Land Suitability Assessment for Pineapple Production in the Akwapim South District, Ghana: A GIS-Multi-Criteria Approach

Emmanuel M. Attua[a] & Joshua B. Fisher[b]

Abstract

Land suitability assessment, in the context of land use planning, is a bridging phase linking land resources assessment to any land use decision-making process. Like elsewhere, land use suitability assessment in Ghana is influenced by inherent conflicts and a complex network of socio-economic and ecological constraints that call for a flexible decision-making support tool able to incorporate multiple evaluation criteria, including the opinions of several stakeholders. In this paper, we report on a GIS-based multi-criteria approach to land suitability evaluation for pineapple production in the Akwapim South Municipality of Ghana. The crop is an important export earner, having contributed significantly to foreign exchange receipts of the country since the 1980s although its cultivation has also increased land use conflicts and aggravated land degradation. The study relied on several decision support tools such as high spatially-resolved remotely sensed data, geographical information system (GIS) and multi-criteria decision analysis (MCDA), including analytical hierarchy process (AHP). The approach enabled decision makers to evaluate the relative priorities of locating sites for cultivation of the crop, based on a set of preferences, criteria and indicators. Weighted Linear Combination (WLC) techniques were used to integrate fuzzy suitability criteria maps of decision groups and a consistency ratio between criteria was calculated using the Saaty matrix cross-comparison technique. An iterative post-aggregation constraint was applied to identify potential sites as basis for delineating potential areas for pineapple cultivation. In the context of potentially high export market demands of the crop and its significant economic contribution to the local economy, this study is of national relevance. Moreover, the results in form of maps may also be used by agricultural managers as decision-support tools, for instance, to outline the most suitable land areas for subsidy support for increased pineapple production in the district.

Keywords: Land suitability, Pineapple, GIS, Multi-criteria evaluation, Fuzzy maps, Ghana

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1.0 Introduction

In recent years, considerable interest has grown around the use of GIS technology for planning and management of environmental resources. One major and useful application of GIS to planning and management is the evaluation of land for its suitability for a particular utility (Klosterman 2001). In this context, land suitability analysis is fundamental to land management decisions, planning and utilization, providing a link between resources assessment and the decision-making process. It concerns the selection of suitable land on the basis of clearly defined objectives such as cropping, irrigation or other management alternatives that are physically practicable, financially feasible and economically viable (FA0 1985). Land suitability analysis aims at identifying the most appropriate spatial pattern for future land uses according to specific requirements, preferences or predictors of some activity (Collins *et al.* 2001). Operationally, land suitability analysis describes a procedure of land appraisal with a specific land use objective in mind (FAO 1976, Corona *et al.* 2008). For a specific sustainable land use, what is required is basically a synthesis of the complex relationships between different attributes of land such as soil properties, land cover, topography and climate, which themselves are dynamically variable. Land suitability assessment is therefore conventionally evaluated by matching requirements of biophysical/ecological, socio-economic and political factors for the particular application with characteristics and qualities of land components (FA0 1985).

Though often described as a decision support system, the adequacy of GIS as a decision support tool has been questioned (Jankowski 1995, Sheppard 2001, Thomson and Schmoldt 2001, Sieber 2003). In terms of decision-making, most GIS packages are primarily based on manual techniques and human judgments and decision rules which are not clearly defined and are therefore incapable of processing multiple criteria and conflicting objectives (Carver 1991), including a subjective integration of geographical information as imposed by the user (Malczewski 1999). To address these limitations, various analytical procedures collectively referred to as multi-criteria decision making (MCDM) methods have been integrated with GIS to strengthen the decision support capabilities of GIS technology (Carver 1991, Malczewski 1999, Jiang and Eastman 2000).

GIS-based land suitability analysis has found extensive applications in several fields including ecological approaches for defining land suitability habitat for conservation of flora and fauna (Pereira and Duckstein 1993, Store and Kangas 2001, Hirzel *et al.* 2006), agriculture (Cambell *et al.* 1992, Kalogirou 2002, Booyanuphap *et al.* 2004, Bingwen 2004,Van Chuong and Böhme 2005), environmental impact assessment (Moreno and Seigel1988), selection of the best site for public and private sector facilities (Eastman *et al.* 1993, Church, 2002) and regional planning (Janssen and Rietveld 1990, Senes and Toccolini 1998). Others include tourism (e.g., Beedasy and Whyatt 1999), agro-ecology (e.g., Mohamed *et al.* 2000, Miller *et al.* 1998), hazard mapping (Barredo *et al.* 2000), soil mapping (e.g., Liengsakul *et al.* 1993) and forestry (e.g., Phua and Minowa 2005, Corona *et al.* 2008).

2.0 Methods for GIS-based Land Suitability Analysis

With recent advancement in mapping technologies of remote sensing, GIS and global positioning systems (GPS), land suitability analysis modelling within the framework of a GIS has enormously expanded (Pereira and Duckstein 1993, Bojorquez-Tapia *et al.* 2001). Collins *et al.* (2001) identify three major groups of approaches to GIS-based land suitability analysis: (i) computer-assisted overlay mapping, (ii) multi-criteria evaluation methods, and (iii) artificial intelligence (AI) methods. The first two are further explained below for their popularity in GIS-based land suitability applications.

2.1 *Overlay Mapping*

Historically, GIS-based approaches to land suitability analysis originate from the applications of hand-drawn overlay techniques used by American landscape architects in the late nineteenth and early 20th centuries (Collins *et al.* 2001). The map overlay approach, according to Malczewski (2004), has been typically applied to land suitability in the form of Boolean operations and weighted linear combination (WLC) and has grown in popularity because these procedures are easy to implement within the GIS environment using map algebra operations. In addition, O'Sullivan and Unwin (2003) suggest that the methods are easy to understand and intuitively appealing to decision makers and therefore continue to play a pivotal role in many GIS applications, including techniques that are in the forefront of advanced land suitability evaluation such as multi-criteria decision analysis (MCDA) (Malczewski 1999), artificial intelligence (AI) or geo-computation methods (Ligtenberg *et al.* 2001, Xiao *et al.* 2002), visualization methods (Jankowski *et al.* 2001), and Web-GIS (Zhu and Dale 2001, Rinner and Malczewski 2002).

