a set of AHP-based multi-criteria to facilitate a GIS-based assessment of the site suitability of SWIPs in the province of Bukidnon, Philippines The results are ultimately intended to improve water security and agricultural productivity in the upland communities of the province through this engineering intervention.

Materials and Methods

Study area

Bukidnon's status as the premier agricultural powerhouse of the Philippines, generating a national leading 162.34 billion pesos in overall agricultural and fisheries output, which includes a dominant 105.58 billion pesos in crops and 36.09 billion in livestock, all in 2025, makes securing its water resources a critical priority for national food security (Virata, 2026).

Bukidnon (Figure 1) is a landlocked province in Northern Mindanao in southern Philippines characterized by diverse topography, including plateaus and mountain ranges. It has a total land area of 10, 498.59 square kilometers, comprising of 2 cities, 20 municipalities and 464 barangays that occupies the central portion of the island of Mindanao. The province is situated between 7°51’ and 8°40’ north latitude and 124°03’ and 125°16’ east longitude. It is situated in a valley basin, bounded by the mountain ranges (Malaybalay Climatological Records, 2023). Bukidnon’s central valley is situated at an elevation of 300 to 500 meters above sea level and is drained by various rivers. The province’s varied topography provides a diverse range of microclimates and soil types that support the growth of various crops. Characterized by a humid climate with no distinct dry season, Bukidnon features a relatively high elevation that results in cooler temperatures compared to other lowland areas in Mindanao. According to the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA, 2024), the province's average temperature typically ranges from 22°C to 32°C, with the warmest months occurring from March to May and the coolest period lasting from November to January.

The province experiences high levels of rainfall throughout the year, with the wettest months occurring from June to November. It has an average annual rainfall of around 2,500 to 3,500 millimeters (PAGASA, 2024). The high rainfall levels make Bukidnon an ideal location for agriculture, as it provides a steady supply of water for crops.

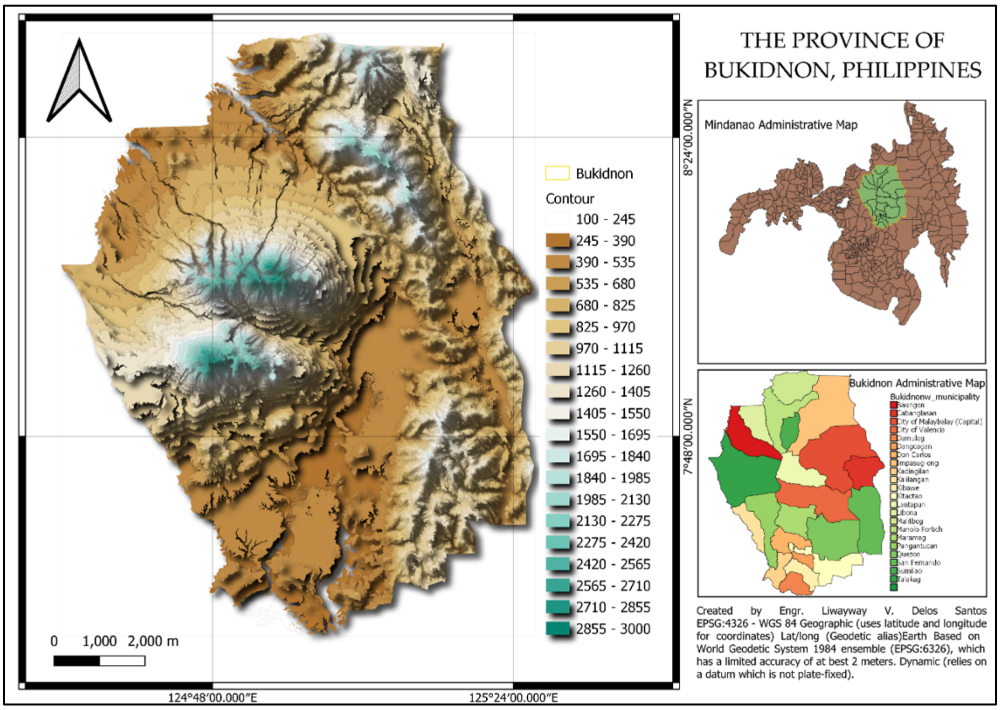

Figure 1. Location map of the province of Bukidnon, Philippines.

