# USING ERDAS IMAGINE MODEL TO DETERMINE SUITABLE INLAND VALLEYS FOR RICE CULTIVATION AT SELECTED SITES IN BRONG AHAFO AND WESTERN REGIONS OF GHANA

**by**

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## DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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**Abstract**

Rice (Oryza sativa) has become one of the major food staples in Ghana. It is estimated that demand for rice in Ghana will increase at a compound annual growth rate of 11.8% from 939,920 - 1,644,221 metric tons from 2010 to 2015. 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 and Western Region of Ghana. A sensitivity analysis was carried out using a stepwise exclusion method, excluding one parameter at a time from the model and the highly suitable area estimated. Parameters that caused least or no change in highly suitable area were completely taken out of the model. Weights of selected parameters were varied to see how changes in weight affect the highly suitable area. Finally, 12 most sensitive input parameters were identified from the initial 22 to include: rainfall, discharge, slope, stream order, length of rice growth, markets, roads, post harvest technology, land tenure, incentive net benefit, soil fertility and credit systems. These were used to model for five suitability classes namely: highly suitable, suitable, moderately suitable, marginally suitable and not suitable. The model results based on parameters having equal weights showed that 0.51% and 11.77% of the total study area were highly suitable and suitable respectively for the Brong Ahafo Region site and 1.42% and 21.41% of the total study area were highly suitable and suitable respectively for the Western Region site. Based on unequal weights, 0.77% and 7.64% were highly suitable and suitable respectively for the Brong Ahafo Region site and 0.86% and 13.57% were highly suitable and suitable respectively for the Western Region site. A 0.6% increase in highly suitable area was recorded whilst 7.84% decrease in area was recorded for suitable area when the results of the original model were compared with those of the modified one.

## Dedication

I will like to dedicate this work to the Almighty Allah, my family, friends and loved ones.

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**LIST OF ABBREVIATIONS**

| | |
|---|---|
| CEC | Cation Exchange Capacity |
| DEM | Digital Elevation Model |
| DN | Digital Numbers |
| ERDAS | Earth Resources Data Analysis System |
| ETM+ | Enhanced Thematic Mapper Plus |
| FAO | Food and Agriculture Organisation |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| ILWIS | Integrated Land and Water Information System |
| IWMI | International Water Management Institute |
| MOFA | Ministry of Food and Agriculture |
| SRTM | Shuttle Radar Topographic Mission |
| USDA | United States Department of Agriculture |
| SPOT | Systeme Pour l'observation de la Terre |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

Inland valleys are a category of wetlands subject to excessive wetness to the extent that the wet conditions influence the choice of possible land use. Wetlands comprise lands with poor drainage which can be due to either flooding or to periodic high groundwater levels. Other broad categories of wetlands are coastal plains, inland basins and river floodplains (Windmeijer and Andriesse, 1993). Wetlands are ecosystems of very high interest for agricultural development as well as for environmental conservation. The ability of wetlands to act as sponge that can hold water for a longer period of time as compared to the surrounding areas and their higher soil fertility have made wetlands attractive for agricultural development (Thenkabail *et al*., 2000). In West Africa, the estimated area of Inland Valleys range between 8-28% of the total geographic area with only about 7-20% of this area cultivated (Thenkabail *et al*., 2000). The inland valley wetland areas are highest in the humid forests, followed by derived savannas, southern Guinea Savanna, Northern Guinea Savanna, Sudan Savanna and Sahel. However the importance of inland valley wetlands actually increases in drier areas, since in these areas its use for lowland rice cultivation is high due to the availability of water compared to the uplands for most of the year (Thenkabail *et al*., 2000). Among the constraints to cultivation in Inland valleys are excessive weed growth, lack of appropriate water management technologies, labour shortage, prevalence of water-related diseases, and unfavourable socio-economic conditions (FAO, 1998). Large proportions of wetlands are inland, along the stream network and/or occur as isolated patches. Most of the inland valleys that remain wet during most parts of the year give rise to many localized wetland ecosystems referred to as “dambos” ,“fadamas”,” mbugas”, and “vleis” in eastern and southern Africa. They usually occur along the lower-order streams and are too small to appear on most maps. However, these inland valleys constitute about 9-18% of the African landscape (Thenkabail and Nolte, 2000).

Land suitability analysis involves the application of criteria to assess where land is most and least suitable for development. Land suitability analysis is a prerequisite to achieve optimum utilization of available land resources for sustainable agricultural production (Perveen *et al.* 2005). It also provides a systematic assessment of land potential for the defined land use, alternative land use, and socio-economic conditions in order to select and put in to practice in a manner that will best meet the needs of the people while safeguarding the resources for future.

In performing land suitability analyses remote sensing and geographic information systems (GIS) data, tools and techniques provide a good platform for data generation, integration, processing and analyses. It also enables the derivation of user friendly and comprehensive outputs in terms of data statistics, maps, and models that could be further refined and verified for performing similar analyses. Although many other traditional methods and techniques could be used in performing land suitability analyses and modeling, computer based GIS modeling enables integration of a wide variety of data in different scales and formats into common format that enables the user to modify and re-define the criteria to derive different outputs using different set of pre-defined conditions and thus providing information that is geographically precise (Gumma *et al.*, 2009). Mapping precise wetland is a very instructive source of information for planners. With effective use of remote sensing and GIS technology, field data can be integrated, manipulated and analysed with other data layers to allow more effective planning and management (Turner *et al*., 2000).

## 1.2 Problem statement

Rice is now a staple food for most people in Ghana. Its consumption has increased over the years. This has led to high importation of rice into the country to fill the wide gap between production and consumption. Urbanization and changing consumer preferences are the main drivers of significant growth in per capita rice consumption, as urban populations consume significantly more rice than rural populations. From a steady level of 7-8 kg before the 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.

Therefore using available land/inland valleys to improve rice production and help reduce hunger. The inability to match the suitability of a given piece of land to a particular crop and or variety and the management practices being used affects crop production. For instance rice yields are affected by extensive weed growth, lack of appropriate water management technologies, labour shortage, prevalence of water-related diseases, and unfavourable socio-economic conditions (FAO, 1998). In order to boost the production of local rice in Ghana, determining sites that would best be suitable for rice production will go a long way in improving rice yields, reduce poverty and address the issue of food security.

## 1.3 Justification

In order for Ghana to be self-sufficient in rice production, it is necessary to evaluate and map out suitable inland valleys to help boost rice cultivation in Ghana. Due to high variability in rainfall patterns, the development of inland valleys in Ghana will help increase yields since water availability in inland valleys is relatively higher as compared to the uplands.

Mapping wetlands is a very instructive source of information for planners. With effective use of remote sensing and GIS technology, field data can be integrated, manipulated and analysed with other data layers to allow more effective planning and management (Turner *et al*., 2000).

Upon this background this study modifies a spatial model developed by Gumma *et al*. (2009) and uses the most sensitive or very important parameters to determine suitable inland valleys for rice cultivation in selected sites in the Brong Ahafo and Western Regions of Ghana.

## 1.4 Objective of the study

The main aim of this study was to adopt and modify a model developed by Gumma *et al.* (2009) for selecting suitable inland valleys for rice cultivation in the Northern and Ashanti Regions for Brong Ahafo and Western Region of Ghana using the Erdas Imagine spatial modeler.

**Specific Objectives**

1. To determine the most sensitive input parameters for determining land suitability for rice cultivation
2. To estimate the land suitability of selected sites in the Brong Ahafo and Western Region of Ghana using limited input data
3. To compare the results obtained from the original model (ie. using many input data) and that of the modified version (ie. using limited input data) using the most sensitive input parameters.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

Inland valleys are one of the many forms of wetlands that are characterized by hydromorphic soils and are typically found along the lower-order streams. These agroecosystems are favourable for rice cultivation, dry-season cropping and have the potential to increase the acreage and yields in Africa if attention is paid to technical, environmental and socio-economic constraints (Juo and Lowe, 1986).

## 2.2 Definitions and Importance of Wetlands and Inland Valleys

According to the US Army Corps of Engineers Wetlands Delineation Manual (USACE) (1987) wetlands are defined as: Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

The Ramsar Convention Secretariat (2006) defined wetlands as: areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters.

The FAO (1998) defines wetlands as areas that are either periodically wet and periodically dry or permanently flooded with a water layer not exceeding several meters.

This definition of wetland clearly excludes open waters that are several meters deep, but includes permanent swamps, floodplains.

Inland valleys are defined as the upper reaches of river systems in which river alluvial sedimentation processes are absent or imminent only. They consist of valley bottoms and minor floodplains, which may be submerged for part of the year (Windmeijer and Andriesse, 1993).

Wetlands remove sediments, nutrients, toxic substances and other pollutants in surface run-off thereby improving the quality of water. The vegetation in the wetlands may also evaporate or transpire much of the water into the atmosphere. They facilitate the movement of large volumes of water into the underground aquifer resulting in the recharge of ground water table. They prevent surface run-off from moving swiftly downstream and overflowing thereby preventing erosion and flood conditions. Wetlands such as mangroves and other forested coastal areas act as wind-breaks and help to dissipate the forces and impact of coastal storm surges (Anku, 2006).

These valleys could potentially provide highly productive environments relative to uplands because of their hydrological characteristics and soils. Inland Valleys are distributed in all the agro-ecological zones of sub Saharan Africa. Inland Valley ecosystems are thus significant in terms of both the total land area they occupy and their potential to become productive growing environments. This potential is particularly important in view of the declining per capita food production and increasing food imports in sub Saharan Africa.

### 2.2.1 Types of Wetlands in Ghana

The Ramsar Convention (2001) identified three main types of wetlands in Ghana. These include:

**Marine/Coastal:** These are wetlands within the coastal zone of Ghana and are predominantly saltwater ecosystems. They are primarily associated with flood plains of estuaries of large rivers and watercourses.

**Inland Wetland**: These are mainly freshwater ecosystems. They occur wherever groundwater, surface springs, streams or run-off cause saturated soils, frequent flooding or create temporary or permanently shallow water bodies.

**Man-Made**: These are wetlands constructed for aquaculture, agriculture, salt exploitation, and water storage and urban/industrial purposes.

## 2.3 Rice Production Systems in West Africa

The West African rice production systems can be divided into four categories based the characteristics of the land on which rice is grown as described below:

### 2.3.1 Hydromorphic rice

Rice grown under hydromorphic conditions is where water is supplied to the rice crop by a shallow ground water table, within the root zone of the rice plant. This condition is usually found on the lower slopes of the toposequence, or in situations where an impermeable soil layer reduces water percolation through the soil. Usually one crop of rice per year is grown under these conditions (Kranjac-Brisavljevic *et al*., 2003).

### 2.3.2 Lowlands or 'inland valleys'

These are considered to be the most suitable areas for rice production in sub-Saharan Africa. In the rice fields, leveling and bunding create suitable conditions, in order to conserve water coming from rain, river, flooding or other sources. Under developed inland valleys, irrigation allows water to be distributed and controlled for efficient rice production. In some areas, basins can be created such that water flow from one basin terrace to another. In West Africa, two to three rice crops can be grown annually under inland valley irrigated conditions, and in some cases, five crops are cultivated over a period of two years (Kranjac-Brisavljevic *et al*., 2003).

### 2.3.3 Upland rice

Rice is grown on free draining soils where the water table is permanently below the root zone of the rice plant and the crop depends entirely on rainfall. Under these conditions, the rice crop can be grown only during the rainy season. Therefore one crop or two is grown depending on the rainfall pattern (Kranjac-Brisavljevic *et al*., 2003).

### 2.3.4 Mangrove swamps

These are found along coastal areas. They are tidal swamps, flooded twice daily, in which rice is grown along the West African coast. Flooding by seawater usually results in high salinity problems during the dry season. Mangrove swamps usually support only one crop of rice each year, although in some places two crops can be grown annually (Kranjac-Brisavljevic *et al*., 2003).

## 2.4 Rice Production Systems in Ghana

Kranjac-Brisavljevic *et al*. (2003) in a survey identified three basic rice systems in Ghana. These include:

**Irrigation schemes**: Under this scheme, water supply is assured usually in the dry season and supplemented with rain in the rainy season. They usually produce two crops per year.

**Inland valley systems**: With this system, rice is grown under rain-fed condition, but water is retained in the soil due to the hydromorphic nature of the soil and its flat relief nature. But in recent times some of these inland valleys are being developed to help control water and extend their use to multiple cropping during the year.

**Upland rice systems:** Rice production depends on sufficient and continuous rainfall.

## 2.5 Land Suitability Analysis

Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976).

### 2.5.1 The USDA Land Capability Classification System

This is undoubtedly the most used land classification system in the world, and its main objective is to classify soil units according to their ability to support general kinds of land use without degradation or significant off-site effects, for farm planning.

In the USDA system, soil mapping units are grouped primarily on the basis of their capability to produce common cultivated crops and pasture plants without deterioration over a long period of time. Capability is viewed by some as the inherent capacity of land to perform at a given level for a general use, and suitability as a statement of the adaptability of a given area for a specific kind of land use; others see capability as a classification of land primarily in relation to degradation hazards, whilst some regard the terms "suitability" and "capability" as interchangeable (FAO, 1976).

At the highest of categorization, eight soil classes are distinguished, namely:

**Class 1 Soils**: have few limitations that restrict their use

**Class 2 Soils**: have some limitations that reduce the choice of plants or require moderate conservation practices

**Class 3 Soils**: have severe limitations that reduce the choice of plants, require special conservation practices, or both

**Class 4 Soils**: have very severe limitations that reduce the choice of plants, require very careful management, or both

**Class 5 Soils**: have little or no erosion hazards but have other limitations, impractical to remove, that limit their use largely to intensive pasture or range, woodland, wildlife food or cover. (Note: usually wet soils).

**Class 6 Soils**: have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, wildlife food or cover.

**Class 7 Soils**: have very severe limitations that make them unsuited to cultivation and limit their use largely to extensive grazing, woodland or wildlife.

**Class 8 Soils**: have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, water supply, or to aesthetic purposes.

In the second level of generalization of the USDA land capability classification system, sub classes specify the kind of limitations. Four kinds of limitations are recognized at this level, namely, risk of erosion; wetness, drainage or overflow; rooting zone limitations, and climatic limitation. The third level of the capability unit provides more specific and detailed information for application to specific fields on a farm.

The major problems faced by The USDA Land Capability Classification System is that; it completely ignores economic factors and the land is not evaluated for specific uses.

### 2.5.2 The FAO framework for land evaluation

The Framework covers all kinds of rural land use: agriculture in its broadest sense, including livestock production, forestry, recreation or tourism and nature conservation.

The Framework is not intended for the distinct set of planning procedures involved in urban land use planning, although some of its principles are applicable in these contexts (FAO, 1976).

The Framework is based on categories that retain their basic meaning within the context of the different classifications and as applied to different kinds of land use. Four categories of decreasing generalization are recognized

**Land suitability Orders**: Indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders represented in maps, tables, etc. by the symbols S and N respectively.

**Land suitability Classes:** reflect degrees of suitability. The classes are numbered consecutively in sequence of decreasing degrees of suitability within the Order. Within the Order Suitable the number of classes is not specified. There might, for example, be three with S1 (Highly Suitable), S2 (Moderately Suitable) and S3 (Marginally Suitable). The number of classes recognized should be kept to the minimum necessary to meet interpretative aims; five should probably be the most ever used.

Within the Order Not Suitable, there are normally two Classes

N1 (Currently Not Suitable) and N2 (Permanently Not Suitable)

**Land Suitability Subclasses:** reflect kinds of limitations, e.g. moisture deficiency, erosion hazard. Subclasses are indicated by lower-case letters with mnemonic significance, e.g. S2m, S2e, S3me. There are no subclasses in Class S1. The number of Subclasses recognized and the limitations chosen to distinguish them will differ in classifications for different purposes.

**Land suitability units:** are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. The units differ from each other in their production characteristics or in minor aspects of their management requirement. Their recognition permits detailed interpretation at the farm planning level. Suitability units are distinguished by numbers following a hyphen, e.g. S2e-1, S2e-2. There is no limit to the number of units recognized within a subclass.

The FAO (1993) procedure for performing land suitability is described below in four steps.

1. Describe promising land-use types; a land-use type is a kind of land use described in terms of its products and management practices
2. For each land-use type, the requirements are determined. Land-use requirements are described by the land qualities needed for sustained production. A land

quality is a complex attribute of land that has a direct effect on land use. Examples are the availability of water and nutrients, rooting conditions and erosion hazard.

3. Conduct the surveys necessary to map land units and to describe their physical properties, e.g. climate, slope, soils. Land units are identified as a basis for the diagnosis of problems. It will be necessary to map these units in more detail, e.g. by dividing land systems into land facets or complex soil mapping units into soil series. The criterion for choice of land units is that they are expected to respond to management in a relatively similar way at the scale of the study.
4. Finally, compare the requirements of the land-use types with the properties of the land units to arrive at a land suitability classification.

### 2.5.3 Direct Overlay

The Direct Overlay method is simply generating a series of transparent maps and placing them on each other so that all the labeling and shading on each of the maps is visible. By inspection, a planner could see how each of the layers relates to the other and be able to make informed decisions on which piece of land is suitable for a particular land use. The main steps in doing a map overlay are described below:

1. Defining the planning purpose and identifying the factors that will contribute to the planning.
2. Investigating each factor’s situation and distribution, making a class classification according to the suitability for some specific land uses and using some gradual colour to identify each factor’s suitability class in a single map.

3. Overlaying two or more single factor maps to get a composite map.
4. Analysing the composite map and finally making the land use planning.

This method has several disadvantages which include: The practical limitations on the number of layers that the eye can interpret at once. As the factors increase, it is complicated to use the colours to represent different suitability classes and to make the overlay. Also all data on the maps are discrete, while some of the variables (e.g., distance from a water line) are continuous. Finally, the relative importance of each layer is not explicit or quantifiable and the results cannot be easily summarised or applied to other planning tasks.

### 2.5.4 GIS Based Land Suitability

This method is a computerised version of the manual overlay as discussed in section 2.5.3. A geographic information system (GIS) is an efficient tool for organizing, storing, analyzing, displaying and reporting spatial information. GIS capabilities for spatial analysis have overcome the drawbacks of the paper map overlay approach. The system enables planners to create and modify a land suitability analysis that makes the best use of available data (CGIA, 2005).

In performing land suitability analyses, remote sensing and GIS data, tools and techniques provide a good platform for data generation, integration, processing and analyses. It also enables deriving user friendly and comprehensive outputs in terms of data statistics, maps, and models that could be further refined and verified for performing similar analyses. Although many other traditional methods and techniques could be used in performing land suitability analyses and modeling, computer based GIS modeling enables integration of a wide variety of data in different scales and formats into common format that enables the user to modify and re-define the criteria to derive different outputs using different set of pre-defined conditions and provides information that is geographically precise (Gumma *et al*., 2009).

In order to utilize the land resources in a sustainable way, a land-use plan that incorporates the different land characteristics has a paramount importance. To incorporate the different land attributes that differ spatially and to identify the best suitable land use, GIS has proved to be the best. GIS, which incorporate database systems for spatial data, were designed and developed enabling the acquisition, compilation, analysing and displaying of topological inter-relations of different spatial information. Moreover the surface and overlay analysis capabilities in GIS can effectively facilitate in handling vast amount of spatial information (Ekanayaki and Dayawansa, 2003).

The steps in a GIS-based Suitability Analysis include:

1. Defining the data needed: These include both field data and secondary data to carry out suitability analysis. Examples are slope, soil fertility, rainfall and discharge.

2. Preparing spatial data layers. Many layers will have to be converted from vector to raster.

3. Providing weightages to spatial data layers. Here all considered factors are examined and based on their relative importance, weights are assigned to them. This means that the more influential a factor is to a particular land use the higher weight of that factor.

4. Model development: An in-build model in a GIS or Remote Sensing software allows the user to create the model, combine and classify multiple data layers to produce a land suitability map.

5. Running the model

## 2.6 Remote Sensing and GIS



Remote sensing is defined as any process whereby information is gathered about an object, area or phenomenon without being in contact with it. Given this rather general definition, the term has come to be associated more specifically with the gauging of interactions between earth surface materials and electromagnetic energy (Eastman, 2006). GIS is defined as a computer based system capable of capturing, storing, analyzing, and displaying geographically referenced information.

The wetland surveys of the world have been mostly localised surveys (EarthSat, 2002). However several studies have shown the potential of Remote sensing data and GIS techniques for mapping out different types of wetlands.