A major criticism of the conventional map overlay approach is related to the inappropriate methods for standardizing suitability maps and untested or unverified assumptions of independence among suitability criteria (Pereira and Duckstein 1993). Heywood *et al.* (1995) contend that in many case studies, the overlay land suitability models have been applied incorrectly and with dubious results because analysts (decision makers) have ignored or been unaware of these underlying assumptions. They suggest that the classical Boolean operations and WLC methods oversimplify the complexity of the process of addressing land use planning problems by focusing on the facts that can be effectively represented in GIS rather than on the right combination of facts and value judgments (that are difficult to represent in a computer environment in general and in a GIS in particular). This limitation, according to Malczewski (2000), can be resolved by integrating GIS and multi-criteria decision making (MCDM) methods.

2.2 *Multi-criteria Decision Making Methods*

The integration of MCDM techniques with GIS has greatly enhanced the conventional map overlay approaches to land suitability analysis (Carver 1991, Malczewski 1999, Thill 1999). A GIS-based MCDA can be conceived as a procedure that combines and transforms input spatial and aspatial data into an output resultant decision. The MCDM procedures (or decision rules) define a relationship between the input maps and the output map. The procedures involve the utilization of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules. Accordingly, two considerations are of critical importance for spatial MCDA: (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDM capabilities for combining the geographical data and the decision maker's preferences into uni-dimensional values of alternative decisions.

A number of multi-criteria decision rules have been implemented in the GIS environment for tackling land suitability problems. These decision rules fall into two major classes: multi-objective and multi-attribute decision making methods (Malczewski 1996). Multi-objective methods are concerned with making deals with the selection of the best alternative based on a series of conflicting objectives (Phua and Minowa 2005). They are relatively inflexible and difficult to implement in land suitability analysis because they are based on mathematical programming models and their potential as tools for GIS-based land-use suitability analysis has been demonstrated in many works (e.g., Diamond and Wright 1988, Cambell *et al.* 1992, Chuvieco1993, Cromley and Hanink 1999). Conversely, multi-attribute decision making methods are data-oriented and much easier to implement in a GIS, especially with regard to the raster data model (Pereira and Duckstein1996, Eastman *et al.* 1995). Consequently, there is a considerable number of GIS multi-attribute applications to land-use suitability analysis.

For nearly two decades, a number of multi-attribute (or multi-criteria) evaluation methods have been implemented in the GIS environment for land suitability evaluation, including WLC and its variants (Carver 1991, Eastman 1997) and the analytic hierarchy process (Banai1993). Among these procedures, the weighted linear combination (WLC) and Boolean overlay operations, such as intersection (AND) and union (OR), are considered the most straightforward and popular (Eastman 2006). The WLC is a simple additive weighting based on the concept of a weighted average (Eastman 2006). The decision maker directly assigns weights of 'relative importance' to each attribute map layer. A total score is then obtained for each alternative by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the products over all attributes. When the overall scores are calculated for all of the alternatives, the alternative with the highest overall score is selected.

The WLC procedure can be operationalized using any GIS system with overlay capabilities. The overlay techniques allow the evaluation criterion map layers (input maps) to be combined in order to determine the composite map layer (output map). The methods can be implemented in both raster and vector GIS environments and some GIS systems such as Idrisi have built-in routines for the WLC method (see Eastman 2006). There are, however, some fundamental limitations associated with the use of these procedures in a decision making process. Jiang and Eastman (2000) give a comprehensive discussion of those limitations and suggest that the Ordered Weighted Averaging (OWA) approach provides an extension to and a generalization of the conventional map combination methods in a GIS.

OWA is a class of multi-criteria operators (Yager, 1988). It involves two sets of weights: criterion importance weights and order weights. An importance weight is assigned to a given criterion (attribute) for all locations in a study area to indicate its relative importance (according to the decision-makers' preferences) in the set of criteria under consideration. The order weights are associated with the criterion values on a location-by-location (object-by-object) basis. They are assigned to a location's attribute values in decreasing order without considering which attribute the value comes from. The order weights are central to the OWA combination procedures. They are associated with the degree of ORness, which indicates the degree to which an OWA operator is similar to the logical connective OR in terms of its combination behaviour. The parameter is also associated with a trade-off measure indicating the degree of compensation between criteria (Eastman 2006).

The parameters associated with the OWA operations serve as a mechanism for guiding the GIS-based land-use suitability analysis. The ORness measure allows for interpreting the results of OWA in the context of the behavioural theory of decision making (Jiang and Eastman 2000). The OWA operations make it possible to develop a variety of land use strategies ranging from an extremely optimistic (the minimum-type strategy based of the logical AND combination) through all intermediate (the neutral-towards-risk strategy, corresponding to the conventional WLC) to an extremely pessimistic strategy (the maximum-type strategy based on the logical OR combination). Thus, OWA can be considered as an extension and a generalization of the conventional combination procedures in a GIS (Jiang and Eastman 2000).

Another multi-attribute technique, which has been incorporated into the GIS-based land-use suitability procedures, is the Analytical Hierarchy Analysis (AHP) method (Saaty 1980). It can be used in two distinctive ways within the GIS environment. First, it can be employed to derive the weights associated with suitability (attribute) map layers. Then, the weights can be combined with the attribute map layers in a way similar to the linear additive combination methods. This approach is of particular importance for problems involving a large number of alternatives represented by means of the raster data model, when it is impossible to perform a pair-wise comparison of the alternatives (Eastman *et al.* 1993). Second, the AHP principle can be used to aggregate the priority for all levels of the hierarchical structure, including the level representing alternatives. In this case, a relatively small number of alternatives can be evaluated (Banai 1993, Jankowski and Richard 1994). This approach is also more appropriate for implementation in the vector-based GIS (Jankowski 1995). It should be noted that AHP can be used as a consensus building tool in situations involving a committee or in group decision-making (Saaty 1980).

There are several problems associated with implementing the MCDM methods in a GIS (Zhou and Civco1996). First, it is well-known that the input-data to the GIS-multi-criteria evaluation procedures usually have the property of inaccuracy, imprecision and ambiguity. In spite of this knowledge, the methods typically assume that the input data are precise and accurate. An approach for dealing with impression and ambiguity in the input data (attribute values and decision maker's preferences) is to use fuzzy set theory and fuzzy logic (Zadeh1965, Fisher 2000).

