Land Suitability Analysis Using Geospatial Techniques: A Proposed Project for Jose Maria College Expansion

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ABSTRACT

Efficient school planning requires a thorough and inclusive plan upon deciding on a suitable site that responds to the needs of the students and designs for future growth. Schools established in a secure and effective environment have a fundamental part in enhancing the capacity and excellence of students. Determining suitable innovative educational sites is essential and challenging to assure efficiency and long-term sustainability. The main objective of this research was to conduct a land suitability analysis using the suitability map generated from GIS-MCDA procedures according to a set of predefined criteria based on national standards. The criteria used for the analysis in this study were based only on the combined factors from the manual of regulations DO No. 88 s.2010, and CMO No. 40 s.2008 published by DepEd and CHED for establishing private institutional sites and buildings. The proposed expansion site is situated in Barangay Indangan Buhangin District, Davao City, with a total area of 40 hectares (400,000 m^2). The result of the suitability map showed that the study area is highly suitable for an institutional site based on the four factors considered in the analysis.

***Keywords*:** *Geographical Information System (GIS), Multi-criteria Decision Analysis (MCDA), Analytical Hierarchy Process (AHP), Suitability Map*

INTRODUCTION

Efficient school planning requires a thorough and inclusive plan upon deciding on a suitable site that responds to the needs of the students and designs for future growth. Schools established in a secure and effective environment have a fundamental part in enhancing the capacity and excellence of students. The determination of suitable innovative educational sites is essential and challenging to assure efficiency and long-term sustainability. The overall aim of this study was to conduct a land suitability analysis using the suitability map generated from GIS-MCDA procedures as a basis for Jose Maria College's proposed expansion.

Education is a critical component of the development process. A school site without any scientific analysis can lead to several global problems. Firstly, it may result in inadequate infrastructure and facilities, compromising the quality of education and hindering students' learning outcomes. Secondly, without proper analysis, schools may be located in areas prone to environmental hazards such as pollution or natural disasters, jeopardizing the health and safety of students and staff. Thirdly, insufficient consideration of demographic factors may lead to inequitable access to education, exacerbating social inequalities. Lastly, the absence of scientific analysis can undermine long-term sustainability, as schools may be situated in ecologically sensitive areas, contributing to environmental degradation (Zuo & Chen, 2018).

In developing nations like the Philippines, people's educational attainment is strongly tied to individual gains and employment prospects. As a result, education influences a country's growth and individual development and the socio-economic development of society, such as population living standards. Education influences several elements of development, including cognitive competency, reading, numerical competence, and problem-solving abilities (Lockheed & Verspoor, 1991). Hence, it is a critical aspect of a country's growth (Jayaweera, 2014). Educational planning is critical, and selecting appropriate institutional sites constitutes an essential part of this plan.

Efficient school planning requires a thorough and inclusive plan upon deciding on a suitable site that responds to the needs of the students and designs for future growth. Schools established in a secure and effective environment have a fundamental part in enhancing the capacity and excellence of students. The determination of suitable innovative educational sites is essential and challenging to assure efficiency and long-term sustainability.

The idea of a land suitability analysis is to map a suitability index for the entire study area rather than to identify the best alternatives. Therefore, the focus of this study was to generate a composite suitability map based on the predefined criteria and GIS-MCDA procedures for the analysis of Jose Maria College’s proposed expansion project. It is required to consider the relevant factors as casual criteria that must be prepared as a GIS dataset for GIS-MCDA-based modeling. By defining and presenting relevant information to planners and decision-makers, identifying appropriate and efficient factors leads to accurate conclusions and practical actions. The analysis goal is expressed as specific, measurable criteria based on relevant data. The criteria used for the analysis in this study were based only on the combined factors from the manual of regulations DO No. 88 s.2010, and CMO No. 40 s.2008 published by DepEd and CHED for establishing private institutional sites and buildings, respectively.

Schools established in a secure and effective environment have a fundamental part in enhancing the capacity and excellence of students and helping society thrive. As a result, schools must be dynamic and active structures. This dynamism is supported by establishing suitable and adequate school sites and buildings (Baser, 2020). Furthermore, the determination of such innovative educational sites is a complex problem that requires the analysis of a variety of criteria (environmental, technical, social, and political). A Geographic Information System (GIS) integrated with Multi-Criteria Decision Analysis (MCDA) can be utilized to address such complex problems (Drobne & Lisec, 2009).

