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MODELING INLAND VALLEY SUITABILITY FOR RICE CULTIVATION

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ABSTRACT

The demand for rice (*Oryza sativa*) in Ghana is increasing at a rate of 11.8% from 939, 920 t in 2010. Though there has been some increase in production it does not match the increase in consumption. This study seeks to determine the most suitable areas for inland valley rice cultivation using computer based models for selected sites (15km by 15km) in the Brong Ahafo Region (BAR) and Western Region (WR) of Ghana. A sensitivity analysis was carried out by excluding the least contributing parameters and varying their weights to determine highly suitable areas. Finally, 12 most sensitive input parameters were identified from the original 22. These were used to model for five suitability classes (highly suitable, suitable, moderately suitable, marginally suitable and not suitable). The model results based on parameters having equal weights showed that 0.5% and 11.8% (BAR); and 1.4% and 21.4% (WR) of the area were highly suitable and suitable and suitable, respectively. Using unequal weights, 0.8% and 7.6% (BAR); and 0.9% and 13.6% (WR) of the area were highly suitable and suitable and suitable, respectively. The study successfully mapped out suitable areas for rice cultivation using spatial models based on limited data set, which can be adopted for use elsewhere.

Keywords: rice, inland valley, sensitivity analysis, suitable sites, model.

1. INTRODUCTION

Rice has in recent years become an important source of food in Sub-Saharan Africa (SSA). It has been noted to be the most rapidly growing source of food (preferred staple) in SSA during the last decade (Sohl, 2005). This trend has drastically increased consumption of the commodity in the region. As a response to the rising demand, there's been an increase in production. For instance, production in West Africa, which remains the hub of rice production in SSA, has more than doubled in the past 20 years, rising from 2.76 million tonnes in 1985 to 5.75 in 2005 (Africa Rice Center, 2007). Production for the whole of Africa was in excess of 20 million tonnes for the first time in 2006 while the annual rate of increase is expected to hit 7% in the future (Somado et al., 2005). Despite these increases, there still remains a productionconsumption gap. For example, between 2001 and 2005, the annual average consumption rate in West Africa was 6.55% compared to a corresponding production growth rate of about 4.5% (Africa Rice Center, 2007).

Reasons for the shortfall in rice production across SSA have been discussed in the literature (FAO, 1986; Somado et al., 2005). Prominent among these are: prevalence of small-scale subsistence farms, low level of mechanization, poor irrigation infrastructure, low yielding varieties, unreliable rainfall and predominance of farms on uplands. According to Lancon and Erenstein (2002), out of the 5 rice ecologies in West Africa, rainfed upland areas alone constitute 44%. In Ghana and Cote d'Ivoire, this figure is as high as 70% and 79%, respectively. However, problems such as droughts, erosion, weeds and termites, which are associated with upland cultivation, often lead to poor yields. Unlike upland areas which experiences water scarcity for most of the year (Thenkabail and Nolte, 2000), inland valleys have a favorable hydrological condition that ensure that water is at, or near, the surface for most of the year.

Inland valleys are defined as the upper reaches of river systems in which river alluvial sedimentation processes are absent or imminent only (Windmeijer and Andriesse, 1993). They occur abundantly in the West African landscape, constituting an estimated 8-28% of the total land area in the sub-region (Thenkabail et al., 2000). They have a high potential for rice development due to a number of reasons including: (1) easy access to river water, (2) high soil fertility relative to uplands, (3) soil moisture availability during dry seasons, (4) high water availability in wet seasons relative to uplands, and (5) availability of groundwater through lateral inflow from higher parts of the landscape. Inland valley lowland rice cultivation greatly contributed to the success of the green revolution in east and south-east Asia. It is believed that intensifying inland valley lowland rice cultivation in West Africa is capable of improving the production volumes of rice to help bridge the consumption-production gap (Fashola et al., 2007).

