Geographic Information Systems (GIS) as a Decision Support Tool for Land Suitability Assessment for Rice Production in Ghana

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Abstract

A land suitability analysis based on the Food and Agriculture Organization/International Institute for Applied Systems Analysis/Agro-Ecological Zone (FAO/IIASA/AEZ) methodology was adopted and modified to suit the environmental conditions of Ghana for the purpose of rice production. The methodology utilizes a Geographical Information System (GIS) approach for establishing a spatial inventory of land resource database to assess potential areas suitable for sustainable rice production. A spatial representation of the results of the thematic suitability assessment for the three cultivars of rice show that the percent of land area very suitable for rice production doubles from medium matured variety to early matured variety, and from early matured variety to very early matured variety. For suitable areas, and for the same sequence as just described, the percent of land area increases by 50%. However, for moderately suitable areas, the percent of land suitable for the crops ranges from 18~23% with very early matured rice variety having the highest percent of area. Areas potentially suitable for cultivation of rice in Ghana range from 26~48% of the total land mass (approx.5~11 million ha) depending on the type of rice cultivars. Whilst the early matured variety can be grown in ecological zones where the LGP is greater than 150days, the medium matured variety should be concentrated in ecological zones with LGP greater than 210 days. Emphasis on rice production should be to target a higher yield per hectare. Farmers should, therefore, be introduced to high yielding and disease resistant varieties to improve upon their yield.

Introduction

Rice production in Ghana is limited to inland valleys which form about 12% of the total land area (Otoo *et al.*, 1995). However, in other countries in the sub-region such as Ivory Coast, rice cultivation is on both lowlands and upland areas, provided the rainfall in the upland areas is adequate to support its growth.

Rice is now an important staple food for many Ghanaians. Its consumption increased from 11.5~26.7 kg/person/year between 1980 and 1995 (FAO, 2000). Areas under rice cultivation also increased steadily from 30.5 ha in 1966 to about 79 ha in 1975 (PPMED, 1976). From 1997 to 2000 about 100,000 ha of land out of which only 0.2% was under irrigation were put under rice cultivation each year (PPMED, 2001). Between 1966 and1975 the average yield was about 1 metric ton per hectare. This has doubled to 2 metric tons/ha after 1975. However, on irrigated plots yields are between 3 and 4.8 metric tons/ha.

It is important that policy makers, researchers and agro investors are aware of areas which have potential to support rice cultivation in the country so as to form the basis for any decision on rice policy. The objective of this study were 1. to use the FAO/IIASA/AEZ methodology in a computer assisted programme (Arc Info GIS) to establish areas which have potentials to support rice cultivation in Ghana under rainfed conditions; 2. to determine the extent and geographic positions of Ghana that will be suitable for three cultivars of rice; 3. to serve as an input into priority-settings for rice research and production.

Materials and methods

Rice, like any other crop, requires a specific range of agro-edaphic and agro-climatic conditions for its growth and production. Soil and landscape characteristics such as texture, drainage, depth to impenetrable layer, *p*H, salinity, and slope are some of the agro-edaphic factors to consider in determining potential areas suitable for rice production. Agro-climatic factors include the length of growing period (LGP) (rainfed rice production), temperature during the growing period, sunshine duration and relative humidity at the ripening stage of the crop.

Before effecting a land suitability assessment, crop specific agro-climatic and agro-edaphic suitability classifications are required separately. This implies that the various agro-climatic and agro-edaphic levels should be rated separately for the crop under consideration.

Several systems of land suitability assessment have been developed. Thus, an increasing number of computer-based systems for land resource appraisal using various approaches (empirical, deterministic, heuristic) and different analytical tools (non-geographical, tabular, geographic and integrated geographical information system) has emerged.

Most notably at international levels is the FAO framework for land evaluation (FAO, 1976). The framework has since been amplified with the publication of guidelines for land evaluation. Several kinds of land uses (FAO, 1983, 1984, 1985; FAO/IIASA, 1991; Siderius, 1984, 1986), and a number of specific methodologies have been proposed (Biot *et al*., 1984; FAO, 1984; Davidson *et al*., 1994; Sys *et al*., 1993, Tang & Van Ranst, 1992; Tang *et al*., 1991; Van Ranst *et al*., 1996; Hall *et al*., 1992).

The LGP, thermal and slope ratings used for this study were based on the AEZ-Kenya studies (FAO, 1993), but were modified to suit the climatic and soil conditions of Ghana.