Ground-based survey of wetlands is very time consuming. Irrespective of the size of wetland the use of remote sensing techniques offers a cost effective and time saving alternative for delineating wetlands over a larger area compared to conventional field mapping methods (Ozesmi and Bauer, 2002; Toyra and Pietroniro, 2005).

The Earth Satellite Corporation and Isciences LLP (2002) examined the use of Remote Sensing imagery for wetland classification and delineation. The important lesson they learnt through this investigation was the potential use of imagery in conjunction with

GIS datasets to investigate the interconnectivity of wetland sites within a larger geographic region. Hence they concluded that these types of analyses at larger spatial scales would greatly enhance capabilities to assess and understand these vulnerable ecosystems as a whole rather than as an isolated entity.

### 2.6.1 Remote Sensing Software- ERDAS IMAGINE

ERDAS IMAGINE is the raster geoprocessing software GIS, Remote Sensing, and Photogrammetry professionals use to extract information from satellite and aerial images. The vast array of tools allows users to analyze data from almost any source and present it in formats ranging from printed maps to 3D models, making ERDAS IMAGINE a comprehensive toolbox for geographic imaging, image processing, and raster GIS needs (Leica, 2007).

### 2.6.2 Remote Sensing images

Remote sensing images consist of photographs of the earth or other planets made by means of artificial satellites. These images have many applications in agriculture, forestry, geology, regional planning, meteorology etc.

Table 2.1: Type of remote sensing images and their uses

| Image type | Resolution | Function | Potential |
| --- | --- | --- | --- |
| Landsat | 30 meters | Used for creating land use/land cover maps, mapping urban change, detecting forest change, | Used to map out wetlands in the Cape Region of the Western Cape Province, South Africa (De Roeck, *et al.*, 2008).Used three different |

| | | | |
|---|---|---|---|
| | | and other environmental phenomena. | images to assess the land use and land cover changes in the Barekese catchment of Ghana (Boakye, *et al*., 2008). |
| SPOT | 2.5 m to 10 m | Used for urban mapping, agriculture and forest management, terrain interpretation | Used together with Landsat and a 1: 15 000 scale aerial photographs to map vegetation type in the Northern Territory of Australia (Harvey and Hill (2001). |
| ASTER | 90m to 15 m | For change detection, vegetation, geology, climate, hydrology, and the generation of Digital Elevation Models. | Used to map palm swamps in the Northern Minas Gerais of Brazil (Maillard *et al*., 2008). |

## 2.7 Image Classification

The main objective of image classification is to categorize all pixels in a digital image into one of several land cover classes or themes. It is a means by which spectral raster data is converted into a finite set of classification that represent the land surface types seen in the image. This categorized data may then be used to produce thematic maps of the land cover present in an image.

There are two main methods of image classification namely the Supervised and Unsupervised Classification techniques as described by Alrababah and Alhamad (2006).

### 2.7.1 Unsupervised Classification

In unsupervised classification, image processing software classifies an image based on natural groupings of the spectral properties of the pixels, without the user specifying how to classify any portion of the image. Conceptually, unsupervised classification is similar to cluster analysis where observations (in this case, pixels) are assigned to the same class because they have similar values. The user must specify basic information such as which spectral bands to use and how many categories to use in the classification, or the software may generate any number of classes based solely on natural groupings.

Unsupervised classification yields an output image in which a number of classes are identified and each pixel is assigned to a class. These classes may or may not correspond well to land cover types of interest, and the user will need to assign meaningful labels to each class. Unsupervised classification often results in too many land cover classes, particularly for heterogeneous land cover types, and classes often need to be combined to create a meaningful map. In other cases, the classification may result in a map that combines multiple land cover classes of interest, and the class must be split into multiple classes in the final map. Unsupervised classification is useful when there is no pre-existing field data or detailed aerial photographs for the area and the user cannot accurately specify training areas of known cover type. Additionally, this method is often used as an initial step prior to supervised classification (called hybrid classification). Hybrid classification may be used to determine the spectral class composition of the image before conducting more detailed analyses and to determine how well the intended land cover classes can be defined from the image.

### 2.7.2 Supervised Classification

In supervised classification, the image processing software is guided by the user to specify the land cover classes of interest. The user defines “training sites” – areas in the map that are known to be representative of a particular land cover type – for each land cover type of interest. The software determines the spectral signature of the pixels within each training area, and uses this information to define the mean and variance of the classes in relation to all of the input bands or layers. Each pixel in the image is then assigned, based on its spectral signature, to the class it most closely matches. It is important to choose training areas that cover the full range of variability within each land cover type to allow the software to accurately classify the rest of the image. Some of the more common classification algorithms used for supervised classification includes the Minimum-Distance to the Mean Classifier, Parallelepiped Classifier and Gaussian Maximum Likelihood Classifier.

Supervised classification can be very effective and accurate in classifying satellite images and can be applied at the individual pixel level or to image objects (groups of adjacent, similar pixels). However, for the process to work effectively, the person processing the image needs to have a priori knowledge (field data, aerial photographs, or other knowledge) of where the classes of interest (e.g., land cover types) are located, or be able to identify them directly from the imagery. This method is often used with unsupervised classification in a process called hybrid classification.

## 2.8 Methods of mapping wetlands

### 2.8.1 On-site Measurement

Wetland mapping using on-site measurements of environmental conditions provides highly detailed data including lists of floral and faunal species, water chemistry, and soil characterization information (Tiner, 1993). The added expense of personnel, equipment, and time rarely justifies the more detailed level of data collected through on-site evaluations when mapping wetlands at a landscape or watershed scale (Harvey and Hill, 2001).

### 2.8.2 Aerial Photographs

Aerial photographs provide synoptic views of study areas, allowing ‘‘big picture’’ understanding of hydrology and vegetation patterns (Harvey and Hill, 2001). Many concerns are still associated with the use of aerial photos for wetland mapping, despite improvements in the quality of aerial photos. A primary concern with landscape-scale wetland maps derived from aerial photos is the extensive time lapse between imagery acquisition and production of the final wetland map (Ramsey and Laine, 1997). Repeatability is another concern with human-derived photo-interpretation products. As concern over global wetland resources continues to escalate, so does the need for automated and reproducible wetland maps (Finlayson and van der Valk, 1995). Using quantitatively derived wetland inventory maps such as in change detection analyses reduces inconsistencies associated with human interpretation and thus improves the power to identify actual wetland changes (Baker *et al*., 2006).

### 2.8.3 Digital Image Processing

Multispectral sensors provide data with increased spectral and radiometric resolutions and decreased spatial resolutions compared to conventional aerial photography. Systeme Pour l'observation de la Terre (SPOT) and Landsat are two satellites with sensors that have been used to produce accurate maps of a variety of wetland types in Australia, Canada, and the United States (Sader *et al*., 1995; Narumalani *et al*., 1997, Kindscher *et al*., 1998; Harvey and Hill, 2001; Townsend and Walsh, 2001; Toyra *et al*., 2002). Data from the Indian Remote Sensing Satellite–Linear Imaging Self Scanning II (IRS–LISS-II) multispectral sensor were used to map wetland meadows in Grand Teton National Park, Wyoming, USA. The lack of middle infrared (MIR) detection on the IRS instrument inhibited the detection of vegetation and soil moisture, which are distinctive features of wetland areas (Johnston and Barson, 1993; Mahlke, 1996).

There are two principal methods of image processing namely:

**Automated Methods:**

The automated methods are based on using one and more of the following: (a) slope derived from Space Shuttle Radar Topographic Mission (SRTM), (b) Tasseled cap Wetness Index (TCWI), (c) Normalized Difference Water Index (NDWI), (d) multi-band vegetation indices (MBVIs), (e) two band vegetation indices (TBVIs), (f) normalized difference vegetation index (NDVI), (g) data fusion involving Enhanced Thematic Mapper Plus (ETM+) and SRTM and then classifying the same. The best of these indices or methods provide an accuracy of less than 30 percent with high errors of omissions and\or commissions (Kulawardhana *et. al.*, 2007)

**Semi-automated Methods**

The semi-automated methods consist of 3 key techniques: (a) image enhancements to highlight wetlands, (b) image display to discern precise boundaries of wetlands, and (c) digitizing directly off screen to separate wetlands from their neighboring landscape. The most useful displays of ETM+ image enhancements (e.g., ratios) and band combinations, displayed as false color composite (FCCs) of red green and blue (RGB) were: (a) Near Infrared/ Short-wave infrared (NIR/SWIR2), NIR/red, NIR/green; (b) NIR, Red, SWIR1; and (c) red, green, blue. The near-infrared (NIR) is centered at 0.825 μm and the short-wave Infrared bands 1 and 2 (SWIR1 and SWIR2) are centered at 1.650 μm and 2.22 μm. The SRTM slope threshold of less than 1 percent was also very useful in delineating higher-order floodplain wetland boundaries (Kulawardhana *et. al.*, 2007)

Islam *et al*., (2007) used semi automated methods to map out wetlands for the Ruhuna river basin in Sri Lanka using Landsat ETM+ and SRTM data. The basin has a diverse landscape ranging from sea shore to hilly areas, flat to very steep slopes (0 to 50º), arid to semi-arid zones, and rain fed to irrigated lands. The overall accuracies of wetland classes varied between 87-94 percent with errors of omission less than 13 percent and errors of commission less than 1 percent.

Kulawardhana *et al.*, (2007) evaluated both semi automated and automated methods of mapping wet lands using Landsat ETM+ and SRTM data in the Limpopo river basin of Botswana, Zimbabwe, South Africa and Mozambique. Many of the automated approaches were useful in delineating open water bodies of large surface areas, flood plains, and associated wetlands. Performance of ETM+ data in delineating wetlands using semi-automated methods was similar to that of 1:250,000 topographic maps but misses a large number of wetlands when compared to 1:50,000 topographic maps. None of the methods were, however, effective in delineating the wetlands of smaller widths, especially the riverine wetlands associated with the lower order streams in upper reaches of the basin. They also failed in delineating many of the localized wetland areas of smaller sizes and the wetlands of seasonal occurrence. As a result, the wetlands delineated by automated approaches showed very low accuracies and\or very high errors. The total area of wetlands delineated within the basin was 5.2 million hectares (Mha) which accounts for 12.5 percent of the total basin area of 41.5 million hectares and included: (a) seasonal and perennial, (b) large flood plains, (c) small inland valleys along the lower order streams, (d) pans or natural depressions, and (e) human made irrigation systems.

Gumma *et al*., (2009) also used the semi-automated method using Landsat ETM+, Ikonos and SRTM data. Spatial models were developed and used to select suitable sites for inland valley rice cultivation. The study was conducted in Tamale and Kumasi in the Northern and Ashanti Regions of Ghana respectively. Spatial data layers were developed for each parameter and were assigned weights based on expert knowledge before they were fed into the model. The model results showed that only 3-4% of the total Inland Valley wetland areas were highly suitable for rice cultivation but 39-47% of the total Inland Valley wetland areas were suitable for rice cultivation. This can be compared to what Kuria *et al*. (2011) did to determine suitable areas for growing rice in the Tana delta in Kenya.

Kuria *et al.* (2011) also used GIS to determine suitable areas for growing rice in the Tana delta in Kenya. The evaluation of land in terms of the suitability classes was based on the method as described in FAO guidelines for land evaluation for rain fed agriculture. Land forms, agricultural lands, soil texture, soil sodicity and salinization of the soils and slope generated from DEM of the area were the parameters they considered in their study. A rice suitability map was prepared identifying the various areas in four classes namely; (1) most suitable, (2) suitable, (3) less suitable and (4) unsuitable for rice cultivation.

Perveen *et al.* (2005) used the Multi-Criteria Evaluation and GIS approach to determine land suitability for rice cultivation in Haripur Upazila, Thakurgaon district of Bangladesh. The parameters they considered included; six soil parameters (soil texture, soil moisture, soil consistency, soil pH, soil drainage and soil organic matter), slope and land type. Expert opinion was used to assign weights to the parameters based on relative importance of one parameter over the other. The results obtained from the study indicated that the integration of remote sensing, GIS and application of Multi-Criteria Evaluation could provide a superior database and guide map for decision makers considering crop substitution in order to achieve better agricultural production.

# CHAPTER THREE

# MATERIALS AND METHODS

This chapter presents the materials and methods used in determining the most sensitive data and carrying out the study in the Brong Ahafo Region and Western Region sites. Here, the methodology used in collecting secondary and field data such as soil sampling, field survey to collect socio-economic data, development of spatial layers are elaborated. Also methods of soil analysis are presented.

## 3.1 Study area

The field study was carried out in the Brong Ahafo and Western Regions and the results compared to that of Gumma *et al*., (2009) for the Northern and Ashanti Regions of Ghana. The Brong Ahafo Region site is located in the Kintampo North District between latitude 8º 14' 59''N and 8º 6' 45''N and longitude 1º 44' 24''W and 1º 36' 11''W (Figure 3.1). It covers an area of about 225km² and located at about 7.5km from the district capital Kintampo, along the Kintampo-Tamale highway. The Western Region site is located in the Elembele District between latitude 5 º 5' 59''N and 4 º 57' 49''N and longitude 2 º 28' 34''W and 2 º 20' 25''W (Figure 3.1). It also covers an area of about 225km$^2$ and is located at about 3.5km from the district capital Essiama, along the Essiama-Aiyinase highway.

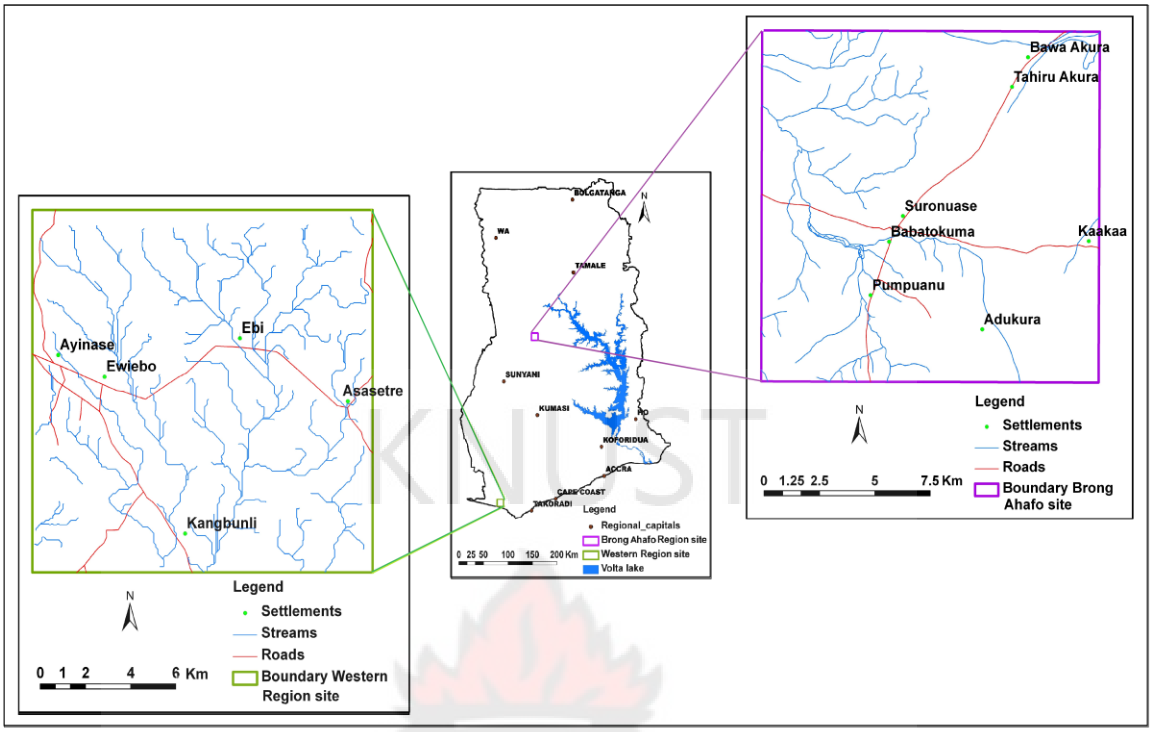


Figure 3.1: Location map of study areas

### 3.1.2 Soils

Soil types in the Brong Ahafo Region site consist of Dystric leptosols (Bramin), Dystric fluvisols (Sene), Dystric planosols (Gulo), Eutric gleysols (Kupela), Plinthic lixisols (Kpelesawgu) and Ferric lixisols (Murugu). Soil types in the Western Region site consist of Xanthic ferralsols (Atuabo), Dystric fluvisols (Sene), Haplic arenosols (Beraku), Eutric gleysols (Kupela) and Gleyic arenosols (Brenyasi). The distribution of soil types in the two study areas are shown in Figure 3.2.

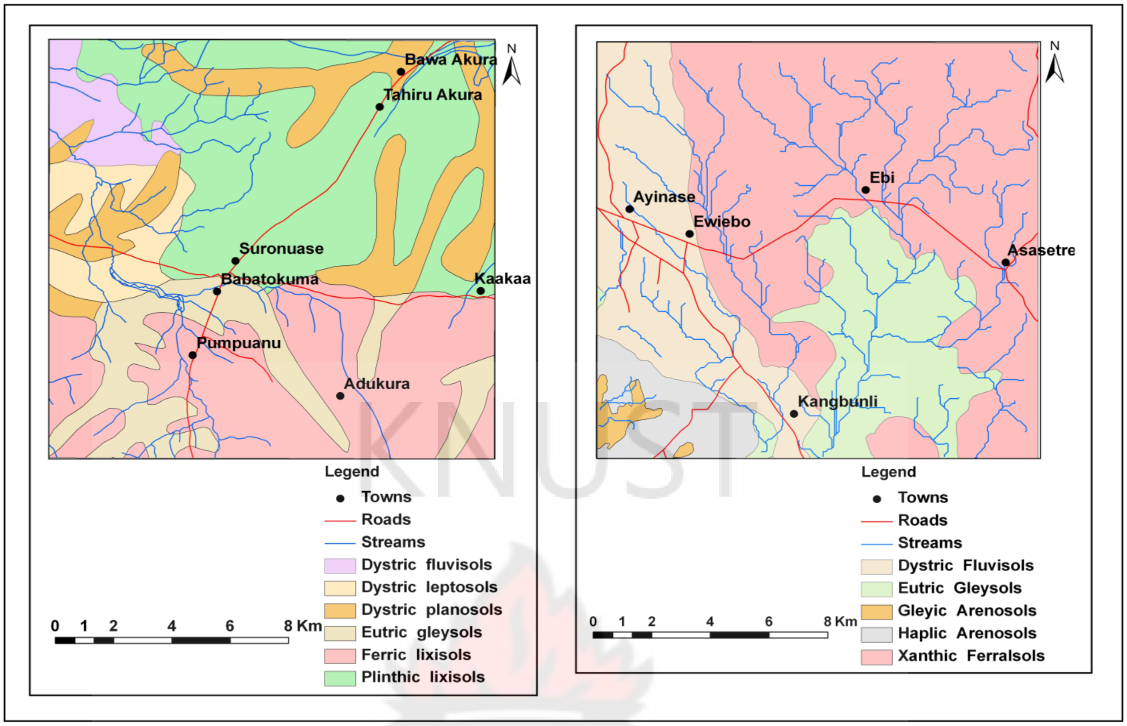


Figure 3.2: Soil map of study areas

### 3.1.3 Climate

The Brong Ahafo Region site experiences a modified Tropical Continental climate or modified Wet Semi-equatorial climate. This is because the site lies in the transitional zone between the Wet Semi-equatorial and Tropical Continental climates. The site experiences two seasons namely raining and dry. The raining season has double maxima (peak) rainfall pattern (i.e. major and minor). The major raining season starts in early March and reaches its peak in June, and tapers off gradually through July. The minor season starts in late August and reaches its peak in September/November. The mean annual rainfall ranges from 1150 mm to 1250 mm (Kintampo weather station). The mean daily temperature in the area is about 24ºC in August and 30ºC in March. The relative humidity is high, varying from 90-95% in the rainy season.

The Western Region site lies in the equatorial climatic zone and experiences a double maxima rainfall pattern averaging 1,600 mm per annum (Aiyinase weather station). The two rainfall peaks fall between May-July and September-October. In addition to the two major rainy seasons, the site also experiences intermittent minor rains all year round. This high rainfall regime creates high moisture conditions culminating in high relative humidity, ranging from 70-90% throughout the year. The mean daily temperature in the area is about 20ºC in August and 29ºC in March.