Identification of the most suitable inland valleys for rice cultivation is an important first step in promoting inland valley low land rice cultivation in West Africa. Suitability analysis involving the most critical factors in rice cultivation can lead to the selection of optimal areas within available inland valleys for rice cultivation and subsequent good yields. In this regard, Gumma et al. (2009) conducted suitability analysis to determine best areas for rice cultivation in the inland valley wetlands of Ghana. The study was conducted at local scale (15x15km) in two regions of Ghana - Ashanti and Northern regions. They developed a spatial model (using Erdas Imagine Model Maker) that combined spatial layers of influencing factors which were grouped into bio-physical, technical, socio-economic and eco-environmental factors. 22 and 16 (see Table-1) factors for Ashanti and Northern regions, respectively were combined in a multi-criteria evaluation to determine best areas for rice cultivation in the inland



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valleys. Although this study is useful and provides an insight into the identification of best inland valleys for rice cultivation, replicating it in other parts of the country (and in the sub-region) is challenging due to the relatively large number of factors that were considered. The amount of time and resources needed to generate similar layers for other regions is considered expensive and unsustainable. Thus, although all factors are considered important for the development of inland valley rice cultivation, it is imperative to reduce the total number of factors to a relatively small number. For example, Perveen *et al.* (2005) determined land suitability for rice cultivation in Haripur Upazila Thakurgaon district of Bangladesh with a total of eight parameters. Kuria *et al.* (2011) also used six parameters in a similar study in the Tana delta, Kenya.

The objectives of this study therefore are three fold:

- a) To conduct sensitivity analysis using the spatial model developed by Gumma *et al.* (2009) to reduce the influencing factors to the most sensitive ones.
- b) To implement the methodology for two different regions using the new set of influencing factors obtained in (a) above.
- c) To ascertain whether there's an appreciable difference in results when all factors (as used in Gumma *et al.* 2009) are used as against using only the sensitive factors.

Group	Ashanti Region	Northern Region
Bio-physical	Rainfall, Potential Evapotranspiration (PET), Length of Growing Period (LGP), specific discharge, stream order, slope, Land Use Land Cover (LULC)	Rainfall, Potential Evapotranspiration (PET), Length of Growing Period (LGP), stream order, slope, Land Use Land Cover (LULC), soils, soil depth, soil fertility
Agronomic experience, agriculture Technical technology, water management, post harvest technology technology		
Socio-economic	Major and minor settlements, major and minor roads, markets, land tenure, labour force, credit system, extension system, incentives net benefits	Major and minor settlements, major and minor roads, major and minor markets
Eco-environmental	Malaria	Malaria

Table-1. Influencing factors in determining best sites for inland valley rice cultivation (Gumma et al., 2009).

2. STUDY AREA

Rice consumption in Ghana has increased from a steady level of 7-8 kg before 1990, 11.5kg during the 1990's to 27 kg per capita per year for the period of 2001-2005. Future increases are projected by the Ministry of Food and Agriculture (MOFA) based on a combination of overall population growth, rising incomes, and increasing urbanization. Based on these, Ghana's MOFA estimates that demand for rice in Ghana will increase at a compound annual growth rate of 11.8% from 939, 920 metric tons to 1,644,221 metric tons between 2010 and 2015 (Millennium Development Authority, 2010). According to MOFA (2011), total rice produced in Ghana in the year 2010 was 491, 603 metric tons.

The study was carried at local scale in two regions of Ghana - Brong Ahafo and Western. The first site is located between latitudes 8° 14' 59"N and 8° 6' 45"N and longitudes 1° 44' 24"W and 1° 36' 11"W. It falls in the Kintampo North District of Brong Ahafo Region (Figure-1). The site lies in the transitional zone between the Wet Semi-equatorial and Tropical Continental climates and experiences an average rainfall of 1400mm per annum (Kintampo weather station). The mean annual temperature in the area is about 27°C. Relative humidity varies from 90%-95% in the rainy season. The main cultivated crops in the area include: rice, maize, cassava, cowpea and yam.

The second site is located in the Elembele District of the Western Region. It lies between latitudes 5° 5' 59"N and 4° 57' 49"N and longitudes 2° 28' 34"W and 2° 20' 25"W (Figure-1). It lies in the equatorial climatic zone and experiences an average rainfall of 1, 600 mm per annum (Aiyinase weather station). The average temperature of the site is about 29.4°C with a variation in mean monthly temperature ranging between 4 to 5°C throughout the year. This high rainfall regime creates much moisture culminating in high relative humidity, ranging from 70% to 90%. Dominant crops cultivated in the area are cassava, rice, plantain, maize, rubber and coconut.