2.3 *Fuzzy Set Classification in Land Suitability Assessment*

One problem with the traditional multi-criteria approaches to land suitability analysis is that they do not assure a spatial pattern with contiguity or compactness in land allocations for different land use types. A central and critical issue of methodology in land suitability evaluation is how to parameterize and combine land attributes of a different nature in order to model the productive response of target species to a given set of environmental factors. Geo-spatial data consisting of discrete, sharply bounded units is incapable of representing the reality: the continuous nature of variability of environmental factors and their small-scale spatial heterogeneity. Moreover, considerable loss of details may occur when data classified according to such a rigid-data model are retrieved or combined using Boolean methods (Malczewski 2004, Corona *et al.* 2008).

The fuzzy set theory offers a useful alternative in this respect: it permits the gradual assessment of the membership of elements in a set with the aid of a continuous scale of membership (Burrough and McDonnell 1998), the so-called *membership function*, valued in the real unit interval [0, 1] on the Boolean scale and [0, 255] on the byte scale . The fuzzy set classification allows transition from one class to another to be described by means of a membership function.

In the application of land suitability evaluation, the use of a fuzzy set classification is particularly helpful to model the productive response of the target species to single environmental factors. This can be better expressed as a gradual transition (soft classification), rather than as abrupt shifts from one class to another (hard classification). Such a gradual transition can be quantified according to fuzzy membership functions valued in the interval [0, 1] or [0, 255], where 1 or 255 means a complete suitability (the environmental factor matches the ecological requirements of the target species: the so called *optimum* of the species) and 0 means no suitability (Corona *et al.* 2008). The appropriate fuzzy membership function is dependent on the best available knowledge of the target species' ecological requirements, as drawn from literature and field knowledge (Eastman 2006).

Although the fuzzy logic approach to land-use suitability modeling is shown to have fewer limitations than conventional techniques, the approach is not without problems. The main difficulty associated with applying the fuzzy logic approach to land suitability modeling is the lack of a definite method for determining the membership function (Malczewski 2004).

3.0 Study Setting, Objectives and Assumptions

Pineapple is Ghana's most important non-traditional export horticultural crop, which has been contributing significantly to foreign exchange receipts of the country since the 1980s (Takane 2004), albeit with several technical and production constraints (Donkor and Agboka 1997). Currently, exports of pineapples from Ghana are primarily destined for the European market. In absolute terms, however, Ghana's pineapple exports are far below those of her major competitors like Costa Rica and Côte d'Ivôire (Achuonjei 2003). Consequently, increased and sustained future production of the crop in Ghana to satisfy the export market demands has already aroused government's interest (Danielou and Ravry 2005, Ghana Export Promotion Council 2008). Meanwhile, the contribution of the crop to the local economy also remains substantially high, with potential for future increases (HEII 2006, Afari-Sefa 2007).

So far, pineapple production in Ghana has been concentrated particularly in the Nsawam-Aburi corridor (figure 1) of the Akwapim South Municipality, amidst increasing land degradation of most production sites (Attua 1996; 2001, Pahi 2003, Kusimi 2008). The increasing market demands for pineapples continue to push farmers to expand cultivation of the crop, even to marginal lands, thus causing further ecological degradation. This degradation could be controlled, however, through careful land use planning, with the first step of conducting a multi-criteria land suitability assessment for pineapple cultivation, while giving due consideration to environmental protection.

The main objective of our study is to identify the most suitable land areas for pineapple cultivation while conserving the environment. Another objective is to identify such suitable areas in terms of land use/land cover, as potential sites for locating pineapple farms. These identified areas: (a) should practically be changeable in terms of land use/land cover; (b) must contain the minimum physical requirements for pineapple cultivation; and (c) must be associated with a hierarchy of suitability for pineapple cultivation. These objectives can be achieved through a GIS-based MCE.

In order to achieve the above objectives, in the context of available geospatial data, the following assumptions were made: (a) the present land cover pattern is unlikely to change significantly, (b) rainfall is a more critical climatic factor for pineapple cultivation than temperature and (c) it is impracticable to change developed areas (mainly built-up infrastructure), water bodies (mainly rivers and streams), and roads for pineapple cultivation.

4.0 The Study Area

The study area is the Akwapim South Municipality in the Eastern Region of Ghana. Located approximately 23 kilometres from Accra, the national capital, the study area lies at the South Eastern part of the Eastern Region.

between latitude 5°45'N and 5°58'N and longitude 0° 07'W and 0°27'W, and covers a land area of about 503 square kilometres. The Municipality is bordered in the North by the Suhum Kraboa-Coaltar and Akwapim North districts, in the South by the Ga East and Ga West districts and the Tema Municipal Area and in the West by the West Akim Municipal (figure 1). Nsawam, the district capital, is located just 23 km from the national capital, Accra. According to the 2000 population census report, the Municipality has a population of about 120,000, of which about 70% are farmers.

The Akwapim South district comprises the Densu Plains, the Ponpon narrow gorge and the Akuapim Togo mountain range, which rises over 1000 feet above sea-level at Aburi. It is drained by the Densu River and its tributary rivers and streams. The Densu River itself is approximately 115.8 kilometres long and takes its source from the Atiwa mountain ranges near Kibi in the Eastern Region.

The Municipality is covered by two main vegetation types, the moist semi-deciduous forest and the coastal savannah grassland. The forest occupies almost 90% of the municipal area, covering the north, west and all of the area in the east. The remaining 10% is to the south where coastal shrub and grassland vegetation dominates. This forms the transitional zone between the coastal savannah and the rain forest belt.

The entire municipality falls within two distinct climatic zones: the dry equatorial climate of the south-eastern coastal plains and the wet semi-equatorial climate further north from the coast. Both climatic zones are characterized by a bimodal rainfall regime with different intensities (Dickson and Benneh, 1980). The major rainy season begins from May to July and the minor from September to November. Mean annual rainfall is about 800mm near the coast and increases northwards to about 1600 mm. Temperatures are uniformly high throughout the year, with a mean annual temperature of about 27°C. March and April are the hottest months (32°C) while August is the coldest month (23°C).