Land suitability analysis

The land suitability analysis was based on the FAO/IIASA/AEZ methodology which was developed for Africa and applied in Kenya (FAO, 1993). This model was modified to suit the environmental conditions and other land resources data that were available in Ghana. For example, whereas the thermal zone map of Kenya was based on mean daily temperature and was represented by seven thermal classes, i.e. from < 5 °C to > 25 °C, Ghana's thermal zone map was based on number of days in a year when maximum temperature exceeded 35 °C, since it has been established that maximum photosynthesis rate declines after 35 °C for most crops. This modification was necessary because unlike Kenya, mean daily and monthly temperature variations in Ghana are very minimal and, therefore, not significant.

The methodology comprises an environmental approach, and uses a geographical technique for establishing a spatial inventory and database on land resource for assessing sustainable crop production potentials (Fig.1). Three rice varieties of very early (<100 days), early (100-120 days) and medium (120-140 days)

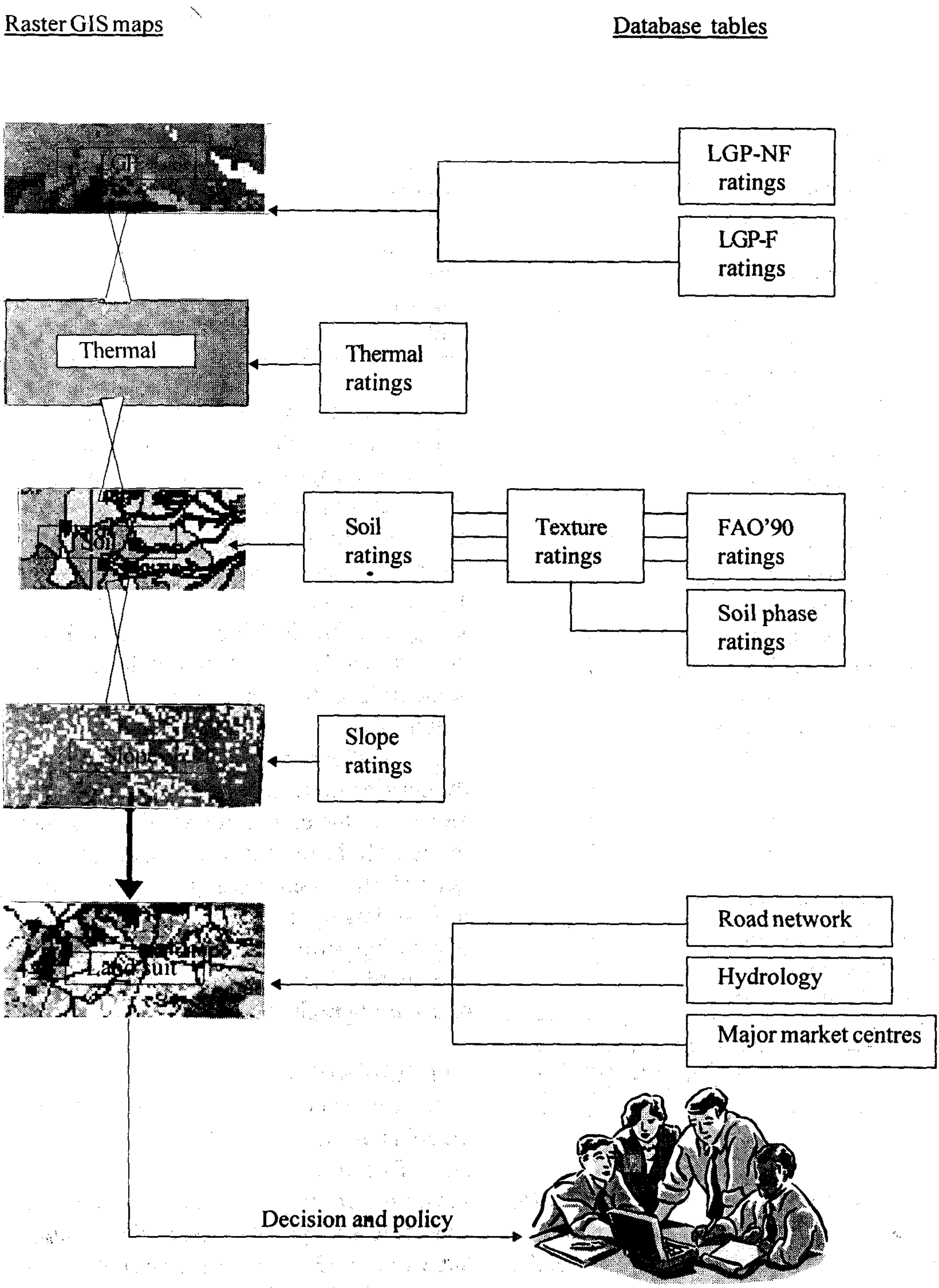

Fig. 1. Database design of land suitability model for rice production

TABLE 1a

Soil ratings for rice

FAO unit	*Ratings*
Ferric Acrisols- Acf	6
Gleyic Acrisols - ACg	3
Haplic Acrisols – ACh	2
Gleyic Alisols – ALg	3
Cambic Arenosols- ARo	4
Haplic Arenosols – ARh	4
Ferralic Arenosols – ARb	3
Chromic Cambisols – CMc	1
Vertic Cambisols – CMv	1
Gleyic Cambisols – CMg	2
Dystric Fluvisols – FLd	1
Eutric Fluvisols – FLe	3
Dystric Gleysols – GLd	1
Eutric Gleysols – Gle	4
Dystric Plinthosols – LPd	4
Eutric Plinthosols – Lpe	4
Lithic Leptosols - LPq	4
Haplic Luvisols – LVh	1
Ferric Luvisols – LVf	6
Chromic Luvisols – LVx	1
Haplic Lixisols – LXh	1
Ferric Lixisols – LXf	3
Plinthic Lixisols – LXp	6
Gleyic Lixisols – LXg	1
Rhodic Nitisols – NTr	1
Eutric Vertisols - VRe	3
Calcic Vertisols – VRk	2
Gleyic Ferralsols - FRg	3
Haplic Ferralsols - FRh	

1= S1(optimal conditions; 2 = S2 (sub-optimal conditions) 3 = S1/S2 (50% optimal, 50% sub-optimal); 4= N(unsuitable); 5 = S1/N (50% optimal, 50% unsuitable); 6 = S2/N (50% sub-optimal, 50% unsuitable)

TABLE 1b

Soil phase rating

Phase	*Ratings*
Duripan	3
Fragipan	3
Lithic	4
Petroferric	2
Rudic	2
Skeletic	3
Salic	4

matured growth cycles were selected for the suitability assessment. The first step involved the selection and definition of the crop's agro-climatic and agro-edaphic requirements which were presented on a spreadsheet as 'look-up' tables. These tables show the suitability ratings of the agro-climatic and agro-edaphic charac-teristics. The next step was to 'match' these requirements with geo-referenced climate, soil and terrain layers. All the land resources layers were converted from vector to raster using the GRID facilities in Arc/Info. Pixel size varied for the different layers was standardized to 1 km^2 for analysis and output grid.

