

Short Research Article

Modeling of suitable areas for rainfed rice growing using multicriteria approach in geographic information system: Case of Denguele (North West of Côte d'Ivoire)

ABSTRACT

For large area in the Côte d'Ivoire and particularly in the Denguele's region, 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 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.

Keywords: *Rainfed rice growing, spatial analysis, multicriteria, Analytical Hierarchy Process, Denguele*

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 region 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. In general, 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. MATERIAL AND METHODS

2.1. Study Area

Denguele's region 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 terrain consists of ranges of hills that are a continuation of the Guinea dorsal. Elevations are those of a semi mountainous terrain 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.

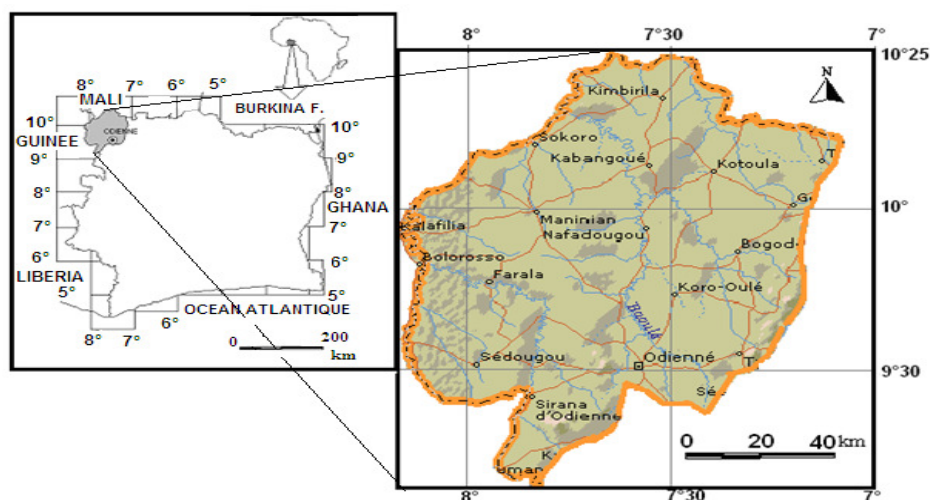


Fig. 1. Study area

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

2.3.1. Criterion Layering

Developing criteria is the fundamental first step in determining the skills rice from GIS that offer data acquisition in digital form functions. They allow validation, management, processing and thematic and multithematic spatial analysis of georeferenced data [13]. Five thematic layers were selected for determination of suitable areas for rainfed rice growing. They are: Land use, Population density, Soil, pluviometry and Slope. 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 (except land use) for the study area and individual class weights (rank) and map scores (weight) were worked out. These weights were applied in linear summation equation to obtain a unified weight map containing due weights of all input variables, which will be further reclassified to arrive a suitable area map. 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 [14]. In this study, the ability to rainfed rice is estimated using GIS techniques that take into account the interpolation and recovery, based on multi-criteria analysis. These criteria are evaluated using the spatial analysis capabilities of GIS raster. Each assessment results in a representative map for all elementary surfaces, their adequacy to the criterion considered [15].

Relief

The relief is one of the first criteria determining the cultivation of rice. Rainfed rice should be growing in low slope. A topographic map at 1/200 000 has allowed to digitize contour. The digital terrain model and the slope map of Denguele were produced by interpolation side points emerging contours.

Land use

The map of the land use is likely to inform any planning decision-making and to develop broad guidelines for regional development. Different layers of the land use (roads, water bodies, protected areas, undeveloped areas and habitats) and Landsat TM satellite images dating from the year 2000. A superposition of these different layers has achieved the map of land use of the region of Denguele.

Population

Demographic data from the National Institute of Statistics (NIS) were used to establish a map of population densities in the region. 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.

Pluviometry

The availability of water resources is one of the most important parameters for rice farming. The integration of this parameter was performed on the basis of the annual rainfall in the region over the period from 1994 to 2004. These data were provided by the Society of Development and Aeroportuaire and Maritime Exploitation (SDAPM). The rainfall amounts of rainfall stations were interpolated using the interpolation functions based on Thiessen polygons. Rain water is required for vegetative growth of the plant in the system of upland rice. This is not the case for the system of flooded rice cultivation.

Pedology

The soil map was extracted from morpho-pedological map resulting from the work of [16]. Rice cultivation is practiced in this region or the actual rainfed system or by the system shallows. 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.