### 3.1.4 Vegetation

The vegetation of the Brong Ahafo Region site falls under the Woody Savannah Zone. However, due to its transitional nature the area does not exhibit typical savannah conditions. It is heavily wooded with relatively taller trees in contrast to trees in the typical savannah grassland areas of the north but shorter than the deciduous forest areas of the south. The type of tree species prevalent in the site includes the Mahogany (*Khaya seneqalensis*), Odum (*Chloiphora excelsa*), Shea (*Vitellaria paradoxa*), Wawa (*Triplochiton scleroxylon*), Dawadawa (*Parkia biglobosa*) etc. These trees are adapted to the environment but are dispersed.

The vegetation of the Western Region site is made up of the moist semi-deciduous rain forest. It is heavily wooded with dense forest containing very tall trees as compared to the ones in the Brong Ahafo site. The site is dominated with plantations of rubber (*Hevea brasiliensis*), oil palm (*Elaeis Guineensis*) and coconut (*Cocos nucifera*).

### 3.1.5 Geology

The Brong Ahafo Region site falls within the Voltaian Basin. The Voltaian Basin is made up of flat-bedded rocks and is extremely plain with rolling and undulating land surface consisting principally of sandstones, shales, mudstones and limestone with an elevation of between 60-150 m above sea level.

The Western Region site falls within the Tarkwaian Group. Tarkwaian rocks are generally confined to belts of Birimian volcanic rocks where they occur as either fault-bounded slices or as unconformably overlying sequences.

## 3.2 Sensitivity Analysis

Sensitivity analysis was carried out on the input parameters used by Gumma *et al.*, (2009) in an earlier study in the Ashanti and Northern Region to obtain critical input parameters to determine the most suitable inland valleys for rice cultivation. These input parameters were slope, Land tenure, Post harvest technology, Markets, Stream order, Labour force, Incentive net benefit, Minor settlement, Length of rice growth, Credit system, Land use land cover, Major settlement, Rainfall, Malaria, Minor roads, Water management technology, Agro technology, Experience in rice cultivation, Specific discharge, Extension systems, Major roads, Potential evapotranspiration for the Ashanti Region and Soil fertility, Slope, Stream order, Length of rice growth, Soil series, Rainfall, Major markets, Minor markets, Potential evapotranspiration, Soil depth, Minor settlement, Major settlement, Major roads, Minor roads, Land use land cover and malaria for the Northern Region.

The analysis was carried out in two stages. Sensitivity of the input parameters was carried out to determine the most sensitive parameters used for the Northern Region and Ashanti Region sites. Secondly, weights of the selected sensitive parameters were also varied to see how variations in weight affect the highly suitable areas.

The sensitivity analysis was done using a stepwise exclusion method, by excluding one parameter at a time from the model and the highly suitable area estimated. The change in highly suitable area was determined by taking the difference between the estimated area when one parameter was excluded and the area obtained when all the parameters were used in the model. This change in area was ranked and the parameter that causes the least change was taken out completely from the model. This was repeated using the remaining parameters to see which parameters have less effect on the model results.

Sixteen and ten most sensitive parameters gave 315.44 ha and 5.66 ha of highly suitable area for the Ashanti and Northern Region sites respectively as compared to the original results of 326.26ha and 4.48ha respectively. The first ten most sensitive parameters for each site were considered and their weights varied and the change in highly suitable area was estimated and parameters which did not respond much to variations in weights were also left out. The parameters determined to be the most sensitive were used to select highly suitable inland valleys for rice cultivation for the Brong Ahafo and Western Region sites of Ghana.

### 3.3 Data collection

#### 3.3.1 Rainfall

A gridded rainfall data at a spatial resolution of 1km was acquired from WorldClim for the Brong Ahafo and Western Region sites (Hijmans, *et al*. 2005). It was re-sampled in Arc GIS to a spatial resolution of 30m.

WorldClim is a set of global climate layers (climate grids) with a spatial resolution of a square kilometer. They can be used for mapping and spatial modeling in GIS or other computer programs.

#### 3.3.2 Slope and stream order

Slope and stream order for the study sites were derived from the Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) at 90m resolution (CGIAR-CSI, 2008).

#### 3.3.3 Soil sampling

To ensure that soil data is collected evenly across the study area, the sites were gridded at an interval of 3km. After interviewing a farmer, soil sample were taken from his/her farm and at areas where rice farms were absent samples were taken at the grid centre. Samples were taken at a depth of 20cm using the soil auger at about 30 points mixed together for analysis. A hand-held GPS was used to take the mean coordinate of each sample location. The samples were air dried, sieved and analysed for soil pH($H_2O$), Total Nitrogen, Organic matter content, Exchangeable Cations ( $K^+$, $Mg^{2+}$, $Na^{2+}$, $Ca^{2+}$), Exchangeable Acidity, Cation Exchange Capacity (CEC). Locations where soil samples were taken are shown in Figure 3.3

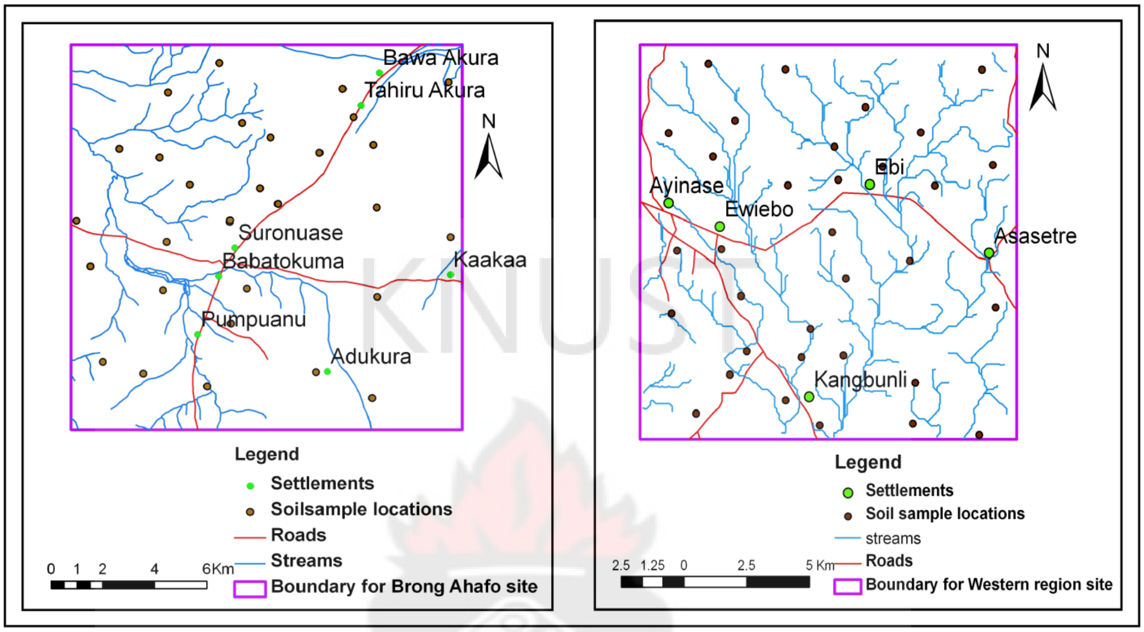


Figure 3.3: Map showing soil sample locations

### 3.3.4 Roads

Road layer for the study area was obtained from the Ghana Survey Department (SDG, 1999). Also a hand held GPS was used to track the routes that were followed during the field work. This was used to update the road layer.

### 3.3.5 Settlements and Markets

Coordinates of settlements and markets within and around the boundary of the study area were taken with a hand-held GPS. The coordinates were taken in the middle of settlements and markets.

### 3.3.6 Length of growing period

Data for Length of growing period was based on a study conducted by the Soil Research Institute and the Ghana Environmental Resource Management Project (SRI-GERMP, 1999). The study categorized length of growing period for rice into five classes based on the minimum number of days required for inland valley rice cultivation in Ghana.

### 3.3.7 Post harvest technology, Credit system, Incentive net benefit and Land tenure

Data for parameters such as Post harvest technology, Credit system, Incentive net benefit and Land tenure were obtained through field surveys using a questionnaire (see Appendix 1). Individual rice farmers were interviewed to determine the methods they use in harvesting rice, threshing rice, how they access credit and how they acquire land for rice cultivation.

### 3.3.8 Field identification of Land use/cover types

An intensive field work was carried out from the 19$^{th}$ June to 1$^{st}$ July 2011 in the Brong Ahafo Region site. During this field work coordinates for eight (8) different land use/cover types at different locations were taken using a hand-held GPS. These included rain fed rice, mixed crops, agricultural plantations, open forest, savannas, bare lands, water bodies and built-up areas. Six GPS coordinates were taken for each land use/cover type. All land use/cover types mapped on the field were evenly distributed over the whole area.

Also, in the Western Region site field work was carried out from 18th August to 1st September 2011. Coordinates for six (6) different land use/cover types were taken using a hand-held GPS. Land use/cover types that were identified include: rain fed rice, agricultural plantations, mixed crops, open forest, water bodies and built-up areas.

### 3.4 Soil analysis

#### 3.4.1 Soil pH

Soil pH was determined in a 1: 2.5 suspension of soil: water using a HI 9017 Micro-processor pH meter. A 20g soil sample was weighed into 100 ml polythene bottle. To this 50 ml distilled water was added from a measuring cylinder and the bottle capped. The solution was shaken on a reciprocating shaker for two hours. After calibrating the pH meter with buffer solutions at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension (Tetteh, 2004). The pH was classified as presented in Table 3.1

Table 3.1: Soil pH classification values

| **Rating** | **Range** |
|---|---|
| Very high | >8.5 |
| High | 7.0-8.5 |
| Medium | 5.5-7.0 |
| Low | <5.5 |

Source: Landon, (1991)

### 3.4.2 Soil organic carbon

Organic carbon was determined by a modified Walkley and Black procedure as described by Tetteh (2004). It involves a wet combustion of the organic matter with a mixture of potassium dichromate and sulphric acid. After the reaction, the excess dichromate is titrated against ferrous sulphate. One gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank were included. Ten milliliter of 1.0 N potassium dichromate solution was added to the soil and the blank flask. To this, 20ml of concentrated sulphuric acid was carefully added from a measuring cylinder, swirled and allowed to stand for 30 minutes in a fume cupboard. Distilled water (250 ml) and concentrated orthophosphoric acid (10.0 ml) were added and allowed to cool. One milliliter of diphenylamine indicator was added and titrated with 1.0 M ferrous sulphate solution.

Calculation

The organic carbon content of soil is:

$$\% \text{ Organic carbon} = \frac{M \times 0.39 \times mcf(V_1 - V_2)}{S} \qquad [3.1]$$

Where M = molarity of ferrous sulphate solution; $V_1$= ml ferrous sulphate solution required for blank; $V_2$= ml ferrous sulphate solution required for sample; S = weight of air-dry sample in grams; mcf = moisture correcting factor (100 + % moisture)/100; 0.39 = 3 x 0.001 x 100% x 1.3 (3= equivalent weight of C); 1.3 = a compensation factor for the incomplete combustion of the organic matter. Data collected were classified based on Table 3.2

Table 3.2: Organic carbon classification values

| Organic carbon content (%) | Rating |
|---|---|
| >20 | Very high |
| 10-20 | High |
| 4-10 | Medium |
| 2-4 | Low |
| <2 | Very low |

Source: Landon, (1991)



### 3.4.3 Total Nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). A 0.5g soil sample was put in a Kjeldahl digestion flask and 5.0 ml distilled water added to it. After 30 minutes, 5.0 ml concentrated sulphuric acid and selenium mixture were added and mixed carefully. The sample was placed on a Kjeldahl digestion appararus for 3 hours until a clear digest was obtained. The digest was diluted with 50.0 ml distilled water and mixed well until no more sediment dissolved and allowed to cool. The volume of the solution was made to 100ml with water and mixed well. A 25 ml aliquot of the solution was transferred to the reaction chamber and 10.0 ml of 40% NaOH solution was added followed by distilled. The distillate was collected in 2% boric acid. The distillate was titrated with 0.02N HCl solution with bromocresol green as indicator. A blank distillation and titration was also carried out to take care of traces of nitrogen in the reagent as well as the water used.

Calculation

The percentage Nitrogen (%N) in the sample was expressed as:

$$\%\ N = \frac{N \times (a-b) \times 1.4 \times mcf}{S} \qquad [3.2]$$

Where N = concentration of HCl used in titration; a = ml HCl used in same titration; b = ml HCl used in blank titration; S = weight of air-dry sample in grams; mcf = moisture correcting factor (100 + % moisture)/100; 1.4 = 1.4 x 0.001 x 100% (14 = atomic weight of Nitrogen). The Nitrogen values were classified as in Table 3.3

Table 3.3: Total nitrogen classification values

| **Total nitrogen** | **Rating** |
|---|---|
| >1.0 | Very high |
| 0.5-1.0 | High |
| 0.2-0.5 | Medium |
| 0.1-0.2 | Low |
| <0.1 | Very low |

Source: Landon, (1991)

### 3.4.4 Exchangeable calcium and magnesium

Exchangeable calcium and magnesium were determined in 1.0M ammonium acetate ($HN_4OAc$) extract (Black, 1986). 25ml portion of the extract was transferred to a 250ml Erlenmeyer flask and the volume made to 50ml with distilled water. Hydroxylamine hydrochloride (1.0ml), potassium cyanide (1.0ml of 2% solution) and potassium ferrocyanide (1.0 ml 2%) were added. After a few minutes, 4ml of 8 M potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01 M EDTA solution to a pure blue colour. Twenty milliliters of 0.01M calcium chloride solution was titrated with 0.01M EDTA in the presence of 25ml 1.0M ammonium acetate solution to provide a standard pure blue colour.

Calculations:

The calculation of the concentration of calcium + magnesium or calcium follows the equation.

Ca (cmol/kg) $= \frac{0.01\times(V_a - V_b)\times1000}{0.1\times W}$ [3.3]

Mg (cmol/kg) $= \frac{0.01\times(V_a - V_b)\times1000}{0.1\times W}$ [3.4]

Where W = weight in grams of oven – dry soil extracted; $V_a$ = ml of 0.01M EDTA used in the titration; $V_a$ = ml of 0.01M EDTA used in blank titration; 0.01 = concentration of EDTA used. The Exchangeable magnesium was classified based on Table 3.4

Table 3.4: Exchangeable magnesium classification values

| **Exchangeable magnesium** | **Rating** |
|---|---|
| >0.5 | High |
| 0.2-0.5 | Medium |
| <0.2 | Low |

Source: Landon, (1991)

### 3.4.5 Exchangeable potassium and sodium

Exchangeable potassium and sodium were determined in 1.0M ammonium acetate ($HN_4OAc$) extract (Black, 1986). A standard series of potassium and sodium were prepared by diluting both 1000mg/l and sodium solutions to 100mg/l. This was done by taking a 25 ml portion of each into one 250ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15 and 20ml of the 100mg/l standard solutions were put into 200ml volumetric flask respectively. One hundred milliliters of 1.0M $HN_4OAc$ solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5 and 10.0 mg/l for potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0nm respectively.

Calculations

Exchangeable K (cmol/kg) = $\frac{(a-b)\times 250\times mcf}{10\times 39.1\times S}$ [3.5]

Exchangeable Na (cmol/kg) = $\frac{(a-b)\times 250\times mcf}{10\times 23\times S}$ [3.6]

Where a = mg/l of K or Na in the diluted sample percolate; b = mg/l of K or Na in the diluted blank percolate; S = air-dried sample weight of soil in grams; mcf = moisture correcting factor. Table 3.5 presents classification of Exchangeable Potassium.

Table 3.5: Exchangeable Potassium classification values

| **Exchangeable Potassium** | **Rating** |
|---|---|
| 0.4-0.8 | High |
| 0.2-0.4 | Medium |
| 0.03-0.2 | Low |

Source: Landon, (1991)

### 3.4.6 Exchangeable acidity

Exchangeable acidity is defined as the sum of aluminum and hydrogen. The soil sample was extracted with unbuffered 1.0M KCl as described by Page *et al*. (1982). Fifty grams of soil sample was put in a 200ml plastic bottle and 100ml of 1.0M KCl solution added. The bottle was capped and shaken for 2 hours and then filtered. Fifty milliliters portion of the filtrate was taken with a pipette into a 250 ml Erlenmeyer flask and 2-3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1M NaOH until the colour just turned permanently pink. A blank was included in the titration.

Calculation

Exchangeable acidity (cmol/kg) $= \frac{(a-b)\times M\times 2\times 100\times mcf}{S}$ [3.7]

Where a = ml NaOH used to titrate with sample; b = ml NaOH used to titrate with blank; M = Molarity of NaOH solution; S = air-dried soil sample weight in grams; 2 = 100/50 (filtrate/pipette volume); mcf = moisture correcting factor (100 + % moisture)/100

### 3.4.7 Cation Exchange Capacity (CEC)

Cation exchange capacity was determined by the sum of exchangeable bases ($Ca^{2+}$, $Mg^{2+}$, $K^{2+}$ and $Na^{2+}$) and exchangeable acidity ($Al^{3+}$ + $H^{+}$). Table 3.6 presents classification of Cation Exchange Capacity. Table 3.6 presents classification of CEC values.

Table 3.6: CEC classification values

| **CEC** | **Rating** |
|---|---|
| >40 | Very highly |
| 25-40 | High |
| 15-25 | Medium |
| 5-15 | Low |
| <5 | Very low |

Source: Landon, (1991)

## 3.5 Generation of Spatial Layers

A spatial layer is a collection of specific elements, such as roads that can be viewed together with other layers for a complete overview of the area, or separately to give a more specific indication of the presence of that particular element.

### 3.5.1 Rainfall



The re-sampled rainfall data acquired from WorldClim which is already in raster format was reclassified into the following five suitability classes presented in Table 3.7.

Table 3.7: Classification of rainfall for inland valley rice cultivation

| **Rainfall(mm)** | **Suitability class** | **Score** |
|---|---|---|
| <700 | Not suitable | 1 |
| 700-1000 | Marginally suitable | 2 |
| 1000-1300 | Moderately suitable | 3 |
| 1300-1600 | Suitable | 4 |
| >1600 | Highly suitable | 5 |

### 3.5.2 Slope

Slope for the study sites was derived from DEM using the ArcGIS software. The DEM was converted to percentage slope and reclassified into five suitability classes as presented in Table 3.8.

Table 3.8: Slope classification for inland valley rice cultivation

| Slope (%) | Suitability class | Score |
|---|---|---|
| >5 | Not suitable | 1 |
| 3-5 | Marginally suitable | 2 |
| 2-3 | Moderately suitable | 3 |
| 1-2 | Suitable | 4 |
| <1 | Highly suitable | 5 |

### 3.5.3 Stream order

The stream order was derived from the DEM of the study sites using ILWIS software. First sinks in the DEM were filled to remove depressions in the DEM using the "fill" function. This ensures that water flows across the land without any stagnation points. Flow direction was determined using the "flow direction" tool to determine the direction in which water will flow naturally. Flow Accumulation representing the amount of water that drains into a particular cell was determined using the "flow accumulation" tool. Different threshold levels were applied to generate stream network. Threshold is the minimum number of pixels that is considered to constitute a drainage link. The best threshold level was selected through visual interpretations made on the derived stream network. The "Drainage network ordering" tool was used to assign unique values to each stream. Then, the "catchment extraction" tool was used to construct catchments around each stream. This final output was then exported as imagine file into Erdas imagine. The stream orders are classified as in Table 3.9.

Table 3.9: Stream order classification for inland valley rice cultivation

| **Stream order** | **Suitability class** | **Score** |
|---|---|---|
| $1^{st}$ order | Not suitable | 1 |
| $2^{nd}$ order | Marginally suitable | 2 |
| $3^{rd}$ order | Moderately suitable | 3 |
| $4^{th}$ order | Suitable | 4 |
| $5^{th}$ order | Highly suitable | 5 |



### 3.5.4 Soil fertility

The soil data based on the coordinates of the samples was interpolated in ArcGIS using the Inverse Distance Weighted (IDW) technique. It determines the value of an unknown point using the known values of nearer points. The radius of search was set to 12 meaning each interpolated value was determined using the values of 12 known surrounding points. The final output of this was in the raster format and exported as imagine file format. A classification of CEC and organic carbon was done and is presented in Table 3.10.

Table 3.10: CEC and Organic carbon classification for inland valley rice cultivation

| **CEC** | **Organic carbon** | **Suitability class** | **Score** |
|---|---|---|---|
| >40 | >20 | Highly suitable | 5 |
| 25-40 | 10-20 | Suitable | 4 |
| 15-25 | 4-10 | Moderately suitable | 3 |
| 5-15 | 2-4 | Marginally suitable | 2 |
| <5 | <2 | Not suitable | 1 |

### 3.5.5 Roads and Markets

Spatial layers for roads and markets were all created using the "Euclidean distance" tool in Arc GIS. It determines straight line distance from each cell in a raster file to a particular feature say a market. The distances were reclassified into the following five suitability classes in Table 3.11.