A set of Arc/Info macros (AML) was designed to implement the logic and essential element of the FAO/IIASA/AEZ modified model. Model execution consisted of three general phases characterised by data type in the following sequence, 1. climate (length of growing periods, thermal zones), 2. soils (FAO soil unit, soil phase, top soil texture), and 3. topography (terrain slope).

Soil information

A driving variable in the land suitability model is the soil type. The FAO 1990 soil classification system was chosen as standard for judging overall suitability. Available soil profile descriptions were, therefore, used to convert the existing soil series to FAO 1990 soil units. In addition, the soil units were assigned moisture storage capacities within the root zone – referred to as the total available water capacity (TAWC). TAWC was derived by following the approach developed by FAO (FAO, 1992). The amount of stored soil moisture that has been assumed as being available to crops has been limited to a maximum of 150 mm for soils other than Arenosols and Vertisols and a minimum of 15 mm for Leptosols. Where soils were characterized with phases such as duripan, skeletic, rudic or saline, the TAWC was halved.

Soil suitability ratings

General soil suitability assessment for each soil association was determined by the dominant soil and up to a maximum of two associated soils where applicable, using a simple statistical weighting (Table 2). The soil phases considered were those that hinder mechanical cultivation, effective soil depth limitation or physico-chemical limitation. The limitations imposed by the presence of lithic, petroferric, rudic, skeletic and salic phases were considered and rated similarly as soil units by crop and level of input.

Another important feature of the soil that was taken into consideration was the topsoil texture. Where the soil texture was coarse and the FAO soil unit designation is not intrinsically coarse textured, the potential yield categories were down-graded one step. The textures considered coarse include fine sand, loamy sand, coarse sand and unsorted sand. The suitability ratings were defined as 1 = S1, 2 = S2, 3 =S1/ S2, 4 = N, 5= S1/N and 6 = S2/N.

A rating of S1 implies that conditions are optimal, whilst S2 indicates sub-optimal conditions. Rating of N means conditions are unsuitable and all land area for a given pixel would be allocated to the unsuitable potential yield category. The other three classes represent intermediate classes and result in fractional degradation of potential yield categories. For S1/S2, 50% of the existing land areas are allocated to S1 and 50% to S2. S1/N down-grades 50% of the land areas as not suitable. Finally S2/N requires that 50% of the land area is allocated to S2 and 50% down-graded as not suitable.

