MAPPING COCOA SWOLLEN SHOOT VIRUS DISEASE DISTRIBUTION IN WESTERN REGION, GHANA

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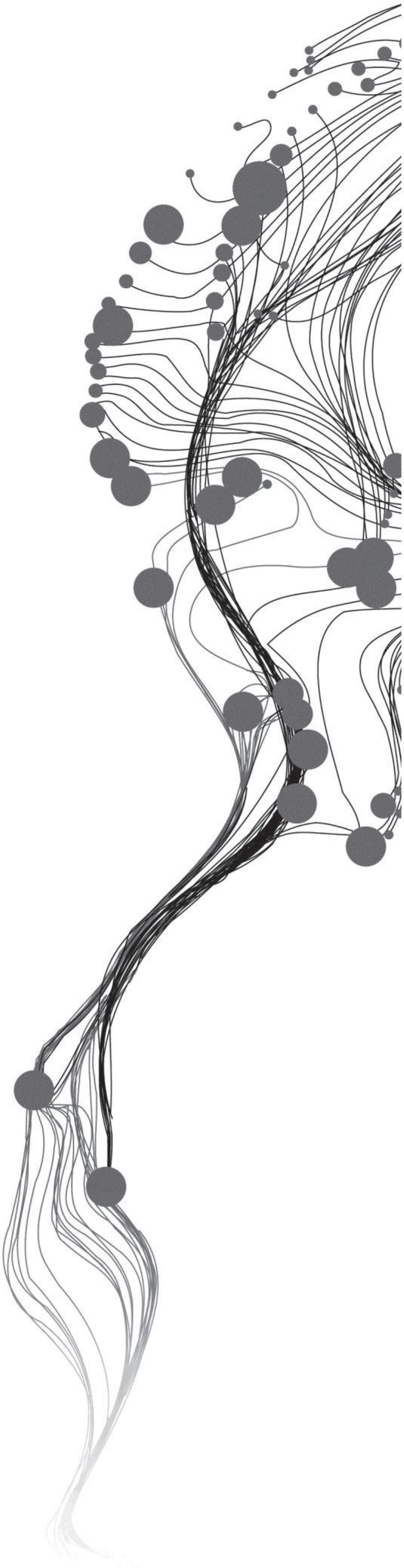

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Thesis submitted to the Faculty of Geo-information Science and Earth Observation of the University of Twenty in partial fulfillment of the requirements of the Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Resource Management

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ABSTRACT

Although the cocoa industry is the major backbone of Ghana's economy, the industry is beset with a lot of problems with the cocoa swollen shoot virus (CSSV) disease being the major one. Available literature suggests that the mealy bug is the main vector which causes the CSSV disease. In addition, environmental factors including; temperature, precipitation, proximity to forest, elevation and aspect also influence the distribution trend of CSSV in the cocoa growing areas.

Despite the conscious efforts made to eliminate or reduce CSSV disease, the eradication process of the mealy bug seems to be slow and ineffective. Little has been done on the study of the spatial distribution of CSSV disease with the aim of eradicating or containing the disease in the field. This has led to the fast spread of the CSSV disease from the earliest cocoa fields to new unaffected areas of production with the Western region being a typical example. Moreover where an outbreak may occur next is also not known. This study was therefore undertaken to model the distribution of CSSV disease, to determine the environmental variables and their relationship to the prevalence of CSSV disease, and to model probable sites for reintroduction of CSSV disease for effective management. The spatial distribution of CSSV was identify by the creation of distribution map, through literature research six environmental variables with influence of the prevalence of CSSV were identified. Statistical analysis was performed to select suitable environmental variables with significant influence on CSSV disease, overlay of presence points with environmental layers was executed to determine locations with influence of CSSV disease, and the probable sites for reintroduction of CSSV disease was model using MaXent to determine sites with greatest risk of CSSV infection. The result indicated that, mapping CSSV disease distribution with Geographic Information Systems (GIS) to determine the actual distribution of the CSSV disease is more efficient and reliable than the visual inspection of cocoa trees for manifestation of stem swelling and leaf symptoms of eradicating the disease. An overlay of CSSV presence points with environmental layers to establish the relationship between environmental variables and CSSV occurrence offered the opportunity to determine locations with influence of CSSV. Furthermore modelling the potential risk sites for reintroduction of CSSV with MaXent provide insight into areas of possible disease outbreaks.

Key words: Cocoa Swollen Shoot Virus (CSSV), Mealy bug vector, Environmental Variables, GIS, MaXent.

Dedicated to my husband, Kofi Appiah Koranteng and my son Jeffrey Appiah Koranteng

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ASCII: American Standard Code for Information Interchange

AUC: Area Under the curve

CGIAR-CSI: Consultative Group for International Agriculture Research Consortium for Spatial Information.

CSSV: cocoa swollen shoot virus

CSSVDCU: Cocoa Swollen Shoot Virus Disease Control Unit

CSV: Comma-Separated Value

DBF: Data Base file

DEM: Digital Elevation Model

Ghana COCOBOD: Ghana Cocoa Board

GIS: Geographical Information Systems

GPS: Geographic Positioning Systems

MaXent: Maximum Entropy

NASA: National Aeronautics and Space Administration

ROC: Receiver Operating Characteristic

SCRA: Supply Chain Risk Assessment

SRTM: Shuttle Radar Topography Mission

USGS: United States Geological Survey

WORLDCLIM: World climate

1 INTRODUCTION

1.1 Background

Cocoa is one of the most flavoured rich food containing cathechin and epicathechin which are responsible for some of its protective properties (Nair, 2010; Orisajo, 2009). As a result of this dual role, it ranks third as a beverage after tea and coffee globally, and it has wider application and usages (Orisajo, 2009). The cocoa mass is used for chocolate, biscuit, and confectionary whereas the butter is used in making sweets, chocolate, and perfumes and in pharmacy (Ploetz, 2007). The pod husk, a by-product, is being utilized in livestock feeds and as a fertilizer.

Cocoa is produced in several countries of South and Central America, Africa, Asia, and Oceania. Cocoa cultivation is situated typically between 10° north and south of the equator. Cocoa is highly prized commodity with its beans being a major export commodity for several countries in West Africa (Bhattacharjee & Lava Kumar, 2007). Current worth of worldwide cocoa industry is estimated at $73 billion dollars with global cocoa production of 3.8 million metric tons a year (Lanaud *et al.*, 2009).

West African nations account for 70% of the cocoa grown for the world market (Orisajo, 2009). Although West Africa is the largest producing continent, the cocoa industry has been beset with a lot problem, including declining productivity due to the damage cause by diseases and pests to the cocoa crop. The most important disease of cocoa in West Africa is the Cocoa swollen shoot virus (CSSV) disease vectored by mealy bugs (Jeger, 2001). CSSV is a more aggressive and invasive in nature and it is causing increasing harm by way of spreading through the key cocoa producing areas of West Africa. (Domfeh *et al.*, 2011)

Cocoa, Ghana's leading cash crop and foreign exchange earner has been threatened by outbreaks of the CSSV disease. In areas where CSSV is endemic, the disease can be severe with a possibility of 80-100% yield losses and by this means production has been on a steady decline (Quainoo *et al.*, 2008b). The diseases of cocoa and their repercussions on the socio-economic development of Ghana has been a source of worry.

Several significant steps have been taken to eliminate the factors accounting for the dangerous decline in production of cocoa for Ghana to reach optimum levels of production. However, initiatives to control CSSV have not been successful over the years (Dzahini-Obiatey *et al.*, 2010). Principal among these initiatives is the eradication program which requires cutting out of the infected trees and symptomless trees in contact with them which has been known to be costly and labour intensive (Quainoo *et al.*, 2008a).

In addition to this has been the introduction of mass pesticides and insecticides administration which is equally expensive. Again, new cocoa breeds with high resistance to virus diseases was developed by Ghana Cocoa Board to control the CSSV disease (Quainoo*, et al*., 2008b). Other researchers tried to deal with the problem by the use of somatic embryo genesis to generate CSSV disease in order to free clonal propagules from infected trees (Quainoo*, et al*., 2008a). Despite the aforementioned steps taken, the CSSV disease continued to spread more than ever. However, little has been done on the study of CSSV disease distribution to contain or control it.

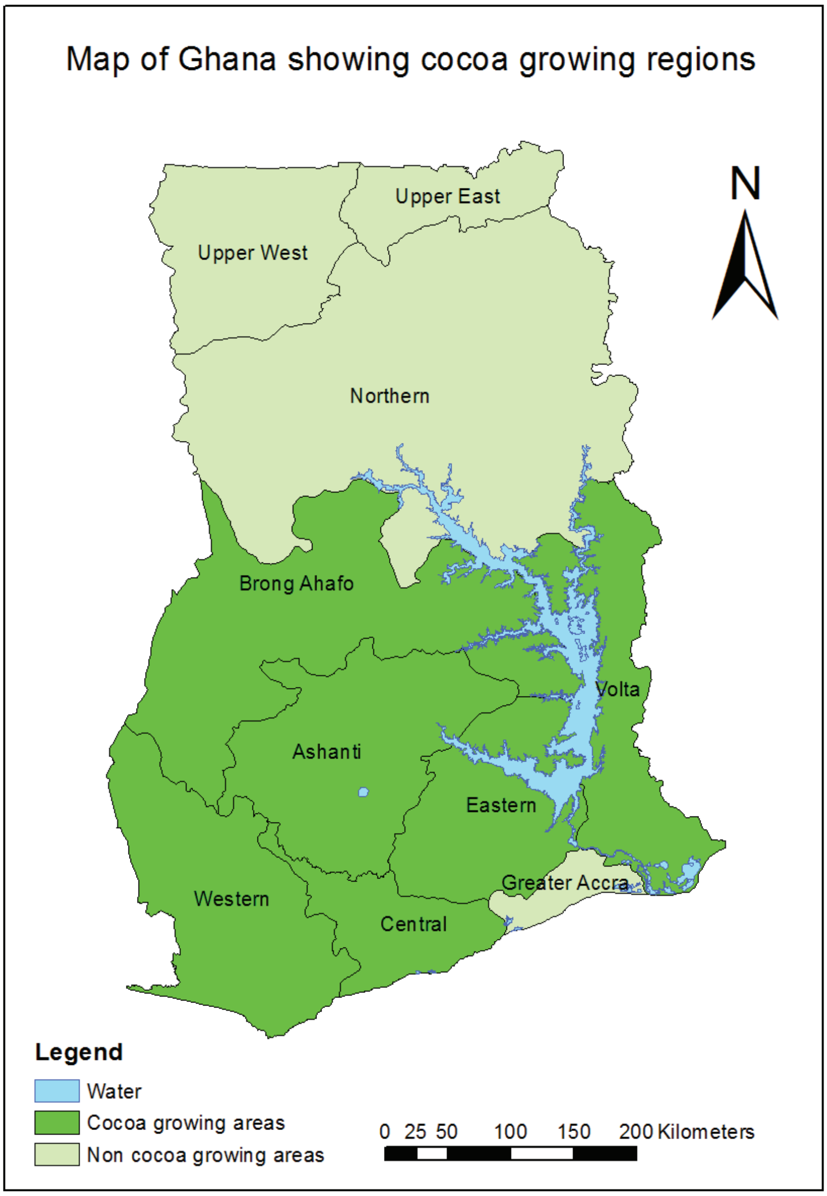


Figure 1.1 : A map of Ghana showing the cocoa growing region

This has led to the fast spread of the CSSV disease from the initial cocoa fields to new unaffected cocoa growing areas with the Western region being a classic example.

1.1.1 Present Situation of CSSV Disease Control in Ghana

The main control measure adopted by the Cocoa Swollen Shoot Virus Control Unit (CSSVDCU) of Ghana Cocoa Board (solely responsible for the survey and control of the CSSV disease in Ghana) in eradicating CSSV cuts out infected and uninfected cocoa trees in contact (Domfeh, *et al.*, 2011). This eradication procedure, considered as expensive and labor intensive has been practiced for over forty (40) years without success (Dzahini-Obiatey. *et al.*, 2010). However, despite intense eradication efforts, consisting of clear cuts and burns, the disease continued to spread, especially from initially infected sites (Ollennu & Owusu, 2002).