Table 3.11: classification of distances for roads and markets

| Distance(meters) | Suitability class | Score |
|---|---|---|
| < 500 | Highly suitable | 5 |
| 500 – 1000 | Suitable | 4 |
| 1000 – 2000 | Moderately suitable | 3 |
| 2000 – 4000 | Marginally suitable | 2 |
| > 4000 | Not suitable | 1 |

### 3.5.6 Length of growth period for rice (LGP)

The Soil Research Institute and the Ghana Environmental Resource Management Project (SRI-GERMP) has categorized Length of growing period for rice based on the minimum number of days required for inland valley rice cultivation in Ghana. Data for this was already in raster format and then shape files for the study site were used to "clip" out the growth period for rice for the study sites. The classification for length of growing period is presented in Table 3.12.

Table 3.12: Classification of length of growing period for inland valley rice cultivation

| Length of growing period(days) | Suitability class | Score |
| --- | --- | --- |
| 90-150 | Not suitable | 1 |
| 150-180 | Marginally suitable | 2 |
| 180-210 | Moderately suitable | 3 |
| 210-240 | Suitable | 4 |
| >240 | Highly suitable | 5 |

Based on this classification, the Brong Ahafo Region site falls within the area considered moderately suitable (181 to 210 days) and the Western Region site falls within the area considered suitable (211 to 240 days) for inland valley rice cultivation.

### 3.5.7 Post harvest technology and Land tenure

Responses from the rice farmers were used to generate layers for post harvest and land tenure. The study area was blocked into regions by digitizing around areas where farmers give the same responses. Taking Post harvest for instance areas where farmers use "tractor trampling" method to thresh rice was blocked and assigned a score with the dominant response taking the highest score. The polygon feature of the area was changed into a line feature before digitizing. After the digitizing it was changed back to a polygon feature then to a raster file and finally exported as an imagine file. Tables 3.13 and 3.14, presents the classification of post harvest technology and land tenure for rice cultivation.

Table 3.13: classification of threshing methods for the Brong Ahafo site

| Methods of threshing rice | Suitability class | Score |
|---|---|---|
| Heap on the ground and beat with stick | Moderately suitable | 3 |
| Tractor trampling | Marginally suitable | 2 |
| Put on tarpaulin and beat with stick | Not suitable | 1 |

Table 3.14: classification of threshing methods for the Western Region site

| Methods of threshing rice | Suitability class | Score |
|---|---|---|
| Put in a bag and beat with stick | Suitable | 4 |
| Heap on the ground and beat with stick | Moderately suitable | 3 |
| Beat against a wooden box | Marginally suitable | 2 |
| Put on tarpaulin and beat with stick | Not suitable | 1 |

### 3.5.8 Credit system

Using the procedure used for soil layers that for credit system was determined. Table 3.15 presents the classification for credit systems for the Western Region site.

Table 3.15: Classification for available credit for Western Region site

| Available credit (GH¢) | Suitability class | Score |
|---|---|---|
| 160.00 | Marginally suitable | 2 |
| 0.00 | Not suitable | 1 |

## 3.6 Developing and running the spatial models

The model was developed using the Erdas Imagine Model Maker tool. Erdas Imagine, is a remote sensing software used for digital image processing, analysis and spatial modeling to create new information. The model contains an input, function and an output (Figure3.4). The spatial layers for each of the input parameters were exported and saved as Erdas imagine file before they were incorporated into the model. In the function the spatial layers were combined using Equation [3.8].

$$\sum(score \times weight\ of\ parameter) \quad [3.8]$$

Then an output name was specified before running the model. The digital numbers (DN) in the raster output were converted into percentages using Equation [3.9].

$$(Pixel\ value \div highest\ possible\ weighted\ score) \times 100 \quad [3.9]$$

The percentages were reclassified into five suitability classes as presented in Table 3.16

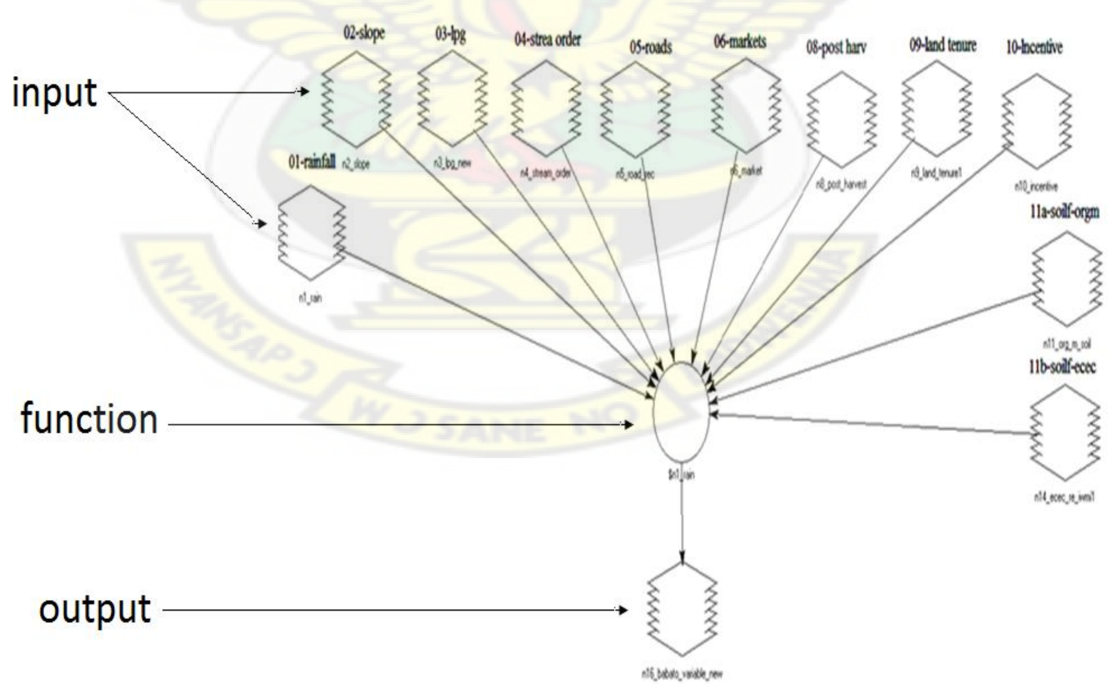


Figure 3.4: A schematic layout of the spatial model built in ERDAS

Table 3.16: Classification of pixel values in percentages

| 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 |

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 given in Table 3.17.

Table 3.17: 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)

### 3.7 Statistical Analysis

This section describes the general statistical procedure used in analyzing data collected from field surveys. The SPSS 10.0 software was used to carry out summary statistics of all data that were collected through field surveys. Minimum, mean, maximum and coefficient of variation were computed for each soil parameter measured.

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

This chapter presents the results and discussions of sensitivity analysis carried out to determine the most sensitive input parameters for inland valley rice cultivation. Based on the most sensitive parameters, model results for land suitability for the Brong Ahafo and Western Region sites are presented. Also results from the original model and the modified version are compared.

## 4.1 Sensitivity analysis

This section presents the results of sensitivity analysis carried out on the data from Ashanti and Northern Region sites.

### 4.1.1 Sensitivity analysis based on the Input Parameters - Ashanti Region site

At Ashanti Region site, the analysis started with 22 input parameters that were reduced to 10. Table 4.1 presents the changes in highly suitable area obtained each time a parameter is excluded from the model and ranked in descending order. The exclusion of Potential evapotranspiration gave the least change of 0.39 ha for the Ashanti Region site. A sample calculation on how the change in highly suitable area was calculated in shown in equation 4.1.

Change in highly suitable area = a – b [4.1]

Where

a − Highly suitable area estimated using all 22 parameters

b − Highly suitable area estimated after Potential evapotranspiration have been excluded

Change in highly suitable area = 326.26 − 325.87 = 0.39ha

Table 4.1: Changes in highly suitable area and corresponding rank by successive exclusion

| **Parameters used** | **Change in highly suitable area(ha)** | **Rank** |
|---|---|---|
| All – Slope | 513.48 | 1 |
| All – Land tenure | 291.42 | 2 |
| All – Post harvest tech | 279.03 | 3 |
| All – Markets | 276.85 | 4 |
| All – Stream order | 183.90 | 5 |
| All – Labour force | 145.71 | 6 |
| All – Incentive benefit | 133.08 | 7 |
| All – Minor settlement | 119.14 | 8 |
| All – Length of rice growth | 111.00 | 9 |
| All – Credit system | 91.33 | 10 |
| All – Land use land cover | 87.53 | 11 |
| All – Major settlement | 78.31 | 12 |
| All – Rainfall | 52.16 | 13 |
| All – Malaria | 50.98 | 14 |
| All – Minor roads | 49.06 | 15 |
| All – Water mang't technology | 47.54 | 16 |
| All – Agro technology | 47.54 | 17 |
| All – Experience in rice cultivation | 32.43 | 18 |
| All – Specific discharge | 28.55 | 19 |
| All – Extension systems | 25.05 | 20 |
| All – Major roads | 10.25 | 21 |
| All – Potential evapotranspiration | 0.39 | 22 |

All: All parameters, (–): Minus sign

The exclusion of Potential evapotranspiration resulted in the least change in highly suitable area of 0.39ha as presented in Table 4.1. Potential evapotranspiration was completely excluded and the procedure repeated using the remaining parameters. The exclusion of water management, minor settlement, extension system, stream order, major roads and major settlement from the remaining parameters resulted in changes in highly suitable area of 0.39, 2.22, 8.16, 12.34, 2.45, 3.43 and 10.82 ha respectively as presented in Figure 4.1A, 4.1B, 4.1C, 4.1D 4.1E, and 4.1F respectively.

Figure 4.1 presents the change in highly suitable area each time a parameter was excluded from the model. The first point in the figure directly above the slope parameter indicates the change in highly suitable area obtained when all the remaining parameters ware used to run the model without the slope parameter (Figure 4.1(A)).

A change of 10.82 ha in highly suitable area was obtained after the removal of Potential evapotranspiration, Water management technology, minor settlements, Extension system, Stream order, Major roads and Major settlements from the model. The highly suitable area obtained at this stage was 315.44 ha with only 3.3% change in area as compared to the original results of 326.26 ha.

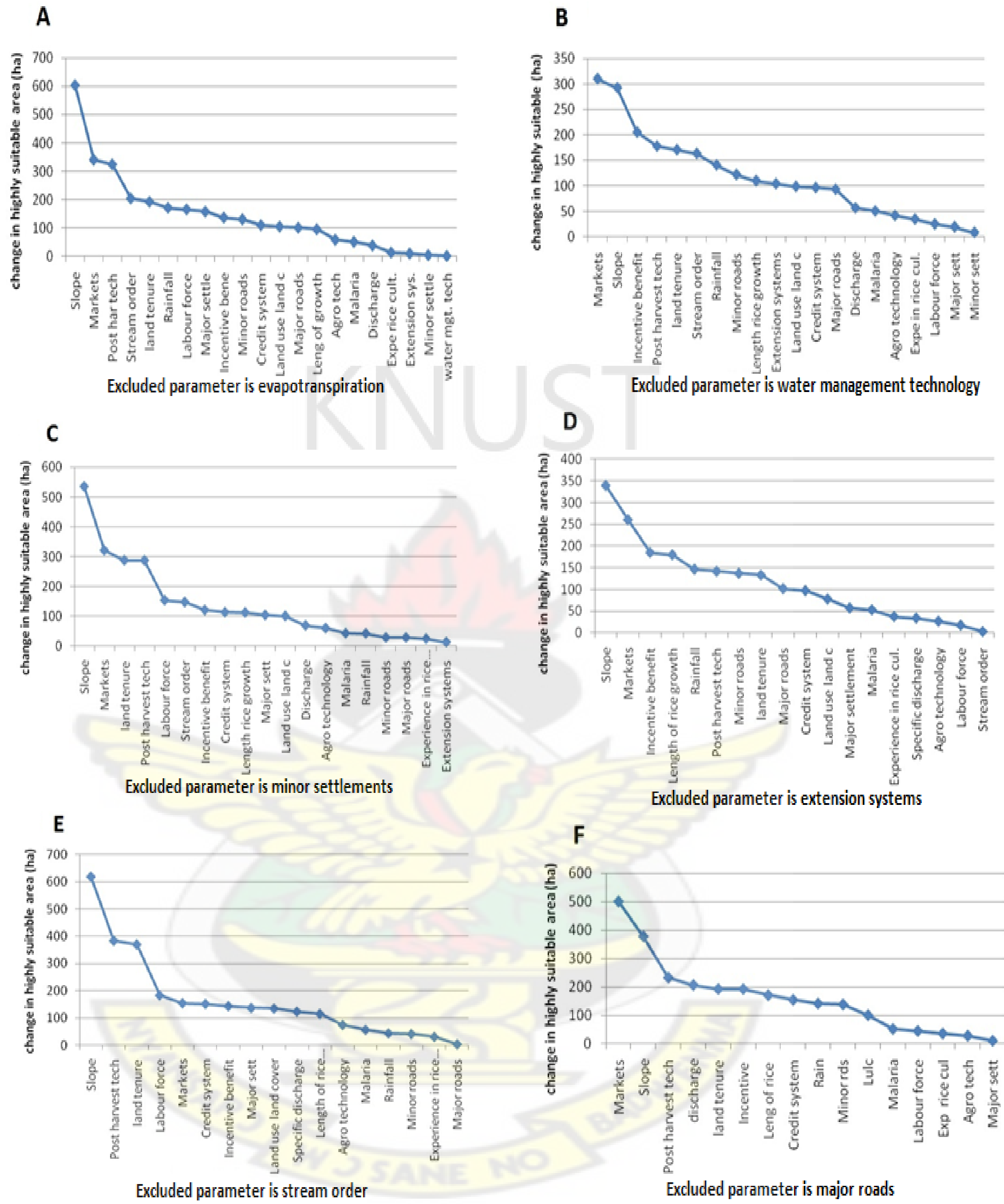




Figure 4.1: Changes in highly suitable area caused by successive exclusion of parameters after: evapotranspiration (A), water management technology (B), minor settlement (C), extension system (D), stream order (E) and major roads (F) were removed.

### 4.1.2 Sensitivity analysis based on the Input Parameters – Northern Region site

At the Northern Region site the analysis started with 16 input parameters that were reduced to 10. Table 4.2 presents the changes in highly suitable area obtained each time a parameter is excluded from the model and ranked in descending order. The exclusion of Malaria gave no change in highly suitable area for the Northern Region site as presented in Table 4.2.



Table 4.2: Changes in highly suitable area and corresponding rank by successive exclusion of parameters.

| **Parameters used** | **Change in highly suitable area(ha)** | **Rank** |
|---|---|---|
| All – Soil fertility | 40.12 | 1 |
| All – Slope | 14.15 | 2 |
| All – Stream order | 10.69 | 3 |
| All – Length of rice growth | 3.96 | 4 |
| All – Soil series | 3.02 | 5 |
| All – Rainfall | 2.90 | 6 |
| All – Major markets | 2.90 | 6 |
| All – Minor markets | 2.90 | 6 |
| All – Potential evapotranspiration | 2.53 | 7 |
| All – Soil depth | 2.53 | 7 |
| All – Minor settlement | 2.53 | 7 |
| All – Major settlement | 2.53 | 7 |
| All – Major roads | 2.53 | 7 |
| All – Land use land cover | 1.18 | 8 |
| All – Minor roads | 0.24 | 9 |
| All – Malaria | 0.00 | 10 |

All: All parameters (–): Minus sign

Also the exclusion of Minor roads, Evapotranspiration, Length of rice growth and Major roads resulted in no change in the highly suitable area. This is presented in Figure 4.2A, 4.2B, 4.2C, 4.2D and 4.2E. Then the exclusion of Land use land cover gave a change of 1.18 ha in highly suitable area.

Figure 4.2A illustrates the change in highly suitable area each time a parameter was excluded from the model. The first point in the figure directly above the soil fertility parameter indicates the change in highly suitable area obtained when all the remaining parameters are used to run the model with the exception of soil fertility and already removed malaria (Figure 4.2 (A)).

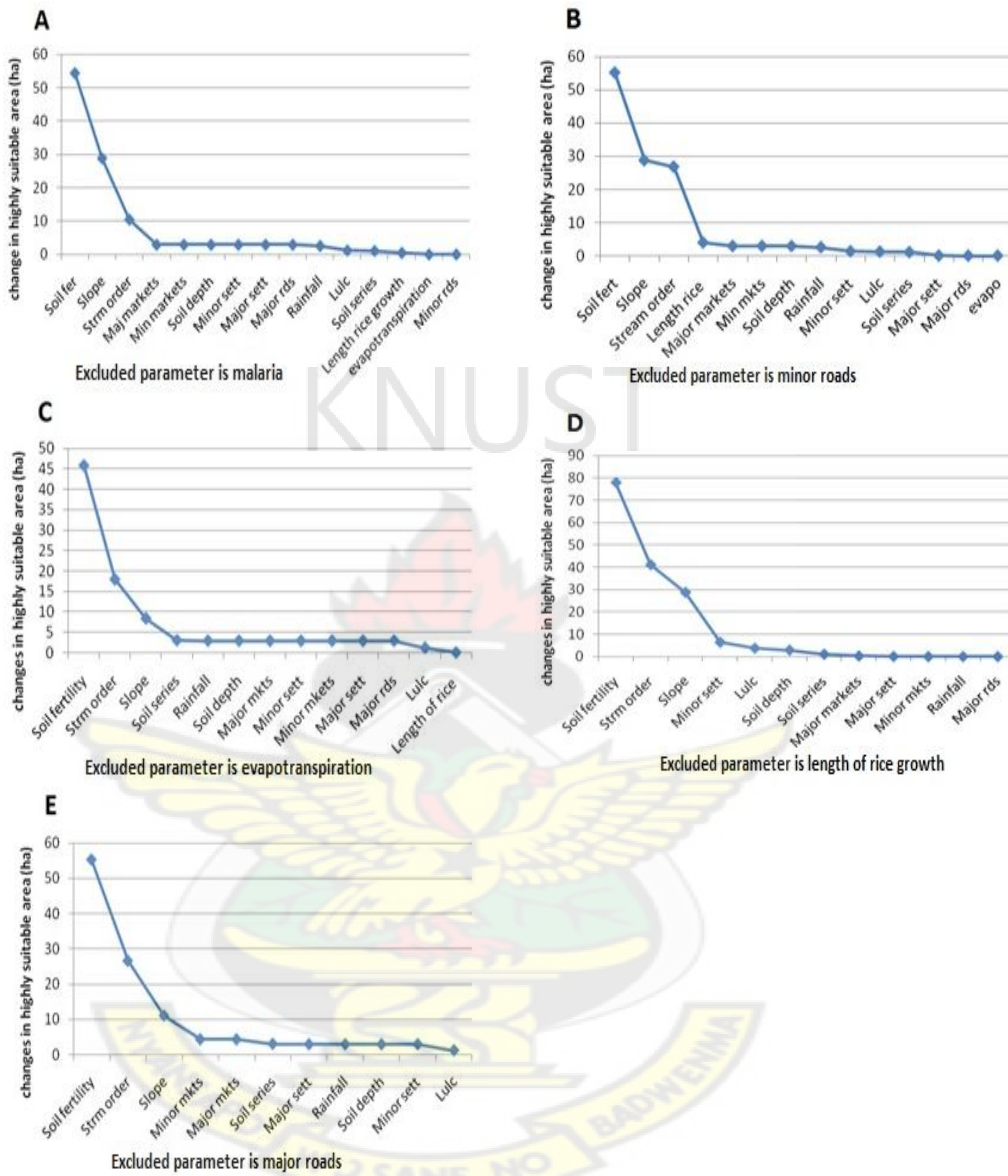




Figure 4.2: Changes in highly suitable area caused by the successive exclusion of parameters after malaria (A), minor roads (B), evapotranspiration (C), length of rice growth (D) and major roads (E) were removed.

### 4.1.3 Most sensitive parameters

Table 4.3 presents the ten most sensitive parameters in decreasing order of importance for the Ashanti and Northern Region sites respectively. Since the main objective is to limit the input parameters to the most sensitive ones and to obtain a set of uniform input parameters for the Brong Ahafo and Western Region site the first ten most sensitive parameters from the Ashanti and Northern Region sites were considered and their weights varied.



