

Article

Establishment of Land Use Suitability Mapping Criteria Using Analytic Hierarchy Process (AHP) with Practitioners and Beneficiaries

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Abstract: The presence of land use conflicts is often unavoidable as land is finite and a scarce resource. With development as a prime goal, the increasing demands for specific uses make the situation more serious than it was before. In the context of land uses, suitability determines the inherent capacity of the land to perform a defined use with optimum efficiency and sustainability. However, single land use suitability analysis could not answer the overall objective of land allocation. Thus, this study considers the primary and general land uses with the valuable evaluation criteria necessary for simultaneous land use suitability analyses. This paper aims at establishing the relevant and necessary evaluation criteria for Multicriteria Evaluation (MCE) using the Analytic Hierarchy Process (AHP) for land use suitability analysis for residential, industrial, commercial, agricultural, and forest land uses. The factors which could be used as indicators in land suitability analysis were derived from both literature review and through experts' knowledge. Correspondingly, the relative importance (weights) of the criteria established were derived using pairwise comparisons through the AHP technique readily available for subsequent GIS analysis. Last, the criteria developed are general in nature and could be replicated and/or altered depending upon the local needs and situations.

Keywords: land use suitability analysis; evaluation criteria; criteria weights; land use; AHP; MCE; preference subjectivity



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1. Introduction

Land use planning is the systematic assessment of the physical, social, and economic factors in such a way that it encourages and assists land users in selecting options which increase their productivity, enhance sustainability, and meet that needs of the society [1]. It is an integral process which aligns the complexities from the technical facets to the societal concerns expressed by the population which is affected. In the context of land use planning, conflicting interests and priorities are always inherent as land is a finite and scarce resource and the ways to use it are vast and variable. The presence of increasing land demand leads to numerous land use conflicts resulting in enormous conversion of land use. Especially the conversion from agricultural land to other uses constitutes a major problem. Depending on the demographics, economics, and industrial growth, these land use conversions into built-up and industrial areas are constantly practiced without consideration of the land's suitability and sustainability [2]. This connotes that land use planning is always a continuous process whereby needs are constantly re-examined to adhere to the existing demands, changing environment, and practices in the course of development.

In the context of both urban and rural development land use, planning takes an important role. Along with the persistently increasing population, the growth in the industrial sector indicates progress in economics and the standard of living, while the growth in agriculture indicates the adequacy of food to maintain the basic quality of

living [2]. Sustaining forest conservation supports important human necessities, wildlife protection and preservation, as well as hazard management. However, in the path to development, not all types or aspects of growth can be catered for given to the finite nature of land. Growth in the industrial sector is likely to cause more pollution to the environment, and thus endanger human health more than the agricultural sector [2]. Therefore, to maintain balance and sustainability, careful and responsible planning should be done depending upon which type of development is put through without compromising and totally neglecting other important land uses [3].

With careful planning, proper allocation of lands should be observed. This entails relying on land suitability for a specific function to ensure optimization and overall efficiency of the land [2]. Evaluating the land predicts the land's suitability for a specific use type in a given area [4]. Thus, with land suitability, it does not only consider the demands for land uses, but more importantly the capability of the land to function in the desired use. The lands are then classified and grouped in terms of their inherent capacity and suitability for a defined use. This is properly addressed by incorporating into the classification a wide range of factors to consider from the physical attributes of the lands, environmental issues, and socio-economics, among others.

Land suitability assessment is carried out in numerous ways from qualitative to quantitative approaches. FAO [5] then interprets "land suitability evaluation" as an assessment process which takes into account the performance of the land when used for a specified purpose. Identifying and putting into practice the future alternative land uses to best meet the needs of the people while protecting and preserving the resources for the future is the main objective of the systematic assessment of land use [6]. The assessment process is guiding towards the optimal use of land through the provision of important information regarding the opportunities and constraints in the use of a given land [7]. In addition, the assessment process then determines the suitability of land for a specific use through land suitability analysis considering land properties and user needs [8–10].

The land use suitability analysis then assesses the suitability of the land for a particular type of use (agriculture, forest, industrial, etc.) and more importantly it determines the level of suitability to which decisions can be made [8]. It provides the necessary information about different limitations and the possible opportunities for the land use under investigation based on the land capabilities [11]. From a technical and quantitative point of view, land suitability analysis is a decision problem involving several factors that measures the relative importance of the criteria to be used in the analysis [12]. Different sets of criteria could be used in the analysis ranging from the physical attributes of the land, to the soil properties and socio-economic aspect, to list just a few of the sets of criteria to be considered. This suggests that the land use suitability analysis is an interdisciplinary approach which may include information from different domains including soil science, meteorology, social science, economics, and management [13].

GIS and remote sensing technologies have become more advanced in their capabilities and have become very popular in the past few decades for land use suitability analysis, land use planning, and other land-related spatial studies [14–16]. Although GIS and remote sensing have already established a wide array of universally accepted applications, human involvement is still a core factor in any undertaking such as the widely accepted participatory approaches in land use planning, developmental studies, and land management activities [17–19].