The rapid spread of CSSV has resulted in the increase of area under cultivation rather than increase in productivity, the reason being that generally farmers found it much easier to abandon their cocoa fields when their trees were infected with CSSV disease in favour of clearing new, virgin forest sites (Clough *et al.*, 2009). Abandoning of diseased and aged cocoa fields for cultivation of new fields due to the fast spread of CSSV has led to decrease in the lands available for natural environments (Frimpong *et al.*, 2007).

This phenomenon of environmental fragmentation has been recognized as major threat to biodiversity and one of the primary causes of the present deforestation crisis, which threatens the sustainable use of land and survival of many species (Asase *et al.*, 2010). Halting deforestation by reducing extensive cultivation (clearing of more cultivable lands) therefore enhances the eradication of CSSV disease (Bongiovanni & Lowenberg-Deboer, 2004). Figure 1 below depicts hectares of land area cleared for the cultivation of cocoa and yield of cocoa in tons harvested between the years 2007 to 2012.

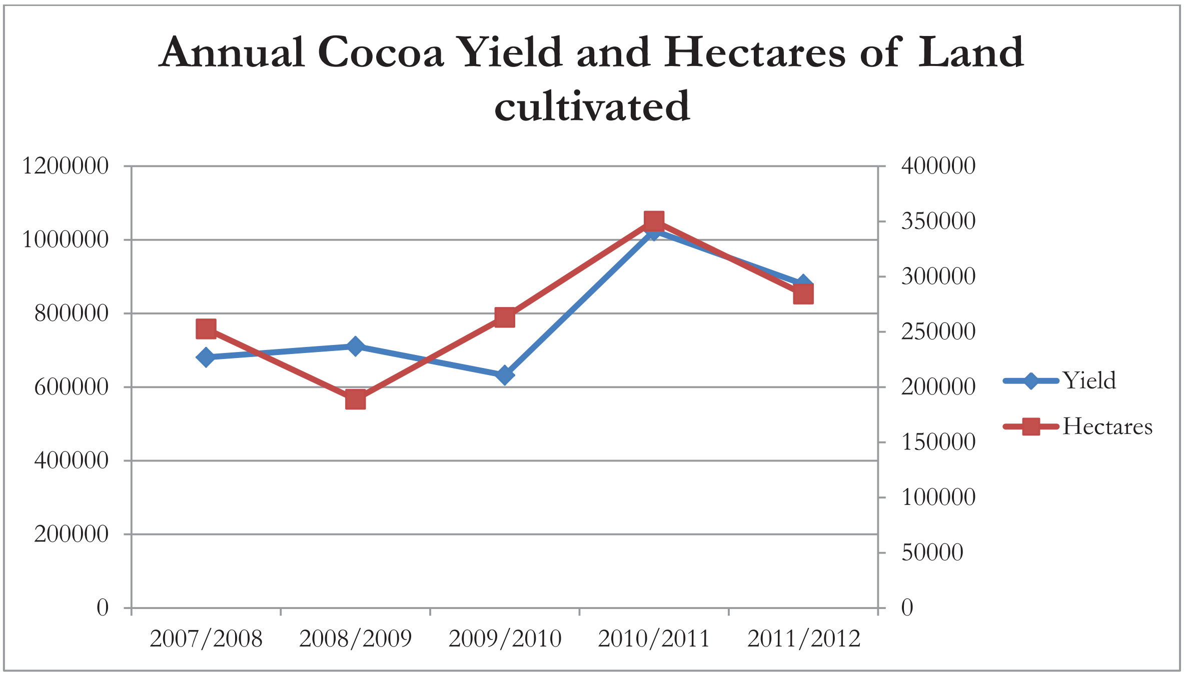


Figure 1.2 : Hectares of land area cultivated for cocoa and the yield in tons between within five years.

Achieving consistent production at high levels without causing further damage to the environment requires improvements in control measures (Gockowski & Sonwa, 2011). However, the current method of detecting CSSV in the field by visual inspection of cocoa trees for presence of stem swelling and leaf symptoms has failed in eradicating CSSV disease over the years (Ollenu, 2003). This process also impedes detection of CSSV disease at the latent stage. Improvement in control measures requires incorporation of novel approach of disease management to expedite the current eradication process.

1.1.1.1 Mapping Scheme of CSSVDCU

Within the cocoa industry, a region is broken down into districts and the district is further broken down into cocoa sectors, cocoa blocks and cocoa areas in order to delineate cocoa fields from other land use types. The district map comprises boundaries of sectors, blocks and the cocoa fields, with the CSSV outbreak fields. At the block level, non-disease and diseased cocoa fields and cocoa types are shown in the cocoa block map with the following attribute information: cocoa fields sizes, sizes of CSSV outbreaks and number of estimated trees involved.

There are three types of cocoa breeds cultivated by cocoa farmers in Ghana and four classes of cocoa age groups. The three types of cocoa breeds which are cultivated extensively by cocoa farmers in Ghana namely: Amelonado, Amazonia and Hybrid. In most cases some farmers plant all the three types described officially as Mixed Types. As a result of the large size of cocoa fields in the western region, the region has been divided into two (the western north and south regions) to ensure effective and efficient management of the CSSV disease.

1.2 CSSV monthly progress report

In addition to the cocoa maps, there is a monthly progress report of the Cocoa Swollen Shoot Virus Disease Control Unit (CSSVDCU) containing the statistical records on CSSV control undertakings. The importance of the statistical records available to this study was the information on age class and type of cocoa. Table 1 and 2 represents tables of cocoa types and age class in the study area prepared by the CSSVDCU.

Table 1.1 : Summary of cocoa types

District	Area Of Country Surveyed		Area Of Cocoa	% Of Cocoa	Cocoa Type (Ha.)							
	No. Of Blocks	Area Of Blocks	(Ha.)	Relative Density	Amelonado		Amazon		Hybrid		Mixed	
					Area	%	Area	%	Area	%	Area	%
Essam	24	6,196.49	5,289.30	85.36	-	-	5,274.22	99.71	15.08	0.29	-	-
Juaboso	27	7,091.60	6,401.91	90.27	-	-	2,349.60	36.70	1,015.01	15.85	3,037.30	47.44
Boako	20	7,754.55	6,885.06	88.79	-	-	5,229.98	75.96	1,160.68	16.86	494.40	7.18
S/Bekwai	9	3,824.96	1,857.24	48.56	-	-	11.75	0.63	590.82	31.81	1,254.67	67.56
Enchi	15	2,362.82	2,014.86	85.27	0.31	0.02	717.66	35.62	67.77	3.36	1,229.12	61.00
Akontombra	24	6,858.38	6,323.47	92.20	56.47	0.89	747.60	11.82	360.37	5.70	5,159.03	81.59
Dadieso	16	4,429.94	3,264.15	73.68	134.07	4.11	325.93	9.99	42.26	1.29	2,761.89	84.61
Total	**135**	**38,518.74**	**32,035.99**	**83.17**	**190.85**	**0.60**	**14,656.74**	**45.75**	**3,251.99**	**10.15**	**13,936.41**	**43.50**

Table 1.2 : Summary of cocoa age class

	Area Of Country Surveyed		Area Of Cocoa	% Of Cocoa	A 1-7 Yrs		B 8-15 Yrs		C 16-30 Yrs		D Above 30 Yrs	
District	No. Of Blocks	Area Of Blocks	(Ha.)	Relative Density	Area	%	Area	%	Area	%	Area	%
Essam	24	6,196.49	5,289.30	85.36	15.67	0.30	19.98	0.38	5,253.65	99.33	-	-
Jeboso	27	7,091.60	6,401.91	90.27	139.48	2.18	3,514.71	54.90	2,747.72	42.92	-	-
Boako	20	7,754.55	6,885.06	88.79	530.99	7.71	1,125.15	16.34	5,228.92	75.95	-	-
S/Bekwai	9	3,824.96	1,857.24	48.56	67.07	3.61	1,176.97	63.37	613.20	33.02	-	-
Enchi	15	2,362.82	2,014.86	85.27	49.73	2.47	64.90	3.22	1,900.23	94.31	-	-
Akontombra	24	6,858.38	6,323.47	92.20	111.89	1.77	265.63	4.20	5,899.22	93.29	46.73	0.74
Dadieso	16	4,429.94	3,264.15	73.68	11.95	0.37	221.01	6.77	2,995.63	91.77	35.56	1.09
Total	**135**	**38,518.74**	**32,035.99**	**83.17**	**926.78**	**2.89**	**6,388.35**	**19.94**	**24,638.57**	**76.91**	**82.29**	**0.26**

It has been observed that the method of analysing field data and the presentation of field information in tabular forms do not offer detail insight as to the spatial distribution of the CSSV disease and the opportunity to do further analysis of the information provided. However, modelling has the capacity to allow for graphical presentation of the CSSV and flexibility to do further analysis of the CSSV disease towards its eradication.

Consequently, modelling of the spatial distribution of CSSV with geographic information systems (GIS) has the capability to identify areas with high concentration of CSSV disease for effective eradication. Modelling the potential risk sites could also serve as risk map to assess the possibility of CSSV infections in the study area (Richard S. Ostfeld, 2005). Identifying the distribution of CSSV disease will therefore offer CSSV policy makers: Management of CSSVDCU of Ghana Cocoa Board in designing appropriate methods to overcome the challenges with the eradication programme rather than the ad hoc manner in dealing with the CSSV menace (McCallum, 2001).

1.3 Mapping CSSV spatial distribution with Geographic Information Systems (GIS)

The spatial distribution of CSSV could be better understood by way of mapping locations of diseased cocoa fields with Geographic Information System (GIS). This will make the management of CSSV disease outbreak efficient and easier, and also make available other spatial analysis tools to assess diverse procedures in preventing and eradicating the CSSV disease.

In GIS, distribution maps are geographical representation of point data on a map through the use of colours that indicate the density of some variables. Distribution maps allow users to quickly visualize the concentration of CSSV locations in the study area. Being able to understand the density of point's locations will make it much easier to comprehend patterns in data especially when using colours.

Effective identification of CSSV distribution in the field is central to early detection of infected sites for treatment. Detecting CSSV for timely eradication can help disease managers eliminate emerging infected fields before they have the chance to become widely established, thus eliminating the need for costly and resource-intensive control procedures. Rehabilitation of existing diseased cocoa fields and aged fields will increase productivity and thereby increase national income to improve socio-economic development of Ghana (Gockowski & Sonwa, 2011).

1.4 Modelling CSSV Potential Sites of Risk with MaXent

The effective approach to control and eradicate crop disease is to model suitable habitats of the disease of interest. Modeling of crop disease is a rapidly expanding discipline within plant pathology in epidemiology. Modelling aims to understand the main determinants of epidemic development in order to develop sustainable strategies and tactical management of diseases (Van Maanen and Xu, 2003). Hence modelling CSSV spatial distribution will uncover the underlying factors accounting for the distribution of CSSV disease using species distribution models (SDMs) (Richard S. Ostfeld, 2005).

SDMs are computer mock-up models which support the development of models that have been developed in the past decades and could be of significant use to the study. SDM predicts the distribution of species by combining known occurrence records with digital layers of environmental variables (Elith & Leathwick, 2009). One outstanding standard of the computer mock-up models is the predictive risk models which can be effective alternative for ordering the probable sites for reintroduction of CSSV disease.

There are a number of modelling algorithms which have been applied in disease modelling. One exceptional standard is the Maximum Entropy (MAXENT) which has been found to perform best among many different modelling methods and may remain effective despite small sample sizes (Wisz *et al.*, 2008). MAXENT is an entropy-based machine learning programme that estimates the probability distribution for species occurrence. Two types of model input data are needed for its effective use; known species occurrence records and a suite of environmental variables.

1.5 Problem of the study

Several approaches have been used in implementing the control of CSSV disease over the years, however little has been done on the spatial distribution of CSSV to control and monitor the disease (Domfeh*, et al.*, 2011). The probable sites for re-introduction of CSSV disease are not known. Presently the cocoa industry faces the challenge of determining where an outbreak may occur, and where the outbreak may move next. Late discovery of disease outbreaks and incomplete treatment of diseased fields have hampered the effectiveness of the eradication procedure in Ghana, where the official eradication (cutting out programme) has been practiced over forty years and millions of infected trees have been removed (Dzahini-Obiatey. H et al, 2010).