METHOD

The idea of a land suitability analysis is to map a suitability index for the entire study area rather than to identify the best alternatives. Therefore, the focus of this study was to generate a composite suitability map based on the predefined criteria and GIS-MCDA procedures for the analysis of Jose Maria College's proposed expansion project. The study area is situated in Barangay Indangan Buhangin District, Davao City, located with the GPS coordinates 7°10'15.68" North 125°35'43.34" East. The total study area is 40 hectares (400,000 m^2), however, only 20 hectares (200,000 m^2) were needed for the expansion project.

The criteria used for the analysis in this study were based only on the combined factors from the manual of regulations DO No. 88 s.2010, and CMO No. 40 s.2008 published by DepEd and CHED for establishing private institutional sites and buildings, respectively. Four (4) factors were identified as follows, including their corresponding datasets needed.

1. Size – total area
2. Accessibility/Traffic situation in the school vicinity
3. Reasonable distance from schools already existing
4. Location and distance from distractive establishments

Datasets Needed:

1. Land area
2. Distance of road infrastructures
3. Distance of existing schools
4. Distance of distractive establishments

This study started by reviewing and comparing the national standards published by the DepEd and CHED to come up with a valid list of criteria for institutional sites and buildings. Then, used an MCDA technique to rank and weight the identified criteria into a hierarchical structure. The research proceeded with the creation of an analytical model that executed the spatial operation on the study area and generated a suitability map for the analysis.

GIS-MCDA

GIS is a technology that can capture, save, retrieve, modify, analyze, compare, and display spatial environmental data (Bell, 2007). GIS seeks to identify the most suitable spatial pattern for future site locations based on some activities' specific criteria (Joerin et al., 2001).

MCDA is a unique decision-making tool that integrates information and knowledge from different disciplines, developed for complex multi-criteria problems that help in choosing better alternatives and analysis of decision process by considering not only the quantitative but also qualitative advantages and disadvantages of decisions (Ishizaka & Nemery, 2013). MCDA helps decision-makers make an informed judgment to choose a better alternative based on implicit or explicit criteria with exact weights attached to them that allow for precise estimation.

The integration of GIS with MCDA creates a strong spatial decision support system capable of producing land suitability maps in a timely manner. It may be used as a decision-making tool to support the design and development of sustainable plans. The use of GIS-MCDA can also provide a comprehensive approach to the assessment of land suitability.

AHP Technique

AHP is an MCDA that is well-suited to dealing with complex problems and has been utilized in GIS-based land suitability processes.

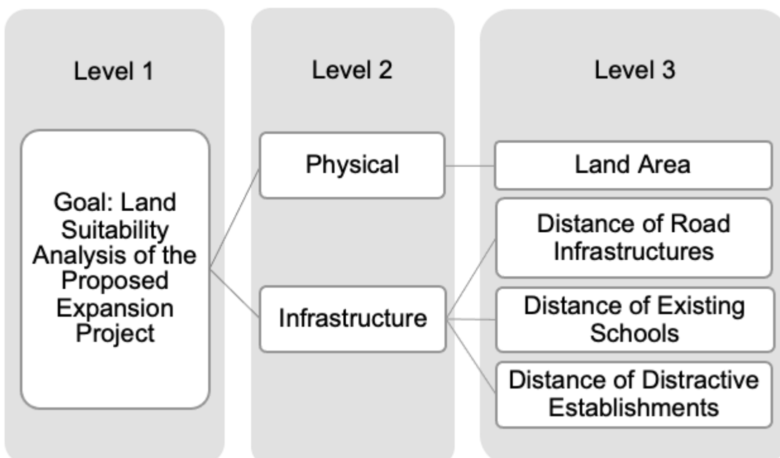


Figure 1: The AHP Model for Land Suitability Analysis.

For the analysis, all criteria (factors) were classified into different levels using hierarchical structures (Malczewski, 2004). The goal is stated clearly at the first level of the hierarchy and is further defined at lower levels. This technique was implemented using the pairwise comparison matrix that simplifies preference ratings among decision rules.

After the factors were listed and grouped into hierarchies, weights were assigned to each one to quantify their relative importance on a scale of 1 to 9 (Saaty, 1980). The higher the weight, the more important the factor is. It simplifies complicated decisions by reducing them to a series of pairwise comparisons. This procedure encompasses both subjective and objective parts of the decision-making process. Additionally, the method adds an additional stage that verifies the consistency of the decision-maker’s judgments in order to minimize decision-making bias.