Different evaluations using multiple criteria have received attention in the context of decision-making based on GIS, which are perceived useful in solving issues involving a large set of variables and covering extensive territories which are sometimes inaccessible [20–23]. Thus, various land use suitability studies have been incorporating people's preferences through the GIS-based MCE using the experts as the decision-makers. As land use suitability is a multidisciplinary approach, it incorporates different domains of science, and thus increasingly more criteria have been used in the analysis which are weighted indicative of their relative importance on the optimal growth conditions for

the specific land use. As MCE could be understood as a world of concepts, approaches, models, and methods that aid an evaluation according to several criteria, then land use suitability analysis could be expressed in MCE [24]. Overall, the main purpose of MCE techniques is to investigate numerous alternatives considering multiple criteria and conflicting objectives [25].

In MCE, the set of evaluation criteria is one of the most important elements that must be properly established such that a reliable result can be derived. The criteria can be generally categorized as “Factors” or “Constraints”. In the context of land use suitability and site selection, Factors are those criteria with spatial reference that influence (enhance or detract) the viability of the objective under consideration [26,27], while Constraints are the criteria which exclude the area from the analysis.

Proper selection of the criteria to be used in MCE requires careful attention. The number of criteria must not be too small or too great in order to derive the desired results. A large number of criteria for one objective tends to confuse decision-makers, while too few criteria may be insufficient to provide all the necessary relevant information [28]. In the MCE technique, there exist a comparison of the relative merits of the spatially related criteria. Its goal is to integrate information from multiple criteria to produce an output map of suitability levels [27].

Following the GIS-based MCE approaches, various researches used the methodology in land use suitability analysis and site selection studies including for land suitability for maize farming [29], which used precipitation, soil type, temperature, soil pH, elevation, and slope as evaluation criteria; land suitability analysis for emerging fruit crops in Central Portugal [30] where they used mean annual temperature, mean total annual rainfall, chilling hours, crop heat units, mean relative humidity, biogeography, elevation, soil pH, and soil organic matter as criteria for evaluation; land suitability zoning for ecotourism planning and development [31] by combining geo-morphometric, hydrologic, landscape and community indicators; and a study on sustainable land use of coastal areas [32] using both ecological and socio-economic factors.

In view of the increasing amount of literature of land use suitability using GIS with MCE, AHP has been notably used in many publications as an approach in MCE. With the MCE method commonly implemented in decision support systems, it compares alternative courses of action based on multiple factors and identifies the solution with best performance [33,34]. This premise considers land use suitability analysis as a decision-making problem as it is executed with numerous and various types of criteria and alternatives in the analysis. Perhaps it is one of the reasons why AHP in MCE gained more popularity in the recent decades. Furthermore, aside from its simple structure, the AHP has attracted the interest of many researchers mainly because of its effective mathematical properties [35]. It is a method of measurement through pairwise comparisons and relies on the judgements of experts to derive priority scales and which preference consistency can be determined [36].

For instance, GIS and AHP techniques were used in a study on agricultural suitability analysis [8] using a combination of the parameters of great soil group, land use capability class, land use capability sub-class, soil depth, slope, aspect, elevation, erosion degree, and other soil properties as evaluation criteria. Another study applied the same technique on settlement development based on land use suitability [37] using the clean air availability, flood prone areas, land availability, accessibility, and distance to service center as the evaluation criteria, and AHP was also used in weight determination in land suitability analysis for industrial development [38] using land use, railway accessibility, road accessibility, distance from river, and proximity to urban areas as criteria. The combination of GIS and MCE with AHP was even used in beekeeping site selection studies [10,39], ecotourism site suitability studies [31,40], and in looking for sites suitable for petrol stations [41].

Even in the successful derivation of weights or the priority scales, the experts performing the pairwise comparisons are exposed to a degree of subjectivity in their preferences as humans tend to be subjective anytime especially in decision-making processes. This is supported by the conclusion made and asserted that subjectivity is always omnipresent in

decision-making [42]. Although the premise that “The rule would seem to be: Be objective wherever possible” is appreciated [43], still it is recognized that the decision-maker’s contribution to the decision process is the subjective part. The observation was further affirmed and posited that subjectivity still plays a major role, such that the outcomes of decisions are sometimes less as expected [44]. As for AHP, the work for a common framework for deriving preference values from pairwise comparison matrices is subjective in terms of determining the value of the pairwise comparison matrix [45]. Moreover, inconsistencies in the preferences for the pairwise comparison are often attained as the decision-makers are dependent on their subjective assessment [46].