TABLE 2

Statistical weightings for dominant and associated soils for map polygons

No. soil types	*Statistical weighting (non-leptosols)*	*Statistical weighting (leptosols)*
1	Soil 1*1.0	Soil 1*1.0
2	(Soil 1* 0.7)+(Soil 2 * 0.3)	(Soil 1* 0.5)+(Soil 2 * 0.5)
3	(Soil 1* 0.6)+(Soil 2 * 0.2) +(Soil 3 * 0.2)	(Soil 1* 0.34)+(Soil 2 * 0.33) + (Soil 3 * 0.33)

Leptosols are soils with depth < or = 30 cm to impenetrable layer.

Climate data

A 30-year period (1961-1990) climate data consisting of rainfall, temperature and evapotranspiration were proccessed to obtain the length of growing periods (LGP) and thermal zones maps.

LGP ratings

LGP rating 'look-up' tables for the model are shown in Tables 3a and 3b. The numbers in the Tables 3a and 3b refer to ratings used to partition land area into one of five potential

TABLE 3a

LGP-NF rating for rice

LGP class	*LGP-NF (days)*	*<100 days variety*	*100-120 days variety*	*120-140 days variety*
5	90-119	4	5-4	5
6	120-149	4-3	5-4	5
7	150-179	3-2	4-3	5-4
8	180-209	1-2	3-2	4-3
9	210-239	1	1-2	3-2
10	240-269	1	1	1-2
11	270-299	1	1	1
12	300-329	1	1	1
13	330-364	1	1	1
14	365	1	1	1

TABLE 3b

LGP-F (Hydromorphic) rating for rice

LGP class	*LGP-NF (days)*	*<100 days variety*	*100-120 days variety*	*120-140 days variety*
5	90-119	4-3	4	5-4
6	120-149	3-2	4-3	4
7	150-179	2-1	3-2	4-3
8	180-209	1	2-1	3-2
9	210-239	1	1	2-1
10	240-269	1	1	1
11	270-299	1	1	1
12	300-329	1	1	1
13	330-364	1	1	1
14	365	1	1	1

1 = very suitable, 2 = suitable, 3 = moderately suitable, 4 = marginally suitable, 5 = unsuitable, 1-2 = 50% very suitable and 50% suitable; 3-2 = 50% moderately suitable and 50% suitable; 4-3 = 50% marginally suitable and 50% moderately suitable; 5-4 = 50% unsuitable and 50% marginally suitable. LGP-NF– length of growing period for areas not covered by Fluvisols and Gleysols; LGP-F — length of growing period for areas covered by Fluvisols and Gleysols on < 2% slope.

yield categories. Each single digit number corresponds to a potential yield category: 1 = very suitable (VS), 2 = suitable (S), 3 = moderately suitable (MD), 4 = marginally suitable (mS) and 5 = unsuitable (NS). Hyphenated double-digit numbers indicate an equal partitioning of land area between two of the potential yield categories.

Thermal zone

Many tropical crops are sensitive to high maximum temperatures and associated high evapo-transpiration demands. On this basis, thermal classes were defined representing different frequencies of occurrences of high maximum temperatures. The average annual occurrence of maximum temperatures above 35 °C (Table 4) was calculated from historical daily maximum temperature for 54 meteorological stations.

Thermal zone ratings

From the FAO-AEZ methodology (Kassam *et al.*, 1977), crops are classified into climatic adaptability groups according to their distinct response to photosynthesis. Based on this photosynthetic response to temperature and light an agro-climatic rating table for each thermal zone was constructed. The thermal zone ratings (Table 5) were defined and interpreted in the same manner as the soil suitability ratings.

Landform information

The most important landform information is the slope. In order to get this information, a digital elevation model (DEM) was

TABLE 4

Thermal zone interpretation

Thermal zones (class)	*Annual frequency of occurrence Tmax > 35 °C*	*Temperature characteristics*
1	< 5 days	No hot season
2	5-29 days	Short hot season
3	30-89 days	Moderately hot season
4	90-150 days	Long hot season
5	> 150 days	Very long hot season

TABLE 5

Thermal zone ratings for rice

Thermal zone class	*Days T max >35°C*	*Ratings*
1	0-5	1
	5-29	1
3	30-89	1
4	90-150	1
5	> 150	3

1 = S1(optimal conditions; 2 = S2 (sub-optimal conditions); 3 = S1/S2 (50% optimal, 50% sub-optimal); 4 = N(Unsuitable); 5 = S1/N (50% optimal, 50% Unsuitable); 6 = S2/N (50% sub-optimal, 50% unsuitable)

TABLE 6

Slope rating for rice

Slope class (%)	*Ratings*
0-2	1
2-4	3
4-8	2
8-16	5
16-30	4
30-45	4
>45	4

1 = S1(optimal conditions; 2 = S2 (sub-optimal conditions); 3 = S1/S2 (50% optimal, 50% sub-optimal); 4 = N (unsuitable); 5 = S1/N (50% optimal, 50% unsuitable); 6 = S2/N (50% sub-optimal, 50% unsuitable)

constructed from 1:50,000 digital contour maps of 15.24 cm vertical intervals.