The pair-wise comparison matrix comprises generating a consistency ratio (CR) to verify the credibility of the relative importance utilized. This number denotes the probability that the ratings were given at random. According to Saaty, a degree of consistency is fairly acceptable if the CR is less than 0.10 (10%). If it is larger than 0.10, the consideration is inconsistent, and the AHP may give insignificant results (Saaty, 1980).

The following equations were used to compute the consistency ratio (CR) in this analysis.

CR = Consistency Index (CI) / Random Consistency Index (RI)

Where:

CI = (λ_{max} - n) / (n -1)

λ_{max} = Principal eigenvalue.

n = Number of factors.

RI = Number of factors being compared, see Table 1.

Table 1: Random Consistency Index (RI), n 1 – 5 (Saaty, 1980).

n	1	2	3	4	5
RI	0.00	0.00	0.58	0.90	1.12

Weighted Overlay

A weighted overlay is a geospatial analysis method that generates an integrated analysis from many inputs using a standard measuring scale of values. After the factor maps were weighted and reclassified. The overlay tool in QGIS was used to create the final suitability map using the mathematical expression shown below.
Where:

S = suitability;

W_i = weight of factors i; and

X_i = criterion score of factors i.

RESULTS

The factors were mapped and transformed into the geographic information system language using QGIS, an open-source GIS with various mapping features that delivers standard GIS functionality. Each factor was then reclassified using the spatial analysis tool from QGIS, raster calculator. Upon reclassifying, the factors were analyzed based on their suitability considerations.

Factor 1, 'Land Area'

Figure 2: Factor Map 1, 'Land Area'.

Factor map 1 is non-spatial data, implying it is independent of geographic location. For factor 1 suitability, the bigger the land area, the higher the suitability value.

Factor 2, 'Distance of Road Infrastructures'

From accessibility, being closer to a road simplifies transportation access to school. However, proximity to a road can be connected with increased noise levels, pollution, and incidences, typically in larger urban areas. These concerns were not considered during the reclassification process, and the distances were given a score based on their proximity. Hence, the closer the road, the higher the score, the farther the road, the lower the score.

