Modeling of Suitable Areas for Rainfed Rice Growing Using Multicriteria Approach in Geographic Information System: Case of Denguele (North West of Côte d'Ivoire)

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Authors' contributions

This work was carried out in collaboration of all the authors. Authors ABKW designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors BD, ZAK and IS managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Short Research Article	

ABSTRACT

For larger areas in the Côte d'Ivoire and particularly in the Denguele's land, agriculture is the main source of income. Thus, the search for suitable sites for the valorization of this activity requires the collection and organization of data available. The aim of this study is to propose a model for the selection of suitable areas for rainfed rice growing using multicriteria evaluation and GIS. Multicriteria analysis were performed by the combination of Analytical Hierarchy Process (AHP). Five thematic maps were considered such as population density map, land use map, slope map, pluviometry map and soil map. Different classes were identified for each thematic map. Using AHP, a paired comparison matrix was prepared for criteria classes and individual class weights and map

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scores were worked out. These weights were applied in linear summation equation to obtain a unified weight map containing due weights of all input variables. Finally all the weighted maps were reclassified to arrive the best suitable areas for rainfed rice growing. Areas that are classified as very good and good occupy about 74.04% of the total area of the region and are located in the north and south. The interpretation of the results allowed to note the contributions and limitations of the methodology used.

1. INTRODUCTION

The increasing population is a challenge for developing countries. They have to use quality agriculture to meet the nutritional needs of this population. Thus, the need to achieve security and food self-sufficiency by covering the rice needs is a major focus of all policies for agricultural development. However, the hazardous choices of sites double by bad policy outreach have not caused the takeoff of rice production especially in an area where agriculture employs 87% of the workforce [1]. This is contributing to the development of rice in Côte d'Ivoire generally and particularly in the area of Denguele that this study was initiated. Indeed, it is important that all parameters involved in this type of development are taken into account for sustainable actual implications [2]. Also, to achieve self-sufficiency in agricultural production, land evaluation techniques should they be integrated in order to develop models for predicting suitability of land for different types of agriculture [3]. It seems desirable to use a multidisciplinary approach that allows us to offer a tool for decision support for the identification of agricultural land including rice-growing areas. There will be sought for this region, natural predispositions that characterize suitable sites for this crop [4]. To deal with it, multi-criteria evaluation models and GIS have been developed for the identification of suitable sites for this type of development. Generally, the analysis of the relevance of such tools is to identify the most appropriate spatial model for future land use based on specific requirements, preferences or expectations of a particular activity [5]. This leads into the world of systemic modeling, which, according to Thériault and Claramunt [6], is the best field of application of spatial analysis and geographic information systems (GIS). The integration of GIS and multi-criteria analysis is a privileged and indispensable way to evolve GIS into real systems decision support [7,8]. This approach has already been applied by several authors for choosing a suitable site [9-12]. The aim of this study is to propose a model for the selection of suitable areas for rainfed rice growing using multicriteria evaluation and GIS.

2. MATERIALS AND METHODS

2.1 Study Area

Denguele's area is located in north-western Côte d'Ivoire, between 7° and 8°15' W longitudes and 9° and 10°25' N latitudes (Fig. 1). It has a humid tropical climate with two main seasons: a long dry season from November to May and a big rainy season from June to October. The rainfall varies between 1400 and 1600 mm. The ground consists of ranges of hills that are a continuation of the Guinea dorsal. Elevations are those of a semi mountainous ground that often exceed an altitude of 800 m. The ground is largely covered by a very diverse savannah (woody, tree, shrub and grass). The hydrographic network is made up of two major rivers: Baoulé and Kouroukelé. The hydrographic regime is characterized by floods in August, September and October followed by a rapid depletion in November and December.

2.2 Materials

The material consists of data and software. The approach used in this study requires a compilation of cartographic data and satellite images provided by the Abidjan Center for Mapping and Remote Sensing (CCRS) and alphanumeric data on population and climate. The software ArcGIS 10 and Envi 4.3 have been used for data processing.