2.3.2 Elaboration of Suitability Map

GIS and multicriteria proved to be relevant in the choice of selecting potential sites for rainfed rice growing. He 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 [17-22]. This multi-criteria evaluation involved the selection of assessment, standardization of criteria and weighting factors according to matrix Saaty criteria. All these steps are summarized in the flowchart in Figure 2.

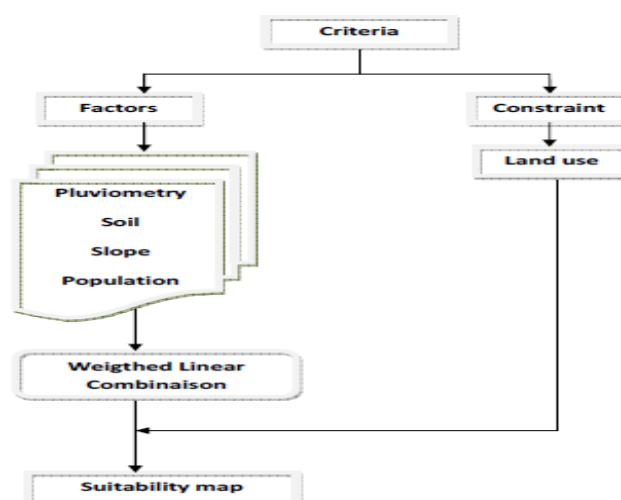


Fig.2. Method to model the suitability area of rainfed rice growing

2.3.2.1 Categorization of evaluation criteria

Objective evaluation criteria and relevant are identified in relation to the search for suitable areas for rainfed rice cultivation. 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 aptitude" shall be classified according to the relative importance of the contribution of this particular criterion, in order to achieve the ultimate goal. This results in a series of maps which will be aggregated by weighted linear combination. 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 factors or as defined in Table 1.

Table 1. Table of categorization of criteria 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 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.

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151 2.3.2.2 The standardization of the factors

152 The creative process of the relative importance of each criterion is known as the
 153 standardization of criteria [23]. Thus, from the perspective of being able to integrate several
 154 factors (qualitative and quantitative) in the model it should be make them comparable, in
 155 other words, to express the ability of different factors on a common scale. This study is
 156 based on the weighted linear combination (WLC) where the factors were standardized on a
 157 continuous scale of suitability from 0 (least likely) to 10 (most suitable). Thus, for the criterion,
 158 slope, the assignment was made based on the assumption that a small slope would promote
 159 lowland rice and an average slope supports a rainfed rice growing. Soil type was
 160 standardized criterion taking into account the presence soils which are lateritic soils and
 161 ferruginous soils for rainfed system and favorable for the system lowland waterlogged soils.
 162 However, the maximum rainfall varies very few have on the region. Thus, this test will be 10
 163 marks for polygons having collected at least 1600 mm of rain per year and the note 5 for
 164 rainfall below 1600mm / year. For the lowland rainfall system does not occur really. The
 165 values of the population density occurred during this study were standardized in the range of
 166 0-10 as they are high, medium or low conducive to rice farming system. Each evaluation and
 167 leads to a representative map for all elementary surfaces of the study area, their ability to
 168 grow rice according to the criterion considered.

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170 2.3.2.3 Weighting of the factors

171 Before the combination of different criteria, weighting of these is necessary. The method
 172 developed by Saaty [24] was used for this purpose. This is the method of pairwise
 173 comparisons or Analytical Hierarchy Process (AHP). It produces standardized weighting
 174 coefficients whose sum is equal to "1". The weight of the factors indicates their relative
 175 importance compared to all others. The weight of the factors are determined from a series of
 176 pairwise comparison of these criteria taking into account the relative importance of two
 177 criteria for suitability for rainfed rice cultivation. Their importance is determined on a
 178 numerical scale of 9 levels (Table 2), and arranged in a matrix of decision or a comparison
 179 matrix by pairs.

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

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Expression of a criterion relative to another	Weight
Same importance as	1
Moderately more important than	3
Strongly more important than	5
Very important that	7
Extremely more important than	9
Moderately less important than	1/3
Strongly less important than	1/5
Very less important than	1/7

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184 *2.3.2.4 Aggregation of the criteria*

185 Once the weighting of evaluation criteria is made, it is easy to combine them and come to a
186 decision on the optimal composite suitability for rice cultivation. This operation is called multi-
187 criteria evaluation or aggregation of criteria. The method by complete aggregation allows
188 compensation between criteria. A low capacity factor for a given area can be compensated
189 by another with a high degree of aptitude because the importance of each factor is
190 determined by the weight that it assigns. The most common technique is the weighted
191 average, which fully integrates all the criteria considered in one [25-26]. It involves
192 multiplying each layer-factor by its weighting and then summing the results to produce a
193 proficiency index on a scale of 0 to 10. This approach has been used individually for the four
194 factors of decisions to produce an index of suitability for rainfed rice. Once the four deciding
195 factors are evaluated, a weighted linear combination is performed after assigning to each
196 decision factor a weighting coefficient (Table 3).