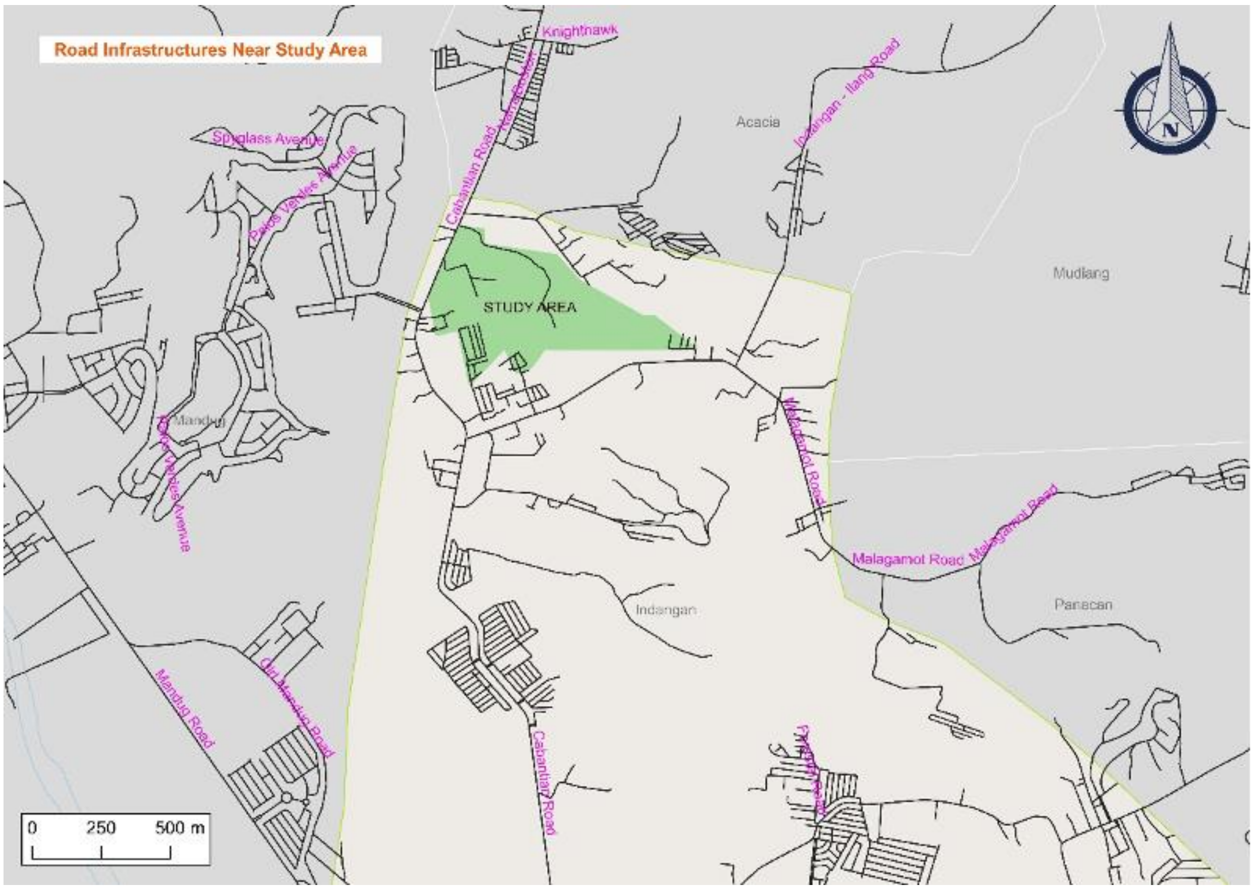


Figure 3: Factor Map 2, 'Distance of Road Infrastructures'.

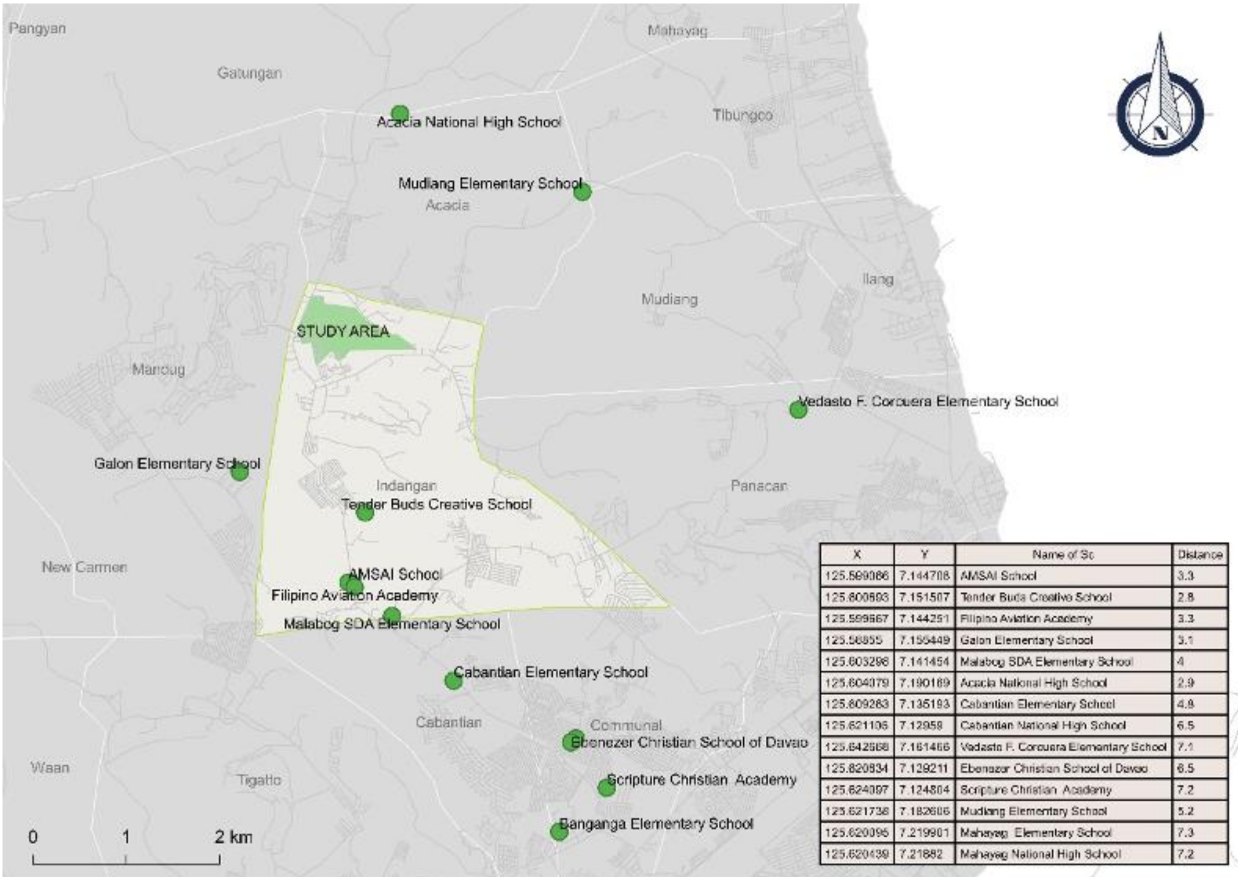
Factor 3, 'Distance of Existing Schools'

There were fifteen (15) existing schools within 2 to 8 kilometers away from the study area as shown in the table below. Most of the schools were elementary and high school.