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Figure-1. Map of study areas.

3. DATA AND METHODOLOGY

Figure-2 gives an overview of the methodology employed in this study. Using the original model and spatial layers developed by Gumma *et al.* (2009), a sensitivity analysis was performed to identify parameters that affect the model results the most. These parameters were deemed the most important parameters that need to be considered when implementing the methodology in other parts of the country. Based on this, data were collected at local scale (15x15km) in two other regions (Brong Ahafo and Western Region) to determine best sites for inland valley rice cultivation. Results obtained were validated using an independent set of ground truth data (rice cultivation areas). By way of testing the suitability of the most sensitive parameters in accurately determining best sites for inland valley rice cultivation, the original model (by Gumma *et al.*, 2009) was run again, this time using only the most sensitive parameters as determined by the sensitivity analysis. Results obtained were then compared with the original results. The sections below give further details on each of the steps outlined above.



Figure-2. Methodology and workflow adopted in this research (AR: Ashanti Region, BAR: Brong Ahafo Region).

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3.1. Sensitivity analysis

The aim of the sensitivity analysis was to reduce the number of input parameters in determining best sites for inland valley rice cultivation to the most sensitive ones. It was also intended to obtain a uniform set of input parameters for use in subsequent analysis. The original model and spatial layers as developed by Gumma *et al.* (2009) were used at this point.

The analysis was conducted using a stepwise exclusion method. In this approach, a parameter is excluded at a time and the model is executed. For each of these runs, the area predicted as highly suitable for inland valley rice cultivation was noted. This figure was then compared with the same quantity (highly suitable area) when all parameters are used in the model. Thus for each parameter exclusion, a change was estimated (i.e., difference between highly suitable area when all parameters are used minus when a parameter is excluded). These changes in area were then ranked and the parameter that causes the least change was considered least sensitive to the model and thus discarded. The process was then repeated using the remaining parameters until there was no appreciable difference in the ranked changes. At the end of the iteration, twelve parameters were found to be the most sensitive to the model (i.e., both the Ashanti and Northern Region sites). These parameters were found to be predominantly bio-physical and socio-economic. Table-2 presents results of the sensitivity analysis.

Fable-2. Parameters	identified to	be the most	sensitive.
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Bio-physical	Technical	Socio-economic
Rainfall, stream order, discharge slope, soil fertility, Length of Growing Period (LGP)	Postharvest technology	Land tenure, roads, markets, credit systems, incentive benefit

3.2. Data collection and database development

Data were collected from various sources for the development of spatial layers for the twelve most sensitive parameters earlier identified. Primary and secondary data sources were used.

3.2.1. Primary data collection

These include a soil survey, administration of questionnaires (for farmers) and Global Positioning System (GPS) surveys. The soil survey was conducted to derive information on soil fertility. To ensure that soil data is collected evenly across the sites, the sites were gridded at an interval of 3 km. Soil samples were taken on rice farms that fell within a grid. On grids that had no rice farms, samples were taken at the centre. Samples were taken at a depth of 6 to 20 cm using the soil auger at about 30 points. Individual samples were mixed together for analysis. A hand-held GPS was used to take the geographical coordinate of each sample location. The samples were air dried, sieved and analyzed for soil pH(H₂O), total nitrogen, organic matter content, organic carbon content, exchangeable cations (K⁺, Mg²⁺, Na²⁺, Ca²⁺), exchangeable acidity and cation exchange capacity (C.E.C). In order to obtain information on post harvest technology, land tenure, credit systems and incentive benefit, a questionnaire was developed and administered on farms where soil samples were taken. Questions asked include harvesting method, threshing method, access to credit, yield per acre and how land is acquired for rice cultivation. Information derived from this exercise assisted in generating spatial layers of these parameters. A GPS survey was conducted to map all markets in and around the study area.