In the decision-making process, the choices and preferences of the decision-makers are bounded by some factors which drives them to make the decisions. One, if not the most important, factor in decision-making is the availability of information. Many researchers believed that a decision-maker tends to be indecisive when there is lacking information necessary to determine the best choice [45,47,48]. Just like in land use suitability analysis and other decision functions, the experts executing the preferences are those knowledgeable of the problem sought. As to any level of information about the subject they hold, it gives them the confidence to choose and weigh the options. Their judgements are expressed as professional opinion and expertise in a particular area which reflects their knowledge and information acquired [43]. Thus, their preferences are subjective and their choices are affected by the sufficiency of information. Furthermore, in a decision-making process, the term “subjective uncertainty” is described as that which comes from scientific ignorance, uncertainty in measurement, impossibility of confirmation or observation, censorship, or other knowledge deficiency [49]. On another note, a study conducted and tried to explore how decisions and the desire for coherency shape subjective preferences over time [50]. The work explained that people exhibited an increased preference for the chosen-unique and shared patterns. This demonstrates that the people tend to generalize their preferences learned from the initial choice to the novel patterns by virtue of their association.

In a large group, decision-making involving various decision-makers, bringing more complexity and uncertainty to the process [51]. It is expected that no unanimous decision can be derived due to the existence of heterogeneous preferences. This could be attributed to the different backgrounds of the decision-makers such as practices, experiences, and nature of work. The existence of heterogeneous preference formats are most common challenges in large-scale groups [52] in which decision-maker’s diversified educational backgrounds, knowledge, experiences, and decision habits utilize different formats to express their individual preferences [51].

Generally, the whole study aimed at developing a Decision Support System using MCE for land use planning. This paper aims at establishing the relevant and necessary evaluation criteria for MCE using AHP for land use suitability analysis for residential, industrial, commercial, agricultural, and forest land uses. Although there are a lot of studies on land suitability and site selection, most of the works just focus on single suitability analysis or for specific land use. As such, the results could not answer the overall objective of land allocation for the whole sustainable development of the land. Therefore, this study considers the primary and general land uses with the valuable evaluation criteria necessary for simultaneous land use suitability analyses.

The paper starts with the conceptual descriptions of land use suitability analysis on the one hand and MCE-AHP on the other. The subsequent sections describe the methodology how these two concepts can be and are linked in current literature, followed by an analysis how and when MCE-AHP is used as part of land use suitability analysis. We conclude by identifying how both the concepts and applications can be improved and what are the further steps for research.

2. Materials and Methods

Vital in the process of land use suitability analysis is the determination of criteria [8] and the selection of criteria that has spatial reference is an important step in MCE [53].

In this study, the selection of evaluation criteria for each land use suitability was based on a critical review of literature, experts' knowledge, and the researchers' understanding and professional experience in suitability mapping. The literature review was conducted to gather and derive the most relevant and most frequently applied criteria in land use suitability and site selection, and to detect which of these criteria are most commonly used in a GIS-based MCE. The literature search and selection process relied on multiple credible research repositories including amongst others Research Gate, Science Direct, and Google Scholar. Important keywords for the search queries, such as "land use suitability", "evaluation criteria", "site selection", "land use planning", "AHP", and "MCE/MCDA" were used. A long list of criteria per land use were made (Appendix A) after an initial review of related literatures of around 80 papers. After two rounds of pre-testing with PhD students and professionals of related fields, a list of most probable sets of criteria including eight (8) criteria for residential areas, nine (9) criteria for commercial areas, six (6) criteria for industrial areas, and seven (7) criteria for agricultural areas were derived to be used in the first round of data collection.

The first round of the data collection proper involved the selection of criteria for land use suitability from the already listed probable criteria. Twenty (20) pre-identified experts and decision-makers were then allowed to choose among the prepared list and the possibility to add other criteria which they believe are necessary for land use suitability analysis. The experts in this research are practitioners and researchers who are working and are practicing for at least five (5) years in any institution in the fields of land use planning and mapping, universities and related agencies in the Philippines as recommended. The selection of experts was based on the significance (e.g., citation index and/or standard use in class) of their publications and their visibility during conferences and teaching and working in this particular field. The experts were allowed to answer and respond through personal face-to-face interviews using a structured questionnaire and online platform via google docs. Based on the results of the first round where majority of the experts chose, a short list of criteria per land use was made considering the guidelines recommended [54].

The new list of criteria was then used for the second round in which the experts and decision-makers responded using the AHP method. AHP is a classical land suitability analysis procedure which gives a systematic approach in making proper decision for site selection [55]. The goal of having a second round of priority making among relevant criteria was to zoom in to the core indicators based on practical experience and perceived relevancy. As land use planning needs sound decisions, important factors should be considered in order to give an ample of options upon which important decisions can be made. In this concept, AHP can be considered as a decision-making and forecasting method that gives the percentage distribution of decision points in terms of the factors affecting the decision, which can be used if the decision hierarchy can be defined [56]. It assists the decision-making process by allowing decision-makers to organize the criteria and alternative solutions of a decision problem in hierarchical decision model [57].

In performing the pairwise comparisons of the AHP approach, the decision factors (criteria) are compared with each other by the experts and decision-makers using the preference intensity evaluation or the scale of relative importance in Table 1 in a scale of 1 to 9 where 1 signifies that the two factors (i.e., F_1 and F_2) compared are equally preferred, while 9 signifies that one factor is having extremely preferred as compared to the other. The values 2, 4, 6, and 8 represent the median values over the preferred values, say 2 is between 1 and 3, and 4 is between 3 and 5. A comparison matrix is then made with the results of the preference intensity evaluation and correspondingly normalize the values in order to solve for the principal Eigen value (λ).

