Pertanika J. Sci. & Technol. 33 (S1): 83 - 107 (2025)

PERTANIKA JOURNALS

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Evaluation of Suitability of the Taguibo River Irrigation System Diversion Dam, Philippines

James Villamor Ariston[2], Christian Dave Domingo Ungab[2], Aljon Ente Bocobo[1,2]*, Arnold Gemida Apdohan[1,2] and Antonietto Ortega Cacayan Jr.[1]

[1]*Department of Agricultural & Biosystems Engineering, College of Engineering and Geosciences, Caraga State University, Ampayon, Butuan City, 8600, Philippines*

[2]*Center for Resource Assessment Analytics and Emerging Technologies (CREATE), Caraga State University, Ampayon, Butuan City, 8600, Philippines*

[3]*Caraga State University,Ampayon, Butuan City, 8600, Philippines*

ABSTRACT

The Taguibo River Watershed and Forest Reserve (TRWFR) is the main source of water consumption and irrigation supply in Butuan City, but the irrigation supply is often insufficient, particularly during dry seasons. Competing demands for water further exacerbate the problem, leading to a reduction in water available for irrigation. This study aims to assess the Taguibo River irrigation system diversion dam using the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) tools. The dependable flow of the diversion dam was investigated to assess the sustainability of water, which resulted in 466.94 lps, and the AHP analysis identified river discharge as the most important factor in suitability assessment. The generated suitability map shows the specific sites suitable for dam construction within the river, covering approximately 88,599.17 m^2 or 0.16% of the study area. The existing suitability map, in contrast, focused on the entire study area and disregarded the river network as a criterion, resulting in a much larger proportion (68%) of the area being deemed suitable. Overall, the study found that the Taguibo River irrigation system diversion dam is highly suitable based on the selected criteria, and the current suitability map provides valuable information for site selection and construction.

Keywords: Analytical hierarchy process, dependable flow, gis, suitability map, Taguibo river, diversion dam

ARTICLE INFO

Article history:
Received: 8 November 2023
Accepted: 5 November 2024
Published: 31 January 2025

DOI: https://doi.org/10.47836/pjst.33.S1.05

E-mail addresses:
james.ariston@carsu.edu.ph (James Villamor Ariston)
christiandave.ungab@carsu.edu.ph (Christian Dave Domingo Ungab)
aebocobo@carsu.edu.ph (Aljon Ente Bocobo)
agapdohan@carsu.edu.ph (Arnold Gemida Apdohan)
antoncacayan@gmail.com (Antonietto Ortega Cacayan Jr.)
*Corresponding author

INTRODUCTION

The Philippines has natural resources and abundant water bodies. According to Lapong and Fujihara (2008), it has 130 km^3/year of internal water resources. In Region

ISSN: 0128-7680
e-ISSN: 2231-8526

13 (Caraga Region), there are 30 classified rivers, including the Taguibo River, which is known as a Water Quality Management Area (WQMA), six marine water, one lake, and 19 unclassified water bodies, according to the Department of Environment and Natural Resources (EMB, 2019). Due to these vast water resources, dams for domestic and irrigation water supply are essential for economic development. However, the government gave less priority to the water governance sector and institutional framework, such as supporting building structures (Lapong & Fujihara, 2008). The Taguibo River watershed forest reserve (TRWFR) is a major source of potable water that supplies over 40,000 concessionaries or more than 200,000 individuals. In addition, it supplies water for irrigation purposes to 762 hectares of rice lands and is a source of livelihood for occupants of the watershed (BCWD, 2015; EMB, 2019). However, providing adequate water through the service area is currently a problem for the Taguibo River irrigation system diversion dam, especially in the dry season. So, this study focused on site suitability assessment of the Taguibo River irrigation system diversion dam using the analytical hierarchy process (AHP) and provided a suitability map of the study area using geographic information system (GIS) tools.

The use of GIS for accurate decision-making, modern technology is useful as this involves the implementation of complex matters that give the users the ability to understand the problems through analyzing the spatial, producing digital maps, and thus saving time, effort, and cost to reach an optimized solution. A geographic Information System (GIS) is a system of computer software, hardware, and data personnel that input, manipulate, analyze, and present the data and information related to a specific location on the earth's surface (Ali, 2020). AHP is a tool for multi-criteria decision analysis (MCDA) used to logically evaluate and compare several frequently conflicting factors to make the best possible solution (Alpagut et al., 2021). The analytical hierarchy process is a structured technique for organizing and analyzing multiple criterion decisions (Shukla et al., 2013). The process is to decompose a decision problem into a hierarchy of simpler sub-problems and analyze it independently (Bataineh et al., 2018), and it is one of the most common multi-criteria decision analysis (MCDA) methods used in site selection (Midatana et al., 2018). The result was compared to the existing suitability study to find the difference between the two methods used.

MATERIALS AND METHODS

Study Area

The study area was at the Taguibo River Watershed Forest Reserve in Butuan City, Agusan del Norte (Figure 1). The Taguibo River is a vital water source for irrigation and drinking purposes for the residents of Butuan City. The watershed is geographically situated at 125°31'00" to 125°43'16" N latitude and 8°158'00" to 9°05'34"E longitude. It has a total land area of 4,367.44 hectares, covering four barangays: Barangay Anticala in Butuan

City, Barangay San Antonio in Remedios Trinidad Romualdez (RTR), Barangay Mahaba in Cabadbaran City, and a portion of Barangay Kulambugan, Sibagat, and Agusan del Sur. The area continues towards the coastal areas of Magallanes, making a total land area of 12,438 hectares. BCWD, NIA, Taguibo Aquatec Solutions, DENR and LGU Butuan manage the area.

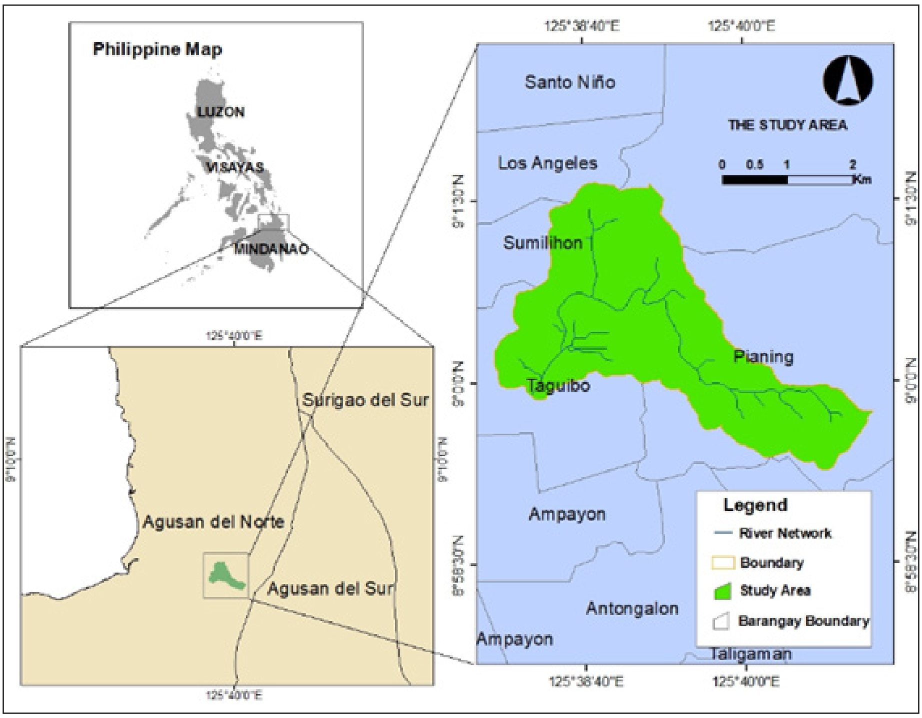

Figure 1. Study area

The watershed's minimum and maximum surface elevations range from 93.0351 m to 1883.9800 m. Based on the Digital Elevation Model (DEM), it possessed a hilly, mountainous surface with soil mostly belonging to the hydrologic soil group B, with loamy and silty loam soils. Moreover, the watershed has a Type II climate, with rainfall spreading evenly throughout the year.

Methodological Framework

Figure 2 shows the methodological framework of this study. Several data were collected from different sources to assess the location suitability of existing diversion dams. These data were then subjected to pre-processing, processing, and aggregation to extract the needed information, using ArcGIS 10.4 and HEC-RAS 6.3.1 to produce and extract maps from the datasets.