2.3 Methods of Elaboration of Suitability Areas

2.3.1 Multicriteria decision making

Multi-criteria decision is a field in which the applicability to daily situations and computing tools is very important. However, its integration into GIS has not been fully developed. Therefore, the method used in this work integrates

multicriteria evaluation into GIS as a supportive tool to build a spatial model that allows locating the most suitable areas for rainfed rice growing. To do so, the Analytic Hierarchy Process (AHP) by Saaty [13] was used. It consists in the development of the structure of a multi-criteria problem [14]. The AHP method calculates the required weights associated with the respective criterion map layers with the help of a preference matrix, in which all relevant criteria identified are compared against each other on the basis of preference factors. The weights can then be aggregated. For the classification of rainfed rice growing suitability within our case study area, we used the AHP's ability to incorporate different types of input data, and the pairwise comparison method for comparing two parameters simultaneously. The application of AHP process involves the following steps.

2.3.2 Selection of evaluation criteria

The set of criteria selected should adequately represent the decision-making environment and contribute towards the final goal. Rainfed rice growing suitability assessment is a multiple criteria evaluation process. Each evaluation criterion is represented by a separate map in which a 'degree of suitability' with respect to that particular criterion is ascribed to each unit of area [15]. Muticriteria method became one of the most useful methods for the analysis of land use and environmental planning, as well as the classification of agricultural land suitability [16-21]. In this study, five main criteria, namely: topography, soil types, density of population, rainfall and land use were selected based on the knowledge of local experts and have been classified in constraints or factors Table 1.
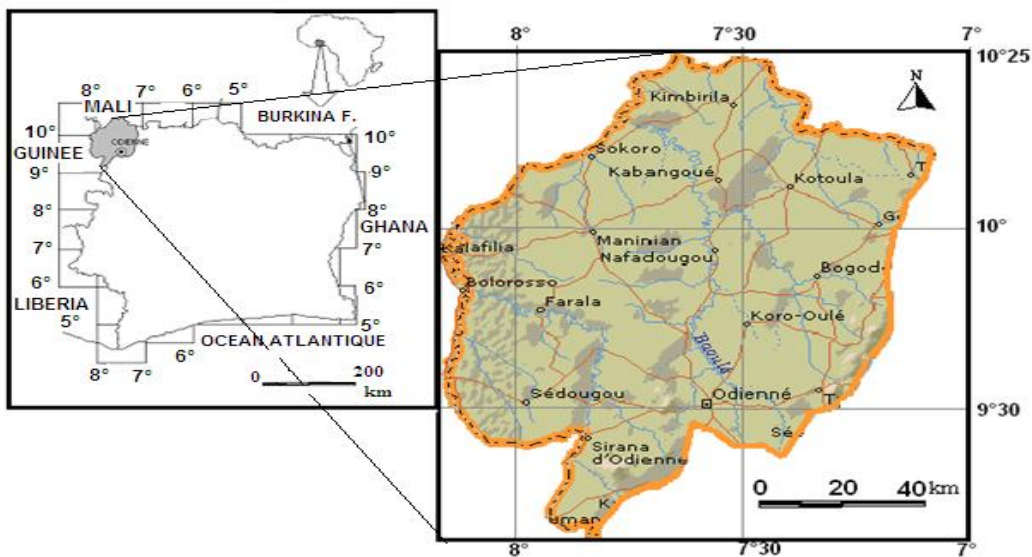

Fig. 1. Study area

Table 1. Table of criteria's categorization in constraints or factors

Parameters	Criterion type
Land use	« Constraints layer»; mask on built locations, uncultivable surfaces, the placeholders agglomerations, roads.
Pluviometry	« Factor layer »; aptitude defined according to the importance of annual rainfall. This factor will be strongly; moderately or weakly favorable.
Soil type	« Factor layer »; aptitude defined according to nature of the soil and also according to the culture system (rainfed).
Population density	« Factor layer »; aptitude defined according to the employable human resources in the fields. This factor will be strongly; moderately or weakly favorable.
Relief	« Factor layer »; aptitude defined according to the slope: strongly, medium or inappropriate.