The current approach has been largely ineffective as the disease is still present and continues to spread throughout the country (Dzahini-Obiatey*., et al.*, 2010). Consequently, there is the need to adopt a more effective and efficient tool of intervention in solving the problem. Hence the need for a novel approach that is able to accurately map the spatial distribution of CSSV for prediction of potential areas of risks as an effective and efficient tool of intervention. Consequently, modelling has become an important factor for consideration due to its numerous benefits.

1.6 Objectives of study

1.6.1 General Objective

The main objective of the study is to model the spatial distribution of CSSV disease for effective and efficient eradication in order to contain the disease. To achieve the main objective, the following specific objectives are proposed

1.6.2 Specific objectives

- To identify the spatial distribution of CSSV in the study area;

- To determine environmental variables that are significantly associated with CSSV
- To model the spatial distribution of CSSV to identify potential area that is at greatest risk.

1.6.3 Research questions

Available literature suggests that the mealy bug is the vectors of the swollen shoot disease after several years of investigations. In spite of this, the eradication process of the mealy bug induced disease seems to be slow and ineffective. Therefore the follow research questions are put forward:

Table 1.3 : Research questions

Research objectives	**Research question**
To identify the spatial distribution of CSSV in the study area;	What is the spatial distribution of CSSV in the study area?
To determine environmental variables that are significantly associated with CSSV disease;	What are the environmental variables that best predict probability of CSSV occurrence?
To model the spatial distribution of CSSV to identify potential areas that is at greatest risk for cocoa cultivation.	Can the probable sites for re-establishment of CSSV be modelled using MaXent?

1.6.4 Hypothesis

H0: There is significant positive relationship between environmental variables such as elevation, aspect, slope, proximity to forest and climatic variables; precipitation, temperature, and CSSV occurrence;

H1: There is no significant relationship between environmental variables such as elevation, aspect, slope, proximity to forest and climatic variables; wind, precipitation, temperature, and CSSV occurrence.

1.6.5 A Brief rationale for inclusion of environmental variables

Environmental variables (annual mean temperature and precipitation, proximity to forest, elevation, slope and aspect) were pre-selected for the study through literature search. The goal is to predict which areas within the study region satisfy the requirements of CSSV survival in relation to the variables. These variables through literature are directly or indirectly linked to CSSV disease history with the potential to affect distribution trend in the study area (Richard G. Pearson *et al.*, 2006; Van Maanen, 2003).

Temperature and Precipitation

To model the geographical distribution of CSSV disease, there is the need to know where the vectors of CSSV prefer to live and what the requirements to its survival are. As a result these variables were selected to represent the range of natural climatic conditions that suit the survival and production of mealy bugs in the study area (Patil *et al.*, 2011). The lower and upper optimum temperature congenial for survival of mealy bug insects was set at 20°C and 30°C respectively which were within the range reported for other mealy bug species (Chong *et al.*, 2003; Chong *et al.*, 2008). The total monthly precipitation required for cultivation of cocoa is at least 1500mm (Patil, *et al.*, 2011).

Terrain (elevation, slope and aspect)

A topographic variable (elevation) influences the climatic variation and vegetation composition and structure of ecosystem; this in turn influences the distribution of species. The assumption for elevation is that the greater the elevation variability of an area, the greater the spatial variability of its micro-climate and therefore the more likely the area will have a larger number of habitats (Rodríguez *et al.*, 2005).

Slope and aspect

The aspect of the slope affects the local climate, the sun rays are in the west at the hottest time of the day. Therefore, the west side of a slope tends to be warmer than the shadowed east facing side of the slope. The effect of direct sunlight and shade on the transmission rate of mealy bug vector of CSSV was higher in the dark than in the light. (R. S. Ostfeld *et al.*, 2005).

Proximity to forest

The proximity to forest represents the distance from every pixel to forest. It was revealed in earlier studies that, the mealy bug originated from the forest (Michael J. Jeger, 2001). Therefore knowing the optimal distance at which forest impacts on CSSV distribution trend in the study area is vital. For this reason, a forest shape file was used to model probable sites for reintroduction of CSSV to display unsuitable sites in the field that should be avoided during cultivation of cocoa in the study area.

Table 1.4 : Preselected environmental variables

Category	Variable	Data Format	Data source
Climate	Precipitation	Raster	WORLD CLIMATE DATA (WORLDCLIM)
	Temperature	Raster	
Topography	Elevation	Raster	USGS/NASA SRTM
	Slope	Raster	
	Aspect	Raster	
Proximity to forest	Forest shape file	Vector	Forestry Commission of Ghana (FCG)

2 BRIEF HISTORY OF COCOA

2.1 Cocoa Production in Ghana

Cocoa cultivation, which has its origin in Central and South America, was introduced into West Africa through the island of São Tomé and Fernando Po and has now become a major cash crop in Ghana. The crop is now the major foreign exchange earner and the backbone of Ghana's economy. Cocoa is indigenous to West Africa rainforest belt that covers countries such as Ghana, Cote d' Ivoire, Nigeria, Togo and Cameroun.

Temperature is influential in selecting sites for cocoa cultivation, which needs a high temperature with no great variations (Orisajo, 2009). A mean temperature of 24 - 28^{0}C with a daily range of less than 10^{0}C is favourable for cocoa cultivation. Cocoa is fairly demanding and requires at least 1500mm of appropriately distributed rainfall and optimum relative humidity of 80% (Orisajo, 2009). These preconditions have defined cocoa growing belt in the southern part of Ghana comprising the Western, Ashanti, Brong - Ahafo, Eastern, Central and Volta region (unpublished document from Ghana Cocoa Board).

For the reason that cocoa is grown throughout the humid low tropics, diverse diseases impact production of the crop. The most potentially dangerous of these diseases is the cocoa swollen shoot virus (CSSV) disease. Even though cocoa for a long time has been the backbone of Ghana's economy, unfortunately the country's production suffered severe setbacks through virus diseases and pests, among other things. As a result, production has been on a steady decline bringing the country (currently) to the second position among the producer nations in the world.

The large numbers of smallholder indigenous farmers are the main players in the cocoa sector. They operate small scale cocoa fields and therefore need control measures that are cheap, simple, cost-effective and sustainable in order to combat CSSV as well as make farming profitable and sustainable. Although, government subsidized inputs are made available to the small holder farmers to help control CSSV disease, they are usually not patronized by the farmers who consider the inputs very expensive. This has led to the fast spread of the disease, leading to low production of the product.

CSSV disease is now present in virtually all cocoa growing areas of Ghana, as well as in neighbouring Togo, Nigeria, Cameroon and Cote d'Ivoire (Ollenu, 2003; Thresh *et al.*, 1988). The virus is indigenous to West Africa, present in forest trees and appears to have transferred to cocoa following the introduction of the crop (Tinsley, 1971).

The damage caused due to CSSV to the cocoa industry is immense, ever since CSSV disease was discovered in Ghana; it has resulted in substantial crop losses leading to the cutting out of millions of trees, and changes to environment and the way of life of whole farming societies as they are forced to migrate; and as the clearance of forests for new cocoa fields is a major challenge for the cocoa industry in Ghana (Dzahini-Obiatey*., et al*., 2010; Ollennu & Owusu, 2002).

The earliest cocoa fields in Ghana were largely in the southeast. Presently, the epicentre of production has progressively shifted to the western part of Ghana (Domfeh*, et al*., 2011). Currently, the Western Region alone produces more than half of the total annual output. There are numerous factors contributing to this westward shift. Key factors responsible for the expansion of cocoa in the western region are: high incidence of disease and diseases, the presence of non-reserved and reserved forest in the region, and farmers historically found it much easier to abandon their fields when their cocoa trees were infected with CSSV or had gone beyond their productive lifecycle.

These challenges augmented by the lack of technical skills and funds on the side of farmers have led to inadequate maintenance of cocoa fields to raise productivity. (Rice & Greenberg, 2000). As a result, clearing of forestland to pay off for diseased and lower outputs is the only option for the farmers. Presently significant proportion of forest reserves have been illegally converted into cocoa field. (Clough*, et al*., 2009). The current situation has serious implications for sustainable cocoa production and the maintenance of the remaining forests in the high forest zone, and in particular the Western Region which accounts for more than 50% of cocoa production in Ghana.

As a result, CSSV disease has emerged recently in the western region as a threat to cocoa production and deforestation crisis which threatens the sustainable use of land and many species. From the year 2006 to 2010 the western region alone accounted for 20,069,898 infected trees out of the 28,486,306 (70.5%) trees removed nationwide (Domfeh*, et al*., 2011). Once the virus is introduced, it has the potential to establish itself and spread rapidly, as tree species with known competency for hosting and transmitting the CSSV are present.

2.2 Transmission of CSSV disease

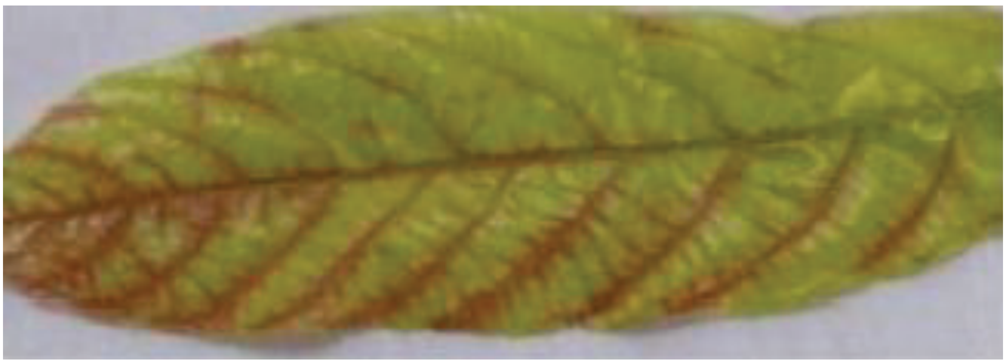
Transmission of cocoa swollen shoot virus disease is vectored by mealy bugs which spread the virus from diseased cocoa trees to non-diseased cocoa trees through wind current, by ants or the mealy bug crawling (Cornwell, 2009; Ollenu, 2003). The propagation of the virus could also convey through virus feeding on diseased cocoa trees which serve as sources of inoculum. Alternatively, the spread could occur through the movement of diseased cocoa pods after harvesting and also by the use of adulterated planting material (Oro, 2012).

Figure 2.1 : Depicts mealy bug the vector of CSSV disease

The virus is spread into gaps of the cocoa pods as well as the bud wood if the virus is in a latent stage. The propagation of the virus is by two ways; short and long distances; short distance propagation is denoted as radial spread caused by the mealy bug moving at short distances between cocoa trees during feeding (M. J. Jeger & Thresh, 1993). Long distance spread on the other hand is caused by movement of vectors over relatively long distances, usually by wind, thereby causing new outbreaks far away from existing diseased areas.

2.1.1 Symptoms of CSSV disease

Symptoms of CSSV may cause both leaf signs and swellings on the stems and roots (Ollenu, 2003). Leaf signs may cause red vein banding as a result of increase of anthocyanin along the veins and veinlet. This is followed by abnormal colour of the plant tissue, resulting from partial failure to develop chlorophyll and may spread out along larger veins giving angular specks. Stem swellings may occur at the nodes, internodes and roots. The most noticeable sign shown by the cocoa pod is change in shape, the cocoa pods become rounder and in some cases become almost spherical.



A

B

Figure 2.2 : Young cocoa leaves of CSSV infected cocoa showing red vein banding
A =relatively younger leaf and
B = relatively older leaf

Diseased cocoa pods exhibit smaller pods and smoother surface than healthy cocoa pods. Some CSSV cause only leaf signs, others cause stem and root signs with only very slight leaf symptoms, whereas others display both type of symptoms. In some instances, the leaf symptoms are temporal whereas in other instances affected cocoa pods may show severe symptoms which could lead to the death of the cocoa plant.

2.1.1.1 Detection and control of CSSV disease

Currently detection of CSSV in the field is carried out by visual inspection of cocoa trees by skilled personnel for the manifestation of stem swelling and leaf symptoms (Ollenu, 2003). Diseased cocoa trees are then labelled before cutting out, together with neighbouring cocoa trees in contact. The prime control measure has been based on a "zero tolerance" philosophy which required that all infected trees and those in contact with them be removed (Dzahini-Obiatey*, et al.*, 2010). Also known as eradication programme, it has been costly both in monetary and political terms.