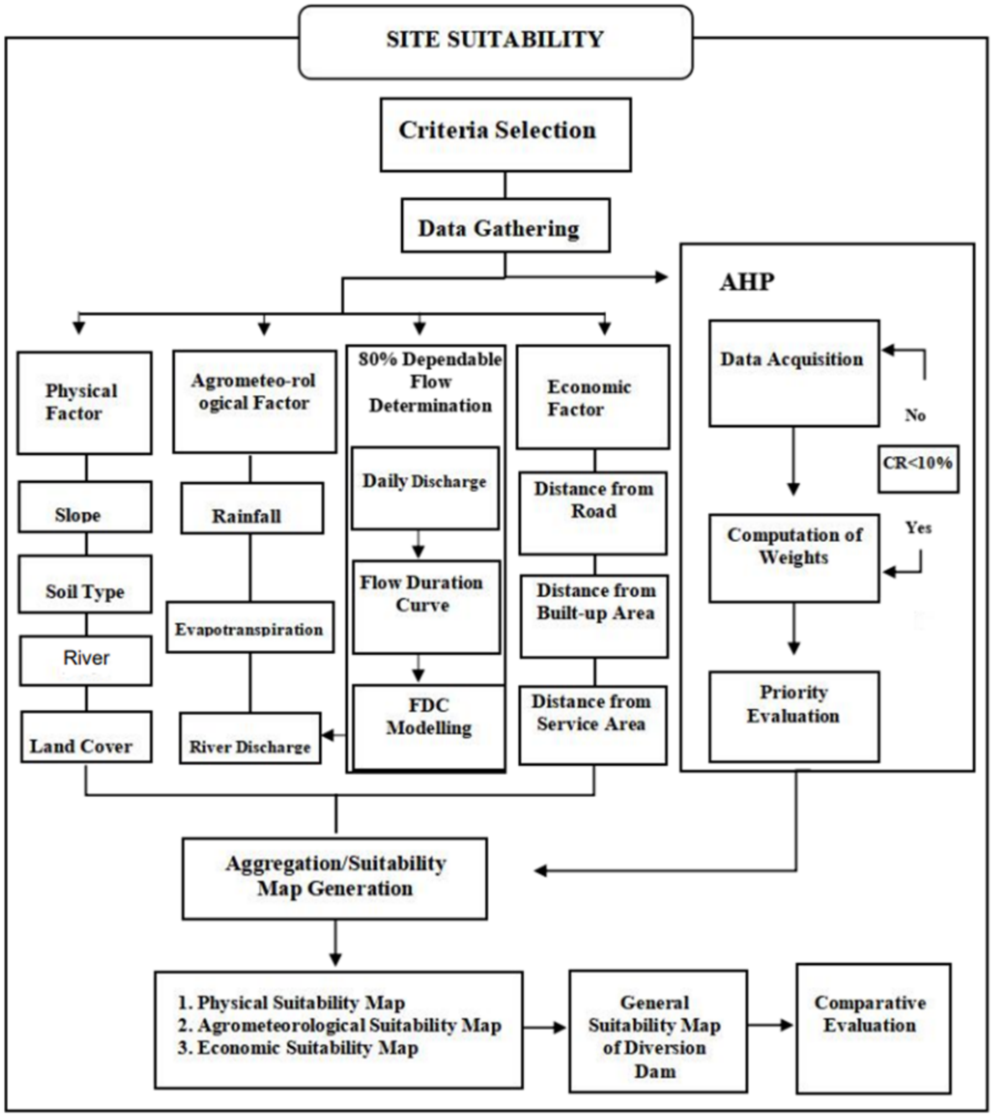

Figure 2. The methodological framework of the study

To be specific, the physical (slope, soil type, river width, and land cover), agrometeorological (rainfall, evapotranspiration, and river discharge) and economic (distance from road, distance from built-up areas, and distance from service area) factors were selected as the main and sub-criteria. On the other hand, the analytical hierarchy process was used to determine the important factors in the selection of site suitability by surveying to collect information from selected experts in different government agencies, private institutions, and individual experts.

Criteria Selection

Site Suitability Analysis (SSA) of a diversion dam needs to determine and select the important criteria that could affect the suitability of the dam on the site (Karakuz & Yildiz, 2022). In this study, 10 criteria were adopted, namely the river network and protected areas. In contrast, the criteria that were used include rainfall, slope, river discharge, soil type, land cover, river width, evapotranspiration, distance from road, distance from built-up areas, and distance from service area (Baltazar et al., 2019) Table 1 lists the adopted criteria with their corresponding description of site suitability for diversion dams.

Table 1
Selected criteria for location suitability

Criteria	:	Description
Slope	:	It is the main factor that influences the safety of a dam.
Soil type	:	It influences diversion dam function in term of runoff amount and seepage.
River Width	:	It affects the foundation of diversion dam construction and how much material will be needed.
Land Cover	:	It affects sediment loads on diversion dams as well as water losses due to evapotranspiration.
River Discharge	:	River flow ensures that there is available water in an irrigation canal.
Rainfall	:	It is an additional source of water for storage.
Evapotranspiration	:	It reduces water storage for irrigation.
Distance from Road	:	It should be located with a multi-ring buffer at 100-meter intervals for repair and maintenance activities.
Distance from Built-up Areas	:	It should be far from built-up areas (residential, commercial) to avoid contamination and pollution.
Distance from Service Area	:	It should have a multi-ring buffer at 0.5 km intervals from its service area to minimize the construction cost.

The selected criteria were organized and grouped into three main criteria. The slope, soil type, river width, and land cover were represented as sub-criteria under the physical main criteria since all the sub-criteria can affect the physical aspects and stability of the diversion dam. Meanwhile, the rainfall, evapotranspiration, and river discharge were kept under agrometeorological main criteria, considering all the selected sub-criteria can greatly affect all the related agrometeorological factors and the water availability of the diversion dam. Lastly, the road, distance from built-up areas, and distance from the service area, represented as sub-criteria, were under the main economic criteria since they mainly affect all the factors related to the economy and the cost of constructing the diversion dam.

Data Collection

Two types of data are GIS data, which was used in map generation, and data for the analytical hierarchy process, AHP, for decision-making analysis (Canco et al., 2021; Chen, 2006). The GIS data were gathered from different sources, including government agencies and institutions, field validation, and through surveys (Table 2).

Table 2
List of collected GIS data and their sources

Data	Source
Digital Elevation Model (DEM)	National and Resource Mapping Information Authority (https://www.namria.gov.ph), 2022
Soil Type	Bureau of Soil and Water Management (https://www.bswm.da.gov.ph/), 2022
Land Cover	CSU-CReATe (Center for Resource Assessment Analytics and Emerging Technologies), 2022
Rainfall	TerraClimate (https://www.climatologylab.org/terraclimate.html), 2023
Evapotranspiration	TerraClimate (https://www.climatologylab.org/terraclimate.html), 2023
River Discharge	CSU-CReATe (Center for Resource Assessment Analytics and Emerging Technologies), 2022
Road Network	CSU-CReATe (Center for Resource and Assessment Analytics and Emerging Technologies), 2022
Service Area	National Irrigation Administration (https://nia.gov.ph), 2023

Specifically, the GIS data, such as DEM, soil type, land cover, river discharge, and road network, were obtained from the Carage State University Center for Resource Assessment, Analytics and Emerging Technologies (CSU-CReATe). On the other hand, the rainfall and evapotranspiration data were gathered from the TerraClimate website. Lastly, the service area was obtained from the National Irrigation Administration (NIA) ASDI-IMO.

Physical Data

The use of thematic maps is a common approach to organizing and visualizing physical data. In this study, thematic maps were used to generate a suitability map of the diversion dam, with a focus on its physical factors. The thematic maps used in this study include the slope, soil map, river width, and land use/land cover map.

Slope Map

The slope was represented as one of the sub-criteria under the physical main criteria. A digital elevation map gathered from the Caraga State University Center for Resource Assessment, Analytics and Emerging Technologies (CSU-CReATe) was used to generate a slope map. It was processed using ArcGIS 10.4 software. The generated slope map was then used to generate a physical suitability map. The processing includes gathering DEM, using the slope tool and clip tool in ArcGIS 10.4 to clip the boundary of the study area, and reclassifying the slope map for the final output.

Soil Map

Soil type was processed by extracting soil type data from the dataset acquired from BSWM through the office of CSU-CReATe. It was then processed using ArcGIS 10.4 to generate the soil-type thematic map. The generated soil-type map was also used to generate the physical suitability map. The process processing includes gathering soil-type GIS data, applying clip tools to clip the study area boundary using ArcGIS 10.4, and reclassifying the boundary soil-type map for the final output of the soil-type thematic map.