Table 4.3: Ten most sensitive input parameters for the Ashanti and Northern Region sites

| Rank | Ten most sensitive parameters for the Ashanti Region site | Ten most sensitive parameters for the Northern Region site |
|---|---|---|
| 1 | Markets | Soil fertility |
| 2 | Slope | Stream order |
| 3 | Post harvest tech | Slope |
| 4 | Specific discharge | Minor markets |
| 5 | Land tenure | Major markets |
| 6 | Incentive net benefit | Soil series |
| 7 | Length of rice growth | Major settlement |
| 8 | Credit system | Rainfall |
| 9 | Rainfall | Soil depth |
| 10 | Minor roads | Minor settlement |

### 4.1.4 Sensitivity of input parameters to weights

Figure 4.3 and Figure 4.4 presents changes in highly suitable area resulting from variations in the weights of the ten most sensitive parameters for both the Ashanti and Northern Region sites. It was observed that soil series, soil depth and major settlement did not respond much to variation in weights. However significant changes in highly suitable area were noted when the weights of soil fertility, specific discharge, land tenure, credit system, postharvest technology, incentive net benefit, length of rice growth, minor roads, slope, rain, markets and stream order were varied.

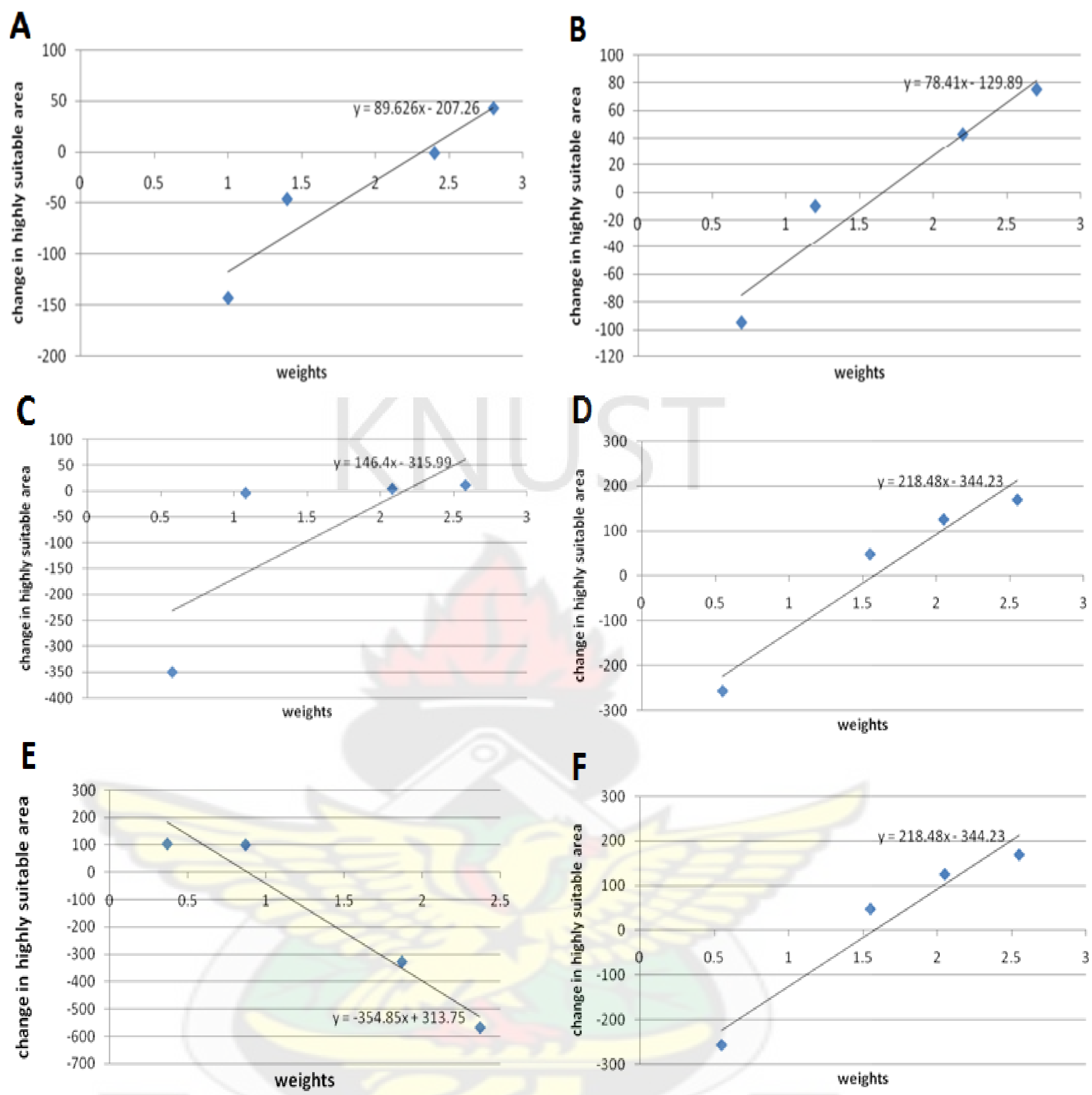


Figure 4.3a: Changes in highly suitable area caused by variations in the weights of sensitive parameters for the Ashanti Region site: discharge (A), land tenure (B), credit system (C), post harvest technology (D), incentive (E) and length of rice growth (F)

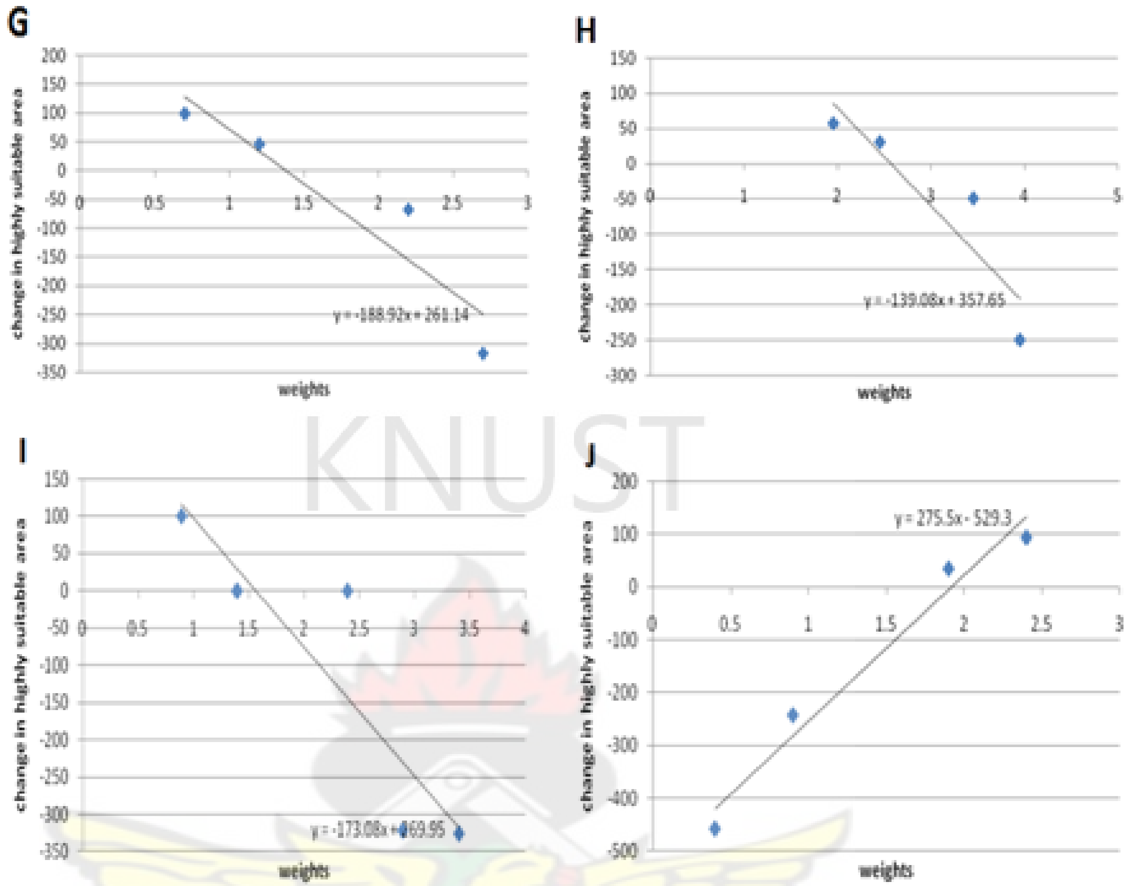


Figure 4.3b: Changes in highly suitable area caused by variations in the weights of sensitive parameters for the Ashanti Region site: roads (G), slope (H), rainfall (I) and markets (J)

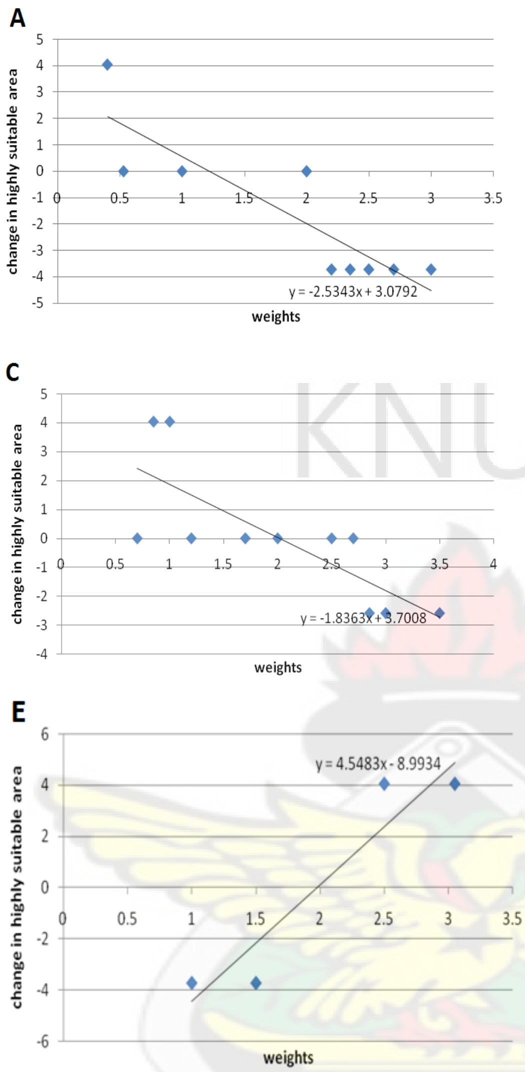


Figure 4.4: Changes in highly suitable area caused by variations in the weights of sensitive parameters for the Northern Region site: soil series (A), soil depth (B), settlements (C), soil fertility (D) and stream order (E)

Varying weights for the ten sensitive parameters (Table 4.3), it was observed that soil series, soil depth and major settlements did not respond much to changes in weight.

Variations in the weight of soil depth do not have an effect on the highly suitable area except when the weight is 1.2 or below. Soil depth of weights 1.2, 0.8 and 0.4 all gave a change of 4.04 ha of highly suitable area. This means that changes in the weight have little effect on the highly suitable area as presented in Figure 4.3(B).

Variations in the weight of major settlement gave change in highly suitable area when the weight was greater or equal to 2.85 and less or equal to 1. Major settlement weights 2.85, 3 and 3.5 all gave the same change of 2.59 ha of highly suitable area. There were also changes when the weight was changed to 1 and 0.85 but the weights between 1 and 2.85 did not give any change in highly suitable area. Thus there was no consistency of changes in weight on highly suitable area based on major settlement.

Significant changes in highly suitable area were observed for the remaining parameters each time the value of the weight was changed. This shows that they are more sensitive than Soil series, Soil depth and Settlement parameters. If soil depth, soil series and settlement are also left out based on the reasons stated above, the remaining sensitive parameters were then used to determine the suitable inland valleys for rice cultivation for the Brong Ahafo and Western Region sites. Finally combining the input parameters from the Ashanti and Northern Region sites, 12 sensitive parameters were selected for use in the Brong Ahafo and Western Region sites: Markets, Slope, Post harvest technology, Specific discharge, Land tenure, Length of rice growth, Incentive net benefit, Credit system, Rainfall, Roads, Soil fertility and Stream order.

## 4.2 Estimating land suitability for the Brong Ahafo Region site

Presented in Table 4.4 are the communities in which rice farmers were interviewed. Majority of the farmers interviewed were from Tahiru Akura representing 32% of the total farmers interviewed. Twenty seven percent of the farmers were from Suronuase, 10% from Bawa Akura and 7.5% each from Mahama Akura, Babatokuma, Nyankuma and Laala Akura.

Table 4.4 Respondent communities in the Brong Ahafo Region site

| **Name of community** | **Number of farmers interviewed** | **Percentage (%)** |
|---|---|---|
| Suronuase | 11 | 27.5 |
| Bawa Akura | 4 | 10.0 |
| Tahiru Akura | 13 | 32.5 |
| Mahama Akura | 3 | 7.5 |
| Babatokuma | 3 | 7.5 |
| Nyankuma | 3 | 7.5 |
| Laala akura | 3 | 7.5 |
| Total | 40 | 100.0 |

Presented in Table 4.5 is the age distribution of respondent farmers in Brong Ahafo Region site. Forty percent of respondent farmers were within 41-50 years, 30% fell within 31-40 years and then 10% each for 18-30, 51-60 and > 60 years.

Table 4.5: Age distribution of respondent farmers in the Brong Ahafo Region site

| Age | Frequency | Percentage (%) |
|---|---|---|
| 18-30 | 4 | 10.0 |
| 31-40 | 12 | 30.0 |
| 41-50 | 16 | 40.0 |
| 51-60 | 4 | 10.0 |
| >60 | 4 | 10.0 |
| Total | 40 | 100.0 |

### 4.2.1 Rainfall for the Brong Ahafo site

Rainfall value for the Brong Ahafo site was the same across the site. It was within the moderately suitable area (1000–1300mm).

### 4.2.2 Slope distribution for the Brong Ahafo site

Presented in Figure 4.6 is the DEM (A) from which slope classes (B) were derived. Areas with slopes not greater than 1% were considered highly suitable for rice cultivation in terms of slope and this constitute about 16% (3631.23ha) of the study area. Areas with slopes ranging from 1-2% were considered suitable for rice cultivation and constitute about 22% (4992.03ha) of the Brong Ahafo Region site.

### 4.2.3 Stream order for the Brong Ahafo Site

Water availability within the study sites was analyzed using the distribution pattern of different stream orders. Typically, Inland valley wetlands occur in 1$^{st}$ to 4$^{th}$ order streams, beyond which they become flood plains (Gumma *et al.*, 2009). The stream orders in the

Brong Ahafo Region site ranged between 1$^{st}$ and 3$^{rd}$ order streams as presented in Figure 4.6(C).

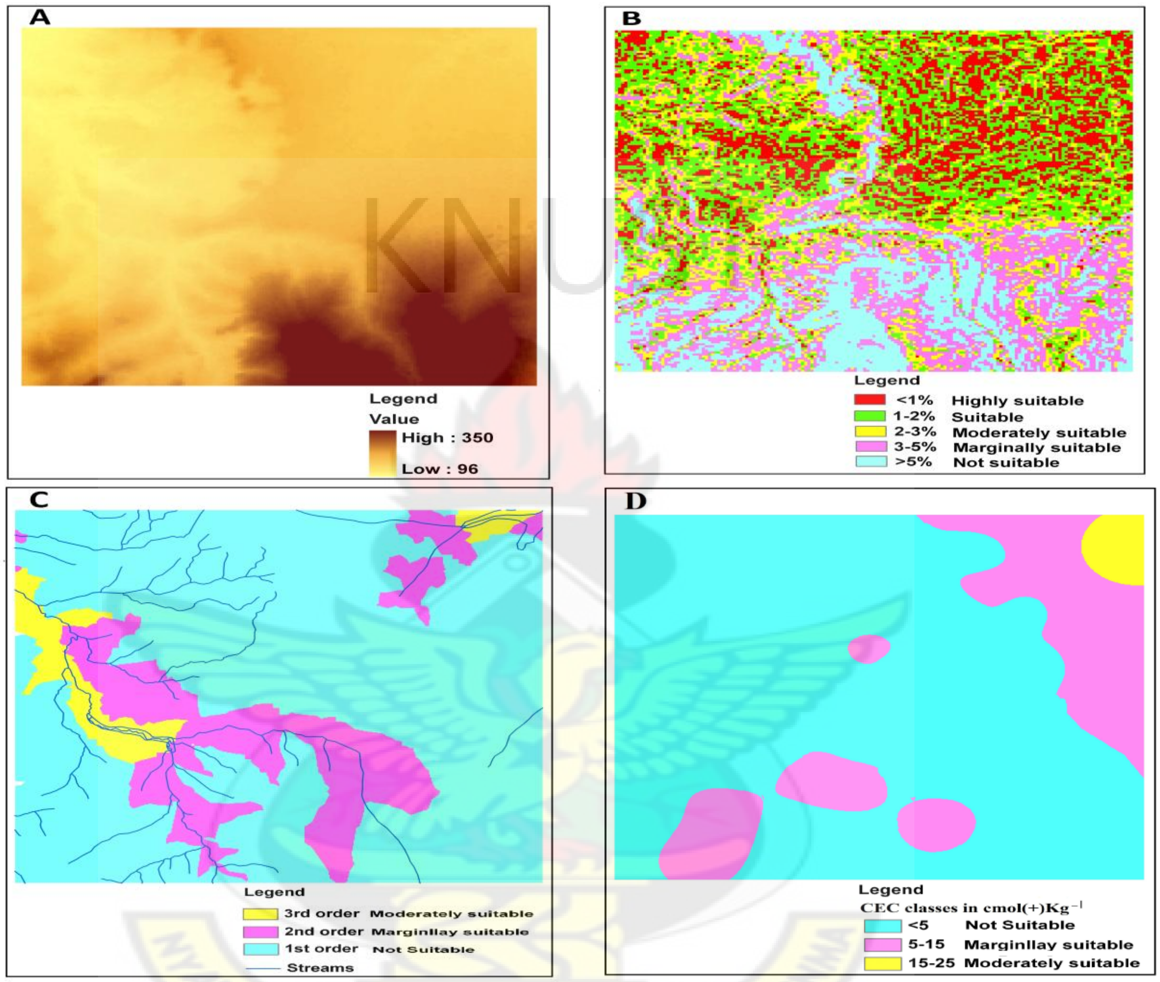


Figure 4.6: Spatial layers for DEM (A), slope (B), stream order (C) and CEC (D) for the Brong Ahafo Region site

### 4.2.4 Analysis of soil properties for the Brong Ahafo site

Presented in Table 4.6 are the mean, maximum, minimum and CV (%) of soil parameters in the Brong Ahafo Region site. Cation Exchange capacity (CEC) and organic carbon were used to generate spatial layers to represent soil fertility parameter.

CEC for the area were generally low with a greater portion of the area having CEC value below 5 cmol(+) $kg^{-1}$ . This means few nutrient reserves are present usually unsuitable for rice, 5-15 cmol(+) $kg^{-1}$ are marginally suitable and 15-25 cmol(+) $kg^{-1}$ are normally satisfactory (Landon, 1991). Organic carbon in the whole area was below 2% (very low). Spatial layer for C.E.C is presented in Figure 4.6D.

Table 4.6: Chemical properties of soils for the Brong Ahafo Region site

| Soil parameter | Number of samples | Mean | Max | Min | CV (%) |
|---|---|---|---|---|---|
| pH($H_2O$) | 30 | 5.94 | 8.0 | 5.2 | 9.6 |
| Organic carbon (%) | 30 | 0.50 | 1.2 | 0.3 | 42.6 |
| Total Nitrogen (%) | 30 | 0.04 | 0.12 | 0.02 | 50.1 |
| Organic matter content (%) | 30 | 0.85 | 2.1 | 0.5 | 42.9 |
| Exchangeable Ca cmol(+) $kg^{-1}$ | 30 | 3.03 | 19.22 | 1.6 | 103.1 |
| Exchangeable Mg cmol(+) $kg^{-1}$ | 30 | 1.4 | 3.87 | 0.1 | 73.0 |
| Exchangeable K cmol(+) $kg^{-1}$ | 30 | 0.1 | 0.5 | 0.06 | 56.8 |
| Exchangeable Na cmol(+) $kg^{-1}$ | 30 | 0.2 | 0.3 | 0.1 | 20.4 |
| T.E.B cmol(+) $kg^{-1}$ | 30 | 4.7 | 23.6 | 2.9 | 79.9 |
| Exchangeable acidity cmol(+) $kg^{-1}$ | 30 | 0.4 | 0.9 | 0.1 | 73.7 |
| C.E.C cmol(+) $kg^{-1}$ | 30 | 5.1 | 23.7 | 3.0 | 71.2 |

### 4.2.5 Roads and Markets for the Brong Ahafo site

Presented in Figure 4.7 are the spatial layers for roads (E) and markets (F). The same distance classes were used with a class interval. The distance indicates the suitability of an area depending on how far it is from the features (roads and markets). Only one market was within the Brong Ahafo site as compared to three in the Western Region site.