Due to its highly developed agricultural sector, particularly within the central and southern plateaus and the northern corridor, Bukidnon serves as an ideal location for intensive agricultural production. Municipalities such as Valencia City, Maramag, Don Carlos, and Quezon represent the province's agricultural core, where the confluence of flat volcanic terrain and high demand for irrigation supports large-scale farming. Additionally, the municipalities of Manolo Fortich, Libona, and Baungon are developed hubs for high-value crops like pineapple, benefiting from integrated road networks that facilitate efficient transport and trade (DA-Region X, 2023).

Required datasets

The datasets required in the analysis for the multi-criteria decision-support model are presented in Table 1. Datasets should be projected to WGS 84/ UTM Zone 51N because Bukidnon sits geographically within this longitude, minimizing geometric distortion for watershed and proximity mapping.

Table 1. Summary of spatial datasets and metadata for Bukidnon SWIP suitability.

Spatial dataset	Primary data source/publisher	Reference year	Data format and resolution	Spatial analysis in QGIS
Digital elevation model (DEM)	Shuttle Radar Topography Mission (SRTM) via OpenTopography	2000 (baseline)/ sourced 2023	Raster grid (30-meter pixel resolution)	Delineation of catchment sub-basins using SAGA Channel Network & Drainage Basins; extraction of slope gradients as percentages using Raster Terrain Analysis; map topographic depressions for reservoirs areas using SAGA Sink Drainage Route Detection.
Climatological rainfall	Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)	2025 climatological records	Tabular CSV (interpolated to 30 m raster)	Spatial interpolation of point-based annual precipitation values across Mindanao Agrometeorological stations using Inverse Distance Weighting (IDW) method, subsequently to be clipped to provincial limits.
Soil texture	Bureau of Soils and Water Management (BSWM)/ Geoportal	2023	Vector shapefile (rasterized to 30 m)	Classify and rasterize soil series based on USDA soil textural triangle to evaluate water-retention capabilities and seepage risks.
Land use and land cover (LULC)	Sentinel-2 Imagery via ESRI/USGS Impact Observatory	2023	Raster grid (10-meter resampled to 30 m)	Extract active agricultural crop zones and calculate using Euclidean Distance to map crop proximity, prioritizing SWIP installation near high-demand agricultural clusters.
Road network	OpenStreetMap (OSM)/ Bukidnon Local Government Unit (LGU) infrastructure reports	2024	Vector line shapefile (rasterized to 30 m)	Classify road surfaces into accessibility classes and calculate distance profiles using GDAL Raster Distance (Euclidean Distance) to assess construction logistics and machinery transport costs.
Hydrologic network (water sources)	Bureau of Soils and Water Management (BSWM)/ SAGA delineated streams	2023	Vector line shapefile (rasterized to 30 m)	Superimpose major rivers with SAGA stream networks (Strahler order 4) to calculate overland flow distances via the SAGA Terrain Analysis toolbox to ensure hydrologic connectivity.
Administrative base maps	National Mapping and Resource	2023	Vector polygon boundaries	Define the formal political provincial, municipal, and

	Information Authority (NAMRIA)			barangay boundaries of Bukidnon to clip, mask, and standardize the spatial analysis.
Irrigation status and exclusions	National Irrigation Administration (NIA) Region X / DA-RFO X	2023	Vector polygon boundaries	Map active national (NIS) and communal (CIS) irrigation systems, existing SWIP service areas, and built-up areas to generate an exclusion mask, isolating the Potential Irrigable Areas (PIAs).

To enable cell-by-cell calculations in the QGIS Raster Calculator, vector datasets must be converted to rasters, and all continuous layers must be resampled to a standardized 30-meter resolution grid to match the digital elevation model (DEM). Each thematic layer later then be reclassified into standardized suitability scores ranging from 3 (unsuitable) to 9 (highly suitable) before performing the final weighing.

Formulation of SWIP site suitability criteria

Eight criteria for site suitability of SWIPs in Bukidnon were selected based on the Philippine Agricultural Engineering Standards (PAES) and a comprehensive review of recent studies and technical report on SWIPs in Bukidnon and comparable Philippine upland regions. The criteria include annual rainfall, watershed area, soil texture, land slope, reservoir area, proximity to agricultural areas, distance to water sources and road accessibility. These factors were weighted and refined using the AHP, incorporating local expert judgment to ensure alignment with the PAES and Bukidnon's specific biophysical context. Each criterion is described herein according to its technical relevance.