Table 1. Preference intensity evaluation by binary comparison relatively between criteria in AHP [58,59].

Preference Intensity	Comparison Status of “i” Relative to “j”	Description
1	Equally preferred	Item “i” is equal priority with “j” or there is no preference
3	Moderately preferred	Item “i” is slightly more important than “j”
5	Strongly preferred	Item “i” is important than “j”
7	Very strongly preferred	Item “i” is more important than “j”
9	Extremely preferred	Item “i” is absolutely more important than “j” and is not comparable
2, 4, 6, 8	Median preference	Show the median values over preferred values

An important note when performing pairwise comparisons among different factors is that inconsistencies may at some point arise especially when dealing with many factors and comparisons. Saaty [58] mentions that AHP allows for some level of inconsistencies, however this level should not exceed a certain threshold. AHP has the capacity to measure the degree of consistency and incorporated in it an effective technique for checking the consistency of the evaluations made by the decision-makers or experts. The technique employs the computation of a suitable Consistency Index (CI) as the deviation or the degree of consistency, where the consistency measures will equal to the number of comparisons considered (n), so the CI will be equal to zero so as the Consistency Ratio (CR) of which to make sure that the original preference ratings are consistent.

In the computation of CI, the normalized relative weights, the normalized principal Eigen vector (Cv_{ij}) and eventually the principal Eigen value (λ) are first computed. The λ is simply the average of the Eigen values of the normalized comparison matrix [60]. Accordingly, the essence of AHP is a solution of an Eigen value problem involving the reciprocal matrix comparisons [61].

As recommended [58], the acceptable CR should be less than 0.10 (or 10%), otherwise there arise an inconsistency of the pairwise comparisons making it unacceptable, thus a need to redo the comparisons and computations. Table 2 shows the Random Index (RI) as suggested by Saaty for small problems to be used in the computation of CR.

$$\lambda = \sum_{i=1}^n Cv_{ij} \quad (1)$$

$$CI = \frac{\lambda - n}{n - 1} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

where CR = Consistency Ratio, CI = Consistency Index, RI = Random Index, n = number of comparisons/parameters. λ is calculated by averaging the value of the consistency vector, and it is obtained from the summation of products between each element of Eigen vector and the normalized relative weight.

Table 2. Random index (RI) values for small problems [58].

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

To validate the preferences of the experts, follow-up questions were made that required experts to justify their choices in the pairwise comparisons. They were likewise allowed to have initial ranking of all the criteria in each set which correspondingly agree to their preferences.

Last, in the case of AHP where different preferences can be derived from a number of experts participating, a consensus must be achieved. The aim is for the group to reach an agreement on the value of each entry in a matrix of pairwise comparisons. In the review conducted on the AHP methodology [62], it is pointed out that at some point achieving a consistent agreement is difficult to obtain with the number of comparison matrices and related discussions. There are different methods in achieving consensus but in any circumstance where it is impossible to convene the experts (distant persons or large number of persons) in one place and make a decision, it is recommended to use the method of geometric mean in convening the different preferences [63]. More specifically in AHP derived priorities, individual preferences are acquired first following the accepted level of consistency. For each preference in the criteria being compared, the collective preference of all the experts is achieved by employing the geometric mean. Adopting the geometric mean instead of the arithmetic mean preserves the reciprocal property as employed in AHP [64].

3. Results and Discussion

3.1. Criteria for Land Use Suitability Analysis

From the initial interviews and explorations in the topic, it became clear that the selection of suitable lands for specific land use requires critical analysis and judgement. This process has two different components. First of all, there needs to be an understanding of the variations, content, and implications of possible land use options, and second one needs to have a sense of what makes the choice for one type of land use preferable, or most or less suitable, than an alternative choice. The former is a rather rational process, often based on existing knowledge and experience, whereas the latter involves both rational and bounded rational decision-making. Although the demands for different uses of land dictate and influence decision-makers, in the rational part of the suitability process the capability of the land for the specific function likewise is an important factor in proper allocation.

The most common land uses include residential, commercial, industrial, agricultural and forest, among others. For this study, mixed-use lands were not included among the options, although this choice could be given extra attention and emphasis in the actual suitability analysis and further research.

Each land use has its own set of criteria identified and selected. The selection of final set of criteria was aligned with the recommendation of Malczewski [54] who argues that a criterion is considered good if it is (1) comprehensive (i.e., clearly indicates the achievement of the associated objective) and (2) measurable (i.e., lends itself to a quantification/measurement). This implies that we must be able to express in linguistic terms the kind of estimates required from the simulation and to establish a measurement scale for each estimate. Likewise, a set of criteria is good if it is (1) complete (i.e., covers all aspects of a decision problem), (2) operational (i.e., is meaningful to a decision situation), (3) decomposable (i.e., is amenable to partitioning into subsets of criteria, which may be necessary to facilitate a hierarchical approach to decision analysis), (4) non-redundant (i.e., avoids the double counting of decision consequences), and (5) minimal (i.e., has the property of the smallest complete set of criteria characterizing the consequences of a decision) [54].