A spatial layer for soil fertility was created by interpolating between the sample points using the Inverse Distance Weighted (IDW) technique. The attributes used are Cation exchange capacity and organic carbon. The "Euclidean distance" tool in ArcGIS was used to create a spatial layer for markets and roads. This tool calculates the straight line distance from each cell in a raster file to a particular feature (i.e., location of a market). Spatial layers for post harvest technology, land tenure, credit systems and incentive benefit were manually created. Manual digitizing was done around farms that gave similar responses. The digitized units were then converted to a raster layer and suitability scores assigned. Although the sensitivity analysis indicated that discharge is an important parameter, data constraint did not permit us to create a spatial layer for it.

3.2.2. Secondary data

Data obtained from secondary sources include a gridded rainfall data at a spatial resolution of 1km from WorldClim, a Digital Elevation Model (DEM) from the Shuttle Radar Topographic Mission (SRTM) at 90m resolution, road layer from the digital database of the National Survey Department and a spatial database of length of growing period from the Soil Research Institute which was developed as part of the Ghana Environmental Resource Management Project (SRI-GERMP) in 1999.

The spatial layer for rainfall was derived from the Worldclim data while slope and stream order for the study sites were derived from the DEM. Hydrological processing of the DEM was conducted with the Integrated Land and Water Information System (ILWIS) software. A depression less DEM was first created using the "fill" routine after which flow direction and accumulation layers were created. A stream network was subsequently created by experimenting with various threshold Figures and selecting the best threshold through visual inspection. Stream orders were created using the "Drainage network ordering" tool. The catchments in which each stream order falls were considered as the spatial units of the stream order spatial layer. The "Euclidean distance" tool in



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ArcGIS was used to create a spatial layer for roads. This tool calculates the straight line distance from each cell in a raster file to a particular feature.

3.2.3. Standardization of spatial layers

Due to the disparate scales (units) of the spatial layers (e.g. mm for rainfall, % for slope, etc.), the parameters were rescaled to a common scale. Suitability classes/scores of between 1 (not suitable) and 5 (highly suitable) were assigned to each layer. Justification for the class breaks is a combination of local knowledge and information in literature. For example, Landon (1991) was used for the soil fertility class. Table-3 provides a summary of the various parameters, the source of data used in creating it, data ranges and their corresponding suitability class/score.

Table-3. Parameters used sources of data, data ranges and suitability cl	lasses.
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Parameter (units)	Source of data	Data range (s)	Suitability class	
Rainfall (mm)	1km gridded data from Worldclim - http://www.worldclim.org/	<700 700-1000 1000-1300 1300-1600 >1600	Not suitable [1] Marginally suitable [2] Moderately suitable [3] Suitable [4] Highly suitable [5]	
Slope (%)	90m Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM)	>5 3-5 2-3 1-2 <1	Not suitable [1] Marginally suitable [2] Moderately suitable [3] Suitable [4] Highly suitable [5]	
Stream order	Hydrological processing of SRTM DEM	1 st order streams 2 nd order streams 3 rd order streams 4 th order steams 5 th order streams	Not suitable [1] Marginally suitable [2] Moderately suitable [3] Suitable [4] Highly suitable [5]	
Distance from roads and markets (meters)	Road layer extracted from the digital database of the national survey department. Markets mapped with a handheld Global Positioning System (GPS)	<500 500-1000 1000-2000 2000-4000 >4000	Highly suitable [5] Suitable [4] Moderately suitable [3] Marginally suitable [2] Not suitable [1]	
Length of growing period for rice (days)	Length of growing period for rice (days) Soil Research Institute of Ghana (SRI)		Not suitable [1] Marginally suitable [2] Moderately suitable [3] Suitable [4] Highly suitable [5]	
Soil fertility (Cation Exchange Capacity (CEC) and Organic Content (OC))	Soil fertility (Cation Exchange Capacity (CEC) and Organic Content (OC))Soil survey and analysis of samples in the laboratory		Highly suitable [5] Suitable [4] Moderately suitable [3] Marginally suitable [2] Not suitable [1]	
Post harvest technology (threshing method)	Farmer responses from questionnaire administered	Threshing on Tarpaulin. Tractor trampling Threshing on ground (heaped) Threshing in a bag	Not suitable [1] Marginally suitable [2] Moderately suitable [3] Suitable [4]	
Credit systems and incentive benefits (Ghana Cedis)	Farmer responses from questionnaire administered	160.0 0.0	Marginally suitable[2] Not suitable[1]	
Land tenure (sources of land for rice cultivation)	Farmer responses from questionnaire administered	Inheritance Family Chief Free	Suitable [4] Moderately suitable [3] Marginally suitable [2] Not suitable [1]	