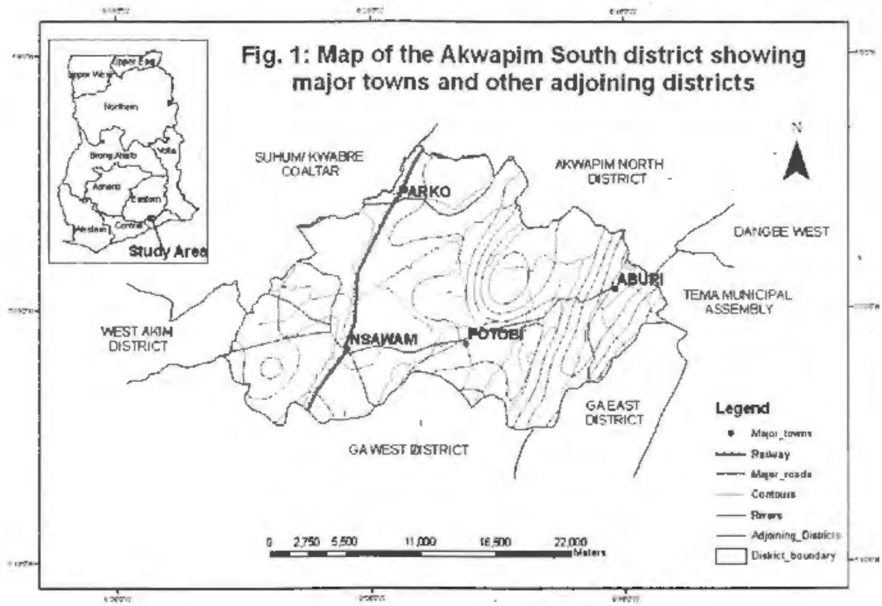

Figure 1: Location map of the Akwapim South Municipality showing the administrative capital and other major towns

Traditionally, the Akwapim South Municipality, particularly the Nsawam-Aburi corridor, is the major centre of pineapple production in Ghana. Amidst increasing land degradation (Attua 1996; 2001, Pabi 2003, Kusimi 2008), pineapple production has largely been by smallholder farmers (Takane 2004). Production has been concentrated in this area probably because of its proximity to large urban markets of Accra, Koforidua and Nsawam and also to the International Airport and major sea port of Accra and Tema (for reasons of exports), respectively. An added advantage is the relatively better transport network connecting the basin to these areas. Also, processing companies producing pineapple juice are concentrated in the cities of Accra, Nsawam and Tema and offer a major domestic market for fresh pineapples (Takane 2004).

5.0 Study Methodology

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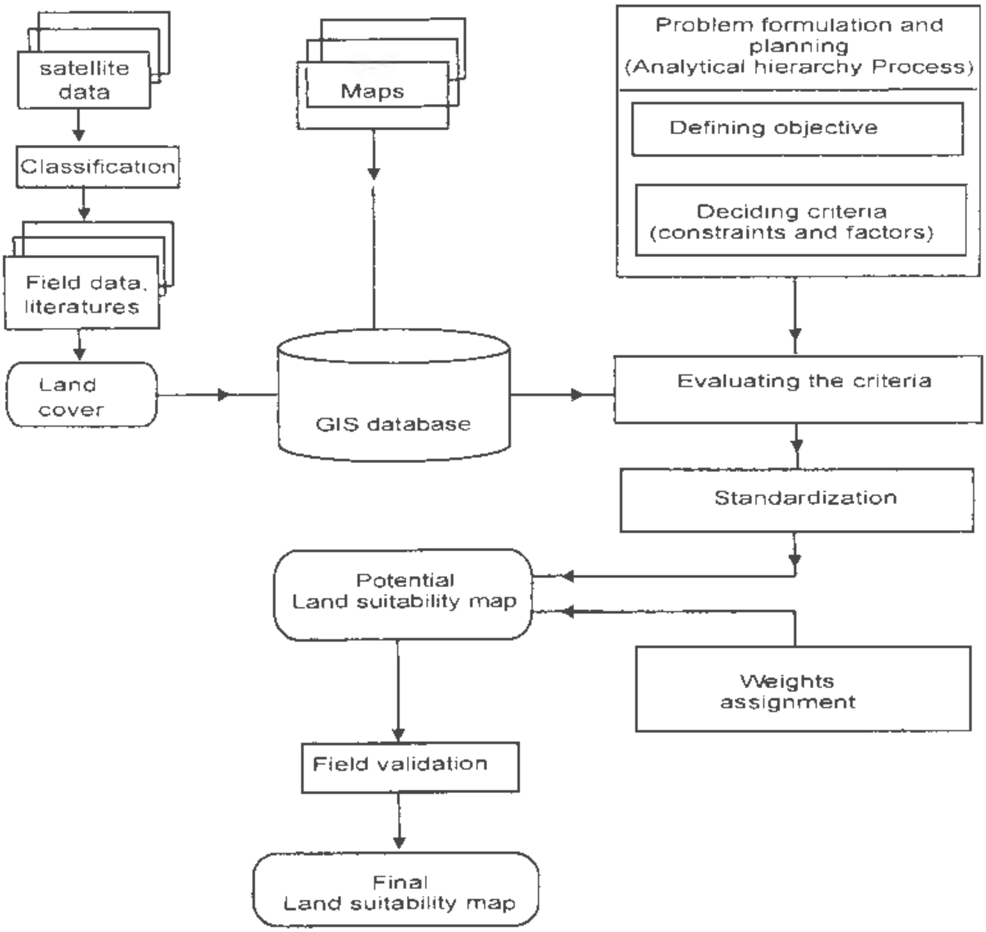
Land suitability for pineapple, as a multi-criteria decision making problem, was formulated based on the local ecological knowledge of eight expert farmers of the crop, as well as the knowledge of other experts comprising three agricultural extension officers, a district agricultural officer and two representatives of buying and processing companies, all drawn from the study area. Firstly, the decision making problem was formulated using the Analytical Hierarchy

Process technique (Saaty 1980). Criteria (as factor and constraint maps) were selected by a panel of seven experts and evaluated using GIS techniques, complemented by field data and the relevant literature. The different phases of conducting the study are detailed and schematically represented in figure 2 below.



Source: Adapted from Phua and Minowa (2005).

Figure 2: Data requirements and decision flowchart for GIS-based multi-criteria decision making.