The Arc/Info program HILLSLOPE was used to generate a surface gradient map (percent slope) with 60.96 cm pixels. The slope map was re-sampled to a pixel size of 243.84 cm. Finally raw slope measurements were 'sliced' into seven categories as follows: 0-2% - flat; 2-4% - gently sloping; 4-8% - undulating; 8-16% - rolling; 16-30 % - hilly; 30-45% - steep; and > 45% - very steep. The terrain slope suitability rating classes for rice (Table 6) was defined on the same sequence as LGP ratings.

Results and discussion

Data processing was implemented using pixel-based spatial analysis operations on the geo-referenced map layers. All map processing was implemented by GRID analytical operations using pixel–wise Boolean logic and relational database linkages. Linked database tables were accessed for analysis during processing of the pixels of each layer. Fig. 1 shows a flow diagram of the database designed to run the land suitability model.

The first analytical operation performed during the execution of the model was the assessment of length of growing period using the LGP map. During LGP suitability analysis, the soils were grouped into fluvic (hydromorphic) and non-fluvic soils. Subsequently, operations to assess land suitability based on thermal zones, soils and slope maps were performed in succession. The suitability ratings at each level were carried over to the next level of analytical operation.

During the next level of analytical operation, existing suitability ratings were down-graded where significant constraint to crop growth occurred, or, otherwise, maintained where optimal growing conditions occurred. The operations generated a map showing the percentage share for each of the five potential yield classes in every raster which covers 1 km^2. The five potential yield categories generated were as follows: Very suitable (VS) – optimal condition with slight or no limitations; Suitable (S) – slight limitations; Moderately suitable (MD) – indicates moderate limitations; Marginally suitable (mS) – indicates severe limitations; Unsuitable (NS) – indicates very severe limitations.

The five final potential yield classes in each pixel were then combined to produce a composite land suitability grid using a suitability index (SI) equation.

$$SI = [\{(VS*0.9) + (S*0.7) + (MD*0.5) + (mS*0.3) + (NS*0.1)\} - 10]/80*100$$

Index values generated by this equation range from 1(least suitable) to 100 (most suitable), and are interpreted in five suitability classes as: Very suitable > 80; Suitable 60-80; Moderately suitable 40-60; Marginally suitable 20-40; Not suitable < 20

After thematic suitability assessment was completed, a pixel may have the following ratings: VS = 0%; S = 20%; MD = 60%; MR = 0%; NS = 20%. This implies that within a pixel of 1 km^2, 20% of the area is suitable, another 20% not suitable and the remaining 60% is moderately suitable.

A composite suitability index of a pixel of 1 km^2 from the above results will be as follows:

$$SI = [\{ 0*0.9) + (20*0.7) + (60*0.5) + ((0*0.03) + (20*0.1)\} - 10]/80*100;$$

$$SI = 45.$$

This implies a moderately suitable result for that pixel. The extent of land classified as potentially suitable for the production of the crops countrywide are aggregated from the suitability profiles of the individual grid cells, which gave results from very suitable to moderately suitable areas.

A spatial representation of the results of the thematic suitability assessment for the three cultivars of rice (Fig. 2, 3, and 4, and Table 7) show that the percent of land area very suitable for rice production doubles from medium matured variety to early matured variety, and from early matured variety to very early matured variety. For suitable areas and for the same sequence as just described, the percent of land area increases by 50%. However, for moderately suitable areas, the percent of land suitable ranges from 18~23% with very early matured rice variety having highest percent area. Summing up the various suitability classes indicates that 48% of total land surface of Ghana has the potential to support the growth of very early matured rice variety whilst 26% of the same area has the potential to support medium matured rice variety.