River Width

River width is typically obtained through bathymetry, which requires actual data from the site. However, due to the unavailability of bathymetric data on the site and the critical weather conditions during the data gathering period, HEC-RAS 6.3.1 software was used to acquire the river width using the slope and elevation of the terrain and Arcmap 10.4 was used for mapping. The process includes processing gathered DEM, identification of the river, bank lines, flow paths, and river cross-section. The cross-section of the river was then interpolated and reclassified for the river width final thematic output map.

Land Use/Land Cover Map

The Land Use/Land Cover (LULC) map was generated by utilizing the available data of the Butuan and Taguibo watershed (upstream) LULC for the year 2021 gathered from Caraga State University-Center for Resource Assessment, Analytics and Emerging Technologies (CSU-CReATe). It was then processed using ArcGIS 10.4 tools, and the output LULC thematic map was used to generate a physical suitability map. This process includes merging the land use and land cover of Butuan City with the land cover of the Taguibo River watershed forest reserve, clipping the merged LULC using the boundary map of the study area, and reclassifying for generating the LULC map final output.

Agrometeorological Data

This study used publicly available data and actual data acquired through field activity to acquire the agrometeorological data, including rainfall, river discharge, and evapotranspiration maps. Agrometeorological data were used to generate the suitability map, as it is one of the main criteria of the suitability map. The ArcGIS 10.4 tools were used to generate the maps.

Rainfall Map

A rainfall map was generated using the downloaded dataset from TerraClimate. This study used the 2021 annual precipitation in ".nc" format. The downloaded annual precipitation for the year 2021 was processed using ArcGIS 10.4 tools. The generated rainfall thematic map was then used to generate an agrometeorological suitability map. The process includes making a NetCDF raster layer, resampling, raster to point, interpolation, and clipping using the boundary using the clipping tools of the GIS tools. The clip rainfall map boundary was then reclassified to finalize the rainfall thematic map output.

Evapotranspiration

The evapotranspiration map was generated using actual evapotranspiration (AET) data from the year 2021, which was also acquired from TerraClimate. The file was also in the ".nc" format. Hence, the process of precipitation and evapotranspiration was quite similar. By loading the data and creating a netCDF raster layer, resampling was done to create lower pixel size and higher resolution. The dataset was also projected to WGS 1984 UTM Zone 51N. The resampled data was clipped to the downstream boundary to extract the evapotranspiration data within the boundary. The process includes first downloading the annual evapotranspiration from the TerraClimate website, next making the NetCDF raster layer, resampling, raster to point, interpolation, and clipping the output using the boundary map of the study area through ArcGIS 10.4 tools. The clipped AET map was then reclassified for the final evapotranspiration thematic map output.

River Discharge

A river discharge map was created using the actual daily discharge during the monitoring of streamflow from May to October. It was generated using ArcGIS 10.4, where the base map was used to locate the data collection station. The process includes utilizing cross-section points, adding dependable flow data attributes, interpolation, and reclassifying the output for the final river discharge map.

Economic Data

A variety of factors impacting an area's suitability were systematically assessed and prioritized using a multi-criteria decision analysis (MCDA) technique. With this methodology, each criterion is evaluated according to its relative significance and influence on the decision-making process as a whole. Several economic considerations were taken into account in this analysis, including distance from roads, built-up areas and service areas. The MCDA approach ranks and weighs these variables to provide a comprehensive suitability map that shows places according to their development potential and economic feasibility (Romano et al., 2015).

The design and implementation of a diversion dam project heavily rely on integrating spatial data using ArcGIS 10.4 technologies. Making educated decisions in complicated projects requires the ability to visualize, analyze, and interpret geographical data, made possible by the robust geographic information system (GIS) platform ArcGIS (Goncalvez, 2021).

Overall, using ArcGIS 10.4 tools in this context improves the analysis's efficiency and accuracy (Charles et al., 2024) while also helping to design and carry out the diversion dam project more successfully by ensuring that economic concerns are sufficiently considered.

Distance from Road

The distance from the road was created by using the Mindanao roadmap dataset. It was narrowed down by clipping the road map layer with the downstream boundary, leaving the road network inside the boundary. The generated distance from the road thematic map was used to generate the economic suitability map. The process includes the gathering of GIS Mindanao roadmap data from Caraga State University-Center for Resource Assessment, Analytics and Emerging Technologies (CSU-CReATe), clipping the roadmap using ArcGIS 10.4 tools, applying multi-ring buffer at 100-m intervals, and reclassifying for distance from road map final output.

Distance from Built-up Areas

Distance from built-up areas was generated by utilizing the extracted land use/land cover LULC map. The ArcGIS 10.4 tools were used to generate the thematic maps. The generated distance from the built-up area thematic map was then used for economic suitability map generation. The process includes gathering the LULC thematic map, extracting the built-up area, and assigning multi-ring buffers to measure the distance from built-up areas at 100-m intervals. The map was also clipped using the boundary map of the study area and then reclassified for the distance from the built-up area, which is the thematic map's final output.

Distance from Service Areas Map

Distance from the service area was created using the service area dataset from the National Irrigation Administration (NIA) ASDI-IMO. The dataset was loaded to the ArcMap as a reference in generating its distances through the multiple-ring buffer tool. The generated distance from the service area thematic map was then used for economic suitability map generation. The process includes generating a service area thematic map from the National Irrigation Administration (NIA-ASDI IMO), applying polygon-to-point tools using ArcGIS 10.4 tools, and a multi-ring buffer at 0.5 mm intervals. Lastly, the specified boundary of the study area was clipped and reclassified for the distance from the service area thematic map final output.

Dependable Flow Determination

The dependable flow in irrigation networks was calculated by considering the availability of irrigation data (Zukhrufiyati et al., 2019). Dependable flow calculation can also be done through SNI No. 6738: 2015 concerning the calculation of dependable flow with a discharge–duration curve if the data is available. Equation 1 was used to calculate the reliable flow using the frequency approach. The process includes the daily discharge data acquisition, flow duration curve calculation, and modeling of the flow duration curve using the dplot.

$$Probability\ of\ occurrence = \frac{m}{n+1} 100\% \quad [1]$$

Where P(X≥x) = probability of the occurrence of variable X (flow of discharge_≥) that is greater than x(m³/s)

m = data rank

n = the amount of data

X = a discharge data series

x = the dependable flow if the probability matches the designation

Daily Discharge Data Acquisition

The daily discharge data of the Taguibo River was acquired from the CSU-Center for Resource and Assessment Analytics and Emerging Technologies (CReAte) through the project entitled Water Resource Assessment and Modeling of the Selected Watershed in the Caraga Region for Sustainable Domestic and Irrigation Supply. The available daily discharge data for 2022 was from the project gathered only from one station located near the Taguibo River diversion dam. Since 1-year data was unavailable, the available daily discharge data and selected data from the unpronounced season from May to October 2022 were utilized.

Flow Duration Curve

The flow duration curve (FDC) represents the daily discharge of water against the percentage of time that a particular discharge was equaled or exceeded (Longobardi & Villani, 2013). Microsoft Excel was used to calculate the dependable flow of the river. The daily discharge data was first enumerated with the corresponding date to perform the calculation. Next, the streamflow was sorted from highest to lowest and provided rank in the next column, with rank 1 as the highest discharge and rank 178 as the lowest rank. The next column was the probability of recurrence, which was calculated using Eq. 1, while Eq. 2 was used to determine the return period on the last column**.** The summary of statistics was calculated, and the sum, mean, and standard deviation were also provided.

$$Return\ Period = \frac{\text{rank}}{n^{th}\ rank} \qquad Return\ Period = \frac{\text{rank}}{n^{th}\ rank} \qquad [2]$$

FDC Modeling

Dplot software was used to plot the calculated flow duration curve to show that data falls with an 80% probability of recurrence. In plotting the calculated dependable flow, the table generated in Excel was copied and pasted with the corresponding table in dplot software. Lognormal distribution was used to model the distribution of the different probabilities of recurrence. The modeling exhibited two lines: (1) the actual data calculated using the flow duration curve and (2) the frequency line.

AHP Data Acquisition

An interview was conducted with selected experts related to the topic. The experts were chosen from different government institutions, private offices and individual experts. There were five engineers from the National Irrigation Administration (NIA) regional office, Bancasi, Butuan City, Philippines, and five individuals from different agencies: one expert from the NIA ASDI-IMO office, Brgy. Ambago, Butuan City, Philippines, one from City Agriculturist Office, Brgy. Tiniwisan Butuan City, Philippines, one from the water district, Agusan del Sur, Philippines, one from the Department of Social Worker and Development (DSWD), Philippines, and one private civil engineer individual expert.