This has led to the destruction of millions of trees, with new farms getting rapidly infected. High annual losses of cocoa production through destruction of trees often cause loss of popularity of a ruling party among rural folks (Danquah, 2003). However, the eradication of CSSV is solely funded by the government of Ghana, and as a result commits huge allocation of national resources that otherwise could have been spent on other aspects of cocoa production (Thresh, 2003).

2.2 Study Area

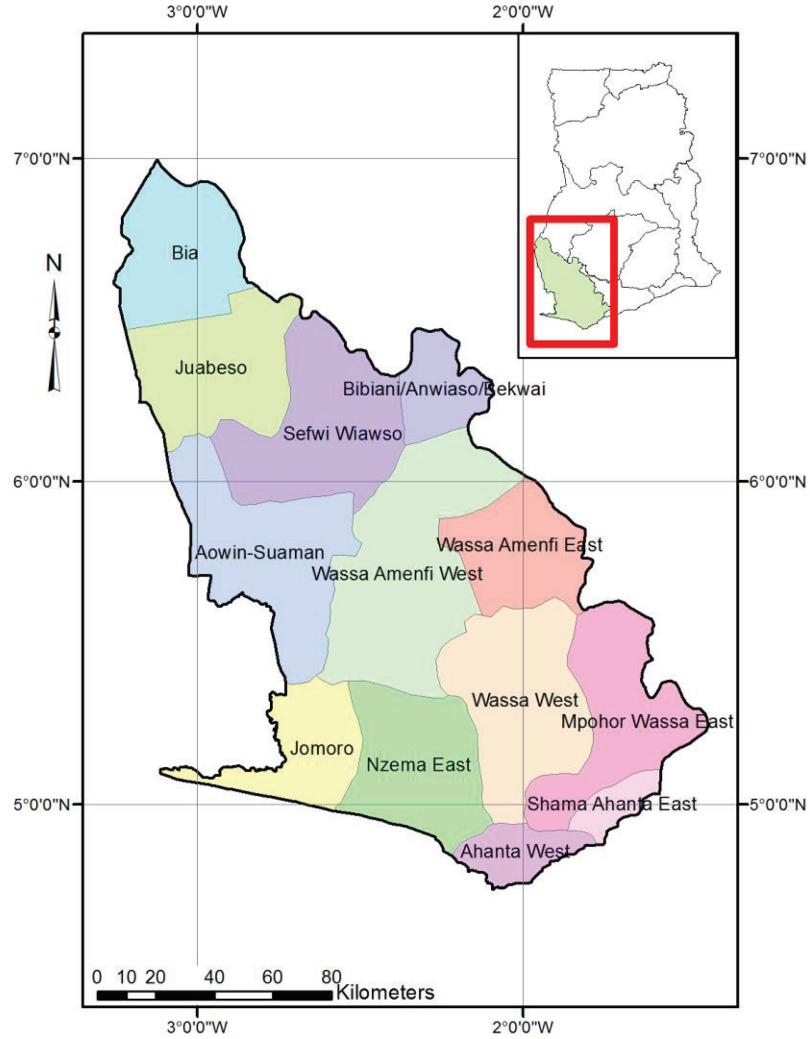
2.2.1 Location and Size of Western region

In this study, the Western region of Ghana was selected as the study area. It is located between latitude 4°00' to 7°00 north, and between longitude 3.07° west and 1.07° east. The region covers an area of 23,921 square kilometres, representing about 10 per cent of total land surface of Ghana. Western region is situated in the south-western part of Ghana, and shares boundaries with three regions in Ghana, including the Central Region on the east, Ashanti and Brong-Ahafo regions, and to the west it shares boarder with the Republic of Cote D'Ivoire.

The southernmost part of Ghana, is at Cape Three Points, near Busua, is in the Ahanta West District of the region. The region has 192 kilometres of tropical beaches on the Atlantic Ocean and a tropical climate characterized by adequate temperature all year round. The region has 75 per cent of its vegetation within the high forest zone of Ghana. The south-western areas of the region are renowned for their rain forest, intermixed with patches of mangrove forest along the coast and coastal wetlands, while a large expanse of high tropical forest and semi-deciduous forest is also found in the northern part of the region.

The Western Region has twenty four (24) forest reserves, which account for about 40 per cent of the forest reserves in Ghana. Prominent among them are the Bia Reserve, Cape Three Points National Park, the Ankasa/Nini Suhyien Forest and Game Reserve. The Region lies in the equatorial climatic zone with temperatures, ranging from 22°C at nightfall to 34°C during the day. The Region is the wettest part of Ghana, with a double maxima rainfall pattern averaging 1,600 mm per annum.

The binary rainfall peaks fall between May-July and September-October. In addition to the two major rainy seasons, the region also experiences intermittent minor rains all the year round. This high rainfall regime creates much moisture culminating in high relative humidity, ranging from 70 to 90 per cent in most parts of the region. Agriculture predominates in all districts, accounting for over 70 per cent of occupation in the region. Agriculture remains the biggest industrial activity in the region employing more than 50 per cent of workers in the region.



Smallholder farming is predominant in the region. The weather conditions is favourable for the production of tropical cash crops such as cocoa, coffee, oil palm, black pepper and citrus and other agricultural crops such as maize, cassava, and plantain. The study was carried out in the Western region of Ghana as a result of current dominance of CSSV in the region with frantic efforts by various governments and Development Partners to control the menace of the disease.

Western region is the last frontier of forest in Ghana, modelling the distribution of CSSV for effective rehabilitation of diseased fields will enhance the eradication programme to promote intensive farming to halt deforestation and loss of biodiversity. Furthermore data on diseased and healthy cocoa fields are available and are fairly distributed in the study area.

3 MATERIALS AND METHODS

3.1 Data and research approach

The approach for the study was in three interrelated segments. The first segment created a distribution map for CSSV disease in the study area through the use of secondary data collected from the Cocoa Swollen Shoot Virus Control Unit (CSSVDCU) of Ghana Cocoa Board.

The second segment established the relationship between climatic/environmental parameters and the incidence of CSSV. This segment also dealt with the association between proximity to forest and the prevalence of CSSV disease. The third segment modelled the probable sites for reintroduction of CSSV by the use of Maximum Entropy software. The fourth stage of the study dealt with collection of sample points for validation of output maps created.

3.2 Data for CSSV Disease Distribution and Probability Map

3.2.1 Data for CSSV distribution map

The spatial data used for mapping the spatial distribution of CSSV was a digital regional cocoa map of the study area (Western region of Ghana) acquired from the CSSVDCU. This map contains the cocoa fields without CSSV (absence data) and cocoa fields with CSSV disease (presence data) as shape files. In this cocoa map, the sectors, blocks and cocoa field boundaries contained attribute information including cocoa types, CSSV outbreak sizes, number of outbreaks, sizes of cocoa fields and estimated number of trees infected with CSSV representing the dataset. The method used in the collection of data was based on the systematic survey and total measurements of all cocoa fields in Ghana.

3.2.2 Statistical data

Together with the spatial data, the monthly progress report which contains the statistical records on CSSV control undertakings was used. The important data from the monthly progress report to this study includes; age classes of cocoa and summary of cocoa types. This type of data was based on total measurement of the cocoa fields and handled separately in the monthly progress report and not linked to the digital cocoa map.

3.2.3 Environmental variables for probability map

Topographic variables: elevation, slope and aspect from a digital elevation model (DEM) were downloaded from Consortium for Spatial Information (CGIAR- CSI) website to model the probable sites for reintroduction of CSSV. A DEM is a digital representation of a land surface in a computer, that is a sample of elevation points for x, (northing), y, (easting) and z (elevation) values that are recorded (Skidmore, 1989). DEMs are currently one of the most important data used for geo-spatial analysis because subsequent information for various applications can easily be derived (Toutin, 2002). A forest shape file from the Forestry Commission of Ghana database was also used to model the probable sites for re-introduction of CSSV disease.

Climatic variables including precipitation and temperature sourced from the world climate (WorldClim) dataset was used to model the probable sites for reintroduction of CSSV disease. WorldClim is a set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometre. The data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (Robert J. Hijmans, 2005). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables

3.2.4 Modelling spatial Distribution of CSSV

The map of spatial distribution of CSSV disease in the Western region of Ghana was created by combining the cocoa maps of the Western North and South sourced from the CSSVDCU in ArcGIS.

First Segment

Mapping the distribution of CSSV disease

One of the significant constituents of this study was the CSSV presence points to identify the spatial distribution of CSSV disease in the study area. The presence and absence shape files of CSSV disease were collected by the CSSVDCU of Ghana COCOBOD from March 2010 to August 2012. Ten per cent of the data collected within the period of March 2010 to August 2012 was used in the creation of the CSSV distribution map due to the fact that the data was current and already in digital format.

The geographical coordinate system of the cocoa map was converted from Accra, Ghana grid to WGS 1984. The CSSV presence and absence points were identified by finding the centroid points of the shape files containing diseased and non-diseased fields. This was achieved by opening the attribute table, add field, the field area was selected to calculate the area of the shape files, afterwards the calculate geometry tool was used to define the X and Y coordinates of the centroid points. Subsequently seventeen thousand two hundred and eighty five (17,285) sample points were identified.

Due to the large number of the presence points, the data (presence points) were collated in Microsoft excel and the simple random sampling technique was performed to select one thousand, seven hundred and twenty eight (1,728) sample points representing ten per cent of the presence points for the creation of the distribution map to avoid bias. After the determination of the CSSV occurrence applicable for the study, the data was organized in Microsoft Excel. ArcMap was used to transfer the CSSV occurrence data into a distribution map by joining the cocoa map shape file with the CSSV occurrence data.

Percentage of cocoa fields infected with CSSV per district in the study area was further derived by dividing the total size of diseased fields by the total land size cultivated with cocoa and multiplied by one hundred (100). For example the equation used to calculate the percentage of infection for Essam

=665.53/54687.83*100, the 665.53= the total size of cocoa fields infected with CSSV disease and the 54687.83 = the total land size cultivated with cocoa in the Essam district.

The number of CSSV outbreaks and cocoa fields as observed by the field staff of the CSSVDCU and the area recorded with GPS was used to create pie chart to display the total number of outbreaks, cocoa area and the area covered in hectares. Previous studies (Ollennu & Owusu, 2002) has revealed that Amelonado and Amazonia cocoa breeds are highly susceptible to CSSV, hence the introduction of hybrid cocoa breed which has tolerance to CSSV and is high yielding (Thresh, 2003).

Based on this assertion, the monthly progress report from the CSSVDCU which contains the summaries of cocoa types and age classes were used to identify the types of cocoa and age classes of cocoa in the study area. Information on the types of cocoa and age classes will offer insight into possible spread of CSSV. The statistical data from the monthly progress report was organized and analysed in Microsoft excel spread sheet to perform analysis on cocoa types and age class of cocoa.

Graphs were created to indicate the cocoa types whether Amelonado, Amazonia Hybrid or the combination of the three officially termed as Mixed type and their age classes in the study area. The interpretations of age class of cocoa are; age of cocoa between one to eight years (A) class of cocoa, age class from eight to fifteen years (B) class of cocoa, age class of cocoa from sixteen to thirty years (C) class of cocoa, and age class of cocoa above thirty years(D) class of cocoa.

3.2.5 Determination of environmental variables with influence on CSSV distribution

3.2.5.1 Analysis of Environmental variables

A digital elevation model (DEM) was used to derive the environmental variables: elevation, slope and aspect. A forest shape file was sourced from the Forestry Commission of Ghana to derive the variable proximity to forest. Annual precipitation and temperature data was also sourced from the World climate (Worldclim) database.

3.2.6 Selection of Environmental variables

Through literature search, six environmental variables were pre-selected. These pre-selected environmental variables were analysed to enable the final selection of suitable variables to model the probable sites for re-introduction of CSSV in the study area. To achieve this, statistical analysis was performed to determine the relationship between the environmental variables and CSSV occurrence. The sample analyst in ArcGIS was used to create a table that shows the values of cells from the raster image (point) locations of the environmental variables and the presence points.

The sample analyst selects random points based on user inputs; therefore values obtained were randomly selected. The values were exported to Microsoft Excel, the presence points were plotted against the environmental variables. The values of correlation coefficient for each of the variables were determined.