Conclusion

The method of using computerised geo-reference data is faster, and gives more accurate results provided the database is accurate. The accuracy of a land suitability

Fig 2. Potentially suitable areas for rainfed, very early matured rice variety (<100 days growth cycle)

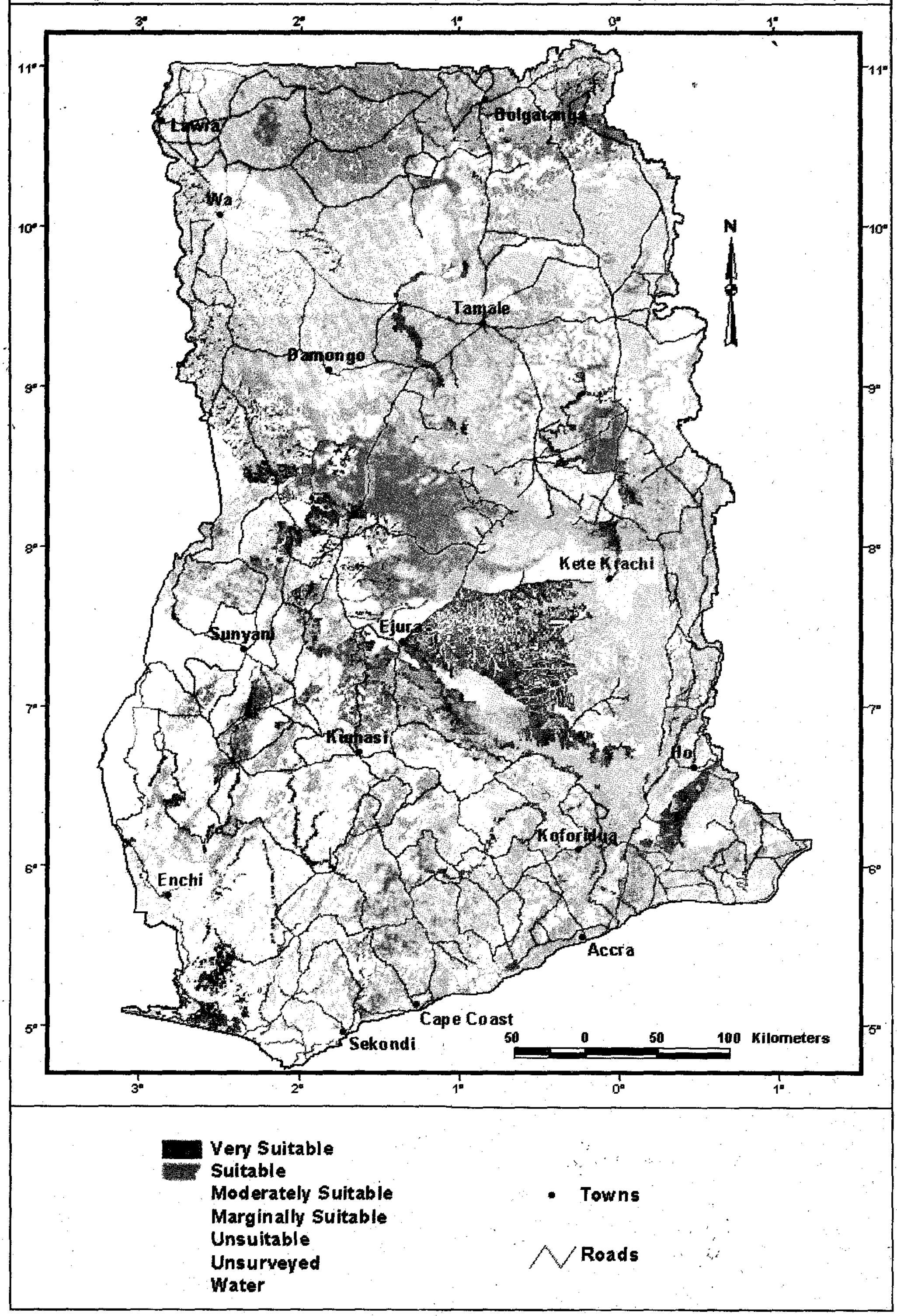

Fig 3. Potentially suitable areas for rainfed, early matured rice variety (100 - 120 days growth cycle)