Computation of Weights

The pairwise comparison accuracy was calculated using the Consistency Ratio (CR) (Equation 3), which is equivalent to the ratio of the Consistency Index (CI) (Equation 4) and Random Index (RI) to identify the accuracy of the respondents' answers. When the CR is less than 10%, the comparison between criteria is acceptable; otherwise, the CR allows for re-evaluation.

$$Consistency\ Ratio = \frac{\text{CI}}{\text{RI}} \qquad [3]$$

CI can be calculated by,

$$Consistency\ Index = \frac{\lambda max - n}{\text{n} - 1} \qquad [4]$$

Where λmax = (Weight1*S1 + Weight2*S2 + Weight3*S3+...........), and n = number of criteria. For random index (RI), a 1.49-constant value was used from Table 3 since it has an overall 10 criteria. The geometric mean was calculated using the (Equation 5) (Dong et al., 2010):

$$Geometric\ Mean\ (G.M) = \sqrt[n]{X_1 * X_2 * X_3 \dots X_n} \quad [5]$$

Where n is the number of returns in the series, and X_i is the variable.

Table 3
Average random consistency index (RI)

Number of criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Random Index	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Priority Evaluation

The selected 10 criteria were grouped into three main factors: physical factors (slope, soil type, river width, and land use/land cover), agrometeorological factors (rainfall, rover discharge, and evapotranspiration), and economic factors (distance from road, distance from built-up area, and distance from service area). Based on the experts' feedback, the three main factors were evaluated according to their importance. All the graded main criteria were then compared.

Suitability Map Generation

The data acquired were compiled and analyzed in one manner, such as the computed weights from the selected criteria, the generated thematic layers, namely, the rainfall, slope, river discharge, soil type, land cover, river width, evapotranspiration, distance from road, distance from built-up areas, and distance from service area maps. All the thematic layers were loaded to ArcGIS 10.4, and the weighted criteria were used as a reference in performing weighted overlay to generate the suitability maps.

Physical Suitability Map

The weighted overlay tool, a GIS tool that allows users to combine multiple layers of data into a single map layer, was used to generate the suitability map for physical conditions. In this case, the tool measured the suitability of each location based on the physical factors considered.

Agrometeorological Suitability Map

The weighted overlay tool was applied to generate the agrometeorological map. The weighted overlay tool is a GIS tool that allows users to combine multiple layers of data into a single map layer. In this case, the tool was used to measure the suitability of each location based on the agrometeorological factors considered. The thematic maps were overlaid: the evapotranspiration, river discharge, and rainfall maps. The process includes the generation of rainfall, evapotranspiration, and river discharge thematic maps. All the thematic maps were then overlaid using ArcGIS 10.4 tools. Lastly, the scale value of weight in specific sub-criteria was applied to produce the agrometeorological suitability map.

Economic Suitability Map

The available maps generated using the multi-ring buffer tool were utilized to create the suitability map for economic factors. The multi-ring buffer tool is a GIS tool that creates concentric buffers around a feature or set of features. In this case, the tool created maps showing the distances from the road, built-up areas, and service areas. The process economic suitability map includes generating thematic maps, namely, distance from the road, distance from the built-up area, and distance from the service area. All the generated thematic maps were then overlaid using ArcGIS 10.4 tools and the assigned scale value of weights to generate the economic suitability maps.

General Suitability Map of Diversion Dam

The three main criteria, physical, agrometeorological, and economic, are the factors in determining the suitable sites for the diversion dam. Therefore, the three suitability maps for each aspect were used to create the suitability map for the diversion dam. The three suitability maps were overlaid using the weighted overlay tool and configured with their corresponding weightage value based on the AHP results. The process includes the generation of physical, agrometeorological, and economic suitability maps. Then, I overlaid all the suitability using ArcGIS 10.4 tools and applied weighted criteria gathered from the experts to generate the final AHP suitability map.

RESULTS AND DISCUSSION

Dependable Flow Analysis

Figure 3 shows the flow–duration curve of the stream of the Taguibo River irrigation system diversion dam derived using dplot software. The actual flow was also aligned with the frequency line ($\log10(y) = 3.053-0.4564s(x)$) using a lognormal distribution.

The results of this analysis revealed that the stream's flow follows a lognormal distribution pattern, which is a commonly observed distribution pattern in hydrology, particularly in subtropical and temperate climates. This finding is important because it allows water resource managers and planners to more accurately predict the frequency and probability of different flow rates, which can help them make informed decisions about water allocation and irrigation planning.

Overall, the analysis shows that the Taguibo River irrigation system diversion dam has a dependable flow of 466.94 lps with an 80% probability of recurrence. This means that the stream discharge occurs or is exceeded 80% of the time. These findings provide important information for water resource management and irrigation planners in the area and highlight the value of using flow duration curves and lognormal distribution to analyze water flow data.

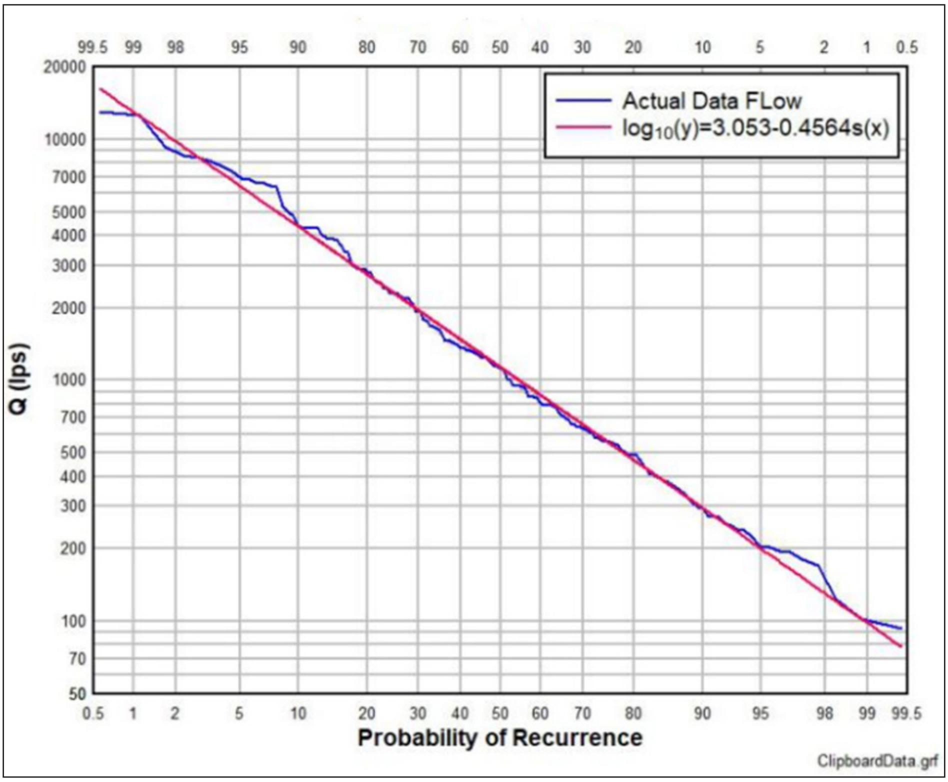

Figure 3. Flow–duration curve of Taguibo River irrigation system diversion dam using dplot

Weighted Criteria Analysis

The study used an analytical hierarchy process to assess the site suitability of the Taguibo River irrigation diversion dam for decision-making. Ten criteria were developed and grouped into three major aspects. These are physical (slope, soil type, land cover, and river width), agrometeorological (rainfall, river discharge, and evapotranspiration), and Economic aspects (distance from service areas, distance from road, distance from built-up areas). Table 4 shows the results of the ten respondents who were experts in their chosen field to determine the relative importance of the criteria and graded each main criterion and sub-criteria. This study normalized and calculated the graded criteria and sub-criteria provided by the experts using the geometric mean method to determine the weight.

The agrometeorological factor was the most important aspect, with 0.41 weight, followed by the physical factor, which had 0.38 weight. Lastly, the least important was the economic factor, with 0.21 weight. The agrometeorological aspect was the most important factor, according to a few experts, since it involves the availability and sufficiency of the water supply, which is the main issue considered for water diversion (Bacci et al., 2020). Although physical factors could determine the effectiveness of the dam, safety, and foundation (Baltazar et al., 2019), it has resulted as the second most important. Lastly, the expert respondents from the City Agriculture Office of Butuan City and the National Irrigation Administration Office-Regional Field Office considered the economic factor as the least priority due to its dependence on the transportation of materials needed for construction and funding issues, which can be resolved by increasing the funds (Baltazar et al., 2019).