Objective evaluation criteria and relevant are identified in relation to the search for suitable areas for rainfed rice growing. The criterion is the basic element of a decision. It is a factor or a constraint and can be measured or evaluated. The constraint is a Boolean test that limits our analysis to specific areas and therefore excludes plots declared unfit to culturing in rainfed rice. For each of the identified criteria, the procedure calculates a test map that measures for the criteria specified level of suitability or incapacity of space unit for growing rice. These 'degrees of suitability' then need to be rated according to the relative importance of the contribution made by that particular criterion, towards achieving the ultimate goal. This results in a series of maps which will be aggregated by weighted linear combination (WLC).

To obtain the models of maximum suitability, we followed a methodological process with the elements and processes that are presented in Fig. 2.

2.3.3 Data collection and preparation using GIS

Data preparation is the first fundamental step in rainfed rice growing suitability area analysis. Our methodology is based on GIS analysis. In which, suitability areas are evaluated by applying different GIS analytical techniques, including interpolation and overlay based on multi-criteria analysis and AHP. For this to happen, the following datasets were prepared:

- **Topographic map** 1/200 000 (Center for Mapping and Remote Sensing) is used to create DEM, and derivate layer such as slope. The relief is one of the first criteria determining the cultivation of rice. Rainfed rice should be growing in low slope.
- **Pluviometry data** (Society of Development and Aeroportuaire and Maritime Exploitation from 1994 to 2004) is used to create pluviometry layer. The availability of water resources is one of the most important parameters for rice farming. Rain water is required for vegetative growth of the plant in the system of upland rice.
- **Population data (**National Institute of Statistics) is used to create the population density layer. It is necessary to take into account human resource especially young

people which represent 87% of the working population. A high population density often indicates an abundance of labor needed for rice cultivation.

- **Pedology map** 1/200000 was extracted from the work of Eschenbrenner and Badarello [22] is used to derive soil layer. For rainfed system, soil must have good drainage and deep groundwater. These soils may also have different textures, structures as well as different physical and chemical properties. They must be deep, moderately deep or shallow. For the system of lowlands, soils are often poorly drained and constantly flooded. The texture of these soils can be sandy, silt and clay depending on the topography and nature of the original material. These soils are found in the valleys of the rivers. In this study, we limited ourselves only to the soil type.
- **Landsat TM image** (Center for Mapping and Remote Sensing) was used to derive land use layer through image classification techniques. The map of the land use is likely to inform any planning decision-making and to develop broad guidelines for regional development.

After these spatial datasets were prepared, including all necessary geometric and thematic editing of the original datasets, a topology was created. All vector layers were then converted into raster maps having the same "common measurement scale" and the spatial datasets were processed in ArcGIS and the spatial analyst tools were used in logically performing the WLC operation. Reclassification tool was used to convert the floating raster maps to integer raster maps and to set the common measurement scale. The fundamental principle of the analysis is the possibility of connecting information, based on knowledge, to make decisions or previsions; the knowledge can be taken from experience or derived from the application of other tools [23]. Each assessment results in a representative map for all elementary surfaces, their adequacy to the criterion considered [24]. The percentage influence of each raster layer (parameter map) was derived using the AHP procedures. Each input raster was weighted according to its percentage influence. They allow validation, management and processing, thematic and multithematic spatial analysis of georeferenced data [25].
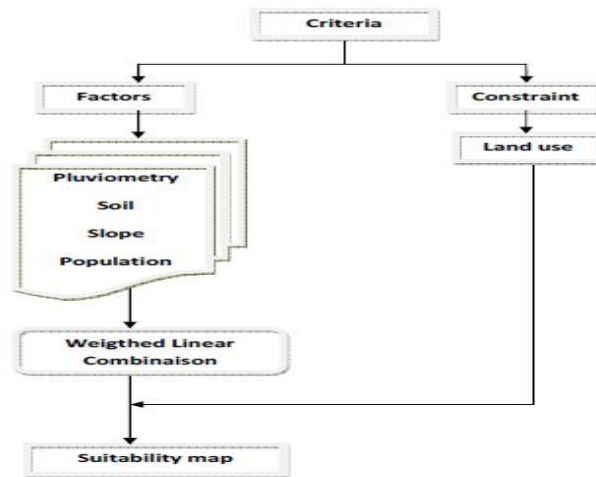
Fig. 2. Method to model the suitability area of rainfed rice growing