Annual rainfall

Past research studies have demonstrated that the depth and distribution of rainfall represent the fundamental hydrological input for water harvesting (Pantano *et al*., 2020). Rainfall is the most critical factor for a SWIP because it directly determines the volume of surface runoff available for storage. Without long-term records – spanning decades, site selection would be based on weather data that ignores the high variability of Mindanao's climate, leading to reservoirs that fail to fill during dry years. Higher annual rainfall correlates with increased irrigation reliability and reservoir storage potential. Considering Bukidnon's Type III and IV climates, having a reliable baseline allows engineers to design structures that can survive the increasing frequency of extreme events, such as flash floods and prolonged droughts, ensuring the SWIP remains a viable climate adaptation tool (PAGASA, 2024).

Watershed area

The watershed area is the most significant variable in determining a site's water harvesting potential. The watershed area must be large enough to generate the surface runoff required to reliably fill the reservoir. Sites with catchments smaller than 10 hectares are often deemed unsuitable due to insufficient upstream drainage (BSWM, 2023). According to Ball *et al*. (2019), a catchment area that is too small typically under 10 hectares cannot maintain the sustained baseflows or necessary upstream hydraulic volumes required for specific eco-hydrological infrastructures, such as constructed in wetlands or major retention ponds. Without this sufficient upstream runoff, the structures would risk drying out, failing to sustain vegetation, or failing to meet hydraulic design parameters. This data also helps manage safety where a watershed must not be so oversized that extreme runoff risks overtopping or washing out the dam structure.

Soil texture

If rainfall determines the availability of water, soil texture determines the landscape's ability to retain it. Soil texture is a critical determinant of hydraulic conductivity and percolation rates. Data on soil composition is essential to prioritize clay-heavy textures such as clay loam, which is favored for their low infiltration rates. This technical parameter is what prevents excessive seepage, ensuring that the reservoir remains functional and provides water to crops even through the dry season (BSWM, 2023). The geotechnical properties of the soil dictate the stability of the earth-fill dam structure. Inadequate parameterization of soil data can lead to serious misinterpretations of stream flow, sediment yield, and nutrient transport, which could ultimately lead to the structural failure of the dam or rapid siltation of the reservoir (BSWM, 2023). Accurate soil data informs the productive capacity of the service area, allowing planners to match the soil's water-holding capacity with the specific crop water requirements of the farmers being served (Philippine Geological Survey, 2023).

Land slop

The data on terrain gradient is essential for both engineering and irrigation efficiency. A gentle to moderate slopes is preferred because it minimizes construction and earthwork costs while ensuring the structural integrity of the earth dam (Manaopanao, 2018). Conversely, steep slopes, typically greater than 18% are avoided because it increases the risk of excessive soil erosion and structural failure (PCAARRD-DOST, 2017). In Bukidnon, slopes of 0 to 3% are prioritized because it provides an optimal balance, offering enough hydraulic head for gravity-fed irrigation while maintaining manageable dam heights (Malaybalay Climatological Records, 2023).

Reservoir area

The reservoir data identifies topographic depressions capable of storing and regulating harvested water (BSWM, 2023). This parameter is guided by the storage-area-elevation relationship, where flatter terrains allow for a larger surface area and a higher storage volume for every meter of dam height (Vicente *et al.*, 2024). Topographic data reveals natural constraints, such as steep, V-shaped valleys, which may limit the formation of a viable storage basin (PCAARRD-DOST, 2017).

Distance from water sources

The proximity to existing hydrologic networks ensures the project's connectivity and sustainability. This data ensures that a SWIP can effectively capture and augment existing water supplies, maintaining connectivity to the local river or stream network. According to Bukidnon Local Government Unit (2024), being able to locate projects within a favorable distance to a river ideally at less than 500 meter allows for more dependable water management and maximize the reservoir's utility.

Proximity to agricultural areas

This data determines the project's functional impact and serviceability to the intended beneficiaries (PCAARRD-DOST, 2017). Proximity data prioritizes locations near established farm clusters to ensure that the stored water reaches the areas with the highest irrigation demand (DA-Region X, 2023). By locating reservoirs near intensive production hubs, planners ensure that the infrastructure investment directly supports community food security and trade.