5.2 Data Requirement and Sources

The relevant data used in this study were selected following an in-depth literature review, consultation with expert farmers and agriculturists, and screening among farming communities for which geo-referenced information was available. The data were multi-disciplinary and included climatic (annual mean rainfall), topographic (slope), pedological (soil texture), hydrological (rivers and streams), demographic (population), transportation (roads) and land cover data. The climatic data were obtained from the Ghana Meteorological Service. Population data of major towns in the study area (from the two most recent censuses of the country, 1985 and 2000) were obtained from the Ghana Statistical Service. Shape files of soil types, roads, rivers and streams were acquired from the ESRI website while slope data were obtained by processing a digital elevation model (DEM) from SRTM (Shuttle Radar Topographic Mission), at a spatial resolution of 90m. A Landsat ETM+ scene (path 193; row 056, 2003 February, 12) was downloaded from the website of the Global Land Cover Facility of the University of Maryland website (http://glcf.umiacs.umd.edu/index.shtml). All geo-spatial data were projected in ArcGIS 9.3 software to a Universal Transverse Mercator (UTM), Zone 30 North, spheroid WGS84 coordinate system and exported to Idrisi (Andes 15.0 edition). Further data extraction, development and mapping were done using the Idrisi software.

5.3 Data Processing and Integration

5.3.1 Land cover data

The acquired Landsat ETM+ image was digitally processed and classified to produce a current land cover map of the study area (figure 3). All six reflective bands of the image of the study area (1082 columns x 691 rows) were produced by the Maximum likelihood classification (Pal and Mather 2003) into five land cover categories. Table 1 below shows the land cover classes used and their respective interpretations.

Table 1: Land cover classification scheme used in classification of Landsat imagery.

Land Cover	Explanation
Grass-dominated fallow	Predominantly grass and herb mixture; with or without scattered trees (0-5 trees/hectare)
Tree-dominated fallow	Moderately dense tree cover with herb and bush cover; with or without close canopy (>15 trees/hectare)
Ticket vegetation	Moderately dense herb/thorny bush with scattered trees (<15 trees/ hectare)
Current cultivation	Arable farms either in active cultivation or recently harvested.
Built-up and bare ground	Developed infrastructure and exposed soil surfaces

A more recent Landsat image of the study area could not be used because available images were significantly covered either by clouds or stripped, while use of other high spatially-resolved images was curtailed by prohibitive costs. The accuracy of classification was evaluated by constructing a classification error matrix from random reference samples of 190 ground control points. An accuracy of 73.7 percent accepted.

5.3.2 Development of criteria maps (constraints and factors)

In MCE-GIS applications, criteria are evaluated using GIS and, remote sensing techniques, coupled with field data and literature (Carver 1991). All criteria in the form of maps that contribute to achieving a particular objective ought to be identified and developed. Traditionally, criteria maps are either constraint or factor maps (Eastman 2006). For our study, three Boolean constraint maps were developed. First, areas under development in the form of urban/residential facilities could not be considered as potential production sites and were therefore constrained. On a Boolean scale, all developed areas were assigned a value of 0 whilst all others were assigned a value of 1. To also exclude areas close to human dwellings from future cultivation, a 500-meter buffer was defined around all urban/residential areas (referred to as developed constraint). Because the district is located in a hilly, undulating terrain, soil erosion accompanied by siltation of rivers/streams is a critical environmental concern (Attua 1996, Water Resources Commission 2007). To address this concern, two Boolean constraint maps were applied. First, all areas of slope above 35% gradient were constrained from farming. Second, a 100-meter buffer was created around all rivers and streams.

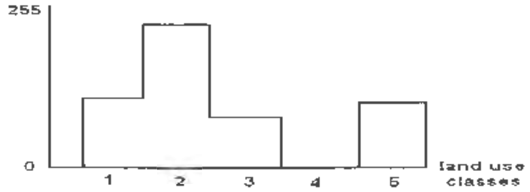
In addition to the above constraint maps, seven other criteria maps were developed. These comprised the current land cover and slope (both in raster formats) and five vector-based maps - annual mean rainfall, soil texture (classified into five according to proportions of clay, silt and sand in samples), rivers and streams (representing supplementary water), population of major farming communities (a surrogate for labour availability and market accessibility) and roads network (surrogate for accessibility to transportation).

In the subsequent steps, the criteria maps were standardized to a fuzzy scale and combined to identify the 'most suitable' sites for cultivation of pineapple. The combination procedure followed the conventional framework for GIS-based MCDM (Malczewski 1999). Three key steps were involved in the combination of the criteria maps, which correspond to the three main components of the GIS-MCDM system developed within an IDRISI-GIS environment. These are described under sections 5.2.3 to 5.2.5 below:

5.3.3 Standardization of criteria with fuzzy method

Various approaches to prepare comparable and standardized criterion maps include deterministic, probabilistic and fuzzy approaches (see Eastman *et al.* 1995 for details). The method used for standardization follows closely that of Corona *et al.* (2008). The different criteria maps were synchronized into comparable measureable units on a byte scale (0-255) and standardized to a continuous scale of suitability, using a multi-criteria fuzzy membership function (Eastman 2006) and evaluated by experts. Table 2 below shows the fuzzy membership functions applied to the standardization of each factor map

Table 2: Fuzzy membership functions used for standardization of criteria maps

<table>
<tr><th>Factor</th><th>Applied fuzzy membership function</th></tr>
<tr><td>Current land use</td><td>
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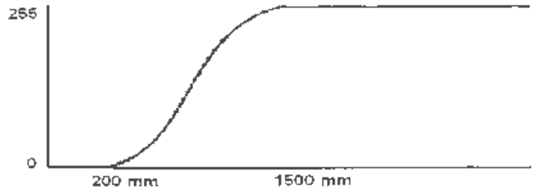
<tr><td>Annual mean rainfall</td><td>
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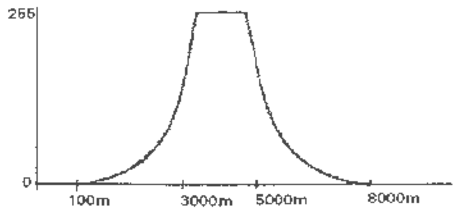
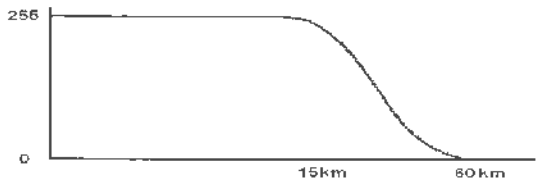
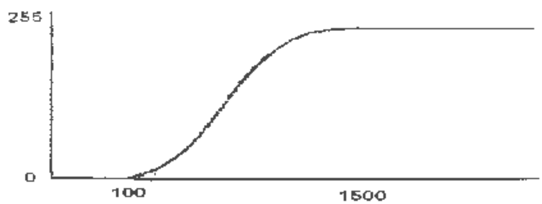
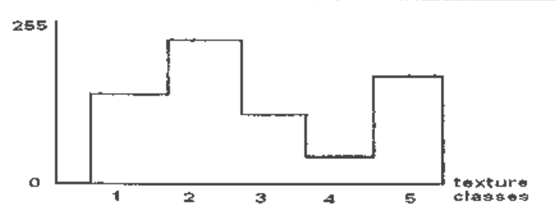
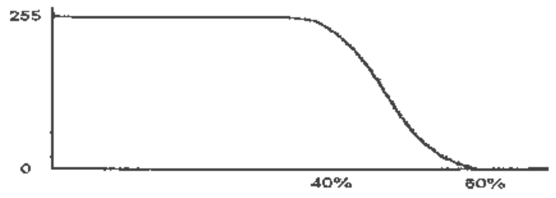
<tr><td>Proximity to supplementary water sources (rivers and streams)</td><td>
</td></tr>
<tr><td>Proximity to roads</td><td>
</td></tr>
<tr><td>Labour availability</td><td>
</td></tr>
</table>