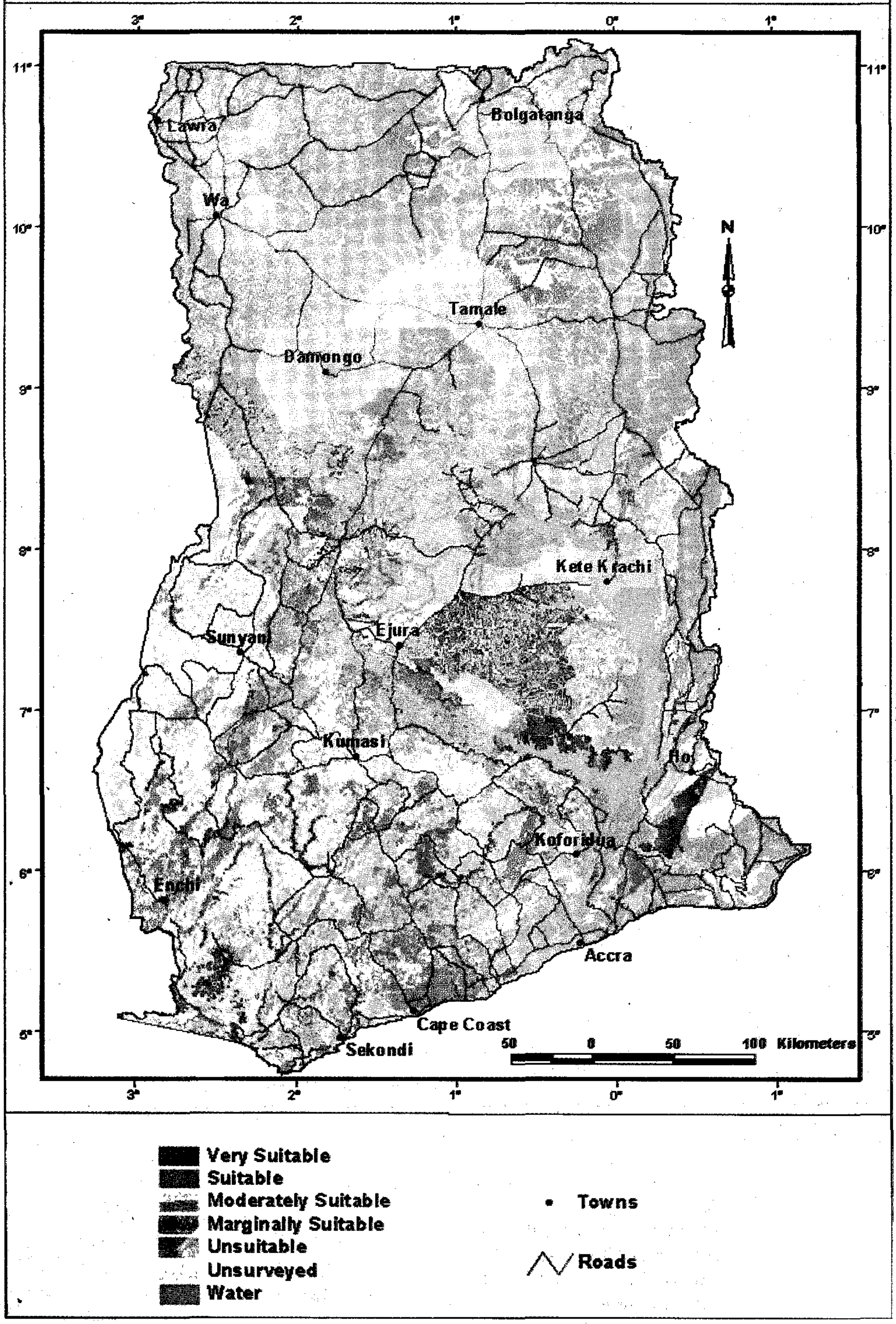

Fig 4. Potentially suitable areas for rainfed, medium matured rice variety (120 - 140 days growth cycle)