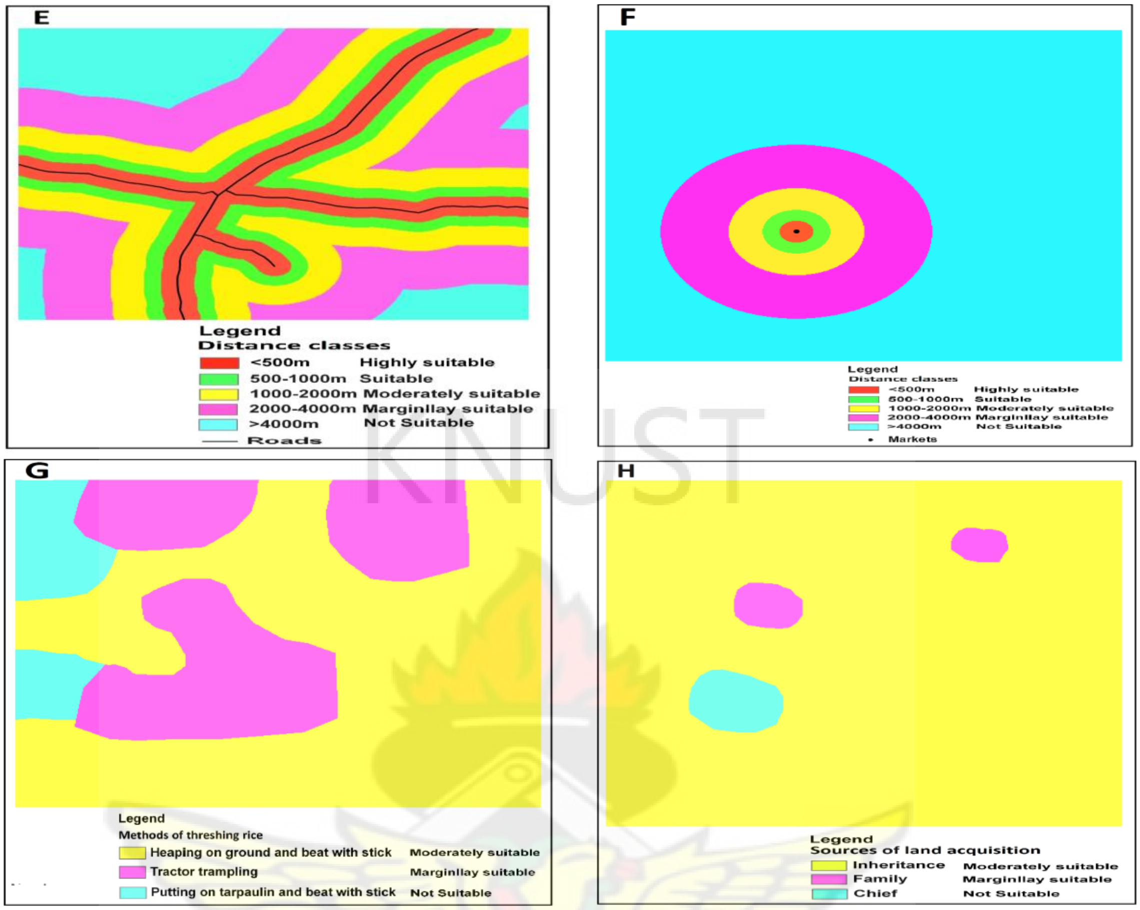


Figure 4.7: Spatial layers for Roads (E), Markets (F), Post harvest technology (G) and Land tenure (H)

### 4.2.6 Length of growth period for rice for the Brong Ahafo Site

Length of growth period for rice in the Brong Ahafo site was the same across the whole area. It is within the class not suitable, ie 90-150 days.

### 4.2.7 Post harvest technology for the Brong Ahafo Site

All the farmers interviewed in the Brong Ahafo Region site use sickle to harvest rice. Presented in Table 4.7 are the methods farmers use to thresh rice. Three methods were identified as: Putting on tarpaulin and beat with stick, heaping on the ground and beat with stick and tractor trampling. The dominant method used is heaping on the ground and beat with stick and this represent 65% followed by 25% for tractor trampling and 10% for those who put on tarpaulin and beat with stick. Though putting on tarpaulin and beat with stick provides better quality than heaping on the ground and beat with stick, majority of the farmers still use the latter due to cost of tarpaulin which may last for only two seasons. Spatial layer for post harvest technology is presented in Figure 4.7G.

Table 4.7: Threshing methods used by farmers in the Brong Ahafo Region site

| Threshing method used | Frequency | Percentage (%) |
|---|---|---|
| Put on tarpaulin and beat with stick | 4 | 10.0 |
| Heap on the ground and beat with stick | 26 | 65.0 |
| Tractor trampling | 10 | 25.0 |
| Total | 40 | 100.0 |

#### 4.2.8 Land tenure for the Brong Ahafo Site

Presented in Table 4.8 are the sources from which farmers acquire land for rice cultivation within the Brong Ahafo Region site. Out of the 40 farmers interviewed, 65% of them acquired the land free (without consulting any chief or family head). These lands were acquired by the government of Ghana for afforestation project but the project was later abandoned. Farmers therefore used the remaining land for cultivating rice and other crops. Fifteen percent inherited their lands from relatives, 10% acquired their land from the chief and 10% use family lands. Only 1 out of the 40 farmers interviewed paid GH₵ 35 for an acre of land from the chief. With the exception of 2 farmers (ie 5%) all the farmers have permanent unrestricted access to land for rice cultivation. The spatial layer for land tenure in the area is presented in Figure 4.7H.

Table 4.8: Sources of land for rice cultivation in the Brong Ahafo Region site

| **Source of land** | **Permanent** | **Annual renewal** | **Total** | **Percentage (%)** |
|---|---|---|---|---|
| Chief | 4 | 0 | 4 | 10 |
| Inheritance | 6 | 0 | 6 | 15 |
| Family | 2 | 2 | 4 | 10 |
| Free | 26 | 0 | 26 | 65 |
| Total | 38 | 2 | 40 | 100 |

### 4.2.9 Credit and Incentive for the Brong Ahafo Site

None of the respondents have ever received credit for rice cultivation. The whole area for the Brong Ahafo site is considered not suitable for rice cultivation in terms of credit system.

Incentive for rice farmers was measured based on yield per acre. Yields in the Brong Ahafo site were generally low. This may be due to the floods that affected parts of the Brong Ahafo region in the year 2010.

### 4.2.10 Model results for the Brong Ahafo Region site

Presented in Table 4.9 are areas and percentages of suitability classes from the model results of the Brong Ahafo Region site. Model results were based on two approaches of equal and unequal weights as explained in Section 3.6. Per the first approach of equal weights, 0.51% (118.5ha) of the total area is highly suitable and 11.8% (2723.5ha) is suitable.

Using the second approach of 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 variable weights was applied. However, the area for suitable and moderately suitable reduced using variable weights. Figure 4.8 shows areas of the suitability classes.

Table 4.9: Land suitability classes in the Brong Ahafo Region site based on equal and unequal weights

| | **Equal weights** | | **Unequal weights** | |
|---|---|---|---|---|
| Suitability | Area(ha) | Percentage (%) | Area(ha) | Percentage (%) |
| Not suitable | 284.7 | 1.2 | 326.9 | 1.4 |
| Marginally suitable | 8000.6 | 34.6 | 12072.1 | 52.2 |
| Moderately suitable | 12007.2 | 51.9 | 8790.7 | 38.0 |
| Suitable | 2723.5 | 11.8 | 1766.9 | 7.6 |
| Highly suitable | 118.5 | 0.51 | 177.9 | 0.8 |

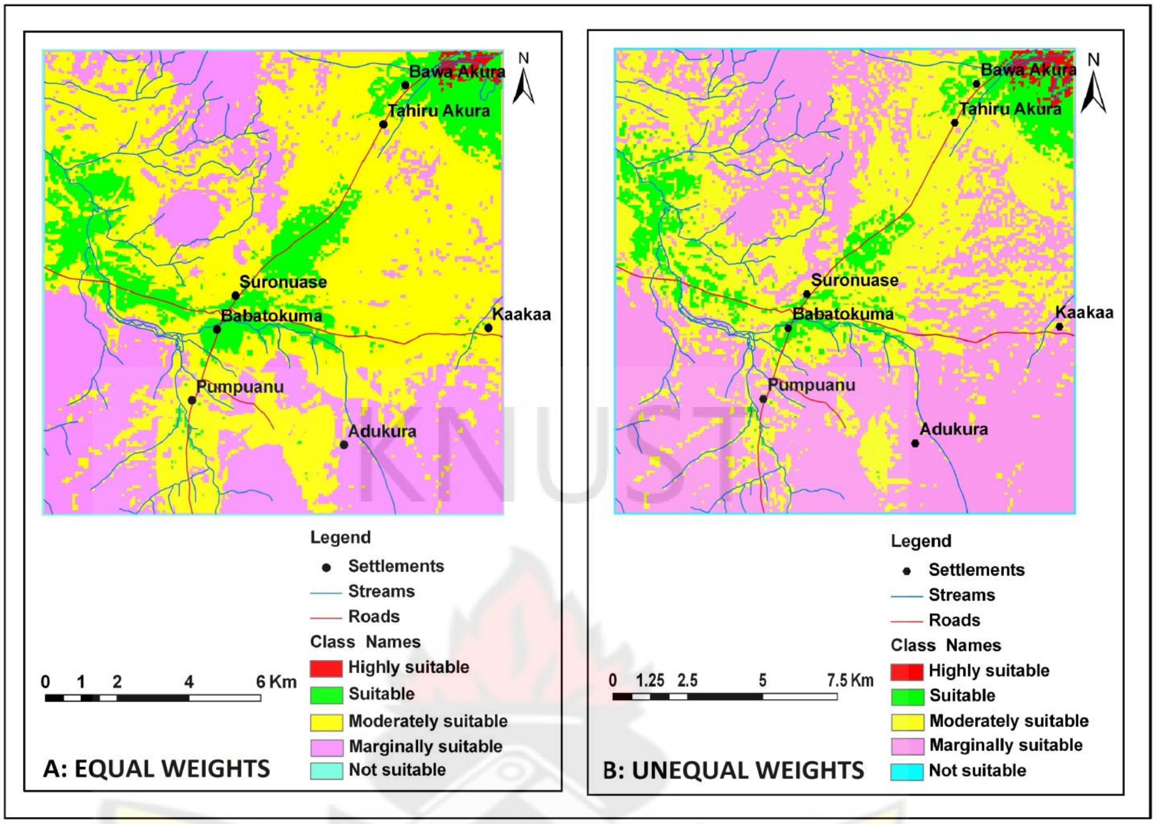


Figure 4.8: Suitability maps for the Brong Ahafo Region site: for equal and unequal weights

While carrying out field surveys, locations of some existing rice farms were measured with a handheld GPS. These points were over laid on the suitability map. It was observed that out of the 18 existing rice farms mapped in the Brong Ahafo Region site, none of the rice farms were within the highly suitable area, 2 within the suitable area, 8 within the moderately suitable area and the remaining 8 were within the marginally suitable area as illustrated in Figure 4.9. This shows that there are limitations to the use of the highly suitable and suitable areas.

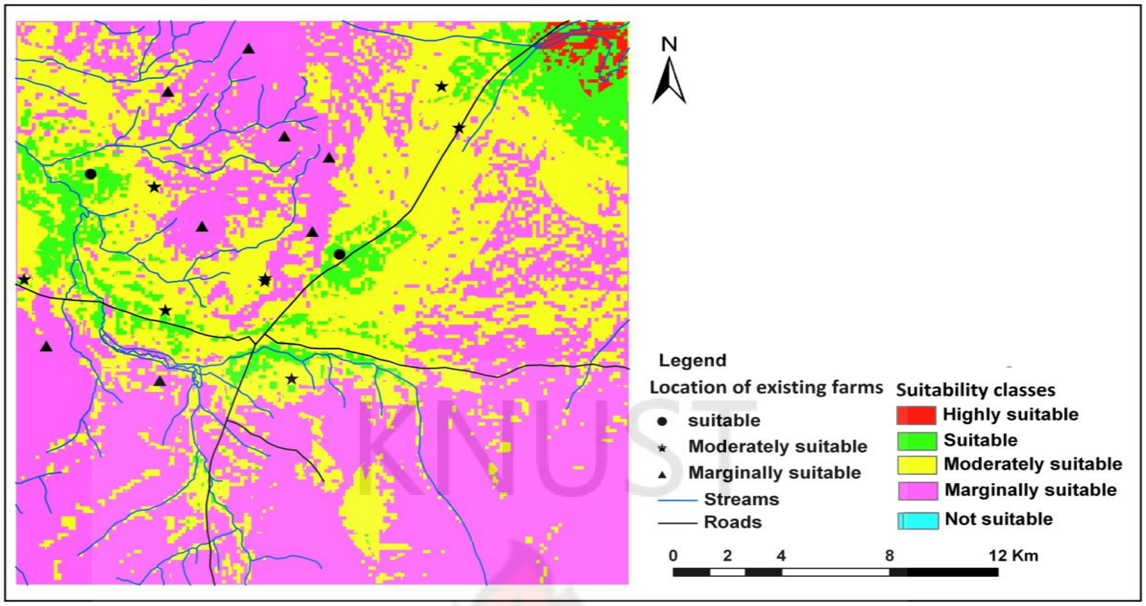


Figure 4.9: Location of existing rice farms on the suitability map of the Brong Ahafo Region site based on unequal weights

## 4.3 Estimating land suitability for the Western Region site

Presented in Table 4.10 are the communities of respondent rice farmers in the Western Region site. Majority of the farmers interviewed were from Kangbunli representing 45.7% of the total farmers interviewed. Twenty percent of the farmers were from Ebi, 14.3% from Aiyinase, 8.6% from Azulenuanu and 5.7% each from Alabokazo and Tandan.

Table 4.10: Respondent communities in the Western Region site

| Name of community | Number of farmers interviewed | Percentage (%) |
|---|---|---|
| Kangbunli | 16 | 45.7 |
| Alabokazo | 2 | 5.7 |
| Azulenuanu | 3 | 8.6 |
| Tandan | 2 | 5.7 |
| Ebi | 7 | 20.0 |
| Aiyinase | 5 | 14.3 |
| Total | 35 | 100.0 |

Presented in Table 4.11 is the age distribution of respondent rice farmers in the Western Region site. Thirty seven percent of the farmers were within 41-50 years, 34.3% fell within 51- 60 years, 20% were within 31- 40 years, 5.7% were above 60 years and 2.9% were within 18- 30 years. The same age group (ie 41-50years) dominated in both study areas, thus 40% and 37% for the Brong Ahafo and Western Region site respectively.

Table 4.11: Age distribution of respondent farmers in the Western Region Site

| Age of farmers | Number of farmers | Percentage (%) |
|---|---|---|
| 18-30 | 1 | 2.9 |
| 31-40 | 7 | 20.0 |
| 41-50 | 13 | 37.1 |
| 51-60 | 12 | 34.3 |
| >60 | 2 | 5.7 |
| Total | 35 | 100.0 |

### 4.3.1 Rainfall for the Western Region site

Rainfall value in the western Region site was the same across the whole site and falls in the area classified as highly suitable for rice in terms of rainfall as it is greater than 1600mm.

### 4.3.2 Slope distribution for the Western Region site

Presented in Figure 4.10 is the DEM (A) from which slope classes (B) were derived. Areas with slopes not greater than 1% occupied about 17.6% (4027.1ha) and are considered highly suitable for rice cultivation, slopes between 1-2% occupied about 10.9% (2479.4ha), slopes 2-3% occupied 3.4% (776.8ha), slopes between 3-5% occupied 20.4% (4641.3ha) and slopes greater than 5% occupied 47.4% (10755.7ha) of the study area. The area is generally hilly.

### 4.3.3 Stream orders for the Western Region Site

Water availability within the study sites was analyzed using the distribution pattern of different stream orders. The streams orders in the Western Region site also ranged between 1$^{st}$ to 3$^{rd}$ order. Spatial layer for stream order in the Western Region site is presented in Figure 4.10(C).

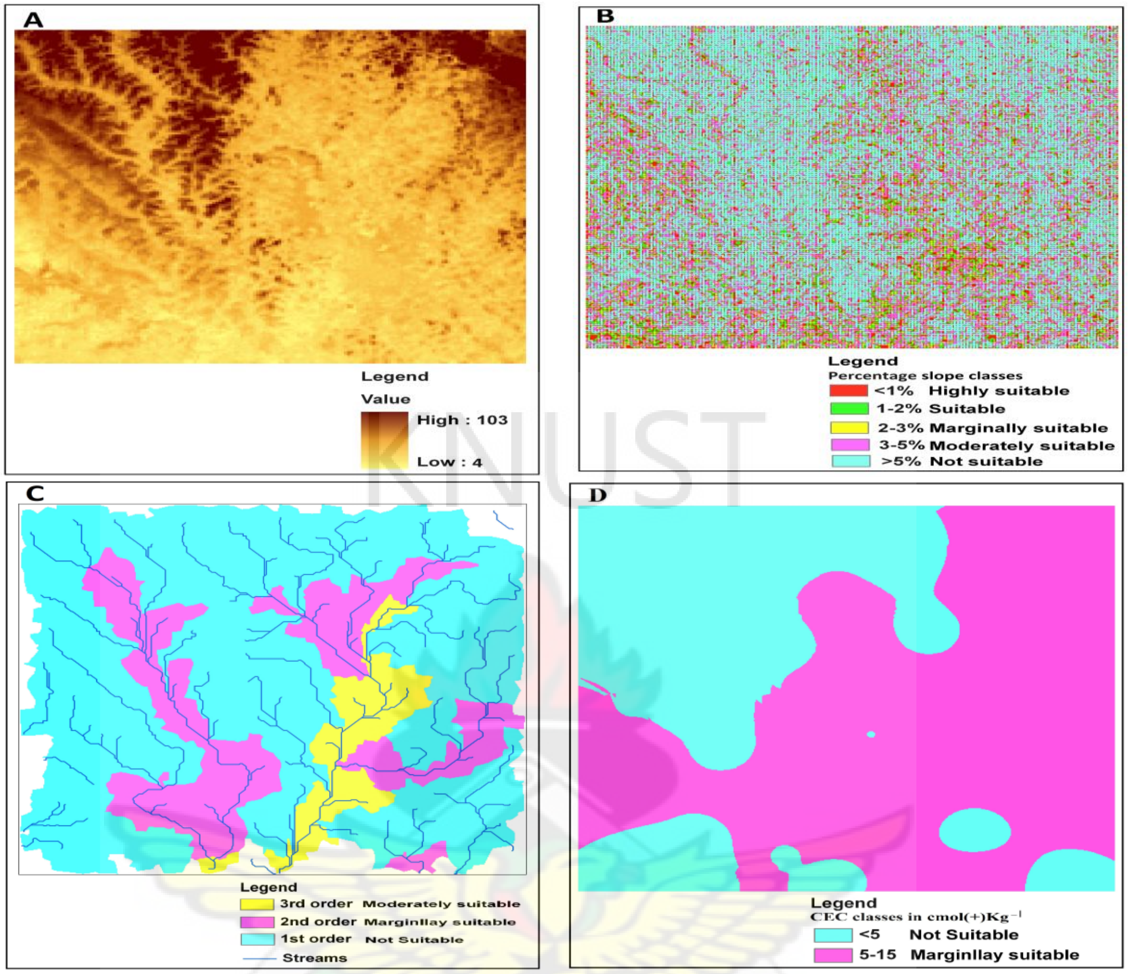


Figure 4.10: Spatial layers for DEM (A), slope classes (B), stream order (C) and C.E.C (D) for the Western Region site

### 4.3.4 Analysis of soil properties for the Western Region site

Presented in Table 4.12 are the mean, maximum, minimum and CV (%) of soil parameters for the Western Region site. The CEC and organic carbon were used to generate spatial layers for soil fertility parameter. CEC for the area was generally low. Portions of the area had CEC value below 5 cmol(+) $kg^{-1}$ . This means few nutrient reserves are present usually unsuitable for rice and then portions with values 5-15 cmol(+) $kg^{-1}$ are marginally suitable (Landon, 1991). Spatial layer for CEC is presented in Figure 4.10(D). Organic carbon in the area was high as compared to the Brong Ahafo site. Spatial layer for Organic carbon is presented in Figure 4.11 (E).