Soil texture	
Slope	

The adoption of a fuzzy approach to modelling the ecological relationship between the productive response of a given crop species and single environmental factors offered a sound alternative to hard classification methodologies since such relationships are intrinsically characterized by zones of gradual transition rather than by sharp boundaries (Corona *et al*. 2008). Classification approaches based on the fuzzy set theory provide the closest approximation between classic mathematical precision and the imprecision of the real world, relatively decrease subjective choices and increase rational decisions. In this manner, these methods create a conceptual structure appropriate to decision making (Jiang and Eastman 2000). Since most environmental factors are continuously variable and spatial heterogeneous, the continuous classification of suitability was considered more appropriate in representing the reality than the commonly applied discrete measure of suitability.

The advantage of the fuzzy standardization is that it permits a gradual assessment of the membership of elements in a set with the aid of a continuous scale of membership (Burrough and McDonnell 1998), valued in the real unit interval of (0 to 1), where 0 represents a no suitability situation and 1 a complete suitability (thus, the environmental factors match the ecological requirements of the target land use – an optimum). On a byte scale, these limits of suitability are expressed as 0 to 255. In our study, fuzzy membership functions were defined on the byte scale.

5.3.4 Assignment of weights for standardization of criteria maps

A number of methods for objective assignment of weights to criteria applied in MCE have been proposed (Eastman 1999). In the context of decision-making, weight assignment to criteria maps was carried out by an independent panel of seven experts, using an Analytic Hierarchy Process (AHP) technique (Eastman 2006). The technique, first proposed by Saaty (1980), derived a principal eigenvector of reciprocals of pair-wise comparisons between the criteria, from a 9-point continuous scale (see Eastman 2006 for details). The comparisons concern the relative importance of any two criteria involved in the determination of the assessment objective, where a value of 1 suggests the two criteria contributing equally to land suitability, while a value of 2 signifies that one factor is twice more important than another, and so forth. The consistency between the judgments was evaluated and a ratio of 0.05 was achieved (Table 3), which was within the acceptable range of < 0.10 (Saaty 1980). This indicated a reasonable level of consistency in the pair-wise comparisons (Malczewski 1999).

Table 3: Pair-wise comparison of weights using AHP for aggregation of the fuzzy suitability values relative to each criterion

	LU	LA	AMR	PSW	PR	S	ST
LU	1						
LA	5	1					
AMR	3	1	1				
PSW	1	1/3	1/3	1			
PR	3	1	1	3	1		
S	1/3	1/3	1/3	1/3	1/3	1	
ST	1	1	1	3	1	3	1
Consistency ratio = 0.05 (acceptable)							

LU = Land use; LA = Labour availability; AMR = Annual mean rainfall;
PWS = Proximity to supplementary water; PR = Proximity to roads;
S = Slope; ST = Soil texture.

2.3.5 Aggregation of standardized criteria maps to final suitability map

Based on the relative importance of each factor in contributing to the study objective, weights assigned independently by experts to the criteria maps were used for aggregation of the standardized criteria maps. Table 4 below shows the eigenvector of respective weights applied to the respective criteria maps.

Table 4: Weights Assigned by Experts for Aggregation of *Standardized Criteria Maps*

Criteria	Weight
Labour	0.09
Land use	0.22
Rainfall	0.20
River	0.08
Road	0.20
Slope	0.05
Soil	0.17

The WLC technique within Idrisi-GIS was used for aggregation of the criteria, on a pixel-by-pixel basis, where each criteria map was multiplied by its weight and summed. A weighted average was calculated and the resultant image multiplied with the three Boolean constraint maps (developed, slope and river buffer constraints) described under section 5.3.2 to "mask out" all unsuitable areas (Eastman 2006) and generate a potential land suitability map. The potential suitability map was field validated from expert farmers' knowledge of 70 randomly selected sites which were considered as potentially suitable for pineapple cultivation and which could be located on the map. An agreement of 87.8 percent was found between the field information and the suitability map and, therefore, the final suitability map was produced (figure 5 below).

5.3.6 Extraction of land suitability area per land use/cover

In the last analytical phase, the land suitability compatible with the current land use/cover types of the area, derived from Landsat imagery (cf. figure 4 below) was extracted. The objective was to provide data on optimal land sites for allocation for pineapple production among the eligible land cover classes of the study area. The land cover classes, particularly built-up and bare grounds, water bodies and higher slopes, whose conversions to pineapple cultivation were unlikely, were set as *constraints* of the analysis (cf. section 2.2.2). Hence, suitability classes were assigned only to pixels falling within polygons of the following classes: tree-dominated fallows, grass-dominated fallows, thickets and current farms). The byte-scaled final fuzzy suitability map was reclassified as follows: pixels assigned suitability from 1 to just less than 150 as marginally suitable, 150 to just less than 200 as moderately suitable and 200 and more as highly suitable (FAO 1976). Using the overlay method (multiplication), maps of each of the three suitability levels were combined with each eligible land cover class, using Boolean operations. Suitability class statistics were calculated for each eligible land cover class according to the three levels of suitability and reported.