The correlation coefficient, measures the strength and direction of a linear relationship between two variables. Positive values indicate a relationship between explanatory (x) and response (y) variables such that as values for x increases, values for y also increase. If x and y have strong positive linear correlation, r is close to +1, for this reason the variables with high r values were selected.

The Euclidian distance tool was also used to calculate for each pixel the distance between forests to infected sites in the study area. A graph was produced and the correlation coefficient calculated to determine the variables' influence on CSSV occurrence. Finally five environmental variables with potential influence on CSSV distributions were selected and summarized in the table below.

Table 3.1 : Selected environmental variables in relation to CSSV disease occurrence

Category	Variable used	Data Format	Data source
Climate	Precipitation	Raster	
	Temperature	Raster	Worldclim
Topography	Elevation	Raster	
	Aspect	Raster	USGS/NASA SRTM
Proximity to forest	Forest shape file	Raster	Forestry Commission

To confirm the statistical analyses performed, the CSSV presence points were overlaid on the selected variables with ArcGIS. This approach assisted to identify locations with high influence of the variables and CSSV disease.

3.2.7 Modelling probable distribution of CSSV with MaXent

3.2.7.1 Presence data

CSSV presence points used in creation of the distribution map were used to model the probable sites for reintroduction of CSSV in the study area. This occurrence records on the CSSV in the study area were collated from existing field measurements collected by the CSSVDCU field officials in the areas where CSSV outbreak have been located from March 2010 to August 2012.

To have a fair representation of the presence points, all the 17,285 presence points were collated in Microsoft excel. The simple random sampling method was used to select one thousand seven hundred and twenty eight (1,728) sample points, representing ten per cent of the total points realized. All disease occurrence points were converted to CSV format as required by MaXent, using Microsoft excel 2007.

3.2.8 Suitable environmental variables

The environmental variables selected were shown to have potential influence on CSSV disease after the statistical analysis in segment two to model the reintroduction of CSSV disease. This was in accordance with what R. G. Pearson (2007) stated that selected environmental variables for modelling species distribution should be based on the association between environmental variables and known species occurrence records (Richard G Pearson, 2007). Established on this information, the five environmental variables with potential influence on CSSV distributions were selected for MaXent modelling and summarized in the table below.

Table 3.2 : Suitable environmental variables selected for MaXent modelling

Category	Variable used	Data Format	Data source
Climate	Precipitation	Raster	World climate
	Temperature	Raster	
Topography	Elevation	Raster	USGS/NASA SRTM
	Aspect	Raster	
Proximity to forest	Forest shape file	Raster	Forestry Commission

Modelling with MaXent

MaXent was selected for the study because it is a general purpose machine learning method with a simple and precise mathematical formulation, and it has a number of aspects that make it well suited for species distribution model (Phillips *et al.*, 2006). Maximum entropy has been found to perform best among many different modelling methods and may remain effective despite small sample sizes (Wisz*, et al.*, 2008).

It requires only species presence data (not absence) and allows the incorporation of both continuous and categorical data. The freely available MaXent software, 3.3.1 version was used for the study. The main requirements of MaXent are that environmental layers must be in ASCII Format and presence data in CSV file. As a result, a CSV file from occurrence coordinates was created with Microsoft excel spread sheet. Environmental layers must be modifyied to be the same extent and then converted to ASCII Format.

Producing a Comma Separated Values (.csv) file from CSSV occurrence coordinates in excel spread sheet.

A CSV file required for the samples points in MaXent was created from longitude (x) and latitude (y) coordinates of CSSV occurrence with Microsoft excel spread sheet. To begin with a data sheet in a row and three columns were created; the first row of the data sheet is a caption line with three columns. The first column bears the name of the species (CSSV) and the second and third columns are the X, Y coordinates occurrence records. The data was converted and saved as a CSV file by selecting save as (comma delimited) (*.csv) and saved.

Modifying Environmental layers to be the same Extent (geographic bound and cell size).

The Environmental layers used including; elevation, slope, total annual precipitation, mean temperature, and proximity to forest were modified in ArcGIS so that all spatial data could have the exact cell size, extent and projection system in order to execute a model. The spatial analyst toolset was turned on to start with the process.

Afterwards, the extract by mask tool was used to clip the topographical layers to have the same extent, cell size and coordinate system (a requirement of MaXent). Subsequently, all the raster layers were converted to ASCII Format by opening the Raster to ASCII tool where one of the environmental Raster layers was selected and converted to ASCII format. The same process was repeated for the rest of the environmental variables.

Running MaXent

One thousand, seven hundred and twenty eight (1,728) sample points of CSSV occurrence records from two and half years of CSSVDCU, presence data and environmental layers were used to estimate the potential distribution of CSSV. After splitting the presence data into two; seventy five per cent (75%) was used to run the model and the remaining twenty five per cent (25%) was used for validating the predictive performance of the model.

The parameters were set as follows; regularization multiplier = 1, maximum number of background points = 10000, maximum iteration = 1000, and convergence threshold 0.00001. After the setting was done the model was set to run. On completion of the run, a probability map was derived with other graphs indicating the performance of the variables used. Subsequently the cocoa map was used as mask to discriminate the areas with cocoa from areas with CSSV disease.

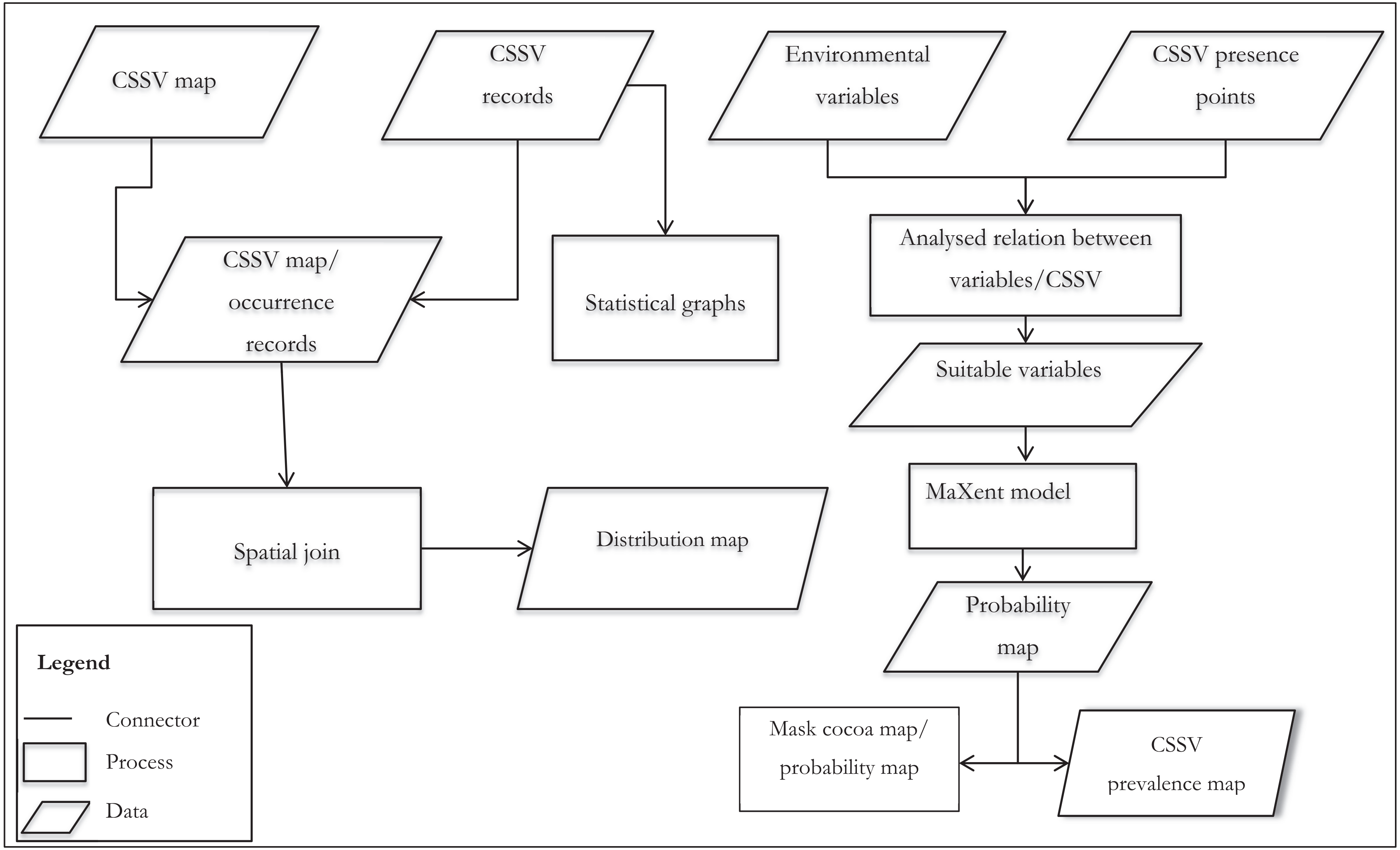


Figure 3.1 : Flowchart of methods

4 RESULT

4.1 Introduction

This segment presents the results of the analysis of the methods described in the previous chapter. GIS was used to create a distribution map of CSSV disease and graphs of cocoa types and age class produced in Microsoft excel. Association between environmental variables and CSSV occurrence was established. Finally a probability map was also created to identify the probable sites for reintroduction of the CSSV disease.

The distribution map of CSSV offered disease managers the opportunity to design tactical means of dealing with the CSSV disease. Analysing cocoa types and cocoa age classes provide insight into areas of possible disease outbreaks. Establishment of relations between environmental variables facilitate the selection of suitable environmental variables for the modelling of probable sites for reintroduction of CSSV disease. The probability map will serve as a risk map for effective management of CSSV disease.

4.2 Spatial distribution of CSSV disease and cocoa

Modelling the distribution of CSSV disease, GIS was used to produce (point) maps to represent the spatial distribution of CSSV disease and cocoa. By this method, the geographical distributions of CSSV disease and cocoa were easily identified as depicted in figure 4.1 and 4.2 (page 24). Percentage (figure 4.3 a) and number (figure 4.3 b) of CSSV disease was calculated, the fields with very high CSSV percentage were shown with deep red shade, high with light red, moderate with yellow shades, low with light green shades and very low with deep green shades as shown in figure 4.3 (page 25).

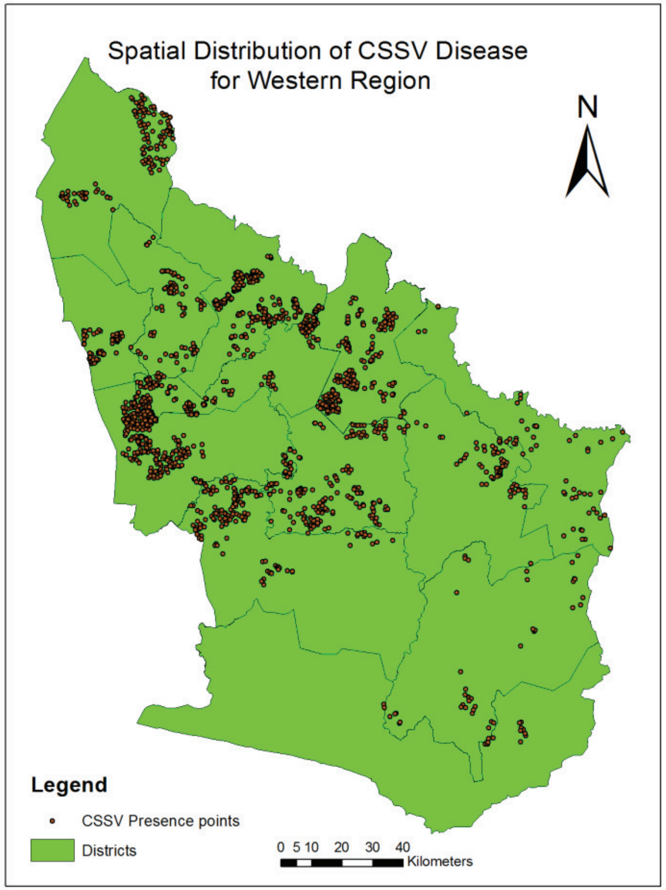


Figure 4.1 : A map showing the spatial distribution of CSSV disease in the study area