Table 4.12: Chemical properties of soil samples for the Western Region site

| Soil parameter | Number of samples | Mean | Max | Min | CV (%) |
|---|---|---|---|---|---|
| pH($H_2O$) | 30 | 5.0 | 5.7 | 4.3 | 6.8 |
| Organic carbon (%) | 30 | 1.4 | 7.7 | 0.5 | 87.9 |
| Total Nitrogen (%) | 30 | 0.1 | 0.5 | 0.03 | 75.0 |
| Organic matter content | 30 | 2.4 | 13.3 | 0.8 | 87.7 |
| Exchangeable Ca cmol(+) $kg^{-1}$ | 30 | 1.2 | 2.7 | 0.5 | 42.9 |
| Exchangeable Mg cmol(+) $kg^{-1}$ | 30 | 0.7 | 1.9 | 0.3 | 66.7 |
| Exchangeable K cmol(+) $kg^{-1}$ | 30 | 0.1 | 0.3 | 0.0 | 50.0 |
| Exchangeable Na cmol(+) $kg^{-1}$ | 30 | 0.2 | 0.3 | 0.1 | 31.3 |
| T.E.B cmol(+) $kg^{-1}$ | 30 | 2.1 | 4.9 | 1.0 | 43.9 |
| Exchangeable acidity cmol(+) $kg^{-1}$ | 30 | 1.0 | 1.5 | 0.5 | 31.7 |
| C.E.C cmol(+) $kg^{-1}$ | 30 | 3.2 | 5.4 | 1.7 | 26.3 |

### 4.3.5 Roads and Markets for the Western Region site

Presented in Figure 4.11 are the spatial layers for roads (F) and markets (G). The same distance classes were used. The distance indicates the suitability of an area depending on how far it is from the features (roads and markets).

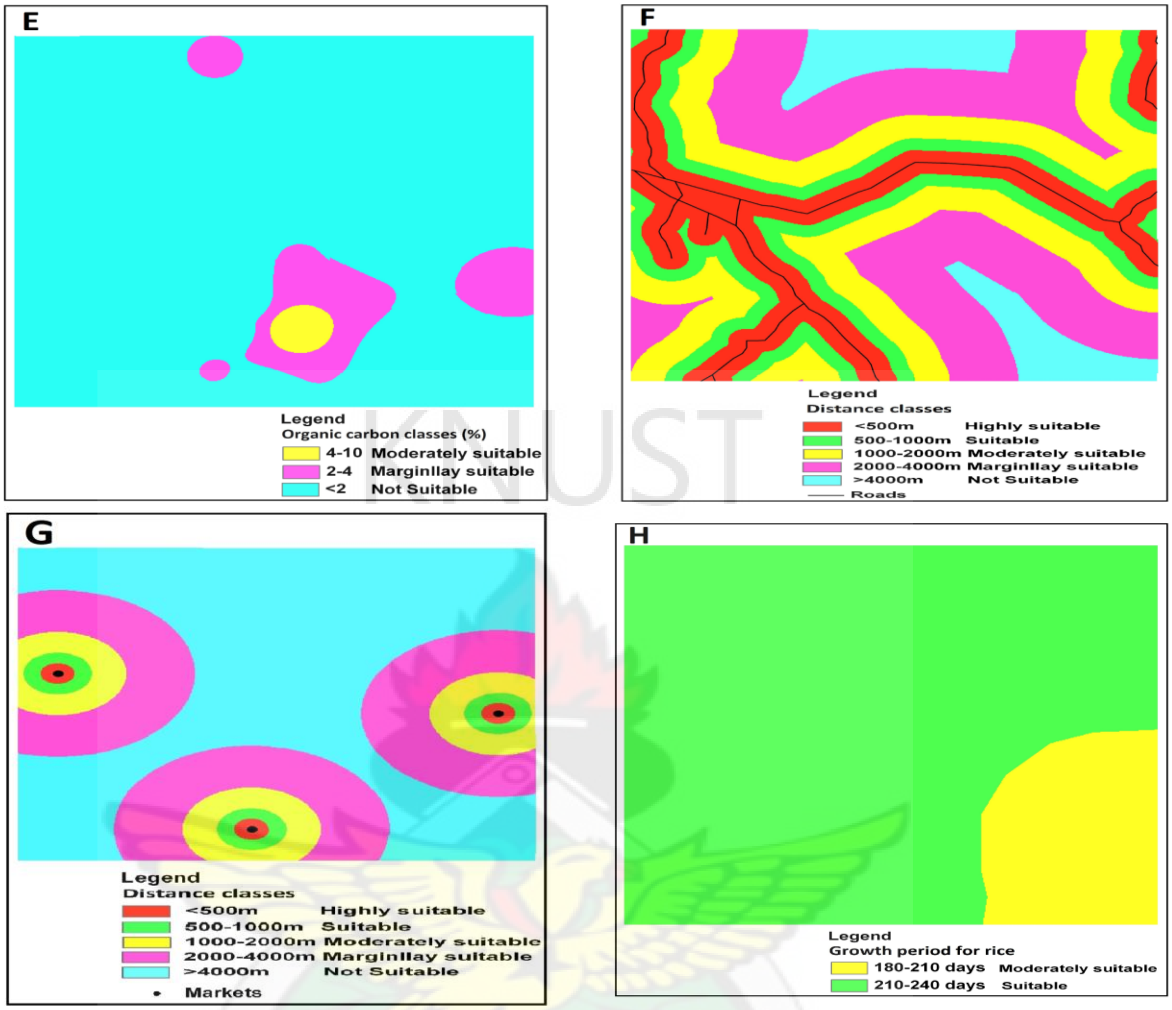


Figure 4.11: Spatial layers for organic carbon (E), roads (F), markets (G) and length of growth period for rice (H)

### 4.3.6 Length of growth period for rice for the Western Region Site

Presented in 4.11(H) is the spatial layer for length of growth period for rice. Parts of the Western Region fall within the suitable class (210-240 days) and moderately suitable class (180-210 days).

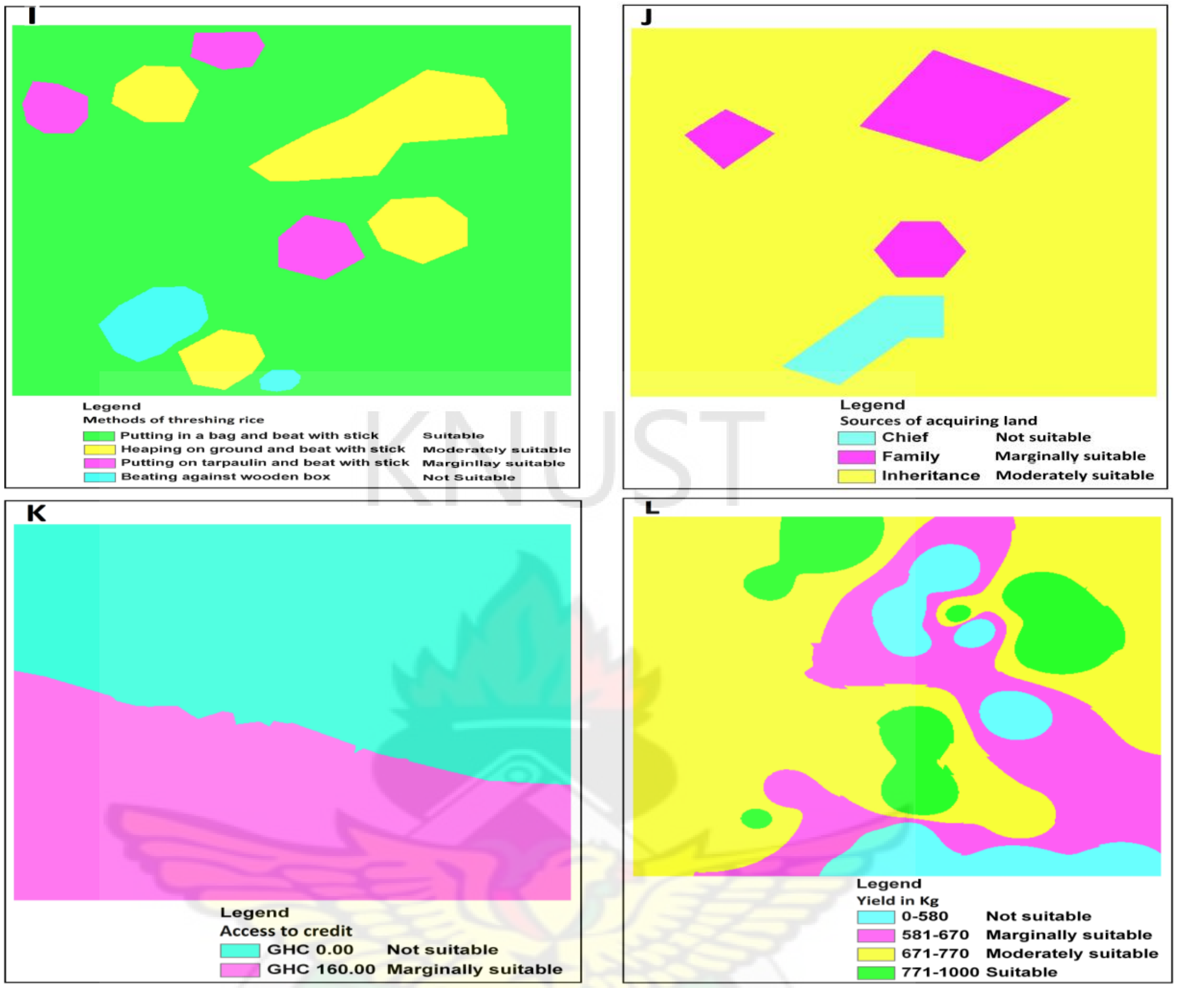


Figure 4.12: Spatial layers for post harvest technology (I), land tenure (J), credit system (K) and incentive net benefit (L)

### 4.3.7 Post harvest technology for the Western Region Site

All the farmers interviewed in the Western Region site used the sickle to harvest rice. Presented in Table 4.13 are the methods respondents use to thresh rice. Four methods were identified as: Putting on tarpaulin and beat with stick, heaping on the ground and beat with stick, Putting in a bag and beat with stick and beat rice straw against wooden box. The dominant method used is by putting in a bag and beat with stick and this represent 34.3%. Spatial layer for post harvest technology for the Western Region site is presented in Figure 4.12(I).

Table 4.13: Threshing methods used by respondent farmers in the Western Region site

| Threshing method | Number of farmers | Percentage (%) |
|---|---|---|
| Put on tarpaulin and beat with stick | 7 | 20.0 |
| Put in a bag and beat with stick | 12 | 34.3 |
| Heap on the ground and beat with stick | 8 | 22.9 |
| Beat against wooden box | 8 | 22.9 |
| Total | 35 | 100.0 |

### 4.3.8 Land tenure for the Western Region Site

Table 4.14 illustrates the sources available for acquiring land for rice cultivation in the Western Region site. Most respondents (71%) acquired land through inheritance, 17% use family lands and 11% acquired land from the chief. With the exception of 2 farmers all the farmers have permanent unrestricted access to land for rice cultivation. Spatial layer for land tenure for the Western Region site is presented in Figure 4.12(J).

Table 4.14: Sources of land for rice cultivation in the Western Region site

| Source of land | Permanent | Annual renewal | Total | Percentage (%) |
|---|---|---|---|---|
| Chief | 2 | 2 | 4 | 11.4 |
| Inheritance | 25 | 0 | 25 | 71.4 |
| Family | 6 | 0 | 6 | 17.1 |
| Total | 33 | 2 | 35 | 100 |

### 4.3.9 Credit system and Incentive benefits for the Western Region Site

Table 4.15 illustrates the number farmers who are able to access credit for rice cultivation in the Western Region site. Out of the 35 rice farmers interviewed 37.1% of them had obtained credit from the Agricultural Development Bank in the past. Farmers received GH₵ 160.00 per acre of land and paid back with an interest of 15.62% per annum. However 62.9% had never received credit for inland valley rice cultivation.

Table 4.15: Access to credit for rice cultivation in the Western Region site

| Access to credit | Number of farmers | Percentage (%) |
|---|---|---|
| Yes | 13 | 37.1 |
| No | 22 | 62.9 |
| Total | 35 | 100 |

Incentive for rice farmers was measured based on yield per acre. Spatial layer for credit systems and incentive benefit for the Western Region site are presented in Figure 4.12(K) and Figure 4.12(L) respectively.

### 4.3.10 Model results for the Western Region site

Presented in Table 4.16 are areas (hectares) and percentages of suitability classes from the model results of the Western Region site. Model results were based on two approaches of equal and unequal weights as explained in Section 3.6. Using equal weights, 1.4% (386.3ha) of the total area is highly suitable and 21.4% (5814ha) is suitable for rice cultivation.

Per the second approach of unequal weights, 0.9% (234.9ha) of the total area is highly suitable and 13.6% (3686.2ha) is suitable for rice cultivation. It was observed that area for highly suitable, suitable and moderately suitable all decreased by 0.56%, 7.84% and 7.05% respectively when unequal weights were used. Though there are decreases in highly suitable and suitable area when using unequal weights, the results are better because they take into account the relative importance of each input parameter.

Table 4.16: Land suitability classes in the Western Region site based on equal and unequal weights

| | **Equal weights** | | **Unequal weights** | |
|---|---|---|---|---|
| Suitability | Area(ha) | Percentage (%) | Area(ha) | Percentage (%) |
| Not suitable | 4531.4 | 16.7 | 4537.0 | 16.7 |
| Marginally suitable | 4094.6 | 15.1 | 8285.0 | 30.5 |
| Moderately suitable | 12334.7 | 45.4 | 10418.9 | 38.4 |
| Suitable | 5814.0 | 21.4 | 3686.2 | 13.6 |
| Highly suitable | 386.3 | 1.4 | 234.9 | 0.9 |

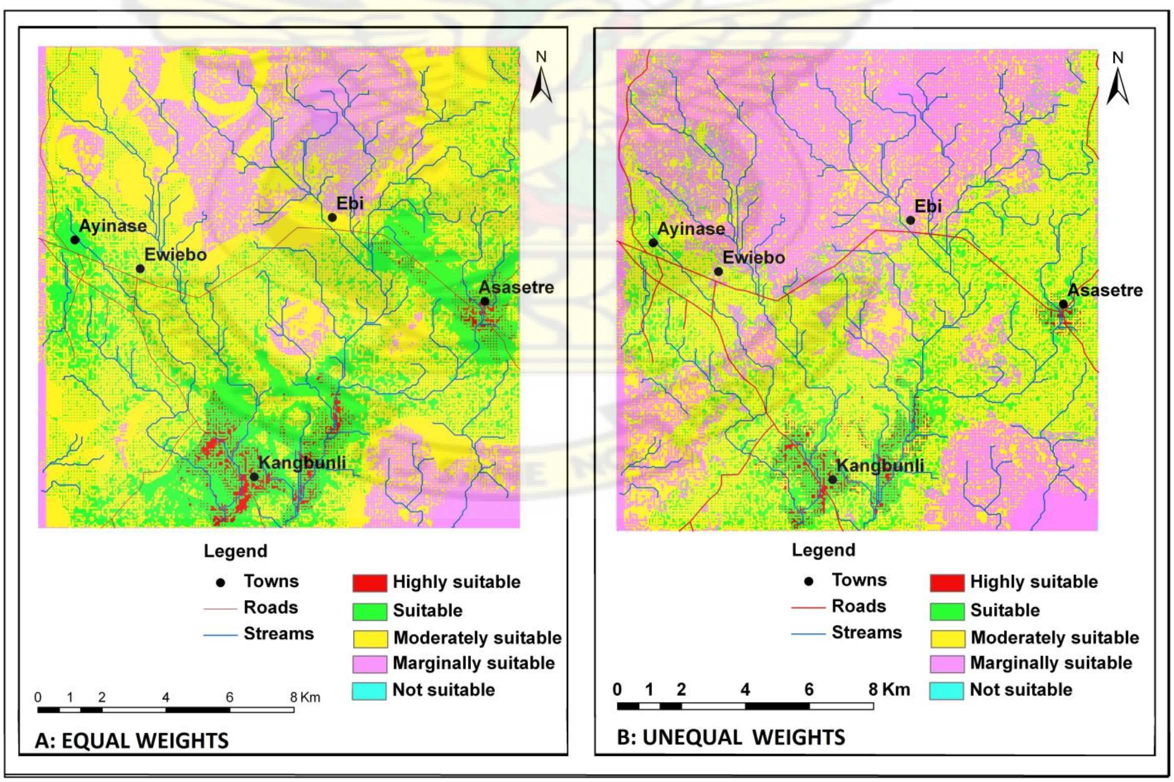


Figure 4.13: Suitability maps for the Western Region site: for equal and unequal weights

After over laying the coordinates of existing rice farms on the suitability map it was found out that out of the 23 existing rice farms mapped in the Western Region site none were within the highly suitable area, 5 were within the suitable area, 5 were within the moderately suitable area and 13 were within the marginally suitable area. This shows that there are limitations to the use of highly suitable and suitable area in both study sites.

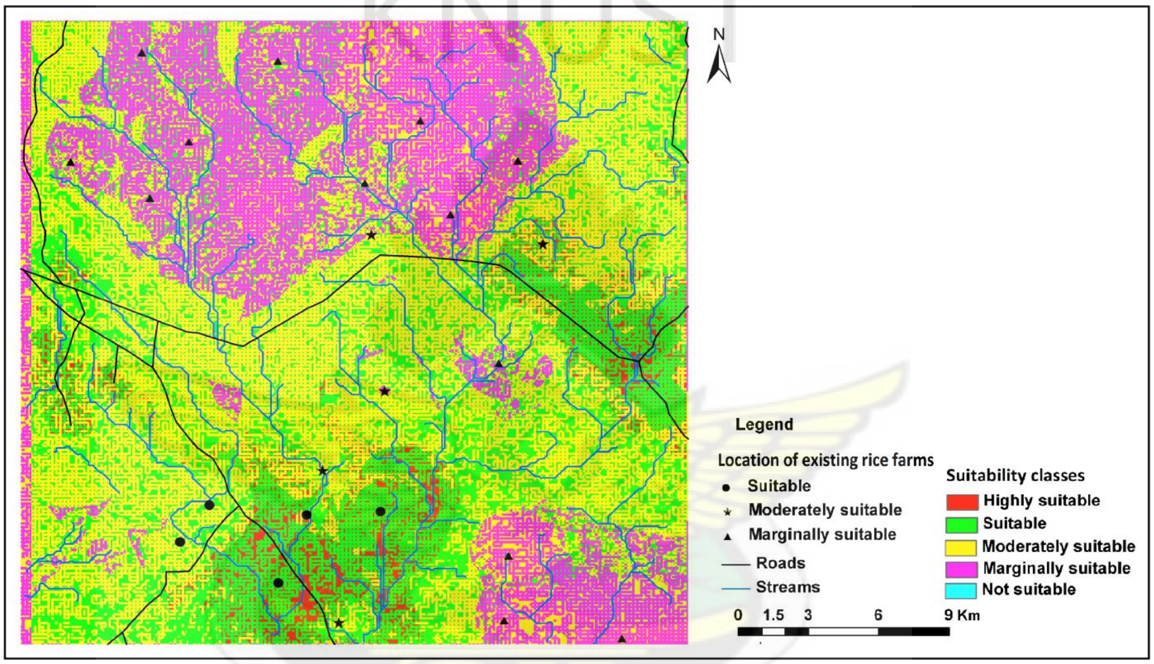


Figure 4.14: Location of existing rice farms on the suitability map of the Western Region site based on unequal weight.

## 4.4 Comparison of original model and modified model

After carrying out the sensitivity analysis, 12 most sensitive parameters were used for the modified model. These parameters (Markets, Slope, Post harvest technology, Specific discharge, Land tenure, Length of rice growth, Incentive net benefit, Credit system, Rainfall, Roads, Soil fertility and Stream order) are all among the parameters used by Gumma *et al.* (2009) in the Ashanti Region site with the exception of soil fertility. Spatial layers of these selected parameters were used to run the model for the Ashanti Region site and these constitute the modified model and compared with the results obtained when all the 22 parameters were used in the original model. Presented in Table 4.17 are areas (ha) and percentages of suitability classes for the original and modified model for the Ashanti Region site. 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 areas 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. The modified version of the model considers only the most sensitive input parameters.