Table 2: Distances of Existing Schools from the Study Area

No.	School	Distance
1	Tender Buds Creative School	2.8 km
2	Acacia National High School	2.9 km
3	Galon Elementary School	3.1 km
4	Filipino Aviation Academy	3.3 km
5	AMSAI School	3.3 km
6	Malabog SDA Elementary School	4.0 km
7	Cabantian Elementary School	4.8 km
8	Mudiang Elementary School	5.2 km
9	Cabantian National High School	6.5 km
10	Ebenezer Christian School of Davao	6.5 km
11	Vedasto F. Corcuera Elementary School	7.1 km
12	Scripture Christian Academy	7.2 km
13	Mahayag National High School	7.2 km
14	Mahayag Elementary School	7.3 km
15	Banganga Elementary School	7.8 km

As indicated in the preceding chapter, this study considered distances more than two (2) kilometers to other schools to be the most suitable. As shown in Figure 4, the closest school to the study area is the Tender Buds Creative School which is 2.8 kilometers away.



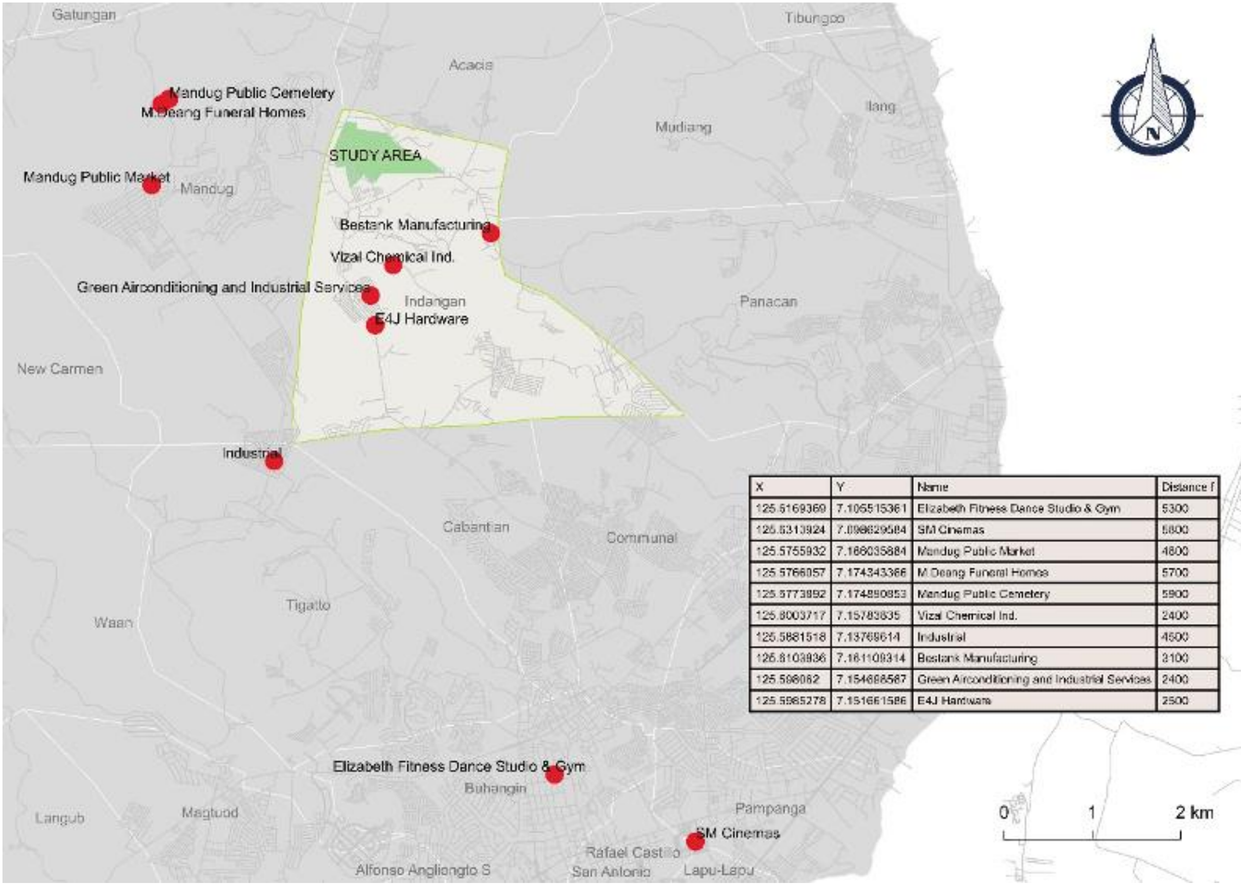
X	Y	Name of Sc	Distance
125.599086	7.144708	AMSAI School	3.3
125.600693	7.151507	Tender Buds Creative School	2.8
125.599567	7.144251	Filipino Aviation Academy	3.3
125.58855	7.155449	Galon Elementary School	3.1
125.603298	7.141454	Malabog SDA Elementary School	4
125.604079	7.190169	Acacia National High School	2.9
125.609283	7.135193	Cabantian Elementary School	4.9
125.621106	7.12958	Cabantian National High School	6.5
125.642568	7.161466	Vedasto F. Corcuera Elementary School	7.1
125.620834	7.129211	Ebenezer Christian School of Davao	6.5
125.624097	7.124804	Scripture Christian Academy	7.2
125.621738	7.182606	Mudiang Elementary School	5.2
125.620095	7.219901	Mahayag Elementary School	7.3
125.620439	7.21882	Mahayag National High School	7.2