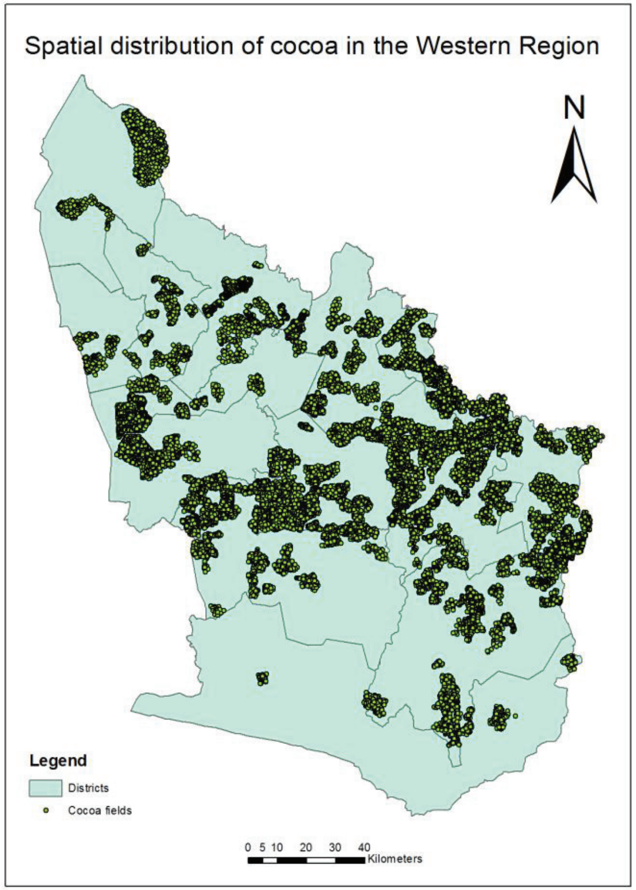


Figure 4.2 : A map showing the spatial distribution of cocoa in the study area

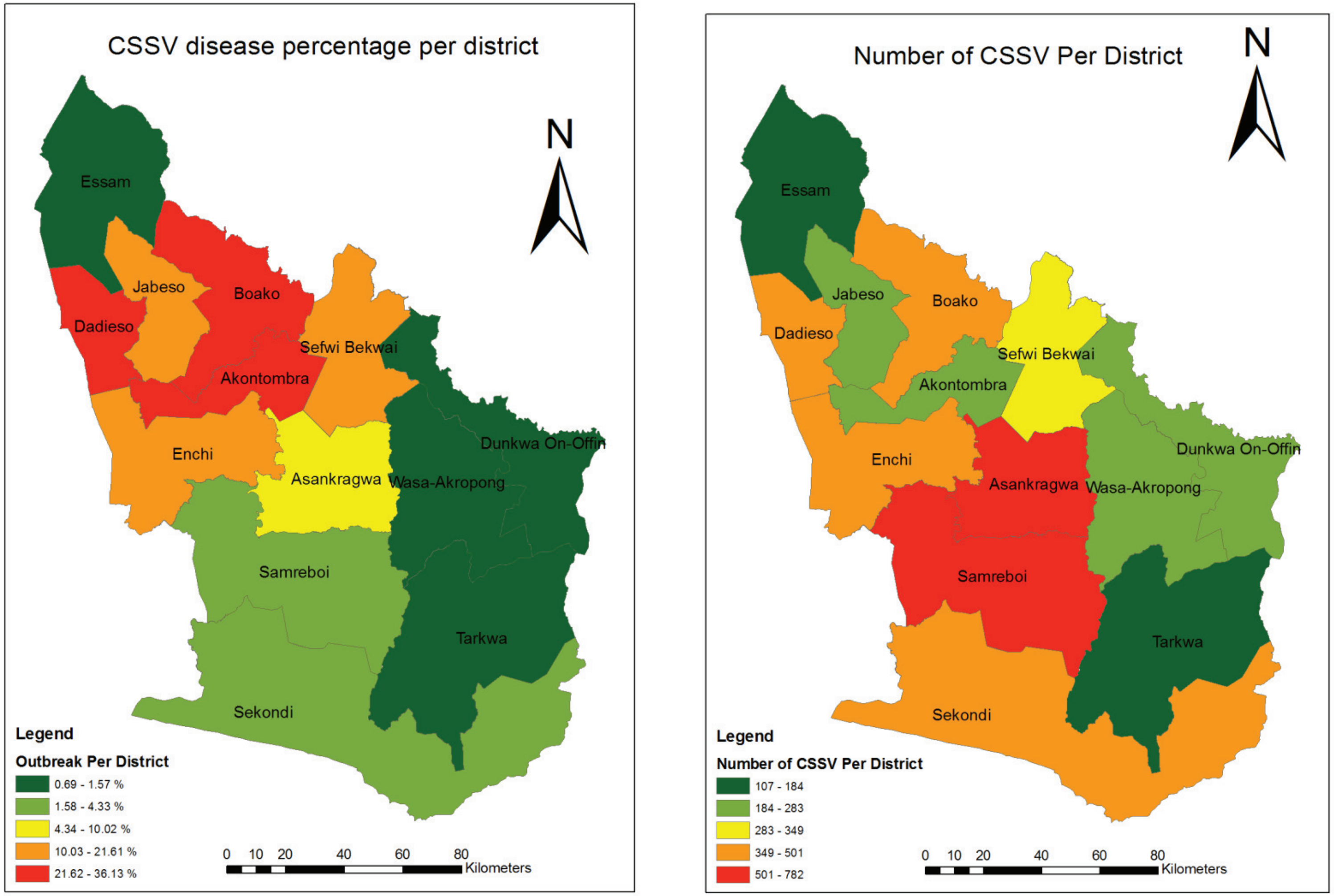
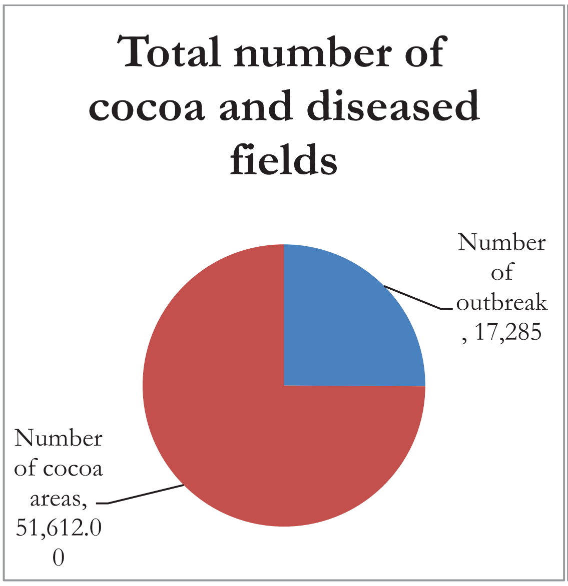


Figure 4.3 : Map (a) showing percentage of CSSV and map (b) showing number of CSSV disease in the study region

During the study, it emerged that the district of Essam has low incidence of the CSSV disease. Explaining the reason behind the low incidence of the disease in the district, the Management of the CSSVDCU stated that though the district once recorded very high incidence of the disease in the past, the Management of CSSVDCU undertook rigorous eradication campaign which significantly reduced the spread and concentration of the CSSV disease in the area. See figure 4.3 above for details.

The total number of outbreaks and cocoa areas recorded by the field staff of CSSVDCU and the total land area covered by the outbreaks and cocoa fields as measured with GPS in hectares was collated in Microsoft excel to create pie chart as shown in figure 4.4 below.



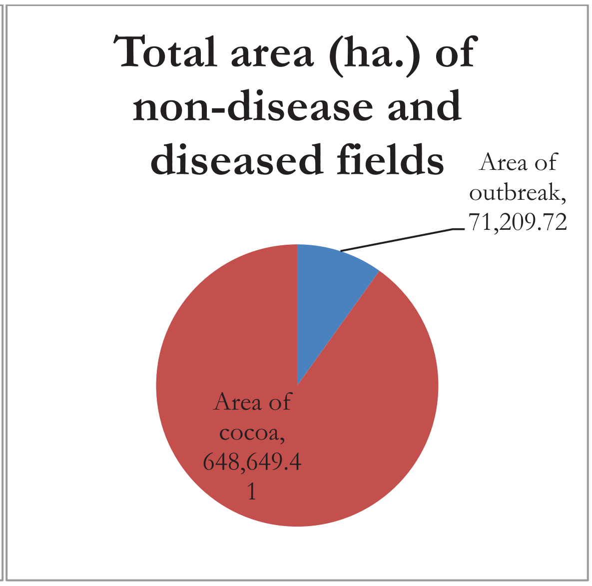


Figure 4.4 : A pie chart depicting the number of cocoa fields, CSSV outbreaks (left) and total area of non-disease and diseased fields in hectares

Graphical presentation of cocoa types and age classes

The analysis performed on cocoa types and age classes indicate that, Amazonia cocoa type is the highest with 65,120.42 hectares of land area, followed by mixed cocoa type with 53,593.50 hectares, Hybrid 22,564.20 hectares and Amelonado 12,181.19 hectares being the lowest breed for the study area.

In relation to the age classes of cocoa, age class between one to seven years (A) class; indicate sapling cocoa field, eight to fifteen years (B) class; matured cocoa field, sixteen to thirty years (C) class; old cocoa field and above thirty years (D) class; very old cocoa field (died out cocoa fields). The highest age class of cocoa is the (C) class, followed by (B) class, (A) and (D) classes.

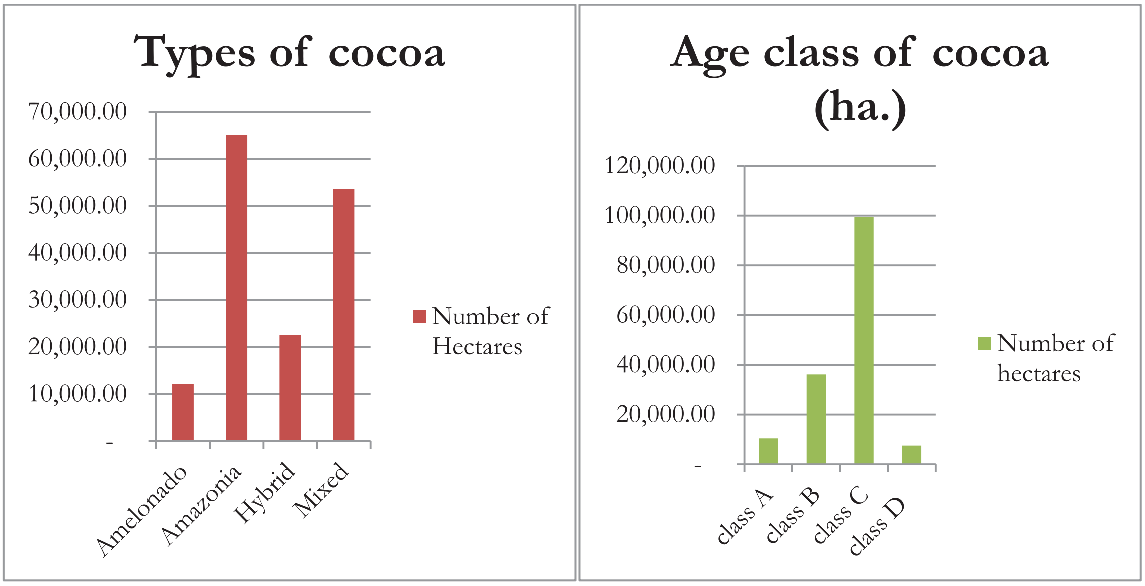


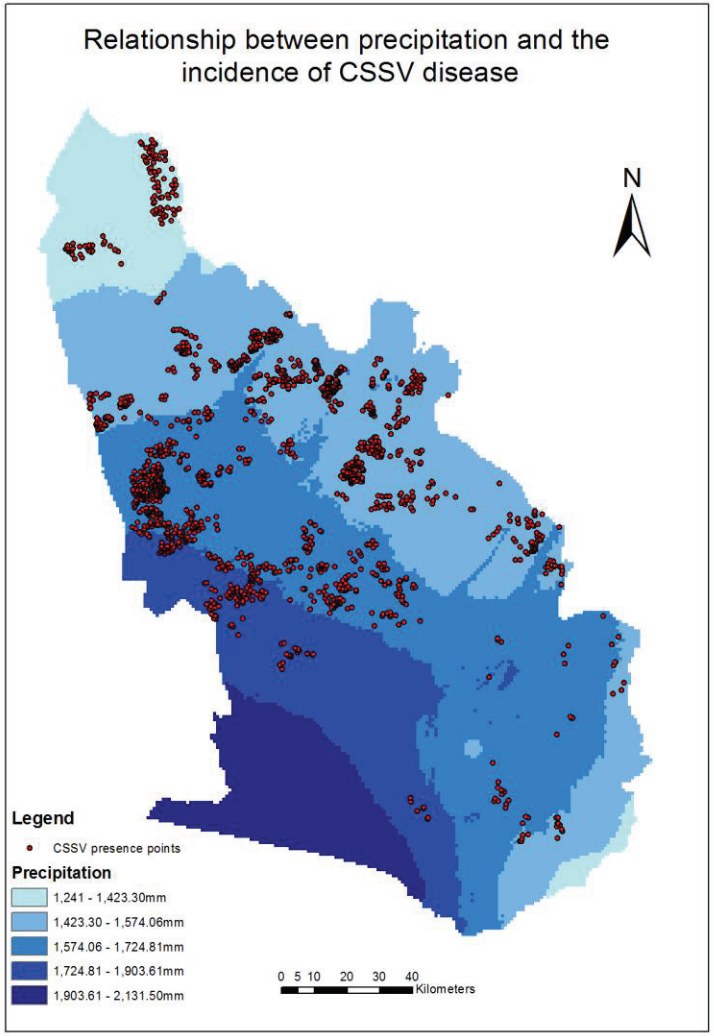
Figure 4.5 : Cocoa types and age classes of cocoa in the study area.