5.3.7 Optimal sites allocation

Delineating contiguous areas of suitable land from the final fuzzy suitability map meant deciding on which locations should be chosen from the set of all locations, each of which has some degree of suitability. To achieve this, a consultative meeting of three expert farmers was arranged for a decision on an appropriate suitability threshold and the required minimum land area for large scale cultivation of pineapple. A suitability threshold of 200 (on the 0-255 scale) and a minimum land size of 1000 hectares were agreed upon and used for a post-aggregation constraint mapping of land suitability. The procedure follows an iterative analysis explained comprehensively in Eastman (2006) and requires that the following data are specified: the name of the suitability map (image), the suitability score threshold to be used, the minimum site size threshold (in hectares) and the name for the output image.

6.0 Results and Discussion

6.1 Land use/Land cover

Figure 4 below shows the land cover map of the study area derived from classification of Landsat satellite imagery and Table 5 depicts the area of each land cover. The dominant land cover is the grass-dominated fallow, which covers 17591.04 hectares (43.44 percent of total land cover) the while tree-dominated fallow forms the second most dominant land cover of 11611.08 hectares or 28.67 percent of total land cover.

Current cultivation covered 6922.26 hectares or 17.09 percent of total land cover and forms the third highest landscape cover. The next extensive land cover class is the built-up/bare ground which constitutes 3132.81 hectares or 7.74 percent of the total land cover. The least land cover type is the, thicket vegetation which forms 1237.86 hectares or 3.06 percent of all land cover.

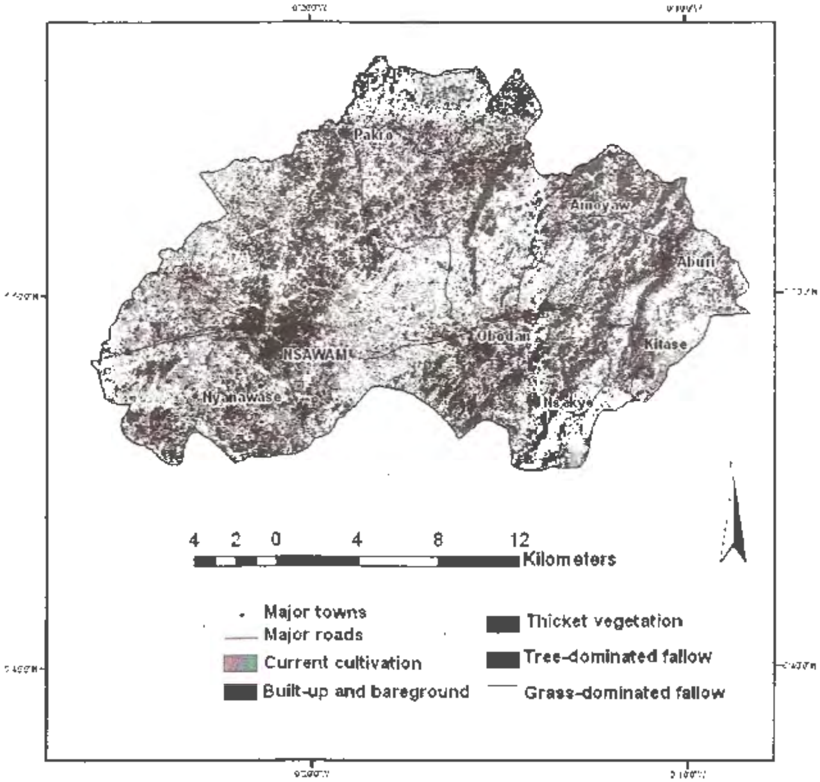


Figure 4: Land cover of the Akwapim South District from classification of 2003 Landsat ETM$^+$ image.

Table 5: Area of Land Cover Classes (in hectares)

Land cover	Total area (hectares)	Percentage
Tree-dominated fallow	**11611.08**	**28.67**
Grass-dominated fallow	**17591.04**	**43.44**
Current cultivation	**6922.26**	**17.09**
Thicket	**1237.86**	**3.06**
Built-up and bare ground	**3132.81**	**7.74**
TOTAL	40495.05	100.00

6.2 Land Suitability Maps

The final fuzzy land suitability for pineapple production is reported in figure 5 and the respective areas classified as highly suitable, moderately suitable or marginally suitable are shown in Table 5.

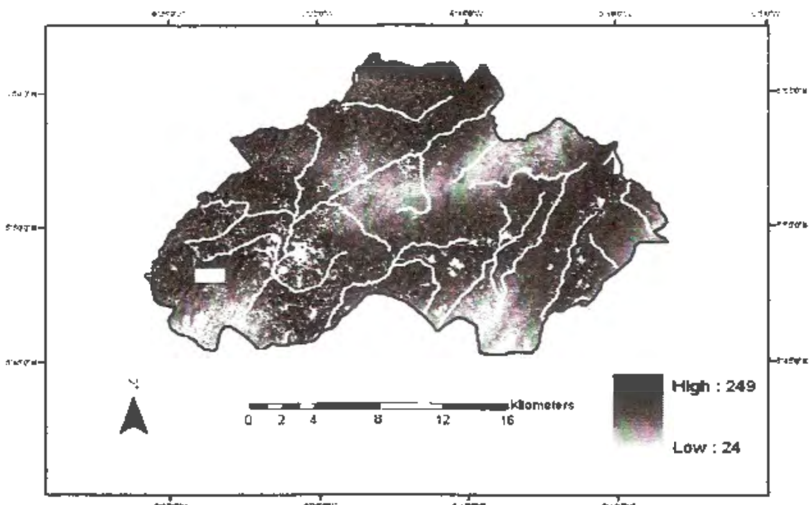


Figure 5: Final land suitability map

The result indicates that 38.61 percent (or 13012.65 hectares) of all eligible land is highly suitable, 41.65 percent (or 14039.46 hectares) is moderately suitable and 19.74 percent (or 6651.27 hectares) is only marginally suitable for pineapple cultivation.

Table 5: Land area at different levels of suitability

Level of suitability	Area (hectares)	Percentage
Highly suitable	13012.65	38.61
Moderately suitable	14039.46	41.65
Marginally suitable	6651.27	19.74
TOTAL	33703.38	100.00

6.3 Land Suitability in Relation to Land Use/Land Cover

Overlay analysis of the land suitability and land use/land cover maps provided data on what proportion of each land cover is highly suitable, moderately suitable or marginally suitable for pineapple production. The data as shown in Table 6 below suggest that tree-dominated fallows cover a total of 10886.04 hectares or 32.16 percent of all suitable land: comprising 2884.50 hectares or 8.52 percent of highly suitable, 7572.33 hectares or 22.37 percent of moderately suitable and 429.21 hectares or 1.27 percent of marginally suitable land.