2.3.4 Standardization of factors

The process of setting the relative importance of each criterion is known as the standardization of criteria. Thus, from the perspective of being able to integrate several factors (qualitative and quantitative) in the model it should be make them comparable, in other words, to express the ability of different factors on a common scale. This study is based on the weighted linear combination (WLC) where the factors were standardized on a continuous scale of suitability from 0 (least suitable) to 10 (most suitable).Thus, for the criterion, slope, the assignment was made based on the assumption that a small slope would promote lowland rice and an average slope supports a rainfed rice growing. Soil type criterion was standardized taking into account that the lateritic and ferruginous soils are favorable for rainfed system and waterlogged soils are favorable for the lowland system. However, the maximum rainfall varies very few on the region (1600 mm). Thus, this criterion was standardized on a scale from 5 (for rainfall below 1600 mm per year) to 10 (for rainfed at least 1600 mm per year). The values of the population density occurred during this study were standardized in the range of 0-10 as they are high, medium or low favorable to rainfed rice system. Each evaluation leads to a representative map, for all elementary surfaces of the study area, their ability to grow rice according to the criterion considered.

2.3.5 Weighting of factors

Before the combination of different criteria, their weighting is necessary. It derives the weights by comparing the relative importance of the criteria

in a pairwise manner. Through a pairwise comparison matrix, the AHP calculates the weighting for each criterion by taking the Eigenvector corresponding to the largest Eigenvalue of the matrix, and then normalising the sum of the components to unity. In our study of the implementation of the pairwise comparison matrix, experts' opinions were asked to calculate the relative importance of the factors involved. Their importance is determined on a numerical scale of 9 levels (Table 2), and arranged in a comparison matrix by pairs for the best suitability area of rainfed rice growing. Different classes were identified for each criterion and these were arranged in decreasing order of weight. Using AHP a paired comparison matrix was prepared for Four criteria (exept land use) for the study area and individual class weights (rank) and map scores (weight) were worked out.

2.3.6 Aggregation of criteria

Once the weighting of evaluation criteria is made, it is easy to combine them and come to a decision on the optimal composite suitability for rainfed rice growing. This operation is called aggregation of criteria. The method by complete aggregation allows compensation between criteria. A low capacity factor for a given area can be compensated by another with a high degree of ability because the importance of each factor is determined by the weight that it assigns. The most common technique is the weighted average, which fully integrates all the criteria considered in one [26]. Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input data to create an integrated analysis [27]. It involves multiplying

each layer-factor by its weighting and then summing the results to produce a proficiency index on a scale of 0 to 10. Once the four deciding factors are evaluated, a weighted linear combination is performed after assigning to each decision factor a weighting coefficient. Indeed, in this study, different map layers characterising rainfed rice growing suitability have been weighted using the weights derived from the AHP process described in previous section. This approach has been used individually for the four factors of decisions to produce an index of suitability for rainfed rice growing. The weights were then combined with the attribute map layers in a manner similar to that used in the linear additive combination methods [28].

Table 2. Rating scale used in Saaty's (1977) AHP model

Weight	Definition
1	Same importance as
3	Moderately more important than
5	Strongly more important than
7	Very important that
9	Extremely more important than
1/3	Moderately less important than
1/5	Strongly less important than
1/7	Very less important than
1/9	Extremely less important than

3. RESULTS AND DISCUSSION

3.1 Thematic Layers Using AHP

Pairwise comparison matrix developed by AHP method explained in the previous section was applied in obtaining the relative weights of each criterion to find the best suitable site for rainfed rice growing in the study area is shown in Table 3.

The paired comparison matrix was prepared for each criterion using Saaty's nine point scale. All the criteria are not equally important; every criterion will contribute towards the suitability at different degrees. The relative degree of contribution of various can be addressed well when they are groups and organised at various hierarchies. Relative importance of the criteria parameters has been well evaluated to determine the suitability by multi-criteria evaluation techniques. Four thematic layers: population density map, slope map, soil map, pluviometry map and technology mentioned above were calculated for the purpose of the work.