Road accessibility

Road proximity data serves as a primary socio-economic determinant for project success as it identifies logistical feasibility of the project. Proximity to existing roads drastically reduces construction costs by facilitating the transport of heavy materials and machinery to the site (Bukidnon Local Government Unit, 2024). A strategic placement near roads also ensures that the increased agricultural yield can be efficiently transported to markets, enhancing the overall economic impact on the community.

Criteria weighting

Following the identification of the site-specific criteria, the study utilized the Analytic Hierarchy Process (AHP) to integrate these parameters into a structured multi-criteria decision making framework, ensuring that each factor is weighted according to its impact on SWIP success. Each criterion was systematically developed into a point or scoring system using AHP, assigned weighting factors reflecting their relative importance, and rated on a suitability scale. Multi-criteria decision analysis (MCDA) using AHP is one of the most widely used methods in decision making for GIS-based site suitability analysis for SWIPs (Saaty, 2008). The flowchart of the AHP-based methodology used in this study is shown in Figure 2.

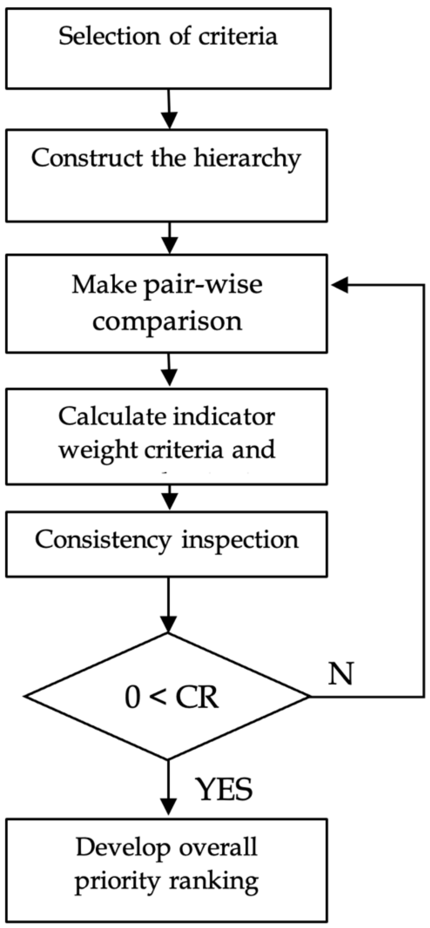

Figure 2. Flow chart of the methodology used for criteria weighting and ranking.

Construction of the hierarchy

fter establishing the importance of each technical parameter through the weighting process, the study then defined the hierarchical structure of these factors as shown in Figure 3. The hierarchical structure is composed of three levels with the goal of determining the suitability index for SWIP (Figure 3). Every sub-criterion has its own unique traits that outline specific qualifications and those details drive the SWIP scoring. These qualifications must have a significant impact on the suitability, feasibility, and long-term viability of Bukidnon's SWIPs. Furthermore, critical values and a significant variation of criterion must be present in the study area. The final set of sub-criteria was chosen and categorized using relevant literature, local expert knowledge, and Philippine Agricultural Engineering Standards (PAES) (PNS, 2017).