Table 6: Total area (hectares) of Land Use/Cover Types at Different Levels of Suitability*

Land cover/land use	Area highly suitable (hectares)	Area moderately suitable (hectares)	Area marginally suitable (hectares)	TOTAL
Tree-dominated fallow	2884.50 (8.52%)	7572.33 (22.37%)	429.21 (1.27%)	10886.04 (32.16%)
Grass-dominated fallow	1988.37 (5.87%)	11310.84 (33.41%)	2184.84 (6.45%)	15484.05 (45.73%)
Thicket vegetation	31.68 (0.09%)	818.82 (2.42%)	206.64 (0.61%)	1057.14 (3.12%)
Current cultivation	103.41 (0.31%)	4871.52 (14.39%)	1452.96 (4.29%)	6427.89 (18.99%)
TOTAL	5007.96 (14.79%)	24573.51 (72.59%)	4273.65 (12.62%)	33855.12 (100.00%)

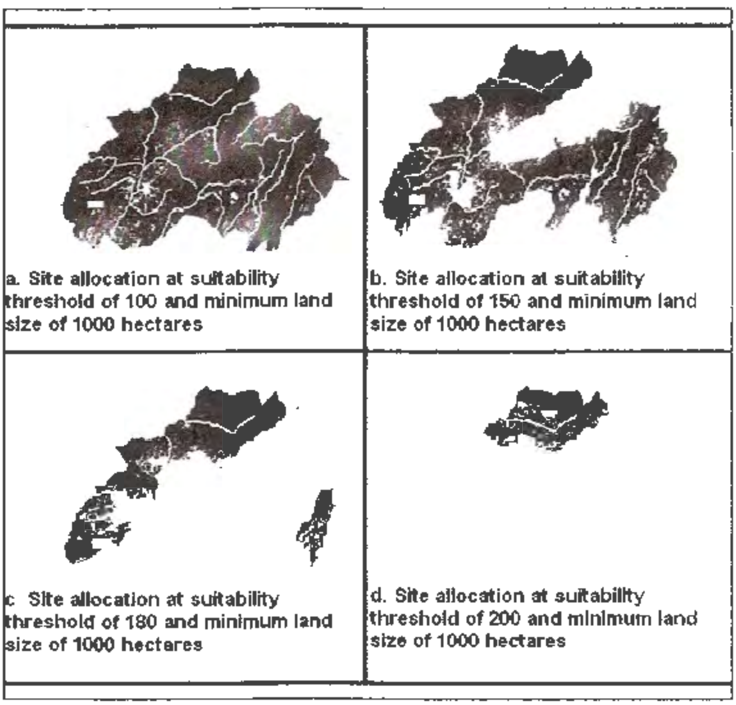
*Percentage of total suitable land shown in brackets

About 15484.05 hectares or 45.73 percent of suitable land is under grass-dominated fallows. This consists of 1988.37 or 5.87 percent highly suitable, 11310.84 hectares of 33.41 percent moderately suitable and 2184.84 hectares or 6.45 percent marginally suitable land. Thicket vegetation covers 1057.14 hectares or 3.12 percent of all suitable land, comprising 31.68 hectares or 0.09 percent of high suitability, 818.82 hectares or 2.42 percent of moderate suitability and 206.64 hectares or 0.61 percent of marginal suitability. Area of suitable land under current cultivation is 6427.89 hectares or 18.99 percent of total suitable land area. This consists of 103.41 hectares or 0.31 percent highly suitable, 4871.52 hectares or 14.39 percent moderately suitable and 1452.96 or 4.29 percent marginally suitable areas.

Comparatively, in terms of potential suitable sites for locating pineapple farms in the district, grass-dominated fallows were the most important, followed by areas of tree-dominated fallows. Land under current cultivation was the third most important land cover suitable for pineapple cultivation and thicket vegetation was the least important of all.

6.4 Optimal Sites Allocation

A user's decision to select a site for cultivation, as explained under section 2.4 above, was based on the degree of land suitability desired and the size of contiguous suitable land intended. The analysis indicates that, on a continuous fuzzy scale, as the threshold of land suitability required is increased, the size of potential contiguous suitable land correspondingly reduces, and vice-versa. Figure 6 (a-d) below demonstrates how changing the suitability threshold while maintaining the same size of minimum land requirement each time, influences optimal land allocation.



a. Site allocation at suitability threshold of 100 and minimum land size of 1000 hectares

b. Site allocation at suitability threshold of 150 and minimum land size of 1000 hectares

c. Site allocation at suitability threshold of 180 and minimum land size of 1000 hectares

d. Site allocation at suitability threshold of 200 and minimum land size of 1000 hectares

Figure 6: Effect of suitability threshold on site allocation

In figure 6a above, the suitability threshold was 100 (on a 0-255 scale) at a minimum land size of 1000 hectares. The result is that nearly all suitable land in the district was eligible for allocation many plots of land, each 1000 or more hectares, would satisfy the user's needs. When user land requirement was defined at an increased suitability of 150 while requiring the same minimum land size of 1000 hectares, relatively more areas of suitable land became ineligible (figure 6b). A further increase of the suitability threshold to 180 and then 200 at a minimum land size of 1000 hectares in both cases correspondingly reduced further the area of eligible land that could be accessed (figures 6c and 6d). In a decision-making context, therefore, a compromise solution is required in the choice of minimum land size and degree of land suitability, for the allocation of potential plots for the cultivation of pineapples.

Summary and Conclusion

In context of a MCDM-GIS framework, suitable areas of land for the cultivation of pineapple were evaluated. The effectiveness of the procedure was in three respects: (a) integration of multi-disciplinary spatial data, (b) incorporation of decision makers' concerns in deriving the study outcomes and (c) generation of fuzzy suitability maps that are flexible for planning and routine applications. This study demonstrates the application of the MCDM approach to addressing the complex decisions of mapping the responses of crop species to environmental attributes and physical limitations of the land. The output fuzzy suitability maps are products that can be used as tools by agricultural land managers for decision-making, including the zoning of areas for subsidy support for pineapple production.

Mindful that both land qualities and the aspirations of society are essentially dynamic, it is pertinent that land suitability analysis is framed within an overall adaptive approach involving frequent re-evaluation of information needs and incorporation of multi-disciplinary perspectives of stakeholders. In this way, land suitability evaluation will not only respond appropriately to society's changing values but also make its application more relevant within the context of a changing environment.

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