3.2 Map of Suitability Area for Rainfed Rice Growing

Map of suitability area for rainfed rice growing was produced in taking into account constraints or land use map. This helps to eliminate the areas unsuitable for rice cultivation. Indeed, geomorphology is characterized by individualized relief materialized by mounts and hills with rigid or tabular summits little accents that emerge from these vast surfaces ironed out for granite bedrock or gneissic and are molded on the mountains unfit for rice cultivation.

Fig. 3 shows three classes ranging from very good to bad. Bad areas occupy 25.97% of the study area. By cons, areas classified very good and good are more representative. They are respectively 41.98% and 32, 06% of the total area of the study area, making a total of 74.04% and are localized to the north and south. The analysis of this map shows that favorable areas for rainfed rice are spread over the vast majority of the area. This is all the more remarkable because the region has enough plateaus that can be useful to agriculture. The proportion of cultivable land associated with low modeling, promote development of agricultural areas.

3.3 Validation of Suitability Map for Rainfed Rice Growing

A field mission of the mapped sites was performed. It appears that all sites mapped do not fully reflect the field reality. Some sites overlap with areas under construction. This overlay can be related to the age of the data and also at the accuracy of processing techniques of the data. Some less favorable sites are cultured because of the framing structures that are present in the region and also the company SODIRO helps farmers practice mechanized farming using tractors and chemical fertilizers. However, some sites are actually suitable cultured and this represents a rate of 60, 71% of good coincidence. In addition, other areas of culture do not also match the aptitude maps made and this represents a rate of 30.29% Fig. 4. Designated sites good and very good are those that can be exploited to allow for better rice production in the region. They are all located on the whole area. It means that the region has enormous potential for the cultivation of rainfed rice.

Table 3. Matrix of pairwise comparison indicating the weighting coefficient of the factors of aptitude for the rainfed rice growing

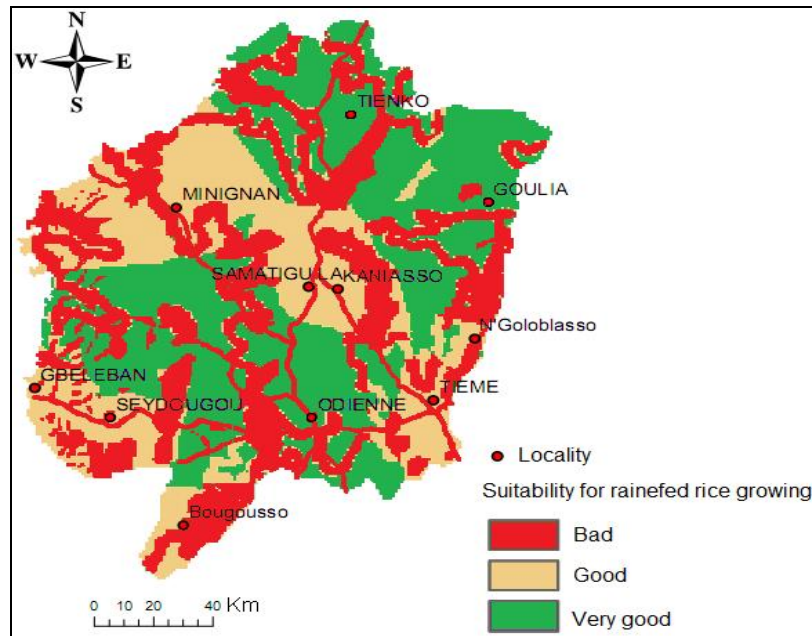| Class	Pluviometry	Slope	Population density	Soil type	Eigenvector	Weighting coefficient
Pluviometry	1	3	5	5	1 ,93	0,33
Slope	1/3	1	3	3	1,65	0,27
Population density	1/5	1/3	1	3	1,46	0,24
Soil type	1/5	1/3	1/3	1	0,96	0,16