Following these principles, we decided that the criteria included in this research had to be general for land use suitability analysis, so that at least most of the rational choices could be derived and distinct from the bounded rational (or politically motivated) choice in suitability analysis. The criteria represent different biophysical and social categories, such as geomorphologic, landscape, and community features. The advantage of opting for such criteria is that they could be replicated, enhanced, and/or amended according to specific contextual objectives where the criteria need to be applied. The experts who

participated in the survey revealed that among the common land uses, the corresponding evaluation criteria as indicators for land use suitability are the following.

Residential Areas. These areas are generally intended for dwelling or residential purposes. It could be those areas for houses in private ownership, commercialized housing, as well as for government sponsored socialized housing projects. There are eight (8) criteria for residential area suitability analysis which include slope, elevation, soil type, distance to shoreline, distance to rivers, distance to main roads, distance to important infrastructures (market, hospital, etc.), and the distance to drainage network.

Commercial Areas. The commercial areas are those places where business operations and offices likely to be located. Shopping centers, markets, restaurants, and other similar establishments are the primary users of these areas. A list of six (6) criteria is included for this suitability analysis which include the slope, elevation, distance to residential areas, distance to terminals/ports, distance to drainage networks, and the distance to main roads.

Industrial Areas. The industrial areas are those places generally intended for possible industrial operations. For developed and developing countries, different industries are vastly rising. Probable location for industrial plants like chemical plants, plastic manufacturing sites, and plants for food and beverages are among the establishments that need to be located in this specific land use. There are three (3) criteria identified for this land suitability analysis: the slope, distance to residential areas, and distance to main roads.

Agricultural Areas. These areas are primarily intended for agricultural production including poultry and dairy products. Farms for different production like rice, coconut, root crops, fruits, and vegetables, among others are to be located in this specific land use. There are four (4) criteria to be used in this suitability analysis including the soil type, soil fertility, rainfall/precipitation, and the access to water (rivers).

Forest Areas. In general, forest areas are those lands under natural or planted stands of trees whether productive or not, excluding tree stands in agricultural production systems. Every country might have different laws governing forests and maybe country specific. For this suitability analysis, there are three (3) criteria that are identified which includes the slope, elevation, and soil type.

3.2. Criteria Weights Using AHP

From the pairwise comparisons of the criteria for each set (land use) conducted and performed by the experts as decision-makers, the weights for each criterion per expert were computed. Tables 3–7 show the different weights of the criteria for the different land uses with 20 experts (A–T). The average weight (arithmetic mean) of the individual weights was computed to reflect the majority preference but will not be used as the final weights of the criteria. Instead, the final weights are based on the geometric mean of the individual preferences in the succeeding tables of comparison matrices. Correspondingly, the standard deviation (SD) is computed to reflect the amount of variation or dispersion of the set of values.

Table 3 shows the criteria to be used for residential areas suitability mapping with the corresponding weights computed using AHP. The data reveal that the experts gave, on average, the highest weight to the criterion distance to main roads with 0.21, followed by the distance to market, hospitals, and other infrastructures with 0.20. From this we deduced that among the different criteria for the selection of suitable lands for residential areas, the experts as decision-makers prefer areas which are highly accessible. On the other hand, the criterion soil type acquired the smallest weight of 0.06 which infers that among the criteria the soil type has their least consideration in the selection of residential areas.

Among the different criteria for commercial areas suitability mapping, the experts and decision-makers gave the highest weight on the average to the distance from residential areas with 0.26 (Table 4). This is followed by the criterion distance from the main roads with 0.25. This reveals that in the selection of suitable areas for commercial use, the experts believed that accessibility of the population to the different commercial establishments is the most important criterion. On the other hand, the criterion elevation is the least important among the set of criteria with an average weight of 0.08.

Table 5 shows the weights of the criteria to be used in the selection of suitable lands for industrial use. The experts revealed that of the three criteria which underwent pairwise comparisons, the criterion distance from residential areas got the largest weight of 0.42. This implies the importance from residential areas to the probable industrial sites like chemical and plastic plants that could cause pollution and human health problems. Accessibility ranked second, as the distance to main roads has an average weight of 0.36 while the criterion slope got the smallest weight of 0.22.

Table 6 shows that among the criteria for the selection of suitable lands for agricultural purposes the soil type is the most preferred criterion with an average weight of 0.33. This implies that a certain agricultural product needs specific soil type where fruits, vegetables, and other staple agricultural products also prefer to grow. Furthermore, the criterion rainfall/precipitation got the smallest average weight of 0.09. The experts and decision-makers believed that rainfall is uncertain so access to rivers as water source for agricultural production is more reliable and hence got a greater weight of 0.29.

Of the different criteria to be used in the suitability analysis for forest areas, the slope has the largest average weight of 0.41 (Table 7). The experts revealed that among the different land uses, forests are the suitable usage for those highly sloping and elevated areas. This is manifested by the criterion elevation that ranked second with an average weight of 0.33 while the smallest weight was given to the third criterion which is the soil type with 0.25.