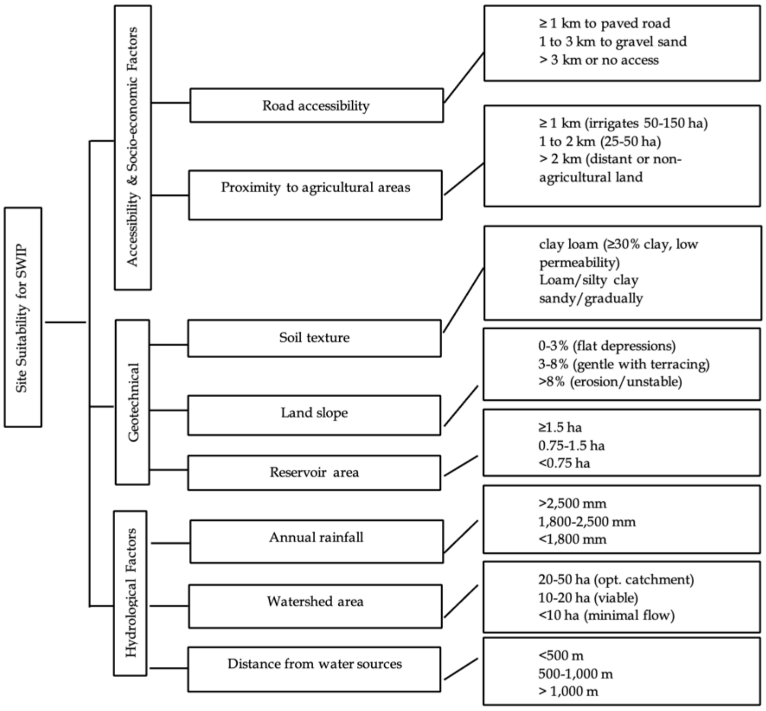

Figure 3. Hierarchical structure of the site suitability evaluation

Derivation of weights for criteria level

After the organization of the criteria into the hierarchical framework shown in Figure 3, the AHP was applied to transform these qualitative relationships into quantitative weights.

A numerical scale that was developed by Saaty (2008) were used to compare the criteria or sub-criteria in the comparison matrices derived from the experts as shown in Table 2.

Table 2. Verbal and numeric scale for the pairwise comparison (Saaty, 2008).

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective.
3	Moderate importance	Experience and judgement slightly favor one element over another.
5	Strong importance	Experience and judgement strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

Note: 2,4,6,8 can be used to express intermediate values

Weighting factors were then assigned to each criterion through expert opinion and literature synthesis to account for differences in their influence on SWIP site suitability. Weightings allowed prioritization. For example, rainfall and soil texture, being critical to water availability and retention, were given higher weights compared to other factors. A parameter with a high weight reflects high impact and a parameter with a low weight reflects low impact on SWIP suitability (Saaty, 2008). The weights of each parameter were assigned according to Saaty's scale of 1 to 9 of relative importance (Table 2). The weights are assigned with consideration of the results of the past local studies.

Ten (10) local experts in the planning, design and management of SWIPs were selected in the AHP. All ten selected experts possessed more than 10 years of active, hands-on professional experience in soil and water resources engineering, agricultural infrastructure planning, or watershed management within Region X (Northern Mindanao). The panel consisted of ten representatives drawn from balanced mix of different academic institutions and local government or district engineering offices across the Region, specifically including agencies and universities operating within the province of Bukidnon. Senior agricultural and biosystems engineers with direct, verified experience in the planning, design, construction, and management of Small Water Impounding Projects (SWIPs). Several of these practitioners had direct involvement in implementing Bukidnon's existing 21 functional SWIP structures. University faculty members and researchers specializing in and primarily teaching soil and water conservation engineering, hydrology, and agricultural engineering. The experts were selected because they are well-versed in the unique volcanic terrains, complex biophysical characteristics, and Type III and IV climate classifications characteristics of the Bukidnon province, ensuring the derived criteria weights were calibrated to local hydrological realities. Pairwise comparison of the various criteria was then performed according to the matrix shown in Figure 4.

Matrix		Ave. Annual Total rainfall 1	Soil texture 2	Land slope 3	Road accessibility 4	Watershed area 5	Reservoir area 6	Distance for water sources 7	Proximity to agricultural sector 8	0 9	0 10	normalized principal Eigenvector
Ave. Annual Total rainfall	1	1	2 1/3	2 1/3	3 2/5	1 7/8	2 1/4	3 1/8	2	-	-	25.20%
Soil texture	2	3/7	1	8/9	1 3/7	1	1 1/3	2 1/4	1 2/9	-	-	12.80%
Land slope	3	3/7	1 1/9	1	1 4/5	7/8	1 1/4	1 3/7	1 2/5	-	-	12.59%
Road accessibility	4	2/7	5/7	5/9	1	3/5	5/8	1 1/9	2/3	-	-	7.58%
Watershed area	5	1/2	1	1 1/7	1 2/3	1	1 2/7	1 1/2	1 1/4	-	-	12.96%
Reservoir area	6	4/9	3/4	4/5	1 3/5	7/9	1	1 1/7	1 1/2	-	-	10.96%
Distance for water	7	1/3	4/9	5/7	8/9	2/3	7/8	1	1	-	-	8.05%
Proximity to agricultural	8	1/2	5/6	5/7	1 1/2	4/5	2/3	1	1	-	-	9.86%
0	9	-	-	-	-	-	-	-	-	1	-	0.00%
0	10	-	-	-	-	-	-	-	-	-	1	0.00%

Figure 4. Summary of pairwise comparison matrix of eight criteria from the survey.