Table 4
Weights of main criteria and sub-criteria from 10 experts

Main criteria	Weight	Sub-criteria	Weight
		Slope	0.169
Physical	0.38	Soil Type	0.317
		River Width	0.265
		Land Cover	0.249
		Rainfall	0.354
Agrometeorological	0.41	Evapotranspiration	0.162
		River Discharge	0.484
		Distance from Road	0.280
Economic	0.21	Distance from Built-up Area	0.290
		Distance from Service Area	0.430

Moreover, the river discharge from agrometeorological aspects was the most important criterion weighted with 0.484, followed by rainfall with a weight of 0.354, and evapotranspiration with 0.162 weight. Meanwhile, soil type from physical aspects was the most important, weighted at 0.317, followed by river width at 0.265, land cover at 0.249, and slope at 0.169 weight. Lastly, distance from the service area was the most important criterion from economic aspects, weighted with 0.430, followed by distance from a built-up area with 0.290 weight, and distance from the road with 0.280 weight.

Furthermore, Table 5 displayed the weight of each sub-criterion. Among the 10 sub-criteria based on the results, river discharge and rainfall from agrometeorological aspects were the highest and second most important criteria, weighted 0.198 and 0.145, respectively. On the other hand, soil type, river width, and land cover under physical aspects were the third, fourth, and fifth important, weighted 0.121, 0.101, and 0.095, respectively. At the same time, the distance from the service area was the sixth most important, weighted at 0.090. Lastly, the three least important criteria were the evapotranspiration, slope, and distance from the built-up area, which have an individual weightage of 0.066, 0.064, and 0.061, respectively.

Table 5
Weights of each sub-criterion applying 10 × 10 matrix

Sub-criteria	**Weight**
Slope	0.064
Soil Type	0.121
River Width	0.101
Land Cover	0.095
Rainfall	0.145
Evapotranspiration	0.066
River Discharge	0.198
Distance from Road	0.059
Distance from Built-up Area	0.061
Distance from Service Area	0.090
Total	1.000

The expert respondent's result among the three significant aspects (agrometeorological, physical and economic) gave the agrometeorological consideration for the highest weight, which directly impacts the area's suitability for a diversion dam.

Physical Suitability Map

The four thematic layers, slope, soil type, river width, land cover maps, and their physical weights scale, were used to generate a physical suitability map using ArcGIS 10.4 tools. The result given in Figure 4 shows that the physical suitability map has five suitability levels: not suitable, low suitability, moderately suitable, suitable, and highly suitable, which are represented in red, orange, green, violet, and blue, respectively.

Generally, the physical suitability map has found only approximately 1% of the total area along the river due to the selected river width sub-criteria. The majority of the labeled sites were found moderately suitable, represented in green color with 40.74% out of 124,162 m^2 or approximately 50,583.6 m^2, followed by highly suitable, suitable, and low suitable sites, with 26.17%, 20.99%, and 9.38%, respectively out of 124,162 m^2. On the other hand, sites that are not suitable are represented in red and have the lowest area, with 2.72% out of 124,162 m^2 or approximately 3,402.03 m^2. Meanwhile, the location of the Taguibo River irrigation system was moderately suitable. In addition, the area not aligned with the river was also considered unsuitable, specifically in Barangay Anticala, Barangay Los Angeles, Barangay Sumilihon and some parts of Barangay Pianing.

Agrometeorological Suitability Map

As shown in Figure 5, the suitability map of agrometeorological aspects labels two levels of suitability: moderately suitable, represented in green and highly suitable, represented in blue.

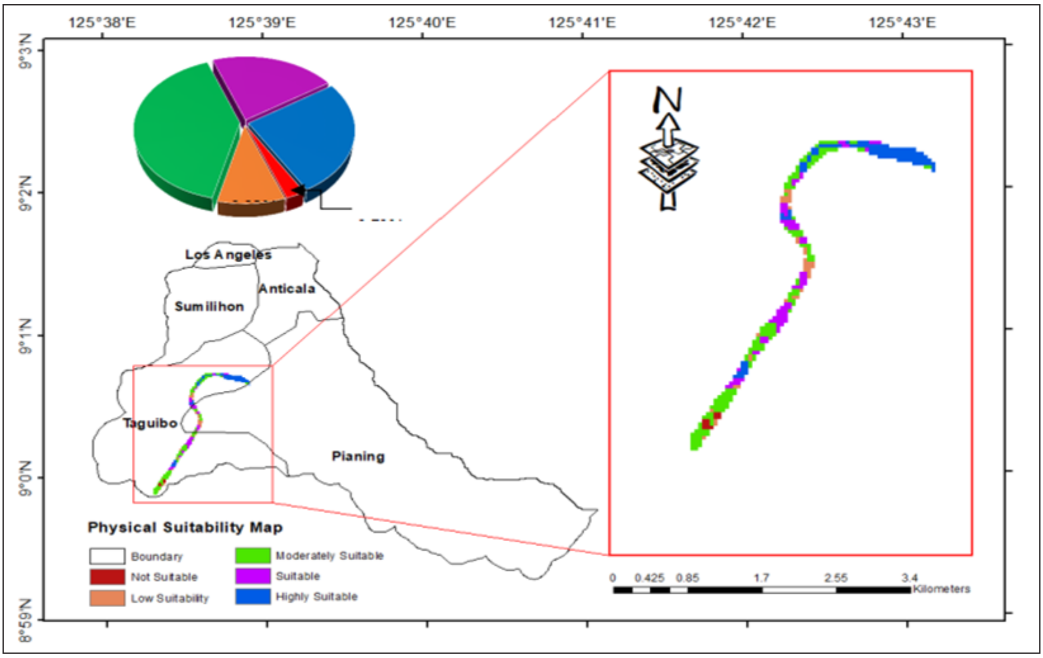

Figure 4. Physical suitability map

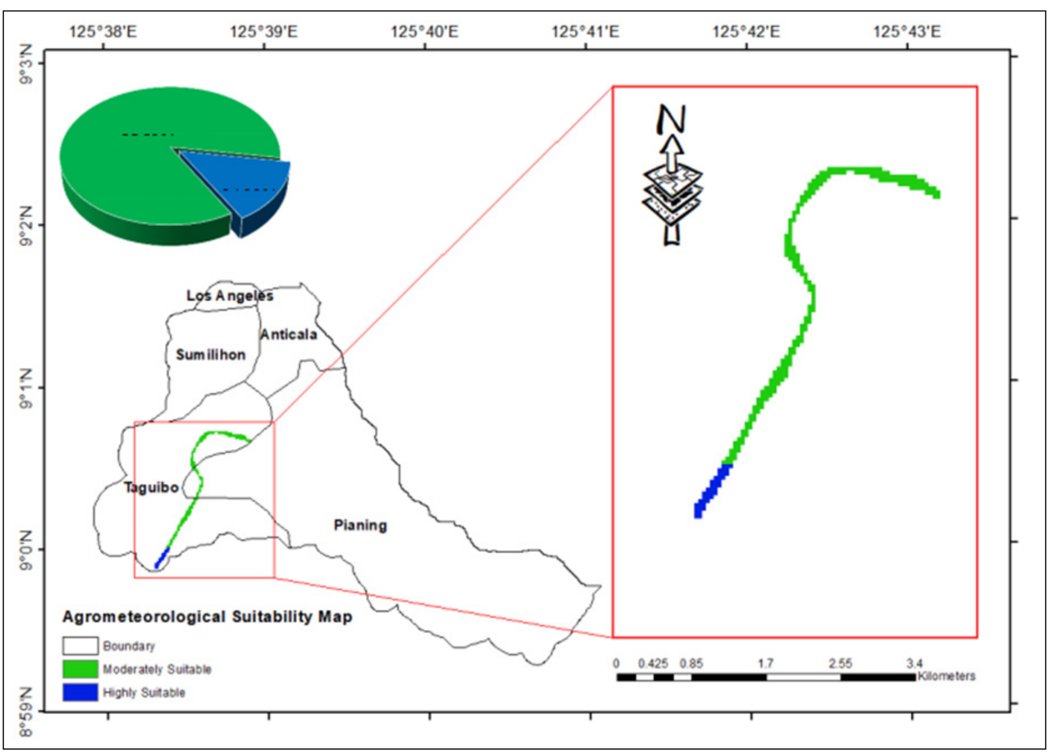

Figure 5. Agrometeorological suitability map

In addition, it was found that there are two labeled sites along the river due to the river discharge criteria. In summary, the majority of the identified sites were moderately suitable and found upstream of the Taguibo River irrigation system diversion dam's location with 85.81% area out of 88,599.17 m^2 or approximately 76,026.95 m^2. On the other hand, the highly suitable sites have an area of 14.19% out of 88,599.17 m^2 total area or approximately 12,572.22 m^2, including the location within the Taguibo River irrigation system diversion dam classified as highly suitable. Moreover, the areas not aligned with the river were also considered suitable, specifically in Barangay Anticala, Barangay Los Angeles, Barangay Sumilihon and some parts of Barangay Pianing.