The above results (Tables 3–7) clearly show that there is no unanimous preference of all the experts regarding the different criteria for all of the land uses. Table 3 shows that although the criterion “distance to main roads” obtained the highest average weight of 0.21 among the criteria for residential areas suitability mapping, it can be noted that two (2) experts gave a computed weight of 0.37 and 0.35 as the highest weights contrary to two (2) other experts who gave a computed weight of 0.06 and 0.07 as the lowest. The same scenario manifested in Table 7, which shows that the criterion “slope” for forest areas suitability mapping garnered the highest average weight of 0.41. However, the experts gave different computed weights with notable highest values of 0.77, 0.70, and 0.69 which are way extreme to other experts who gave weights of 0.05, 0.10, and 0.11 for the said criterion. Therefore, there exists no agreement of preferences as shown in the computed weights.

The results further suggests that the computed weights for each criterion mirrors the experts’ preferences. The heterogeneous preferences are clearly manifested in the preceding tables, which in turn reflect their different levels of knowledge and information on the subject in question [43,49] as well as their practices and work experiences which shows subjectivity. Thus, the occurrence of subjective preferences in group decision-making is influenced by the different backgrounds of the decision-makers. The observation is strongly supported by the authors of [52], who acknowledge that the existence of heterogeneous preferences is the most common challenge in large scale groups in which the decision-maker’s diversified educational backgrounds, knowledge, experiences, and decision habits utilize different formats to express their individual preferences [51].

After ensuring that the pairwise comparisons performed by the experts are consistent with their preferences as reflected by their corresponding collective consistency ratios (Appendix B), the collective preferences of the experts are represented by the computed geometric mean (individual preferences of the 20 experts) of preferences per pairwise comparison. The results were then used to fill in the matrix of pairwise comparison for each of

the land uses in deriving the weights of the criteria. The corresponding computed weights (Tables 8–12) are the final weight of priorities to be used in the subsequent GIS analysis.

Table 8. Pairwise comparison matrix for residential land use suitability using the geometric mean of the preferences with the computed weights.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	Weight
C1	1	1.020	2.305	1.123	1.141	0.490	0.503	0.996	0.11
C2	0.980	1	2.151	1.277	1.298	0.537	0.618	1.040	0.12
C3	0.434	0.465	1	0.461	0.629	0.254	0.295	0.416	0.05
C4	0.890	0.783	2.169	1	1.104	0.311	0.364	0.768	0.09
C5	0.876	0.770	1.590	0.906	1	0.396	0.348	0.642	0.08
C6	2.041	1.862	3.937	3.215	2.525	1	1.219	2.302	0.23
C7	1.988	1.618	3.390	2.747	2.874	0.820	1	1.484	0.20
C8	1.004	0.962	2.404	1.302	1.558	0.434	0.674	1	0.12
Sum	9.214	8.480	18.946	12.032	12.128	4.243	5.021	8.648	1.00

C1: Slope; C2: Elevation; C3: Soil type; C4: Distance from shoreline; C5: Distance from the river; C6: Distance from the main roads; C7: Distance from market, hospitals, etc.; and C8: Distance from the drainage network.

Table 9. Pairwise comparison matrix for commercial land use suitability using the geometric mean of the preferences with the computed weights.

Criteria	C1	C2	C3	C4	C5	C6	Weight
C1	1	1.125	0.336	0.306	0.536	0.267	0.07
C2	0.889	1	0.320	0.330	0.590	0.261	0.07
C3	2.976	3.125	1	1.150	2.250	1.070	0.25
C4	3.268	3.030	0.870	1	1.828	0.696	0.21
C5	1.866	1.695	0.444	0.547	1	0.371	0.12
C6	3.745	3.831	0.935	1.437	2.695	1	0.28
Sum	13.744	13.806	3.905	4.770	8.899	3.665	1.00

C1: Slope, C2: Elevation, C3: Distance from residential areas, C4: Distance from terminals/ports, C5: Distance from drainage network, C6: Distance from the main roads.

Table 10. Pairwise comparison matrix for industrial land use suitability using the geometric mean of the preferences with the computed weights.

Criteria	C1	C2	C3	Weight
C1	1	0.417	0.410	0.17
C2	2.398	1	1.164	0.43
C3	2.439	0.859	1	0.40
Sum	5.837	2.276	2.574	1.00

C1: Slope, C2: Distance from residential areas, C3: Distance from main roads.

Table 8 shows the pairwise comparison matrix of the collective preferences of the experts for the residential land use suitability analysis. Accordingly, the weights are computed with the criteria C6-Distance from the main roads and C7-Distance from the market, hospitals, schools, and other infrastructures garnered the two highest weights with 0.23 and 0.20, respectively, while the criterion with lowest weight is the soil type with 0.05. Table 6 reveals that the experts in general prefer accessibility as the most important criterion in choosing for suitable lots to be used for residential purposes.

Table 11. Pairwise comparison matrix for agricultural land use suitability using the geometric mean of the preferences with the computed weights.