Determination of scores for sub-criteria

After obtaining the weights of the main criteria, the analysis is shifted to the evaluation of sub-criteria, where individual attributes were scored according to their relative influence on the final suitability index. The sub – criteria under each major criterion and the corresponding scoring system are shown in Figure 5. A scale from three (3) to nine (9) was used to reflect the increment from not suitable to highly suitable conditions for SWIP, according to their relative influence (Table 3). This scale was essentially based on the FAO system of suitability classification.

Criteria	Sub-criteria	Ln 1	Ln 2	Ln 3	Ln 4	Ln 5	Ln 6	Ln 7	Ln 8	Ln 9	Ln 10	Score
Ave. Annual Total rainfall	>2,500 mm	9	9	9	9	9	9	9	9	9	9	9
	1,800-2,500 mm	7	7	7	7	7	7	7	7	7	7	7
	<1,800 mm	5	3	3	3	3	5	3	5	5	5	4
Soil texture	Clay loam	7	9	9	9	9	9	7	9	9	9	9
	Loam/Silty clay	5	5	7	5	7	5	5	7	5	7	6
	Sandy/gravelly	3	3	3	3	3	3	3	3	3	3	3
Land slope	0-3%	7	9	9	9	9	9	9	9	9	9	9
	3-8%	5	7	5	5	7	7	7	7	5	7	6
	>8%	3	3	3	3	3	3	3	3	3	3	3
Road accessibility	<1 km- paved road	9	9	9	9	9	9	9	9	9	9	9
	1-3 km - gravel road	7	7	5	7	5	5	5	7	7	5	6
	>3 km or no access	5	3	3	3	3	3	3	3	3	3	3
Watershed area	20-50 ha	9	9	9	9	9	9	9	9	7	9	9
	10-20 ha	7	7	5	7	5	7	5	7	5	7	6
	<10 ha	3	5	3	5	3	3	3	3	3	5	4
Reservoir area	≥1.5 ha	7	9	9	9	9	7	9	9	9	9	9
	0.75-1.5 ha	5	7	7	7	5	7	7	7	7	7	7
	<0.75 ha	3	5	5	5	3	3	5	5	5	3	4
Distance to water sources	<500 m	7	7	9	9	9	9	9	9	9	9	9
	500-1,000 m	5	5	7	5	7	5	7	7	5	7	6
	>1,000 m	3	3	3	3	3	3	5	5	3	5	4
Proximity to agricultural sector	<1 km	9	9	9	9	9	9	9	9	9	9	9
	1-2 km	7	7	7	7	5	7	5	5	7	7	6
	>2 km	3	3	3	3	3	3	3	3	3	3	3

Figure 5. Scoring system for the various criteria and sub-criteria used in this study.

Table 3. Scale for scoring adopted from AHP.

Score	Definition
9	Criterion is highly suitable for evaluation without concerns.
7	Criterion is suitable for evaluation with few concerns.
5	Criterion may be suitable for evaluation with many concerns.
3	Criterion is unsuitable for evaluation.

Evaluation of the consistency of criteria weightings

To address certain degrees of inconsistency expected for the criteria weightings based on the judgments of the individual participants in the AHP., the consistency ratio was determined for the responses. The consistency ratio can be computed using the equation CR = CI/RCI, where RCI = random consistency index value, whose values were obtained from the Saaty's standard for random index (Table 4).

Table 4. Random index based on the number of criteria by Saaty (2008).

n	1	2	3	4	5	6	7	8	9	10
RCI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

To calculate the consistency ratio (CR), the Principal Eigen value (λ) was computed by Eigen vector technique. The Consistency Index (CI) was calculated from the equation 1.

$\lambda_{max} = 8.075$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad \text{(Eq. 1)}$$

where *n* is the number of factors used in the analysis.