Figure 4: Factor Map 3

For Factor 3, new schools should be located apart from the existing schools to accommodate extensive service to the community. Thus, the farther the existing schools were from the study area, the higher the suitability value.

Factor 4, 'Distance of Distractive Establishments'

There were no distractive establishments within 450 meters. As indicated in the preceding chapter and depicted in Figure 5, the closest distractive establishments were industrials located 2,400 kilometers from the study area.



X	Y	Name	Distance f
125.5169369	7.105515361	Elizabeth Fitness Dance Studio & Gym	5300
125.6313924	7.098629584	SM Cinemas	5800
125.5755932	7.166035884	Mandug Public Market	4800
125.5766057	7.174343366	M Deang Funeral Homes	5700
125.5773892	7.174890853	Mandug Public Cemetery	5900
125.6003717	7.15783835	Vizal Chemical Ind.	2400
125.5881518	7.13769614	Industrial	4500
125.6103936	7.161109314	Bestank Manufacturing	3100
125.598062	7.154698587	Green Airconditioning and Industrial Services	2400
125.5985278	7.151661586	E4J Hardware	2500

Figure 5: Factor Map 4

For Factor 4, schools should be located far away from all distractive establishments to ensure the safety and convenience of the educational program. Thus, the farther the distractive establishments, the higher the suitability value.

AHP and Pairwise Result

Each of the factors was weighted using a pairwise comparison matrix based on relative importance on a scale of 1 (equal importance) to 9 (extreme importance). Lastly, a consistency ratio (CR) was calculated to ensure the credibility of the relative importance values used.

Table 3: AHP Pairwise Comparison Matrix Generation

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
Factor 1	1	2	3	3
Factor 2	1/2	1	2	2
Factor 3	1/3	1/2	1	1
Factor 4	1/3	1/2	1	1
Sum of the Factors	2.17	4	7	7

On a pair-by-pair basis, each factor was compared to another. See (row 2, column 2) – Factor 1 (Land Area) was compared to Factor 1 (Land Area), and the given value was 1 since a factor was compared to itself. In row 2, column 3, a judgment value of 2 was assigned between the comparison of Factor 1 (Land Area) with Factor 2 (Distance of Road Infrastructures), and a judgment value of 3 was assigned between the comparison of Factor 1 (Land Area) with Factor 4 (Distance of Distractive Establishments).

The weights assigned to the pairwise matrix was determined solely by the researcher's knowledge and judgment. Since this study is about school expansion, the project's land area or size (factor 1) was prioritized. Therefore, a value of 2 was assigned for factor 1 compared to factor 2 or the distance from road infrastructures. 2 is an intermediate value between equal and moderate importance. Then a value of 3 was assigned to factor 1 in comparison to factors 3 and 4 or the distance between existing schools and distractive establishments, indicating that factor 1 is of moderate importance in comparison to factors 3 and 4.

Table 4: Normalization of Pairwise Comparison Matrix.