Table 4.17: Areas and percentages of suitability classes in the Ashanti Region site

| | **Original model** | | **Modified model** | | |
|---|---|---|---|---|---|
| Suitability class | Area (ha) | Percentage (%) | Area (ha) | Percentage (%) | % 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 |

## CHAPTER FIVE

## CONCLUSIONS AND RECOMEMDATIONS

### 5.1 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 by conducting sensitivity analyses on results of a previous study. The sensitive parameters include: rainfall, slope, stream order, specific discharge, length of growth period, soil fertility, post harvest technology, credit system, land tenure, access to roads and markets and incentive benefit.

The study illustrated the successful application of the spatial model using limited data set based on the most sensitive parameters in two selected sites in the Brong Ahafo and Western Region of Ghana to estimate suitable areas for rice cultivation. Thus cutting down on the number of input parameters that have to be determined for the model to be used.

Model results were based on equal weights and unequal weights of input parameters. At the Brong Ahafo site, 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 are highly suitable and suitable respectively based on unequal weight. At the Western Region site, the study showed that 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.

The study illustrated changes in suitability areas when results obtained from the original model were compared with results obtained using the modified model. The 0.6%

increase in highly suitable area 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. Equal weights can be used as a first approximation and then based on additional information variable weights can be used to improve the model.

Most farmers have sited their farms outside the highly suitable area for inland valley rice cultivation thus indicating some limitations to the use of such areas. Key among them is flooding requiring water control structures for effective use.

## 5.2 Recommendations

- The spatial model should be adopted by the Ministry of Food and Agriculture, Ghana Irrigation Development Authority and other organizations for determining suitable areas for large scale rice cultivation.
- Rice farmers should be encouraged to obtain land title deeds from the Lands Department to secure their farm lands against litigations.
- The Ministry of Food and Agriculture should support rice farmers with better methods of threshing rice as the dominant method used by the farmers “heap on the ground and beat with stick” does not produce quality rice grains.
- The government of Ghana and financial institutions should support rice farmers through provision of access to credit to help them acquire inputs and improved seeds.

- Further studies should address the issue of up-scaling the knowledge acquired from this study to cover a larger area (eg. a whole region or basin) as this study was conducted on a 15km by 15km area.
- Farmers have to be given the knowhow to use the highly suitable and suitable lands for rice cultivation. And also supported by government and other agencies to be able to develop and use highly suitable areas for rice cultivation.

# REFERENCES


Alrababah, M. A. and Alhamad, M. N. (2006). Land use/cover classification of arid and semi-arid Mediterranean landscapes using Landsat ETM. *International Journal of Remote Sensing*, 27: 2703–2718

Andriesse, W., Fresco, L. O., Van Duivenbooden, N. and Windmeijer, P. N. (1994). Multi-scale characterization of inland valley agro-ecosystems in West Africa. *Netherlands Journal of Agricultural Science*, 42(2): 159–179

Anku, S. K., (2006). Managing Wetlands in Accra, Ghana. African Regional Workshop Cities, Ecosystems and Biodiversity Nairobi, 21 September 2006. Available at: http://www.unep.org/urban_environment/PDFs/ManagingAccraWetlands.pdf. (Cited on 27/11/10)

CGIA, (2005). Land Suitability Analysis - User Guide. Available at: http://dcm2.enr.state.nc.us/planning/user_guide_lsa2005.pdf (Cited on 19/11/10)

CGIAR-CSI, (2008). Shuttle Radar Topographic Mission (SRTM) 90m Digital Elevation Data. Available: http://srtm.csi.cgiar.org/ (Cited on 10/11/10)

Baker, C., Lawrence, R., Montagne C. and Patten D. (2006). Mapping Wetlands and Riparian Areas Using Landsat ETM+ Imagery and Decision- Tree-Based Models. *Wetlands*, 26(2): 465–474

Black, C. A. (1986). (ed.) Methods of soil analysis. Part I. Physical and mineralogical properties,including statistics of measurement and sampling. Part II. Chemical and microbiological properties. Agronomy series. ASA. Madison. Wis. USA.

Boakye, E., Odai, S. N., Adjei, K. A. and Annor, F. O. (2008). Landsat Images for Assessment of the Impact of Land Use and Land Cover Changes on the Barekese Catchment in Ghana. *European Journal of Scientific Research*, 22(2): 269–278

De Roeck, E. R., Niko, E. C., Mtemi, H. M., Lievens, H., Batelaan, O., Thomas, A. and Brendonck, L. (2008). Remote Sensing and Wetland Ecology: A South African Case Study. *Sensors*, 8: 3542–3556.

Duadze, S. E. K. (2004). Land use and land cover study of the savannah ecosystem in the Upper West Region (Ghana) using remote sensing. Unpublished PhD. Thesis, University of Bonn, Bonn. 251 pp.

Earth Satellite Corporation (2002). Global: Remote Sensing for Ramsar Sites. Available at: http://sedac.ciesin.columbia.edu/ramsardg/casestudies/earthsat.html (Cited on: 20/10/10)

Eastman, J. R. (2006). IDRISI Andes: Guide to GIS and Image Processing. Clark Labs, Clark University, Worcester, MA, USA.

Ehrenfeld, J. G. (2000). Evaluating wetlands within an urban context. *Ecological Engineering*, 15: 253–265.

Ekanayake, G. K. and Dayawansa, N. D. K. (2003). Land suitability Identification for a production forest though GIS technique. Available at http://www.gisdevelopment.net/application/environment/overview/mi03148.htm (Cited on 22/12/10)

FAO (1976). A framework for land evaluation. Soils Bulletin 22. FAO, Rome. 66pp

FAO (1993). Guidelines for land-use planning. FAO Development Series 1. FAO, Rome. 135pp

FAO (1978). Report on the Agro-ecological Zones Project. Vol.I: Methodology and Results for Africa. FAO World Soil Resources Report 48. Food and Agriculture Organization, Rome, Italy. 158 p.

FAO (1998). Wetland Characterization and classification for sustainable Agricultural Development. Available at: http://www.fao.org/DOCREP/003/X6611E/x6611e03a.htm (Cited on: 01/09/11)

Finlayson, C. M. and Van der Valk, A. G. (1995). Wetland classification and inventory: A summary. *Vegetatio*, 118:185-192

Gumma, M. K., Thenkabail, P. S., Fujii, H., and Regassa, N. (2009). Spatial Models for Selecting the Most Suitable Areas of rice Cultivation in the Inland Valley Wetlands of Ghana using Remote Sensing and GIS. *Journal of Applied Remote Sensing*, 3(1): 21pp

Harvey, K. R and Hill, G. J. E. (2001). Vegetation mapping of a tropical freshwater swamp in the Northern Territory, Australia: a comparison of aerial photography, Landsat TM and SPOT satellite imagery. *International journal of remote sensing*, 22(15): 2911–2925

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G. and Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25: 1965-1978.

Islam, Md. A., Thenkabail, P. S., Kulawardhana, R. W., Alankara, R., Gunasinghe, S., Edussriya, C., and Gunawardana, A. (2007). Semi-automated methods for Mapping Wetlands using Landsat ETM+ and SRTM data. *International Journal of Remote Sensing*, 29(24): 7077-7106

Jamin, J. Y. and Andriesse, W. (1993). Discussion synthesis. Pages 8-16 in: Proceedings first Annual Workshop of Inland Valley Consortium. WARDA, Bouake, Côte d'Ivoire, 8-10 October 1993

Johnston, R. M. and Barson, M. M. (1993). Remote sensing of Australian wetlands: An evaluation of Landsat TM data for inventory and classification. *Australian Journal of Marine and Freshwater Resources*, 44: 235–252.

Johnson, L. B. and Gage, S. H. (1997). Landscape approaches to the analysis of aquatic ecosystems. *Fresh water Biology*, 37: 113–132.

Juo, A. S. R. and Lowe, J. A. (1986). The Wetlands and Rice in Sub-Saharan Africa (Ibadan: International Institute of Tropical Agriculture).

Kindscher, K., Fraser, A., Jakubauskas, M. E. and Debinski, D. M. (1998). Identifying wetland meadows in Grand Teton National Park using remote sensing and average wetland values. *Wetlands Ecology and Management*, 5: 265–273

Kranjac-Berisavljevic, G., Blench, R. M. and Chapman R. (2003). Rice production and livelihoods in Ghana. Available at: http://www.odi.org.uk/resources/docs/3990.pdf (Cited on 25/08/11)

Kulawardhana, R. W., Thenkabail, P. S., Vithanage, J., Biradar, C., Islam Md. A., Gunasinghe, S. and Alankara, R. (2007). Evaluation of the Wetland Mapping Methods using Landsat ETM+ and SRTM Data. *Journal of Spatial Hydrology* Vol.7, No.2, 47pp.

Kuria, D., Ngari, D. and Waithaka, E. (2011). Using geographic information systems (GIS) to determine land suitability for rice crop growing in the Tana delta. *Journal of Geography and Regional Planning*, 4(9): 525-532

Landon, J. R. (1991). A booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Booker Tate, Thame, Oxon, UK, pp 113-125

Leica, (2007). Earth Resources Data Analysis System (ERDAS Imagine8.x) Leica Geosystems A.G. Heinrich-Wild-Strasse, CH-9435 Heerbrugg, Switzerland

.Mahlke, J. (1996). Characterization of Oklahoma Reservoir wetlands for preliminary change detection mapping using IRS-1B Satellite imagery. IGARSS 1996: 1996 International Geoscience and Remote Sensing Symposium, 1769-1771.

Maillard P., Alencar-Silva, T. and Clausi, D. A. (2008). An Evaluation of Radarsat-1 and ASTER Data for Mapping Veredas (Palm Swamps). *Sensors*, 8: 6055-6076

Meyer, W. B. (1995). Past and Present Land-use and Land-cover in the U.S.A. *Consequences*, 1(1): 25-33.

Millennium Development Authority (2010). Maize, Soya and Rice Production and Processing. Available at: http://www.mcc.gov/documents/investmentopps/bom-ghana-english-grain.pdf (Cited on: 01/10/11)

Mitsch, W. J. and Gosselink, J. G. (1993). Wetlands. New York: John Wiley & Sons, pp. 722.

Mitsch, W. J. and Gosselink, J. G. (2000). The value of wetlands: importance of scale and landscape setting. *Ecological Economics*, 35: 25-33.

MOFA, (2011). Production of major crops in Ghana. Statistics, Research and Information Directorate (SRID), Ministry of Food and Agriculture. Available at http://mofa.gov.gh/site/?page_id=5878 (Cited on 20/01/12)

Muller, E., Decamps, H. and Michael, K. D. (1993). Contribution of space remote sensing to river studies. *Freshwater Biology*, 29: 301–312.

Narumalani, S., Zhou, Y., and Jensen, J. R. (1997). Application of remote sensing and geographic information systems to the delineation and analysis of buffer zones. *Aquatic Botany*, 58: 393–409

Ozesmi, S. L. and Bauer, M. E. (2002). Satellite remote sensing of wetlands. *Wetlands Ecology and Management*, 10: 381–402.

Page, A. L., Miller, R. H. and Keeney D. R. (eds.) (1982). Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd Edition. Agronomy series 9, ASA, SSSA, Madison, Wis. USA.

Perveen, F., Nagasawa, R., Uddin, I. and Delowar, K. M. (2005). Crop-Land Suitability Analysis using a Multi Criteria Evaluation and GIS Approach. Available at: http://www.digitalearth-isde.org/cms/upload/Papers%20and%20Abstracts/Perveen.pdf (Cited on: 18/12/11)

Ramsar Convention (2001). "Managing Ghana's wetlands: a national wetlands conservation strategy" Available at: http://www.ramsar.org/cda/en/ramsar-documents-wurl-policies--managing-ghana-s/main/ramsar/1-31-116-162%5E21180_4000_0__(Cited on: 15/01/10)

Ramsar Convention Secretariat (2006): The Ramsar Convention Manual: a guide to the Convention on Wetlands (Ramsar, Iran, 1971), 4th ed. Ramsar Convention Secretariat, Gland, Switzerland,

Ramsey, E. W. and Laine, S. C. (1997). Comparison of Landsat Thematic Mapper and high resolution aerial photography to identify change in complex coastal wetlands. *Journal of Coastal Research*, 13: 281–292.

Riebsame, W. E., Meyer, W. B. and Turner, B. L. (1994). Modeling Land-use and Cover as Part of Global Environmental Change. Climate Change, Vol. 28 45pp

Sader, S. A., Ahl, D. and Liou, W. S. (1995). Accuracy of LandsatTM and GIS rule-based methods for forest wetland classification in Maine. *Remote Sensing of Environment*, 53: 133–144

Semilitsch, R. D. and Bodie, R. (1998). Are small, isolated wetlands expendable? Conservation Biology, 12:1129–1133.

SDG, (1999). Road layer of Ghana, Survey Department of Ghana

SRI-GERMP, (1999). Length of growing period for rice cultivation in Ghana. Soil Research Institute and the Ghana Environmental Resource Management Project

Soils Laboratory Staff. Royal Tropical Institute. (1984). Analytical methods of the service laboratory for soil, plant and water analysis. Part I: Methods for soil analysis. Royal Tropical Institute. Amsterdam

Tetteh, F. K. M. (2004). Synchronising Nutrient Release from Decomposing Organic Materials with Crop Nutrient Demand in the Semi-Decidous Forest Zone of Ghan. Unpublished PhD. Thesis, Kwame Nkrumah University of Science and Technology, Kumasi-Ghana.

Thenkabail, P. S. and Nolte, C. (2000). Regional characterisation of inland valley agroecosystems in West and central Africa using high-resolution remotely sensed data. In: GIS applications for water resources and watershed management edited by John G. Lyon, pp. 266. Taylor and Francis, London and New York.

Thenkabail P. S., Nolte, C. and Lyon, J. G. (2000). Remote sensing and GIS modeling for selection of benchmark research area in the inland valley agroecosystems of West and Central Africa. Photogrammetric Engineering and Remote Sensing, *Africa Applications Special Issue*, 66(6): 755-768.

Thenkabail, P. S. and Nolte, C. (1996). Capabilities of Landsat-5 Thematic Mapper (TM) data in regional mapping and characterization of inland valley agroecosystems in West Africa, *International Journal of Remote Sensing*, 17(8): 1505-1538

Tiner, R. W. (1993). Using plants as indicators of wetlands. Proceedings of the Academy of Natural Sciences of Philadelphia 144: 240–253.

Townsend, P. A. and Walsh, S. J. (2001). Remote sensing of forested wetlands: application of multitemporal and multispectral satellite imagery to determine plant community composition and structure in southeastern USA. *Plant Ecology*, 157:129–149.

Toyra, J. and Pietroniro, A. (2005). Towards operational monitoring of a northern wetland using geomatics based techniques. *Remote Sensing of Environment*, 97: 174–191

Toyra, J., Pietroniro, A., Martz, L. W. and Prowse, T. D. (2002). A multisensor approach to wetland flood monitoring. *Hydrological Processes*, 16:1569–1581.

Turner, R. K., van den Bergh J. C. M., Soderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E. and Van Ierland, E. C. (2000). Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecological Economics*, 35: 7-23.

USACE (U.S. Army Corp of Engineers) (1987). Wetlands Delineation Manual – Technical Report. Department of the Army, Washington, D.C. pp. 127-241.

Van Duivenbooden, N., Windmeijer, P. N., Andriesse, W. and Fresco, L. O. (1996). The integrated transect method as a tool for land use characterization, with special reference to inland valley agro-ecosystems in West Africa. *Landscape and Urban Planning*, 34:143-160.

Wei, A. (2007). Use of Ikonos Imagery to Map Coastal Wetlands of Georgian Bay. Fisheries, 32(4): 167-173

Windmeijer, P. N. and Andriesse, W. (1993). Inland Valleys in West Africa: An Agro-ecological Characterization of Rice-Growing Environments. ILRI Publication 52. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. 160 p.

# APPENDIES

## Appendix 1: Questionnaire used to collect socio-economic data

**Suitability of Inland Valleys for rice cultivation (DAE-KNUST/IWMI) 17/08/11**

1. Name of community…………………………………
2. Age of farmer: ☐ 18 to 30 ☐ 31 to 40 ☐ 41 to 50 ☐ 51 to 60 ☐ above 60 years
3. Do you cultivate rice? ☐ Yes ☐ No
4. List the crops you cultivate in order of decreasing importance.

   a.………………b. ………..…. c. ....................… d. ……….……..e……..……..…
5. How many acres did you cultivate in all? ..……….acres
6. How many acres of rice did you cultivate in the last season? …..…acres
7. How long have you been cultivating rice?....…..................years
8. What was the price of a bag of rice in the last season?

   Paddy: GHC……….....  Milled: GHC……………
9. What size of bag did you use?

   a. 100kg  b. 70kg  c. 50kg  if other, specify…………..

**Post harvest technology**

10. What method do you use in harvesting rice?

☐ Sickle ☐ Combine harvester ☐ Tractor pulled ☐ Strippers ☐ Other, specify………..

11. What method do you use in threshing rice?

☐ Putting on tarpaulin and beat with stick ☐ Heap on the ground and beat with stick
☐ Putting in a bag and beat with stick ☐ Tractor trampling
☐ Beat against wooden box ☐ Rice threshers

12. Distance from farm to the nearest milling service provider/storage point?

☐ 0m to 1km ☐ 1km to 2km ☐ 2km to 5km
☐ 5km to 10km ☐ >10km

13. How will you rank questions 10, 11 and 12 in relation to rice production on a scale of 1 (highest) to 3?

10. ☐ 11. ☐ 12. ☐

**Land tenure**

14. What was the source of your farmland for rice cultivation?

☐ Chief ☐ Inheritance ☐ Family ☐ Cash rental basis ☐ Other, specify…………..

15. What was the cost of your farmland? Cash: GHC…………per acre/ kind: ……………per acre.

16. How long will you have access to your farmland?

☐ Permanent ☐ Annual renewal ☐ 2 to 5 year renewal ☐ Other, specify…..............

17. How will you rank question 14, 15 and 16 in relation to rice production on a scale of 1(highest) to 3?

14. ☐ 15. ☐ 16. ☐

**Credit system:**

18. Have you ever received credit for rice cultivation? ☐ Yes ☐ No

19. If Yes, source? ☐ Bank ☐ Micro finance ☐ Projects ☐ Individuals ☐ Other, specify…………

20. What was the mode of repayment? ☐ Cash with interest ☐ Cash without ☐ interest Kind,

21. If cash with interest, amount received? GHC………amount paid back? GHC..........period …years.

22. If in kind, how many bags of rice did you pay for the amount GH¢…………. for …..years?

Paddy: ………bags for GHC………. /bag Milled: ………bags for GHC………/bag

**Incentive net benefit:**

23. What motivates you to farm rice at your present location?

☐ High yield ☐ Water availability ☐ Close to road
☐ Close to my home ☐ Access to extension services ☐ Close to market

24. Rank the remaining factors under Q23 on a scale of 2 to 6?

25. What was the yield per acre? ……..…bags.

**Labour force**

26. Out of your household how many people help you on your rice farm?..………..

27. On the average how many hired labour do you use? …………

28. How many people in your household fall within the following age ranges?

☐ 1 to 14years ☐ 15 to 64years ☐ 65years and over

29. What other occupations do you have in the area that will affect labour availability for rice cultivation?

☐ Mining ☐ Fishing ☐ Trading ☐ Schooling ☐ Livestock ☐ Other, specify………..

**Agro technology**

30. What inputs did you apply on your rice farm in the last season?

Round-up/Condemn………litre/acre, Urea……..Kg/acre,

NPK……….Kg/acre Amonia………Kg/acre

Herbicide…….litre/acre Pesticide……..litre/acre

31. What is the most important input to you? ……………………

**Pairwise Comparison**

| 1/5 | 1/3 | 1 | 3 | 5 |
|---|---|---|---|---|

← Less important strongly moderately equally moderately strongly more → important

| | Post harvest technology | Land tenure | Credit systems | Incentive net benefit | Labour force | Agro tech |
|---|---|---|---|---|---|---|
| Post harvest tech | | | | | | |
| Land tenure | | | | | | |
| Credit systems | | | | | | |
| Incentive net benefit | | | | | | |
| Labour force | | | | | | |
| Agro tech | | | | | | |