Economic Suitability Map

Figure 6 labels five suitability levels: not suitable, low suitability, moderately suitable, suitable, and highly suitable, represented in red, yellow, green, sky blue, and blue, respectively. Based on the results, most maps were moderately suitable, while the unsuitable area was the lowest.

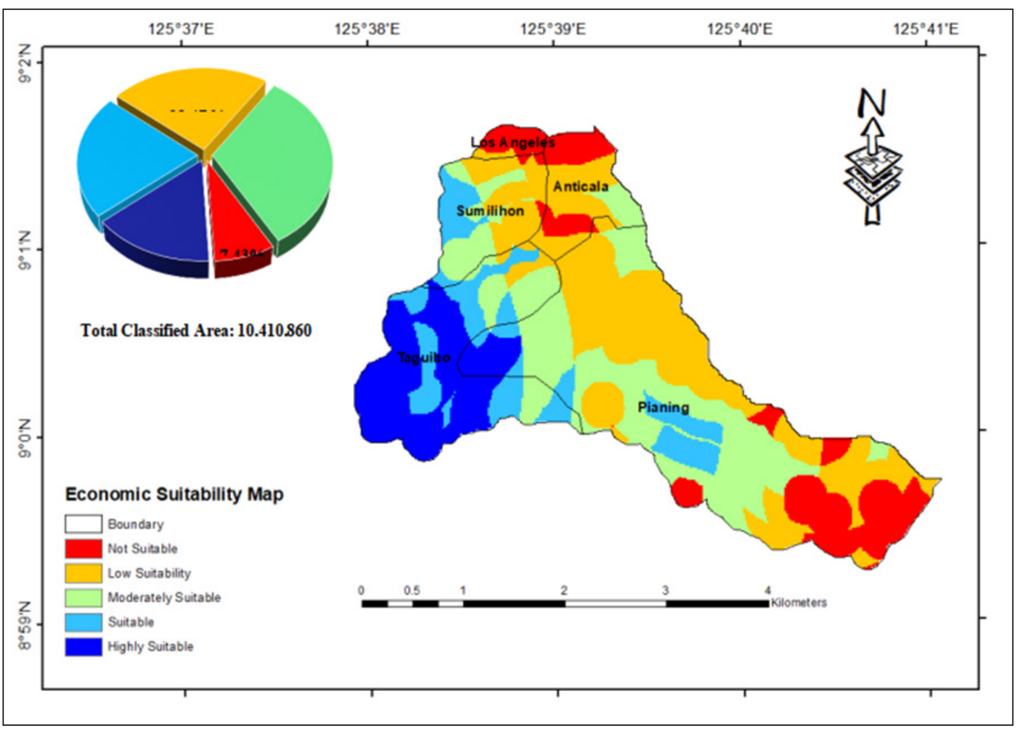

Figure 6. Economic suitability map

In addition, the moderately suitable site was the highest covered area with 32.24% out of 10,410,860 m^2 or approximately 3,356,461.26 m^2, followed by the low suitability site, suitable, and highly suitable sites, with 23.47%, 21.91%, and 14.95% area, respectively out of 10,410,860 m^2 of the total area covered. At the same time, the site that was not suitable was the lowest area covered, with 7.43% out of 10,410,860 m^2 total area or approximately 773,526.898 m^2. In terms of economic aspects, the Taguibo River irrigation system diversion dam was classified as a highly suitable site.

Final Suitability Map

As displayed in Figure 7, the AHP model suitability map shows five suitability levels of identified sites, namely not suitable, low suitable, suitable, moderately suitable, and highly suitable, represented with five different colors, including red, orange, green, purple, and blue. It was found that the majority of the sites were moderately suitable, with 45.67% out of 88,599.17 m^2 or approximately 40,463.24 m^2 area, followed by the low suitable, highly suitable, and not suitable sites with 30.45%, 10.73%, and 9.69% area covered, respectively out of 88,599.17 m^2 total area. On the other hand, the suitable sites identified as the lowest area covered with 3.46% out of 88,599.17 m^2 or approximately 3,065.53 m^2.

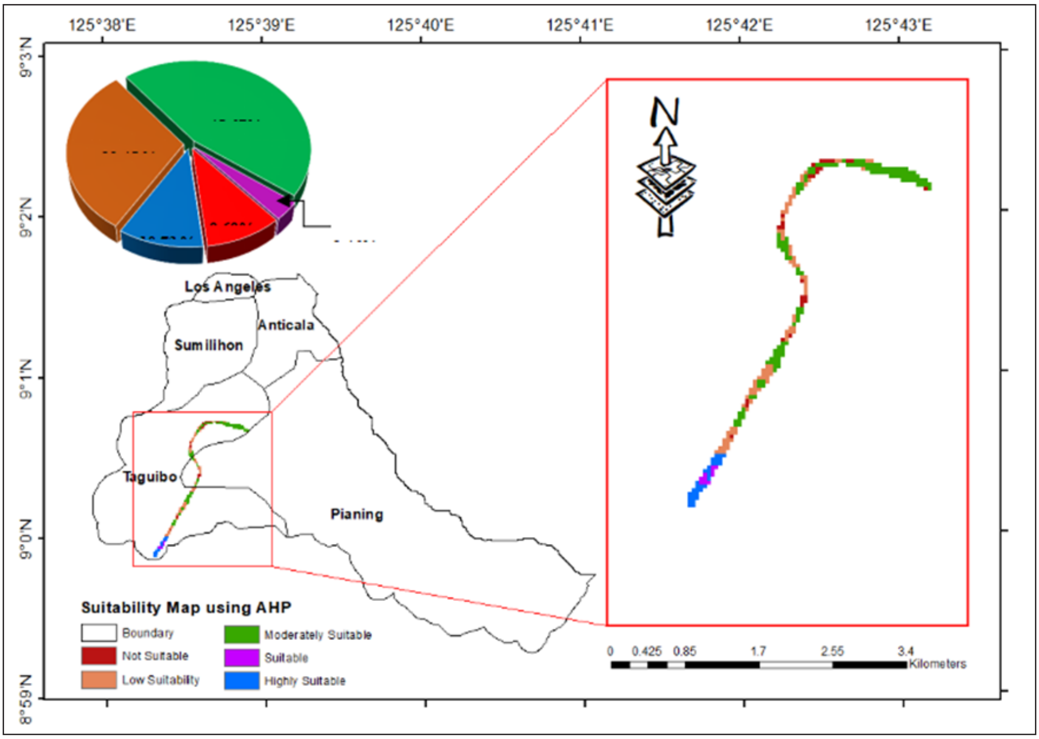

Figure 7. AHP model suitability map

Generally, as observed from the suitability map, all sites identified were located along the river since the diversion dam site selection considered river discharge and river width.

Specifically, the identified sites were located within the major part of Barangay Taguibo, where the Taguibo River irrigation system diversion dam was located, and the last part of Barangay Pianing. The location of the Taguibo River irrigation system diversion dam was identified as a highly suitable site. The results indicate that the criteria selected greatly influence the site suitability selection for the diversion dam. Thus, selecting appropriate criteria that ideally fit with the study area significantly improves the site suitability assessment specifically for the diversion dam.

In addition, Figure 8 shows the summary of the areas identified from the AHP suitability map. Among the Barangays, only two have been classified in the suitability map, Barangay Taguibo and Barangay Pianing, due to the river network classified within their boundary. Barangay Taguibo consists of 8.43% not suitable with an area of 0.64 ha, 28.92% low suitable with an area of 2.21 ha, 46.18% moderately suitable with an area of 3.53 ha, 4.02% suitable with an area of 0.31 ha and 12.45% highly suitable area covering 0.95 ha. Barangay Pianing was classified only into three suitability classes: not suitable, low suitable, and moderately suitable, covering 17.5% (0.21 ha), 40% (0.49 ha), and 42.5% (0.52 ha), respectively. Barangay Taguibo and Barangay Pianing were dominantly classified as moderately suitable in terms of physical and agrometeorological features, which have 38% and 41% influence, respectively, compared to their economic feature for which dominant classification was highly suitable with 21% influence during the overlaying process.