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

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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

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212 **3. RESULTS AND DISCUSSION**

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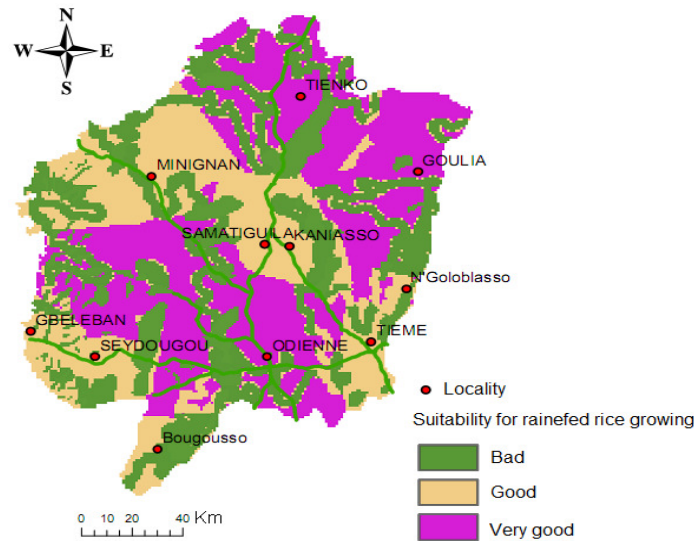
214 **3.1 Map of suitability area for rainfed rice growing**

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

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Figure 3 shows three classes ranging from very good at bad. Bad areas occupy 25.97% of the study area. By cons, zones 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 region. 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.



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Fig.3. Map of suitability for rainfed rice growing
3.2 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 entire region. This means that this region has enormous potential for the cultivation of rainfed rice.

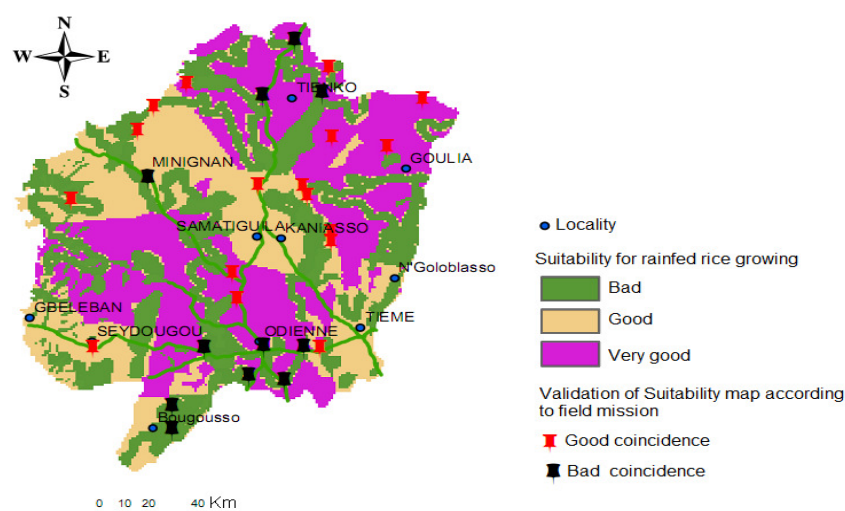


Fig. 4. Map of validation of rice cultivation

3.3 Discussion

Mapping areas suitable for rainfed rice in the region of Denguele was performed by the joint use of GIS and multi-criteria analysis methods. The production of maps of the different factors is based on spatial analysis; therefore they have a relative assessment of different criteria. 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 [27-31]. 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 [32]. 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. The consequences of these inaccuracies of the results of this study are that land that could have been identified as unfavorable soil to a given system did not been and vice versa. 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 [33]. 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 [34]. 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 [35].

4. CONCLUSION

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 aptitude maps obtained are intended to guide development actors on the potential rice areas. They highlight three categories of area: 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. Some of these areas are already the subject of cultivation.

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