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**Normalized Eigenvector**
Factor 1	0.46	0.50	0.43	0.43	0.46
Factor 2	0.23	0.25	0.29	0.29	0.27
Factor 3	0.15	0.13	0.14	0.14	0.14
Factor 4	0.15	0.13	0.14	0.14	0.14

Normalization was computed by dividing each value in Table 4 by its corresponding column total.

Factor 1 was the most important factor weighted at 46% according to the calculated normalized Eigenvector, followed by Factor 2, and Factors 3 and 4 at 27%, and 14% respectively.

The Principal Eigenvalue (λ_{max}) was calculated by multiplying the sum of the products between each of the normalized Eigenvectors by the sum of the factors from Table 10.

Principal Eigenvalue (λ_{max}) = (2.17 x 0.46) + (4 x 0.27) + (7 x 0.14) + (7 x 0.14) = 4.04

Consistency Index (CI) = (4.04 – 4) / (4 – 1) = 0.04 / 3 = 0.01

Random Consistency Index (RI) for n = 4 is 0.90. So, the Consistency Ratio (CR) was calculated as:

CR = 0.01 / 0.90 = 0.01

0.01 < 0.10 OK

Since the computed CR = 0.01 passes the consistency ratio. According to Saaty, a degree of consistency is fairly acceptable if the CR is less than 0.10 (10%). If it is larger than 0.10, the consideration is inconsistent, and the AHP may give insignificant results [96]. Therefore, it indicates that the weighted allocation to the factors provided in Table 10 was satisfactory. Thus, the pairwise comparison of the four factors was consistent.

ANALYSIS

After reclassifying, all factor maps were then overlaid using a raster calculator on QGIS spatial analysis tool, inputting each map according to its relative weights (normalized Eigenvector) to know whether the study area is suitable for the expansion project. Factor 1 was the most important factor weighted at 46%, followed by Factor 2, and Factors 3 and 4 at 27%, and 14% respectively.

The suitability map presents five classes according to their suitability: (1) non-suitable value, (2) low suitability, (3) moderate suitability, (4) high suitability, and (5) very high suitability, represented in colors red, orange, yellow, green, and blue, respectively.