Fig. 3. Map of suitability for rainfed rice growing
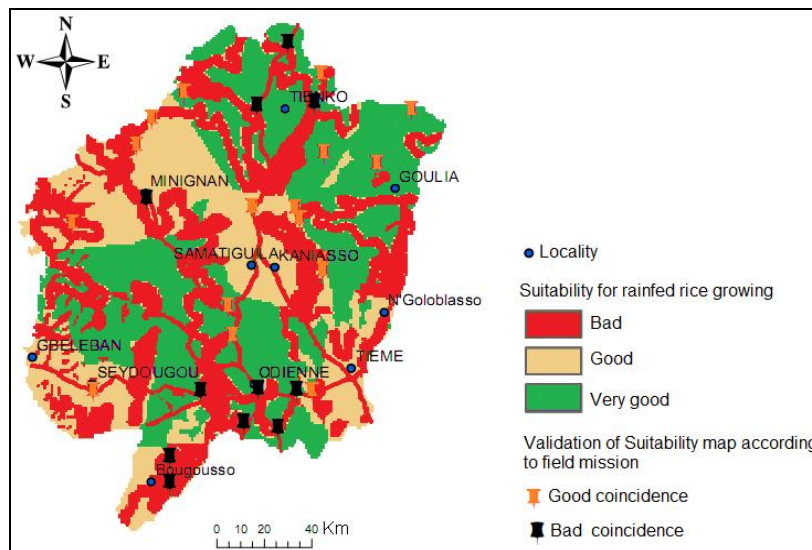

Fig. 4. Map of validation of rice cultivation

3.4 Discussion

Rainfed rice growing suitability has been extracted by weighted overlay techniques based on multicriteria decision making using GIS methods, a process that has resulted in information being portrayed on five thematic layers. Maps produced thus represent spatial variations in a given time. The procedures for spatial analysis based on criteria for the identification and selection of the location of a site has already been proven through various studies [29-33]. Consequently, the results are sound and their reliability depends on the precision of the data and information used. Difficulties were encountered in this study, however. One of the difficulties with this method is the choice of the factors class limits. It operates based on the one hand; the power of discrimination of the operator and his sense of judgment, on the other hand, the criteria values [34]. The class limits adopted are therefore not fixed, but depend on the field reality and targets. In this approach the estimation of some parameters is difficult. Thus, the estimation of soil types suitable is difficult because of the lack of metadata. Also, the data used on soil types are very general and they provide less information on the spatial and specific information related to the different soil types. One of the parameters, whose implementation was difficult, was even layer of the land use. Formations of small size might not have been taken into account in the analyze. This parameter can influence the results obtained in this study. The topographic data used to establish the slope map was generated with a scale of 1/200000 does not offer excellent accuracy. Moreover, the AHP method for weighting criteria, although relatively effective, is difficult. Another problem with this method concerns the choice of the rating scale from 1 to 9 with their mutual correspondence [35]. The choice of the score for a criterion is arbitrary and can influence the calculation of the weight of the criterion considered. However, the AHP method is appropriate in this study because it is effective when the number of actions is reduced [36]. The potential sites map for rainfed rice produced from this approach, however, can be a basic tool for prospecting sites for future projects of rice in the region. In all cases, GIS is and remains one of the best decision-making tools for the development of projects. Enhancing capabilities to optimize the evaluation of development projects in an integrated and structured framework is one of the elements needed to promote sustainable development [37].

4. CONCLUSION

Land suitability map for rainfed rice growing in Denguele were extracted using GIS-assisted multicriteria decision making analysis. These were then compared to a current rice cultivation of the case study area. Integration of GIS and AHP provides best decision tool in selecting appropriate rainfed rice growing area. Five criteria were selected such as land use, slope, population, soil and pluviometry. A paired comparison matrix was prepared for criteria class and individual class weights and map score were worked out. Finally a map of suitable area of rainfed rice growing was produced. The suitability map obtained is intended to guide development actors on the potential rice areas. They highlight three categories of area namely as bad, good and very good. Areas which Classified very good and good are very abundant and are found in the northern and southern part of the region. As for the so-called bad areas, they meet disparately on the entire region. The study revealed that 74.04% of plateaus can be used to develop rainfed rice growing. Some of these areas are already the subject of cultivation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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