The presentation of cocoa types and their age classes in a graphical form as shown in figure 4.5 offers detail information on cocoa and can be subjected to further analysis for other information on CSSV disease outbreak. To wit, the graphical presentation makes it flexible for use by managers of CSSV.

4.3 Relationship between environmental variables and CSSV occurrence

Six environmental variables were selected through literature to establish their relationship to the distribution of CSSV trend in the study area. Statistical analyses performed indicate that five of the variables contribute significantly to CSSV distribution while the contribution of the remaining one was insignificant. The variables with significant relation with the prevalence of CSSV disease include; Proximity to forest, Elevation, Precipitation and Temperature. This is followed by Aspect; however, Slope has very low relationship with the disease.

The analysis was based on the rule that, if x and y have strong positive linear correlation, r is close to +1 The reason for the low relationship between slope and the incidence of the disease may be due to the fact that in Ghana cocoa fields are normally not found on slopes hence their limited influence. In order to confirm the relationship between the environmental variables and CSSV occurrence, the presence points of the CSSV were overlaid on the selected variables to draw effective conclusions. See figures 4.6, 4.7 and 4.8 for detailed information



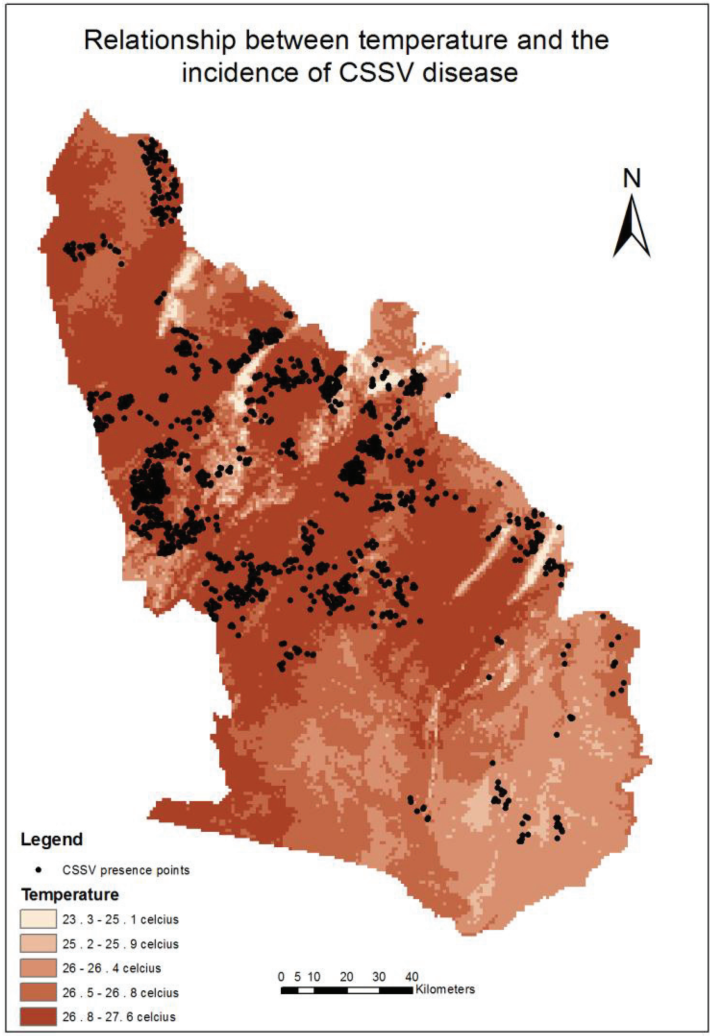


Figure 4.6 : Precipitation (a) and temperature (b) maps overlay with CSSV sample points

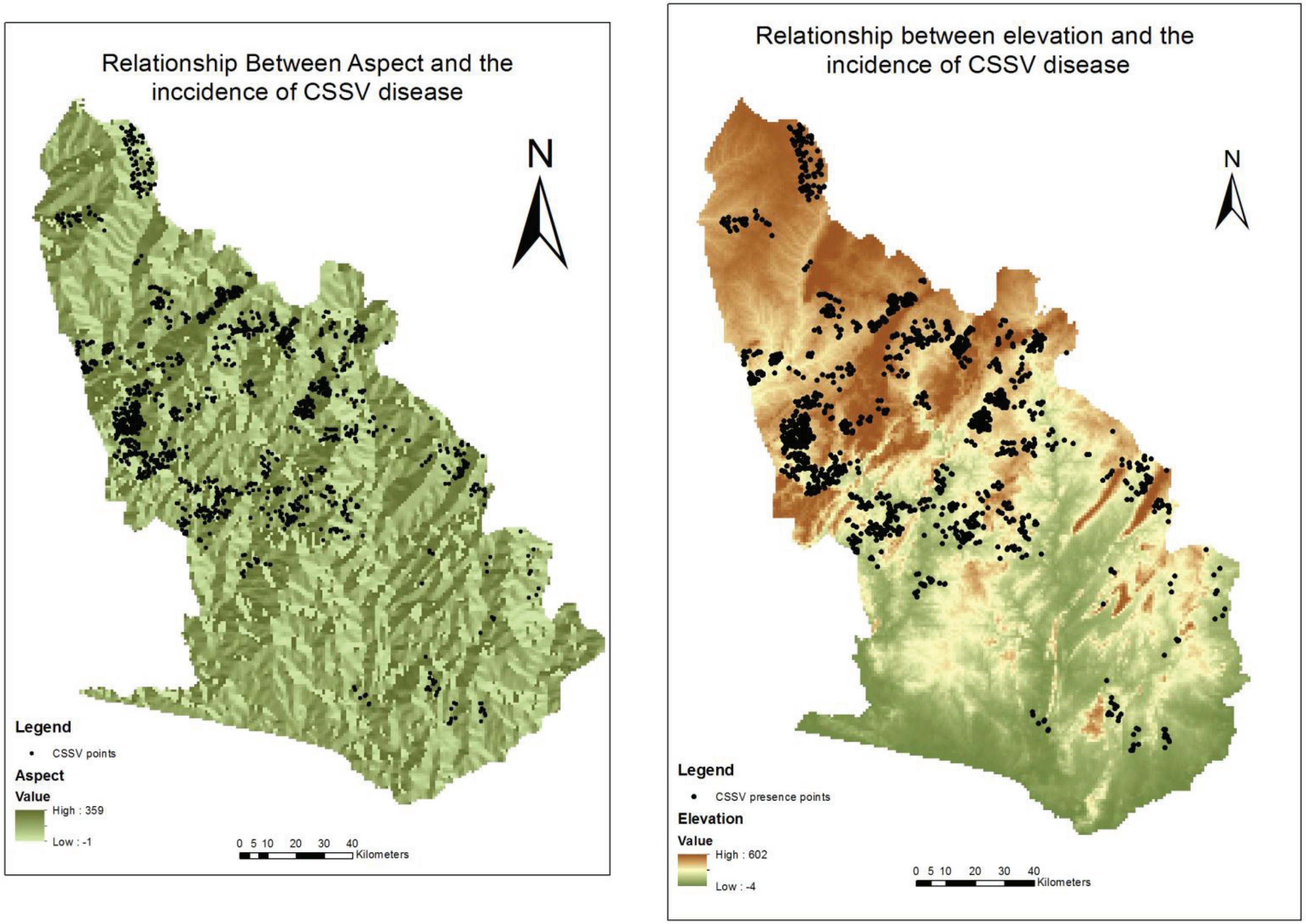
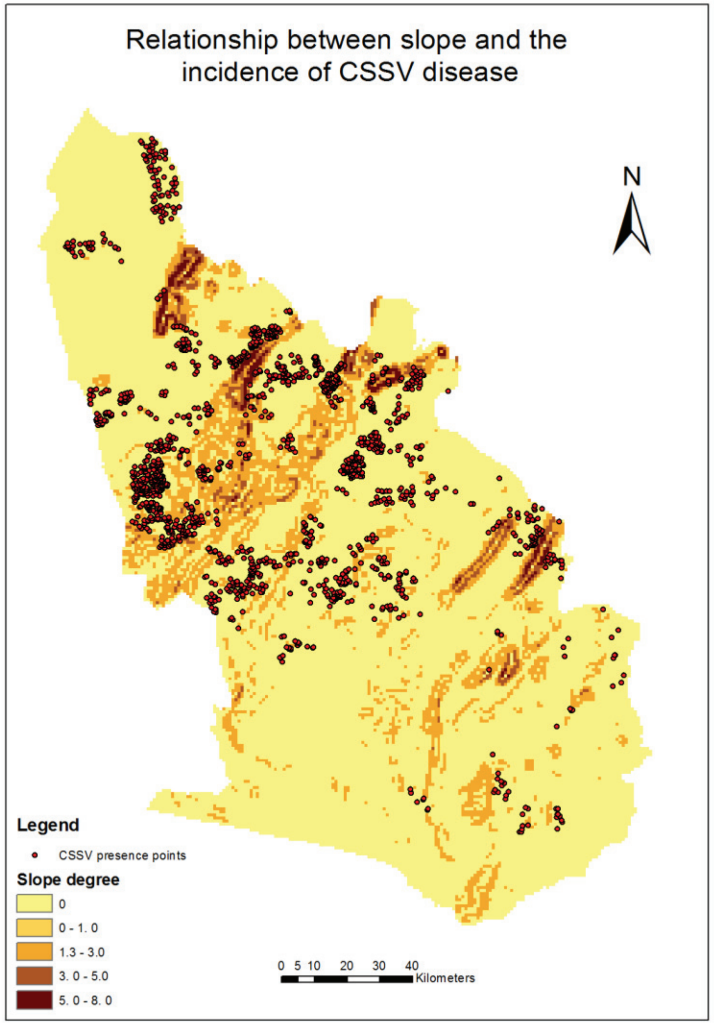


Figure 4.7 : Maps of elevation (c) and aspect (d) overlay with CSSV sample points