An inconsistency of 10% or less is acceptable (Saaty, 1987). If the consistency value is greater than 10%, there is a need to identify the possible causes of inconsistency and to revise the judgement accordingly. When a CR value of 0 is obtained, it means that a perfect level of consistency in the pairwise comparison between the correspondents. The whole AHP was performed based on these principles.

Results and Discussion

Weights for the various SWIP site suitability criteria

The AHP results for the determination of proper weights for the identified site suitability criteria for SWIPs are shown in Table 5. Results indicate that the annual rainfall is the most important criterion among the eight (8) criteria garnering the highest weight of 25.2%, followed by the watershed area with 13% weight, soil texture (12.8%), land slope (12.6%), reservoir area (11%), proximity to agricultural sector (9.9%,) distance to water sources () and road accessibility (7.6%).

Table 5. Final weights for the various site suitability criteria derived from the AHP.

Criterion	Weights (%)	Absolute errors (%)
Average annual total rainfall	25.2	±3.4
Watershed area	13.0	±0.8
Soil texture	12.8	±2.5
Land slope	12.6	±1.3
Reservoir area	11.0	±1.9
Proximity to agricultural sector	9.9	±1.8
Distance to water sources	8.1	±1.3
Road accessibility	7.6	±0.9

The weights shown in Table 5 corresponded to low absolute errors ranging from ±0.8% to ±3.4%, indicating high agreement among the ten local experts who participated in the AHP. The consistency of the AHP results was further validated by the Consistency Ratio, which remained below the 0.10 threshold, confirming that the expert's comparative judgments were logical and rational.

Scores for the sub-criteria

The resulting consolidated scores for the various sub-criteria under each of the major criterion from the AHP are presented in Table 6.

Table 6. Final scores for the various sub-criteria from the AHP.

Criteria	Sub-criteria	Score
Average annual total rainfall	>2,500 mm	9
	1,800-2,500 mm	7
	<1,800 mm	4
Soil texture	Clay loam	9
	Loam/Silty clay	6
	Sandy/gravelly	3
Land slope	0-3%	9
	3-8%	6
	>8%	3
Road accessibility	<1 km- paved road	9
	1-3 km - gravel road	6
	>3 km or no access	3
Watershed area	20-50 ha	9
	10-20 ha	6
	<10 ha	4

Reservoir area	≥1.5 ha	9
	0.75-1.5 ha	7
	<0.75 ha	4
Distance to water sources	<500 m	9
	500-1,000 m	6
	>1,000 m	4
Proximity to agricultural sector	<1 km	9
	1-2 km	6
	>2 km	3

Following the derivation of relative weights and the assignment of sub-criterion scores through the AHP, these values were then integrated into a spatial model using a weighted linear combination. This process transforms the weighted priorities into a composite suitability index, which was then categorized into four distinct classification levels to better depict the site suitability of SWIP in the various parts of the province. This would also facilitate the use of GIS in the site suitability analysis of SWIPs.

Suitability classification

The AHP-based results generated in this study can then be used to facilitate a GIS-based site suitability analysis. The approach is briefly discussed herein using a suitability index, ,which is a function of the weight and the score of each level of criterion. The suitability index is calculated using the equation by *Yin et al.* (2020) (equation 2).

$$S = \sum_{i=1}^{n}(W_i \cdot X_i) \qquad \text{(eq. 2)}$$

where S is the total suitability index; W_i is the weight of the i-th suitability criterion; X_i is the score of the i-th sub-criterion (or criterion attribute); and n is the total number of suitability criteria."The scale for suitability classes adopted from FAO (1977) is shown in Table 7. To facilitate GIS-based site suitability analysis of SWIPs, the suitability values for each pixel can be calculated by combining the suitability and weighted values of the criteria in GIS,

Table 7. Scale for suitability index adopted from land evaluation and FAO (1977).

Suitability Class	Scale	Definition
S1	7-9	Highly suitable with no limiting factors

S2	6-7	Moderately suitable with some limiting factors
S3	5-6	Marginally suitable with severe limiting factors
N	> 5	Not Suitable

Based on FAO's classification (1977), the final suitability can then be classified into four classes. In this classification, S1 indicates an area which is highly suitable for SWIP with no limiting factors, S2 indicates land which is moderately suitable for SWIP with some limiting factors, S3 indicates land which is marginally suitable for SWIP with severe limiting factors, and N indicates land which is not suitable for small water impounding projects in Bukidnon (Table 7).