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3.2.4. Developing and running the spatial models

The mode was developed using the Erdas Imagine Model Maker tool at a 30m resolution. The model contains an input, function and an output. In the function the spatial layers were combined using equation (1).

$$\sum (score \times weight \ of \ parameter)$$
(1)

The digital numbers (DN) in the raster output were converted into percentages using equation (2).

The percentages were reclassified into five suitability classes as presented in table.



Figure-3. A schematic layout of the spatial model built in ERDAS.

Range (%)	Suitability	Score
0 - 34	Not suitable	1
35 - 54	Marginally suitable	2
55 - 64	Moderately suitable	3
65 - 74	Suitable	4
75 - 100	Highly suitable	5

Table-4. Classification of pixel values in percentages.

Two approaches were used in running the model. In the first approach, parameters were assigned equal

weights and in the second approach parameters were assigned variable weights depending on the relative importance of a parameter based on expert knowledge. Weights used by Gumma *et al.* (2009) were adopted as presented in Table-5.

Table-5. Weights of input parameters.

Parameter	Weight
Markets	1.74
Slope	2.95
Post harvest technology	1.05
Discharge	1.89
Land tenure	1.4
Growth period for rice	2.05
Incentive	1.37
Credit system	1.58
Rainfall	1.89
Roads	1.7
Soil fertility	2.32
Stream order	2.05

Source, Gumma et al., (2009)

3. RESULTS AND DISCUSSIONS

3.1. Model results for the Brong Ahafo Region site

Presented in Table-6 are areas and percentages of suitability classes from the model results of the Brong Ahafo Region site. Based on equal weights, 0.51% (118.5ha) of the total area is highly suitable and 11.8% (2723.5ha) is suitable. Based on unequal weights, 0.77% (177.9ha) of the total area is highly suitable and 7.64% (1766.9ha) is suitable. It is observed that the area of highly suitable increased by 0.26% when applying unequal weights. However, the area for suitable and moderately suitable reduced using unequal weights. Figure-4 shows the spatial distribution of the suitability classes.

Table-6.	Land suitability	classes in the Brong	Ahafo Region site bas	sed on equal and	unequal weights.
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	Equal weights		Unequal weights		
Suitability	Area (ha)	(%)	Area (ha)	(%)	No. of rice farms
Not suitable	284.7	1.2	326.9	1.4	0
Marginally suitable	8000.6	34.6	12072.1	52.2	8
Moderately suitable	12007.2	51.9	8790.7	38.0	8
Suitable	2723.5	11.8	1766.9	7.6	2
Highly suitable	118.5	0.51	177.9	0.8	0

(%): Percentage

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Figure-4. Suitability maps for the Brong Ahafo Region site: for equal (A) and unequal (B) weights.

The proximity of North-Eastern corner of the study area to settlements, streams and roads could be the reason why it is identified as most suitable area. Also the dominance of the moderately and marginally suitable areas could be due the presence of only lower order streams $(1^{st}$ and $2^{nd})$ and the absence of roads and settlements in the area.



Figure-5. Location of existing rice farms on the suitability map of the Brong Ahafo Region site based on unequal weights.

3.2. Model results for the Western Region site

Presented in Table-7 are areas and percentages of suitability classes from the model results of the Western Region site. Based on equal weights, 1.4% (386.3ha) of

the total area is highly suitable and 21.4% (5814ha) is suitable for rice cultivation. Then based on unequal weights 0.9% (234.9ha) of the total area is highly suitable and 13.6% (3686.2ha) is suitable for rice cultivation. It



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was observed that area for highly suitable, suitable and moderately suitable all decreased by 0.56%, 7.84% and 7.05%, respectively. Though there is a decrease in highly suitable and suitable area when using unequal weights its

results are better because it takes into account the relative importance of each input parameter. Figure-5 shows the spatial distribution of the suitability classes.