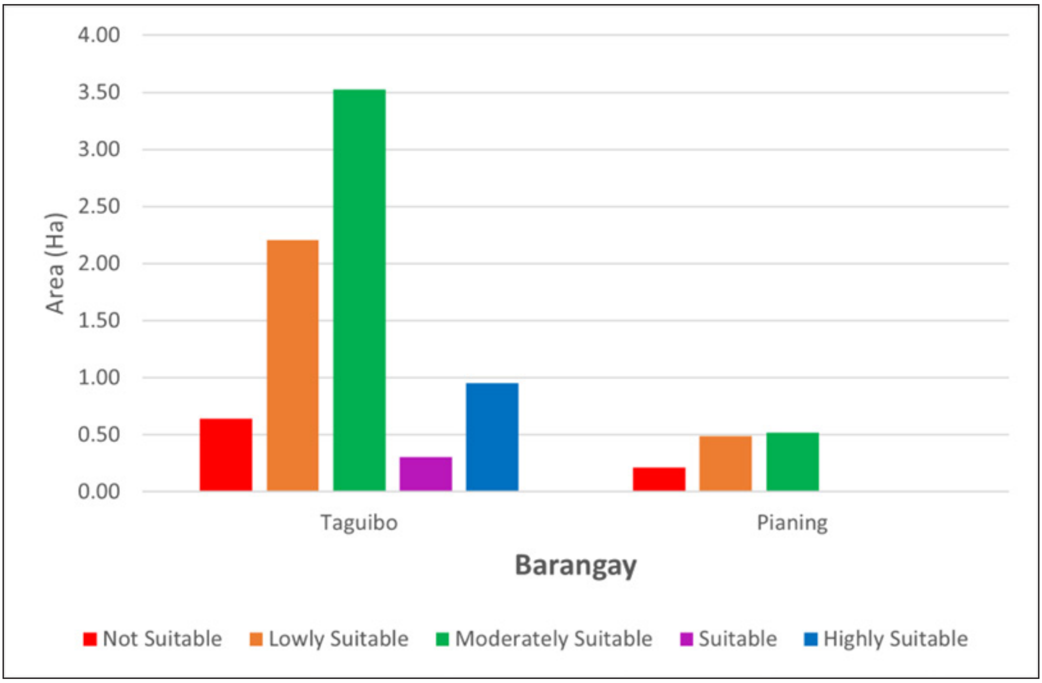

Figure 8. Suitable areas in hectare

Existing (SSIP) Suitability Map

The existing suitability map (Figure 9) was obtained from the CSU-CReAte (Center for Resource and Assessment Analytics and Emerging Technologies) and clipped using ArcGIS 10.4 tools to specify only the study area. The existing map shows two identified sites: highly suitable (purple) and marginally suitable (green).

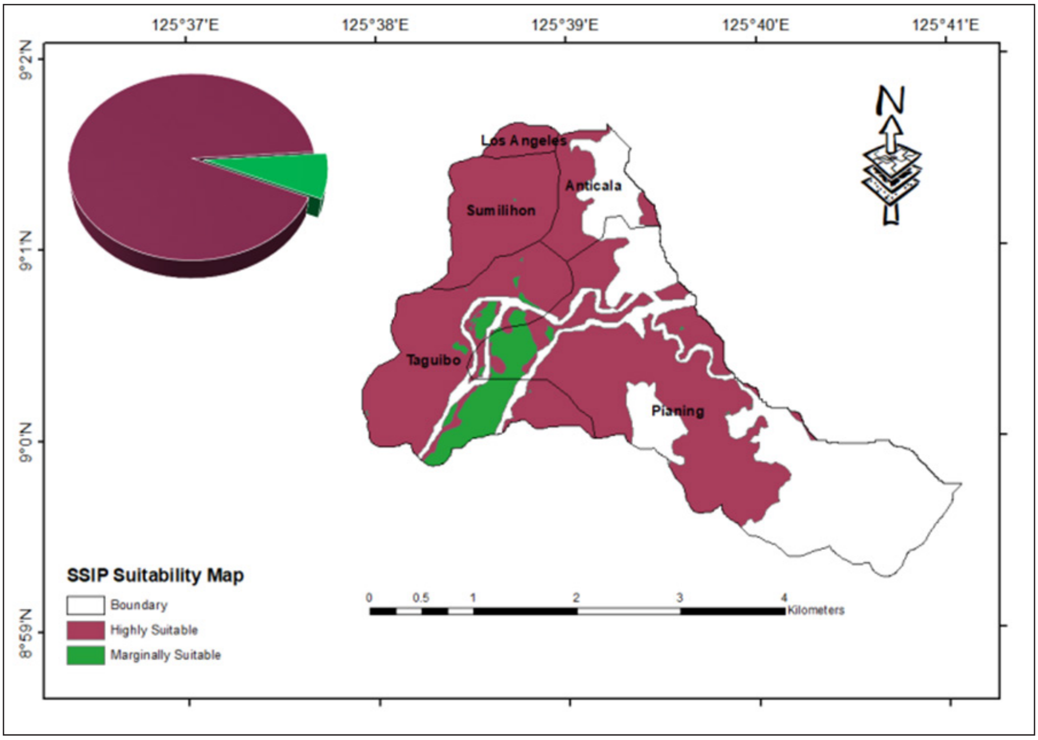

Figure 9. Existing suitability map

Specifically, it was observed that 92.22% (6,765,086 m^2) of the total area of 7,335,812 m^2 were highly suitable sites. On the other hand, the remaining 7.78% (570,726 m^2) of the total area was identified as marginally suitable. However, the map shows that the part of Barangay Pianing was not included as a suitable site since it was a steep slope area, including the upper part of the study area located near the boundary of Barangay Anticala and Barangay Pianing.

Comparative Evaluation

Two methods were used to generate the two different final suitability maps. Both methods used GIS tools in suitability maps. However, in the current suitability map, an analytical hierarchy process, AHP, was used to identify the most important criteria selected to improve the decision-making assessment. The existing suitability map used a standardized protocol to generate suitability maps according to the standard set by the BSWM, National Water Resources Board, and all 13 participating state universities and colleges around the Philippines. In addition, the result of the AHP model suitability map shows more on the specific location as it followed the feedback from the experts. In terms of physical aspects, the Taguibo River irrigation system diversion dam was classified as moderately suitable due to the river width and slope as well as the soil type composition of the location area. In addition, the Taguibo River irrigation system, in terms of agrometeorology, was classified as highly suitable, which is also due to the river discharge and rainfall sub-criteria. Lastly, the Taguibo River irrigation system diversion dam was classified in terms of economic factors as highly suitable since the location of the diversion dam was near the access road and the service area. The result also indicates that the criteria selected significantly influence the generated AHP model suitability map. The existing map generally considers the whole study area, disregarding the river and steep slope areas. In addition, the location of the Taguibo River irrigation system diversion dam was classified as highly suitable based only on the AHP model suitability map since the existing suitability map disregarded the river network as a criterion for site suitability assessment.

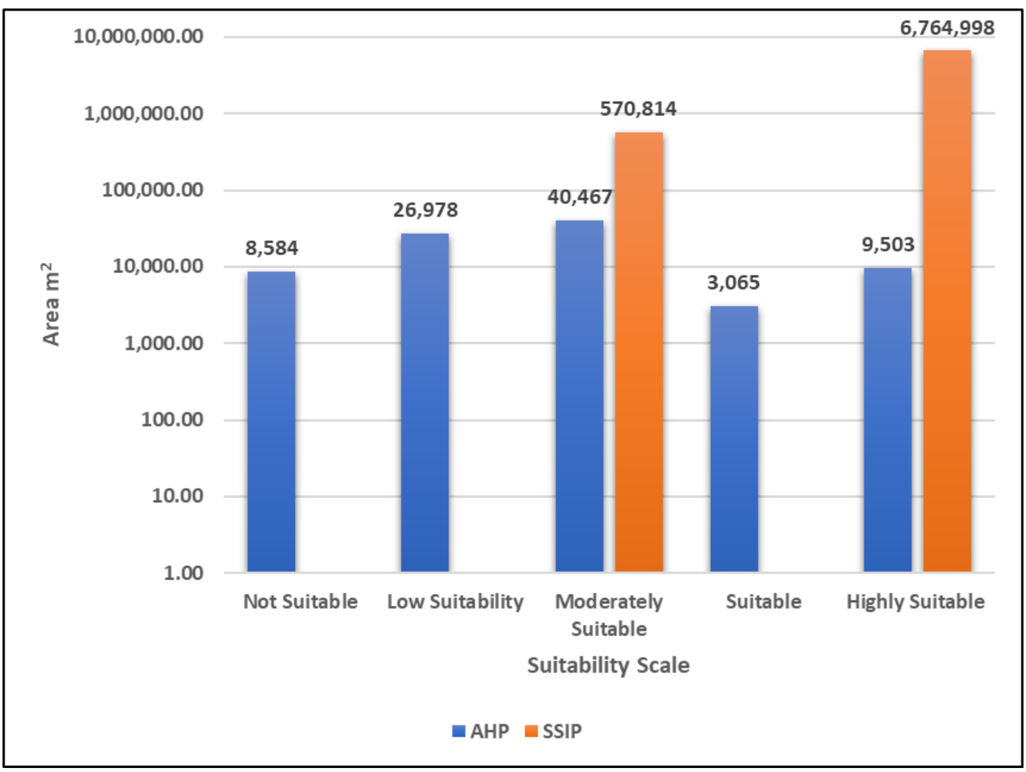

Figure 10. Comparative data (area)