Table 8 presents a comprehensive synthesis of the study's findings. The parameters representing the criteria are organized into three primary factor groups such as hydrological, geotechnical and accessibility and socio-economic factors.

Table 8. Final weights of overall criteria and sub-criteria score for swip site suitability analysis in Bukidnon.

Factor	Criteria	Weight	Sub-criteria	Score
Hydrological factors	Average annual total rainfall	25.2%	>2,500 mm	9
			1,800-2,500 mm	7
			<1,800 mm	4
	Watershed area	13.0%	20-50 ha	9
			10-20 ha	6
			<10 ha	4
	Distance to water sources	8.1%	<500 m	9
			500-1,000 m	6
			>1,000 m	4
Geotechnical factors	Soil texture	12.8%	Clay loam	9
			Loam/Silty clay	6
			Sandy/gravelly	3
	Land slope	12.6%	0-3%	9
			3-8%	6
			>8%	3
	Reservoir area	11.0%	≥1.5 ha	9
			0.75-1.5 ha	7
			<0.75 ha	4
Accessibility and socio-economic factors	Proximity to agricultural sector	9.9%	<1 km	9
			1-2 km	6
			>2 km	3
		7.6%	<1 km- paved road	9

Road	1-3 km - gravel road	6
accessibility	>3 km or no access	3

Results showed that hydrological factors have the strongest influence on the overall suitability of Small Water Impounding Projects (SWIPs), accounting for a combined 46.3% of the total factor weight. This hydrology-centered hierarchy prioritizes water availability and catchment potential as the primary drivers, confirming that even geotechnically sound structures will fail if the hydrologic input is inadequate. This is as to be expected and plausible for water conservation structures for self-evident reasons.

Results also proved to be consistent and comparable with those obtained from similar studies previously cited. For instance, in the studies on SWIP suitability analysis by et al. (2020) in CALABARZON and by Pantano et al. (2020) in Oriental Mindoro, hydrological input stands at the apex of the criteria hierarchy, with annual rainfall consistently receiving the highest priority weight of 40.0%. However, while the criteria developed in this study for Bukidnon similarly positions annual rainfall as the primary driver (25.2%), the remaining weights are distributed more evenly across a broader spectrum of eight active biophysical and socio-economic variables unlike in the previous studies. Furthermore, results of this study for Bukidnon showed that watershed area is a major active decision variable with a weight of 13%, which suggests that in rugged, high-altitude volcanic terrains, catchment size is also a major factor that influences water harvesting potential and reservoir refill capacity.

Conclusions

This study generated a logically-formulated, locally-calibrated SWIP site selection criteria that is compatible with the Philippine Agricultural Engineering Standards. Consistent with past similar studies, hydrological factors proved to have the strongest influence on the overall suitability of Small Water Impounding Projects (SWIPs) in Bukidnon. The selection framework developed in this study could facilitate GIS-based site suitability analysis of SWIPs in the upland areas of Bukidnon and can be used by water resources planners and engineers for the proper planning and design of SWIPs to better contribute to irrigation development, flood management and climate change adaptation in the country. The development of the first-ever site-specific, multi-criteria spatial decision framework for Bukidnon designed specifically for the unique rugged topography and high-altitude with Type III and IV climate classifications also have some policy implications. It can be used as an objective pre-screening tool that can be directly institutionalized within the Provincial Development and Physical Framework Plan (PDPFP) and National Irrigation Administration (NIA) regional master plans.

To further enhance and advance the application, precision, and climate-resiliency of the developed spatial decision-support framework, a number of future research studies are recommended. This includes rainfall analysis, modeling and projection under climate change and climate variability scenarios to better account for the rainfall contribution in the SWIP site selection criteria. The generation of higher resolution digital elevation models also needs to be pursued to improve not only the accuracy of watershed area delineation but also the detection of fine-scale topographical variations, micro-reliefs, and natural depressions essential for precise dam axis positioning. Furthermore, testing the applicability and plausibility of the developed criteria in other upland regions with similar hydrometeorological conditions and with existing successfully implemented SWIPs may also be done as a form of framework validation. Finally, the SWIP site selection framework can be further broadened by incorporating temporal land use and land cover (LULC) changes and by integrating critical socio-environmental variables such as land tenure security, indigenous people's rights, among others.

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