Table-7. Land suitability classes in the Western Region site based on equal and unequal weights.

	Equal weights		Unequal weights		
Suitability	Area (ha)	(%)	Area (ha)	(%)	No. of rice farms
Not suitable	4531.4	16.7	4537.0	16.7	0
Marginally suitable	4094.6	15.1	8285.0	30.5	13
Moderately suitable	12334.7	45.4	10418.9	38.4	5
Suitable	5814.0	21.4	3686.2	13.6	5
Highly suitable	386.3	1.4	234.9	0.9	0

(%): Percentage



Figure-6. Suitability maps for the Western Region site: for equal (A) and unequal (B) weights.

Areas around Kangbunli and Asasetre were identified to be highly suitable. This goes to confirm the fact that these places (particularly Kangbunli) were

already identified for large scale rice cultivation by Ghana's Ministry of Food and Agriculture. Slopes around these areas are generally low.

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Figure-7. Location of existing rice farms on the suitability map of the Western Region site based on unequal weight.

3.3. Comparing the results of the original model and the modified model

After carrying out the sensitivity analysis 12 most sensitive parameters were identified. These parameters, presented in Table-2 above, are among the parameters used in the Ashanti Region site by Gumma *et al.*, (2009) with the exception of soil fertility. Results from the sensitive parameters (modified model) were compared with the original results of all the 22 parameters.

Results from the modified model showed an increase in highly and marginally suitable area by 0.6% and 13.2%, respectively. This may be due to the exclusion

of the less sensitive parameters. However, suitable, moderately and not suitable area decreased by 7.9%, 5.9% and 0.07%, respectively. This clearly shows that there is no significant change between highly suitable and not suitable area. However, changes ranging between 5% and 13% existed between marginally, moderately and suitable area. This change is not much as compared to having to measure all the additional data for original model. Presented in the Table-8 are areas and percentages of suitability classes for the original and modified model for the Ashanti Region site.

	Original model		Modified model		
Suitability class	Area (ha)	(%)	Area (ha)	(%)	% Change
Not suitable	192.5	0.84	176.9	0.77	-0.07
Marginally suitable	3549.9	15.5	6584.8	28.7	+13.2
Moderately suitable	13033.8	56.8	11664.9	50.9	+5.9
Suitable	5849.0	25.5	4046.4	17.6	-7.9
Highly suitable	326.3	1.4	463.4	2.0	+0.6

(%): Percentage

4. CONCLUSIONS

The study has identified 12 most sensitive input parameters out of the initial 22 used for determining highly suitable inland valleys for rice cultivation. The sensitive parameters are: rainfall, slope, stream order, specific discharge, length of growth period, soil fertility, post harvest technology, land tenure, credit system, access to roads and markets and incentive benefit.

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The study has illustrated the use of spatial models based on limited data set in determining suitable areas for inland valley rice cultivation in two selected sites in Ghana. No rice farms were found in areas mapped as unsuitable for rice cultivation at the two selected sites.

The study showed that 0.51% (118.5ha) and 11.77% (2723.5ha) of the total study area are highly suitable and suitable respectively using equal weights and 0.77% (177.9ha) and 7.64% (1766.9ha) of the total study area is highly suitable and suitable, respectively based on unequal weight at the Brong Ahafo site. 1.42% (386.3ha) and 21.4% (5814.9ha) are highly suitable and suitable respectively based on equal weights and 0.86% (234.9ha) and 13.6% (3686.2ha) are highly suitable and suitable, respectively based on unequal weights at the Western Region site. There was an increase of 0.6% in highly suitable area when the results obtained from the original model were compared with results obtained using the modified model. This change is not much compared to having to measure all the additional data for the original model.

Model results provided various categories of suitability, size in hectares and their precise locations. The methods and models developed in this study can be applied across Africa to identify most suitable inland valleys for rice cultivation in particular and the development of agricultural lands in general.

Our inability to create a spatial layer for discharge (though an important parameter) is one of the limitations of our results.

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