Criteria	C1	C2	C3	C4	Weight
C1	1	0.266	0.271	0.307	0.09
C2	3.759	1	1.142	1.196	0.33
C3	3.690	0.876	1	1.161	0.31
C4	3.257	0.836	0.861	1	0.27
Sum	11.707	2.978	3.274	3.664	1.00

C1: Rainfall/precipitation, C2: Soil type, C3: Soil Fertility, C4: Access to water/rivers.

Table 12. Pairwise comparison matrix for forest land use suitability using the geometric mean of the preferences with the computed weights.

Criteria	C1	C2	C3	Weight
C1	1	1.142	1.774	0.41
C2	0.876	1	1.612	0.36
C3	0.564	0.620	1	0.23
Sum	2.440	2.762	4.386	1.00

C1: Slope, C2: Elevation, C3: Soil type.

The pairwise comparisons of criteria for commercial land use suitability analysis are presented in Table 9. Of the six criteria being compared with each other, the experts prefer the criterion distance from the main roads as the most important with the highest weight of 0.28, followed by the criterion distance from residential areas with the second highest weight of 0.25. It can be deduced that in selecting areas suitable for commercial use, the experts favor accessibility and the target market, which is the people who will be occupying the commercial infrastructures and other businesses. On the other hand, the criteria which they believe to be the least important in the selection would be the slope and elevation, both obtained equal weights of 0.07.

In the selection of suitable lands for industrial use, three criteria were compared pairwise (Table 10). Based on the comparisons conducted, the majority of the experts prefer the criterion distance from residential areas as the most important as indicated by the obtained weight of the criterion which is 0.43. This implies that the experts value the health of the people which could possibly be endangered in the presence of industrial plants. The second highest weight is 0.40 for the criterion distance from the main roads which denotes accessibility and the lowest weight belongs to the criterion slope which is the least preferred.

Table 11 shows the pairwise comparison matrix of the collective preferences of the experts for agricultural land use suitability. Of the four criteria being compared to one another, the table reveals that the criterion soil type is the most preferred criterion with the highest weight of 0.33, although only 2% higher than the criterion garnering the second highest weight of 0.31 which is the soil fertility. The lowest in the rank is the criterion rainfall with a computed weight of 0.09. During the cross-checking of the preferences, the majority of the experts reasoned that because of the unpredictable characteristic of rain, they prefer water accessibility through rivers to supply water requirement for agriculture especially for rice production.

Of the three criteria to be used in forest land use suitability analysis using AHP, C1-slope obtained the highest weight of 0.41 followed by the criterion elevation with a weight of 0.36, which is 5% lower than that of the slope (Table 12). The smallest weight belongs to the criterion soil type with 0.23, which implies that among the three compared criteria via pairwise, the experts chose soil type as the least important criterion in selecting suitable lands for forest utilization.

In the tables above, the weights assignment to each of the criterion is necessary in the evaluation of the levels of suitability. Accordingly, the weights are the values assigned to evaluation criteria which are indicative of their importance relative to other criteria under consideration. This implies that the larger the weight, the more important is the criterion in the overall utility [54,65]. This makes the derivation of weights a core stage in defining the decision-maker's preferences. Furthermore, it can be observed that in the literatures reviewed, there is no standard set of criteria to be used in the analysis and assessment of land suitability potential for a certain type of use. Although the knowledge-based approach of choosing the criteria is somewhat subjective compared to automated or data-driven approaches, the former is commonly used in land use planning studies [20,66,67]. The most common characteristics of criteria used in similar studies are those which considers data availability and accessibility [8].

In a group decision-making such as problems involving various decision-makers, a concrete and unanimous decision is oftentimes unattainable. Reaching consensus is particularly challenging for large-scale group decision-making due to complexity and uncertainty caused by large group participants [51]. Although it appears that the experts have heterogeneous preferences, the preceding Tables 8–12 show the convened preferences of the experts regarding the different criteria being compared pairwise. With the widely accepted standard of computing consistency recommended by Saaty, the AHP methodology assures that the experts are consistent with their preferences. Additionally, the use of the geometric mean was recommended to retain the reciprocal property of the matrices [64] and the computed weights are now ready for the corresponding land use suitability analysis.

Although the AHP technique employed in the study successfully derived the relative importance of the sets of criteria reflected by the weights, the use of AHP has been criticized due to a number of weaknesses including ambiguous questions, fixed measurement scales, and varied results [68]. Nevertheless, the technique still retains its popularity in various applications of decision-making processes. As such, in the context of land use suitability assessments, the AHP is an excellent choice since the assessment process is regarded as a decision problem and it is a classical procedure which gives a systematic approach in making decision [55]. The simple characteristic in terms of structure, logical, and effective mathematical properties and consistency in the judgement are the notable features of AHP [35]. Moreover, the qualitative attributes can be quantified in AHP, making it highly accepted in a vast number of applications where decision-making is needed and alternatives are present [69] including for land use suitability assessments.