To compare the two generated maps, the AHP model (Figure 7) and the existing model (Figure 9) suitability maps show differences in the area covered with suitability classification levels. Figure 10 shows that the highly suitable sites in the AHP model suitability map have 9,503 m^2, while the SSIP model has 6,764,998 m^2. On the other hand, by comparing the marginally suitable sites of both models, the AHP model has 40,467 m^2, while the SSIP model has 570,814 m^2. The graph shows that the SSIP model has the highest value of both highly suitable and marginally suitable sites since it generated the model considering the whole study area. In contrast, the AHP model only covered the river networks.

CONCLUSION

The final AHP suitability map of the study area found along the river, with 10.73% out of 88,599.17 m^2 total area of the river was highly suitable or approximately 9,506.69 m^2, and not suitable sites found 9.69% out of 88,599.17 m^2 or approximately 8,585.26 m^2 area covered. Meanwhile, the researchers found that the total area comprising marginally suitable and highly suitable sites in the existing suitability map was approximately 7,335,812.72 m^2 or 733.58 ha out of the total area. 92.22% (6,765,086.49 m^2) out of 7,335,812.72 m^2 were highly suitable, while the remaining 7.78% (570,726.23 m^2) were identified as marginally suitable sites. The comparison for both suitability maps generally differs due to the methods used. The AHP model suitability map shows the specific sites that were suitable and not suitable for diversion dam, which indicates along the river due to the river discharge as part of the criteria, whereas the existing suitability map disregarded the river network as part of the criteria, including the steep slope areas. Thus, selected criteria were generally the main factors in assessing suitability sites.

The study suggested that using GIS tools combined with the AHP approach in decision-making shows significant results based on the suitability map output. However, further knowledge about the AHP methods, such as criteria selection, experts, and technical aspects in terms of how to convey the questionnaire to the experts, was essential to execute the analytical hierarchy process (AHP) and provide accurate results in decision-making. The researchers also suggest conducting field validation to identify the accuracy of the generated AHP model suitability map. In addition, the researchers suggest evaluating the capacity of the Taguibo River irrigation system diversion dam. Moreover, the percentage of reoccurrence of water volume should be evaluated to identify the highest volume of water that affects the diversion dam's capacity.

ACKNOWLEDGEMENT

The authors are thankful to the Department of Agricultural and Biosystems Engineering (DABE), College of Engineering and Geosciences, Caraga State University (CSU), Ampayon Butuan City 8600, Philippines, for the facilities provided during the conduct of this study and also to the Center for Resource Assessment, Analytics and Emerging Technologies (CReATe) under the project entitled "Water resource assessment and modeling of the selected watershed in the Caraga Region for sustainable domestic and irrigation supply."

REFERENCES

Ali, E. (2020). Geographic information system (GIS): Defination, development applications & components. In *Urbanisation in India: Causes, Growth, Trends, Patterns, Consequences & Remedial Measures* (pp. 1-13). Department of Geography, Ananda Chandra College.

Alpagut, B., Romo, A. L., Hernández, P., Tabanoğlu, O., & Martinez, N. H. (2021). A GIS-based multicriteria assessment for identification of Positive Energy Districts boundary in cities. *Energies, 14*(22), Article 7517. https://doi.org/10.3390/en14227517

Bacci, M., Ousman Baoua, Y., & Tarchiani, V. (2020). Agrometeorological forecast for smallholder farmers: A powerful tool for weather-informed crops management in the Sahel. *Sustainability, 12*(8), 3246. https://doi.org/10.3390/su12083246

Baltazar, B. M., Saludes, R. B., Dorado, M. A., Cruz, P. C. S. (2019, October 14-18). *Site suitability analysis of diversion dams in Quezon, Philippines using multi-criteria decision analysis and GIS*. [Paper presentation]. The 40th Asian Conference on Remote, Daejeon, South Korea.

Bataineh, O., Hjeelah, D. A., & Arabiat, S. (2018). Multi-criteria decision making using AHP to select the best CAD software. In A. Abraham, S. Kovalev, V. Tarassov, V. Snasel, M. Vasileva & A. Sukhavov (Eds.) *Proceedings of the Second International Scientific Conference "Intelligent Information Technologies for Industry*" (pp. 106-115). Springer. https://doi.org/10.1007/978-3-319-68324-9_12

BCWD. (2015). *Social development program implemented within Taguibo River watershed forest reserve*. Butuan City Water District. https://bcwd.gov.ph//

Canco, I., Kruja, D., Lancu, T., (2021). AHP, A reliable method for quality decision making: A case study in business. *Sustainability*, *13*(24), Article 13932. https://doi.org/10.3390/su132413932

Charles, A. C., Armstrong, A., Nnamdi, O. C., Innocent, M. T., Obiageri, N. J., Begianpuye, A. F., & Timothy, E. E. (2024). Review of spatial analysis as a geographic information management tool. *American Journal of Engineering and Technology Management, 9*(1), 8-20. https://doi.org/10.11648/j.ajetm.20240901.12

Chen, C. F. (2006). Applying Analytical Hierarchy Process (AHP) approach to convention site. *Journal of Travel Research, 45*(2), 167-174. https://doi.org/10.1177/0047287506291593

Dong, Y., Zhang, G., Hong, W. C., & Xu, Y. (2010). Consensus models for AHP group decision making under row geometric mean prioritization method. *Decision Support Systems, 49*(3), 281–289. https://doi.org/10.1016/j.dss.2010.03.003

EMB. (2019). *Taguibo river water quality: Annual report for CY 2019* (Report CY 2019). Environmental Management Bureau. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://emb.gov.ph/wp-content/uploads/2020/11/FINAL-EMB-ANNUAL-REPORT-FOR-CY-2019.pdf

Goncalvez, A. B. (2021). Spatial analysis and geographic information systems as tools for sustainability research. *Sustainability, 13*(2), Article 612. https://doi.org/10.3390/su13020612

Karakuz, C. B., & Yildiz, S. (2022). GIS-Multi criteria decision analysis-based land suitability for dam site selection. *International Journal of Environmental Science and Technology, 19*(12), 12561-12580. https://doi.org/10.1007/s13762-022-04323-4

Lapong, E., & Fujihara, M. A. (2008). Water resources in the Philippines: An overview of its uses, management, problems and prospects. *Journal of Rainwater Catchment Systems, 14*(1), 57-67. https://doi.org/10.7132/jrcsa.KJ00004978343

Longobardi, A., & Villani. P. (2013). A Statistical, parsimonious, empirical framework for regional flow duration curve shape prediction in high permeability Mediterranean region. *Journal of Hydrology, 507*, 174-185. https://doi.org/10.1016/j.jhydrol.2013.10.019s

Midatana, S., Saran, S., & Ramana, K. V. (2018). Site suitability analysis for industries using GIS and multi criteria decision making. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 4*, 447-454. https://doi.org/10.5194/isprs-annals-IV-5-447-2018

Romano, G., Sasso, P. D., Liuzzi, G. T., & Gentile, F. (2015). Multi-criteria decision analysis for land suitability mapping in a rural area of Southern Italy. *Land Use Policy, 48*, 131-143. https://doi.org/10.1016/j.landusepol.2015.05.013

Shukla, O., Upadhayay, L., & Dhamija, A. (2013, November 20-22). *Multi criteria decision analysis using AHP technique to improve quality in service industry: An empirical study*. [Paper presentation]. International Conference on Industrial Engineering (ICIE-2013), Surat, India, https://doi.org/10.13140/RG.2.1.2747.0881

Zukhrufiyati, A., Triyono, J., Ginting, S., & Irianto, E. W. (2019, September 1-7). *Determination of dependable flow for microhydro power plant in irrigation network*. [Paper presentation]. 3rd World Irrigation Forum (WIF3), Bali, Indonesia.