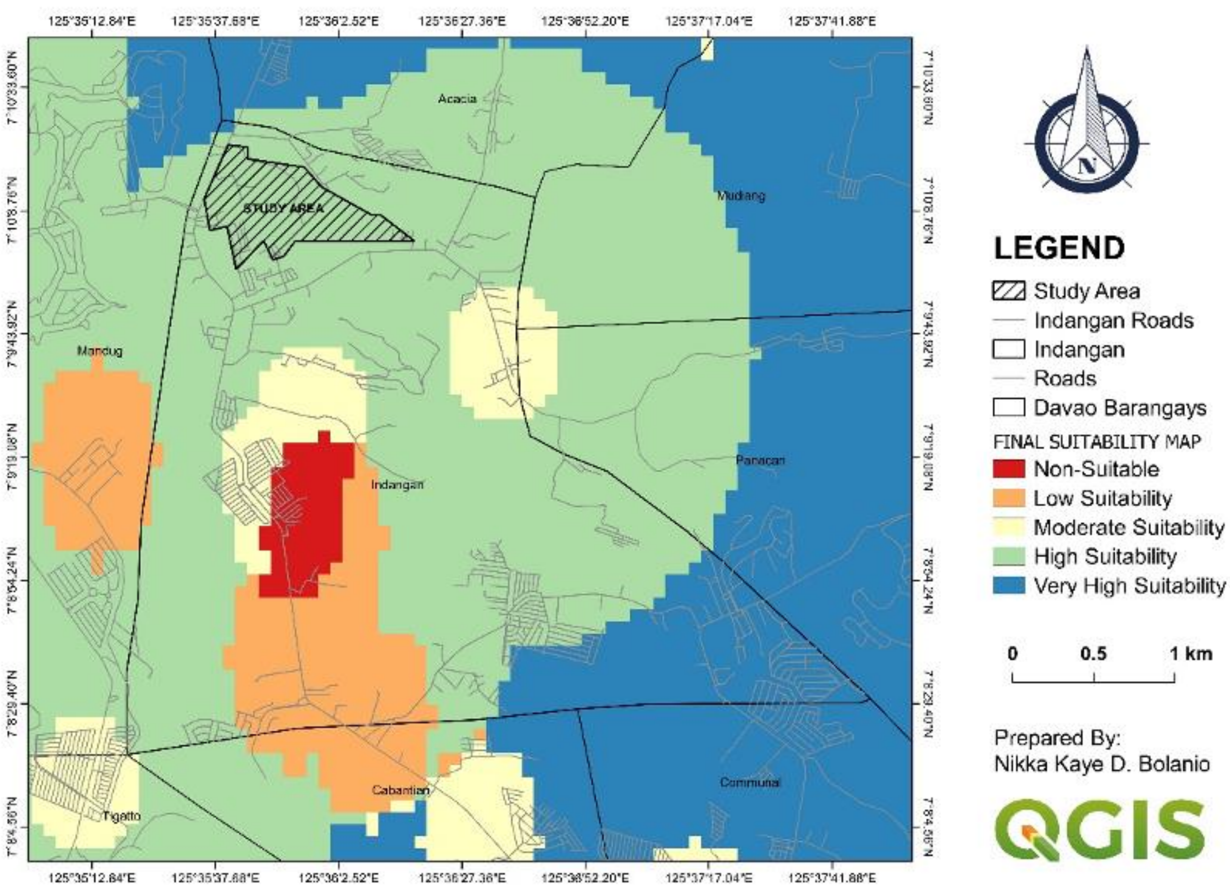


Figure 6: Suitability Map of the Study Area

As shown in the map, the study area has high suitability based on the four factors considered for the analysis of Jose Maria College's proposed expansion project. Other parts in Indangan in orange and yellow areas indicated that they were near distractive establishments and schools or far from roads. In contrast, the red areas indicated that they were both near distractive establishments and schools and far from roads, hence non-suitable for a new school location.

DISCUSSION

The overall aim of this study was to conduct a land suitability analysis using the suitability map generated from a GIS-MCDA procedure for the analysis of Jose Maria College's proposed expansion project. The criteria used for the analysis in this study were based only on the combined factors from the manual of regulations published by DepEd and CHED for establishing private institutional sites and buildings. The factors used in the analysis were; (1) land area, (2) distance of road infrastructures, (3) distance of existing schools, and (4) distance of distractive establishments.

The MCDA technique used in the analysis was the Analytical Hierarchy Process (AHP), which is well-suited to dealing with complex problems and has been utilized in GIS-based land suitability processes. After the factors had been listed and grouped into hierarchies, weights were assigned to each to quantify their relative importance using a pairwise comparison matrix. The procedure encompasses both subjective and objective parts of the decision-making process.. The calculated Consistency Ratio was 0.01, which passes the CR < 0.10. Therefore, the weighted allocation to the factors was satisfactory. Thus, the pairwise comparison of the four factors was consistent. For future research, the land suitability analysis may be seen from several perspectives by employing various MCDA approaches such as Fuzzy-AHP, WLC, and TOPSIS, among others. Furthermore, in suitability modeling, weighting directly impacts the results. It is one of the most vital and complicated steps in suitability analysis.

The factors were mapped and transformed using QGIS, an open-source GIS with various mapping features that deliver standard GIS functionality. Among the four factors considered in the analysis, only Factor 1, 'Land Area,' was non-spatial data, implying it is independent of geographic location. Each factor was reclassified using the spatial analysis tool from QGIS, the raster calculator. Upon reclassifying, the factors were analyzed based on their suitability considerations. The reclassified maps were linked to five (5) suitability values in a new data layer. All factor maps were then overlaid using a raster calculator on QGIS spatial analysis tool, inputting each map according to its relative weights.

According to the suitability map, the whole study area was highly suitable based on the four factors considered for the proposed expansion project. Other parts of Indangan in orange and yellow areas indicated that they were near distractive establishments and schools or far from roads. In contrast, the red areas indicated that they were both near distractive establishments and schools and far from roads, hence non-suitable for a new school location.

Recommendations

There were some recommendations for further research based on the findings of this study. These include the following:

1. The criteria used for the analysis in this study were based only on the combined factors from the manual of regulations DO No. 88 s.2010, and CMO No. 40 s.2008 published by DepEd and CHED for establishing private institutional sites and buildings. In addition to the criteria/factors utilized in this study, other criteria/factors would be considered, such as other national standards from different government agencies and organizations, e.g., the Department of Environment and Natural Resources (DENR) and Department of Public Works and Highways (DPWH). Other factors that would be considered can also be from other GIS-based school siting studies.

2. The study recommends the use of other MCDA methodologies for site selection analysis, such as Fuzzy-AHP, WLC, and TOPSIS among others.

3. Other experts or professionals involved in the planning stage of the project, such as architects, civil and structural engineers, and environmental engineers, were recommended by the research to be decision-makers.

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