4. Conclusions and Recommendations

The evaluation criteria as well as the factors for land use suitability analysis are general in nature. They can be replicated and amended in further studies and other related applications. The weights of each criterion acquired through AHP reflect the mean heterogeneous preferences of the experts as decision-makers and not necessarily true to all locations. This result could be location-specific, but nonetheless it is a good step towards developing a more useful decision support system for land use planning where important and knowledgeable groups of people take part and that their preferences and choices are well taken care of.

Yet, one has to take into account that land use suitability analysis remains a complex process that needs careful and sufficient attention. The process encompasses various domains of knowledge such as in soil science, social science, and management and economics which make it integral to a lot of disciplines. The study clearly demonstrates the complexity of land use suitability analysis, as it draws on multiple evaluation criteria from different epistemic domains. The criteria include soil topography and properties (slope, elevation, soil fertility, and soil type), hazards and climatic factors (distance from shoreline, distance from rivers, and rainfall), and other socio-economic criteria (accessibility, distance to ports, distance to markets, and service centers) which are essential to different facets of social and environmental issues. Furthermore, it incorporates the technical aspect of suitability

analysis through GIS technology and expertise as well as the human aspect through the preferences and decisions which make it more multifaceted.

With the human intervention through the decision-makers, there exist conflicting interests and priorities as land is scarce and irreproducible. As mentioned, it is widely acknowledged that the nature of humans is subjective, and that this influences the preferences manifested at their different levels of knowledge and information on the problem. This area is most likely the center of attention in many undergoing researches in minimizing subjectivity such as in operations research in the decision-making processes. The advantage of using the AHP method is that any issue can be decomposed into a number of factors and indicators, and that a process pairwise comparisons is consistently in line with preferences.

Although consistency in the preferences is reached in AHP, problems in heterogeneous preferences cannot be avoided in large-scale group decision-making which reflects subjectivity such as the results of the study showing extreme preferences over the same criteria compared. Therefore, it is recommended to pay extra attention in the selection of the experts as decision-makers. In this case, a special group of experts per land use should be identified to do the pairwise comparisons. Although the heterogeneous preferences can be addressed through the collective geometric mean, it is recommended that the experts would have a chance to meet and be deciding in one location so as to achieve consensus or agreement if not unanimous. However, this entails more time, effort, and monetary considerations.

Last, although most studies focused on experts as the primary respondents of AHP, it is suggested to make similar studies for land use suitability where other groups of key stakeholders' preferences will be considered, e.g., for agricultural land use suitability analysis, which incorporates the knowledge of the farmers who are actually tilling the lands and the common people's perception on the best sites for residential areas. This calls for a land use planning whereby participation figures are significant and appropriate, i.e., not just with the experts and decision-makers, but also with the beneficiaries and other people who will be greatly affected by the decisions to be made. In other words, only under such conditions one can create a better and more informed decision-making process.

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Appendix A

Initial list of criteria for land use suitability mapping.

- A. Residential land use
 1. Soil type
 2. Slope
 3. Rainfall Intensity
 4. Clean air availability
 5. Flood prone areas
 6. Land viability

7. Land use/land cover
 8. Accessibility/Distance from the main roads
 9. Distance to service centers
 10. Elevation
 11. Distance from the shoreline
 12. Distance from the drainage network
 13. Distance from rivers
 14. Distance from markets, hospitals and other infrastructures
 15. Temperature
- B. Commercial land use
1. Distance from residential areas
 2. Slope
 3. Elevation
 4. Distance from the main roads
 5. Distance from terminals/ports
 6. Distance from the drainage networks
 7. Soil type
 8. Distance from agricultural areas
 9. Distance from rivers
 10. Historical commercial areas
 11. Land use/land cover
- C. Industrial land use
1. Land use
 2. Slope
 3. Railway accessibility
 4. Road accessibility/Distance from main roads
 5. Distance from river
 6. Proximity to urban areas
 7. Distance form residential areas
 8. Soil type
 9. Distance from water source
 10. Distance from commercial areas
 11. Elevation
- D. Agricultural land use
1. Temperature
 2. Nutrient retention
 3. Nutrient availability
 4. Land use/land cover
 5. Slope
 6. Elevation
 7. Erosion level
 8. Soil pH
 9. Salinity
 10. Rainfall/precipitation
 11. Soil fertility
 12. Soil type
 13. Water availability/Distance from river
 14. Land drainage
 15. Soil depth
 16. Base saturation
 17. Mean relative humidity
 18. Topography
 19. Distance to roads

- E. Forest land use
1. Rainfall/precipitation
 2. Slope
 3. Elevation
 4. Land use/land cover
 5. Distance from residential areas
 6. Areas of key biodiversity
 7. Soil type
 8. Soil fertility

Appendix B

Table A1. Consistency Ratio of the pairwise comparisons for the collective preferences.

Land Use	Number of Criteria	Principal Eigen Value	Consistency Ratio
Residential	8	8.043	0.004
Commercial	6	6.023	0.004
Industrial	3	3.003	0.003
Agricultural	4	4.002	0.001
Forest	3	3.000	0.000

The consistency ratio per land use is achieved after filling in the comparison matrices based on the geometric mean of the individual preferences which also achieved consistency prior to the computation of the geometric mean.

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