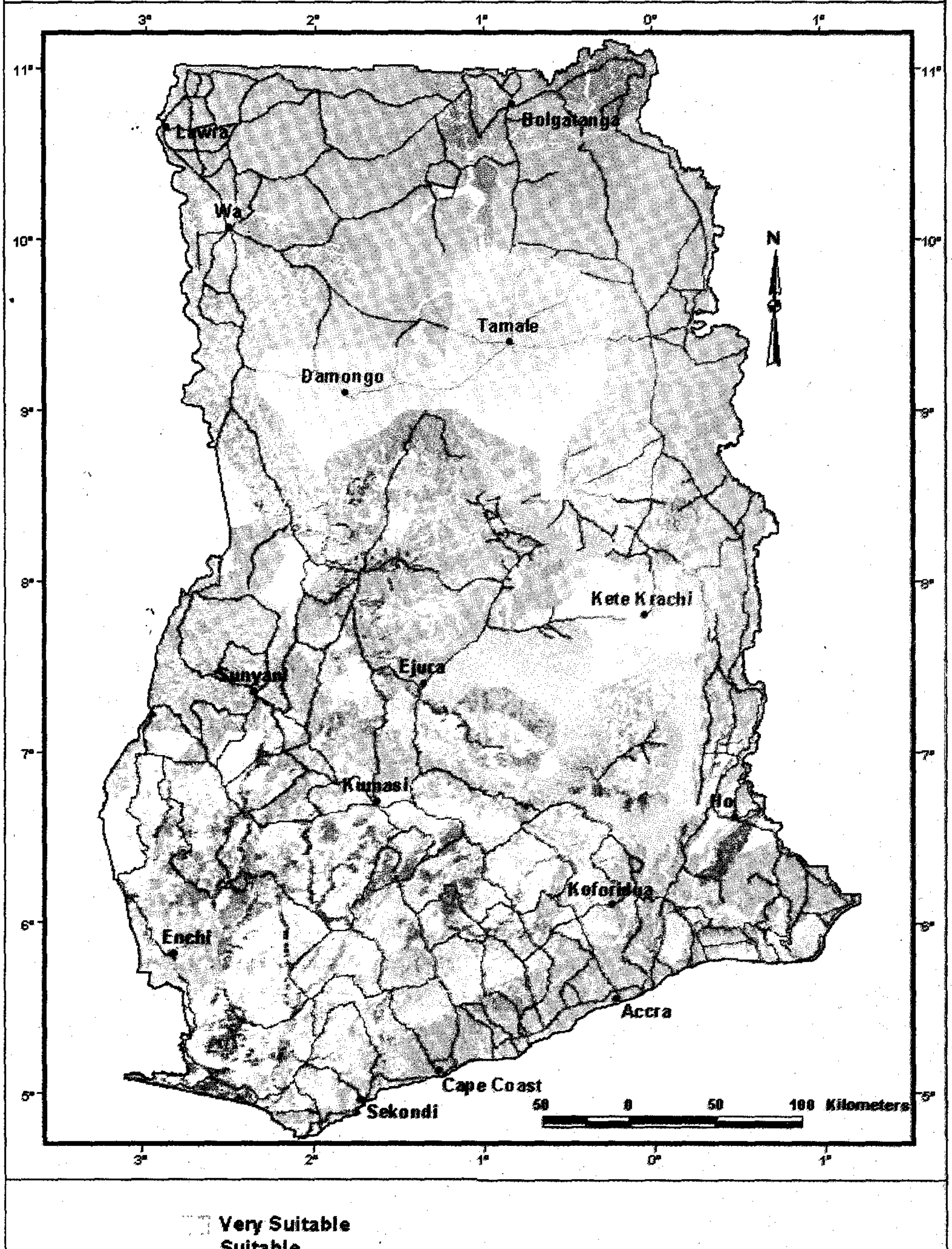

TABLE 7

Comparison of the extent of land variously suitable for the production of the three cultivars of rice

Rice Variety	Very suitable (%)	Suitable(%)	Moderately suitable(%)	Marginally suitable(%)	Not suitable (%)	Potential suitable (%)
<100 days	9.2	15.4	23.3	26.5	25.5	47.9
100-120 days	4.6	10.2	21.7	26.0	37.5	36.5
120-140 days	2.1	5.3	18.1	21.1	53.4	25.5

Potentially suitable represents the sum of very suitable, suitable and moderately suitable areas.
Not suitable areas include 9,339 km^2water bodies and 5,624 km^2 unsurveyed areas.

assessment depends on reliable and accurate climate and soil data, as well as expert knowledge in interpreting the data. It will be an uphill task, if not impossible, to perform this land suitability assessment based on 1 km^2 grid for the whole country using the conventional parametric approach and the same data sets. However, with the computer and the GIS software, the period to achieve results when the datasets are available is drastically reduced. In these studies the land suitability assessment was based on intermediate level of input under rainfed conditions. The length of growing period was, therefore, very critical in determining the potential suitability of the crops.

The results have shown that areas potentially suitable for cultivation of rice in Ghana range from 26~48% of the total land mass (approx.5~11 million ha) depending on the type of rice cultivars. Whilst the early matured variety can be grown in ecological zones where the LGP is greater than or equal to 150 days, the medium matured variety should be concentrated in ecological zones with LGP greater than 210 days. It should be noted that these same areas which has been found to be potentially suitable for rice production could also be suitable for production of other crops such as sugarcane, vegetables and maize. Therefore, emphasis on rice production should be to target a higher yield per hectare. Farmers should, therefore, be introduced to high yielding and disease resistant varieties to improve upon their yield.

By introducing growth and production requirements, the model can be used to establish areas that are potentially suitable for the production of any other crops. Other climatic layers like relative humidity could be added to the model when considering certain crops whose growth and production is very sensitive to this climatic parameter. The model can also be applied directly or modified, if necessary, to determine suitable areas of any crops in the West African sub-region once the land resources datasets are generated. The results obtained from a land suitability assessment could be use to take policy decisions and research priority settings which could promote a sound and sustainable land use planning.

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