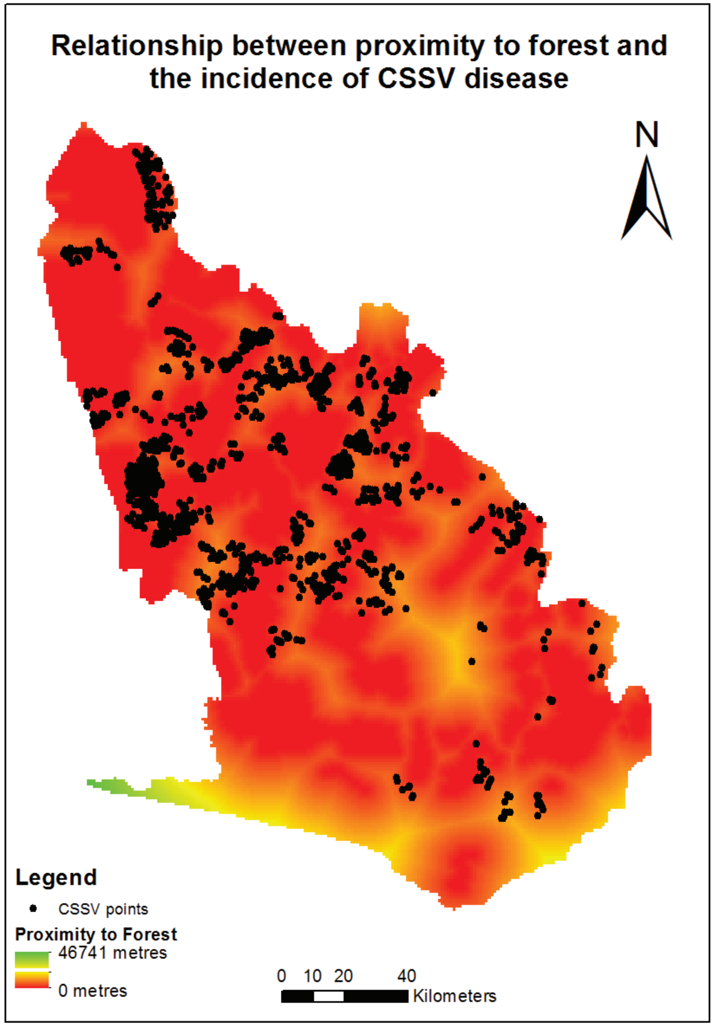


Figure 4.8 : Slope (e) and proximity to forest (f) maps overlay with CSSV sample points

From both the statistical analyses used to select the suitable environmental variables and overlay of presence points of CSSV on the selected environmental layers show relationships between the environmental variables and the incidence of CSSV disease. These variables include: Proximity to forest, Temperature, Precipitation, Elevation, and Aspect. This result is very significant to managers of CSSV in the eradication of the disease for further analysis.

4.4 Modelling probable sites for reintroduction of CSSV disease using MaXent

This section considers it necessary to model the probable sites of re-introduction of CSSV with the use of MaXent to determine the potential areas of risk to improve the current eradication process. The environmental variables of potential influence on the distribution of CSSV were used to model the probable sites for re-introduction of the CSSV disease in MaXent software. Figure 4.9: illustrates the results of the use of MaXent in modelling the probable sites for reintroduction of CSSV.

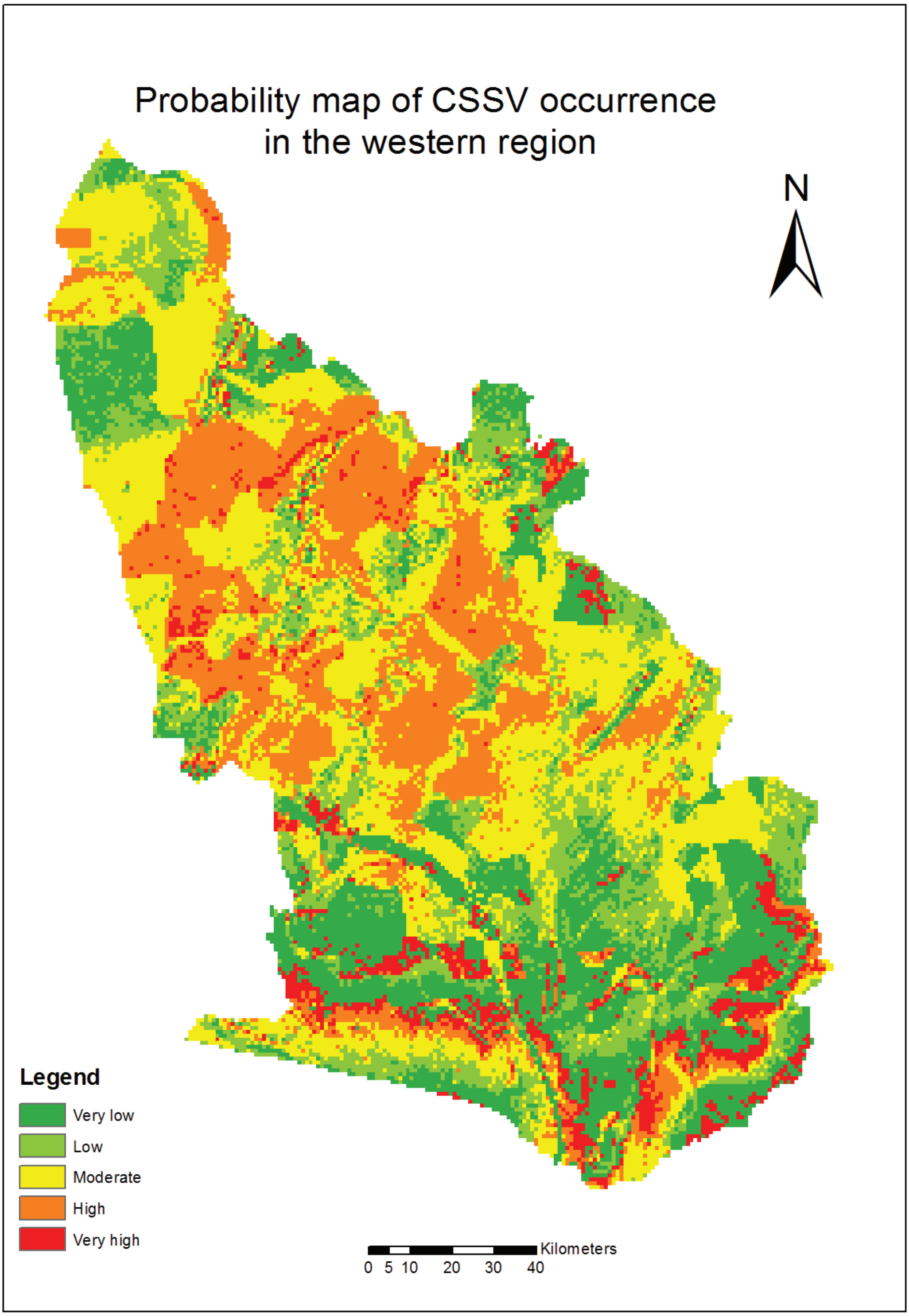


Figure 4.9 : Depicts a probability map of the study area.

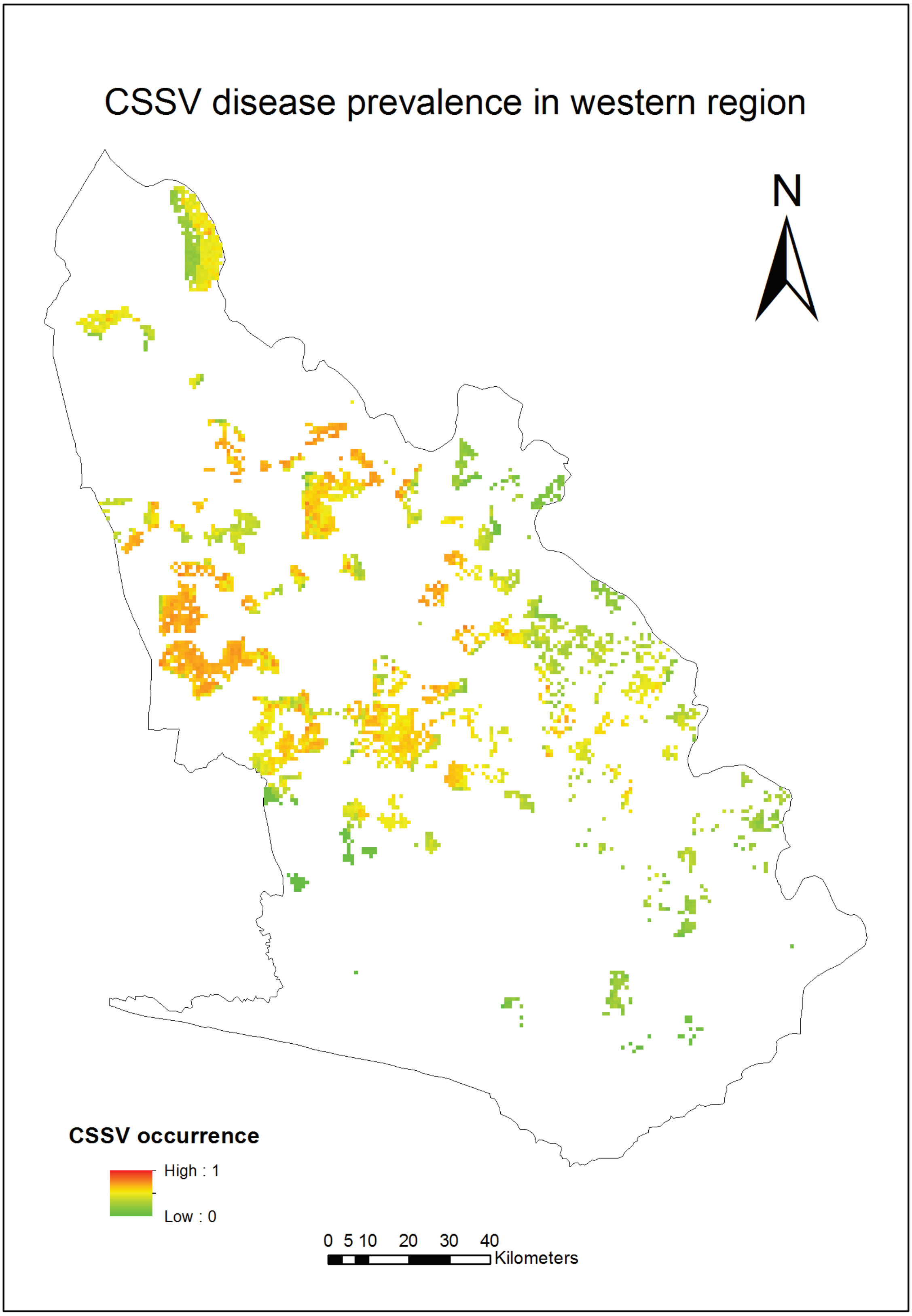


Figure 4.10 : Map showing CSSV disease prevalence in the cocoa growing areas

From figure 4.9, the deep red shades indicate areas of very high probability of re-introduction of the disease. The light red, yellow, light green and deep green shades also indicate areas of High, moderate, low and very low probability of CSSV respectively. Afterwards the cocoa map was used to distinguish areas with cocoa from areas with CSSV disease. Figure 4.10 shows the prevalence of CSSV in the cocoa growing areas in the western region.

Results of average sensitivity vs. 1- Specificity for mealy_bug

Under the average sensitivity vs. 1-Specificity for mealy bug, the Area Under the Curve (AUC) or Receiver Operating Curve (ROC), the MaXent model predicted potential suitable sites for CSSV with AUC of 0.80, which indicated better discrimination of suitable against unsuitable areas for the mealy bugs. Most suitable sites for CSSV were predicted in the central part of the study region.

4.4.1 Analysis of variable contributions

Apart from the probability map, analysis of variable contributions gives estimates of relative contributions of the environmental variables to the MaXent model. The analysis of variable contributions table shows the environmental variables used in the model and their per cent predictive contribution of each variable. The higher the variable contribution, the more impact that variable has on predicting the occurrence of CSSV disease.

Table 4.1 gives percentage of contributions and permutation importance of each environmental variable to the MaXent model. The permutation importance, shows drop in training AUC when values of each variable on training presence and background data are randomly permuted and the model is re-evaluated on the permuted data.

Mean annual temperature is considered to have high influence on the CSSV disease followed by mean annual precipitation. These two variables presented the highest gain compared to other variables.

Table 4.1 : Percentage of contribution of predictor variables to MaXent model for CSSV disease

Variable	Per cent contribution	Permutation importance
Mean temperature mask	31.6	30.7
Precipitation mask	31.4	29.9
Elevation mask	19.4	21.3
Distance to forest mask	15.4	15.6
Aspect mask	2.3	2.5

4.4.2 Jackkknife test result for variables

The jackknifing test shows the training gain of each environmental variable if the model was run in isolation and compares it to the training gain with all the variables. This is useful to identify which variables contribute the most individually. The figure below shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is mean temperature (mtemp_mask), which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is still the mean temperature (mtemp_mask), which therefore appears to have the most information that isn't present in the other variables.

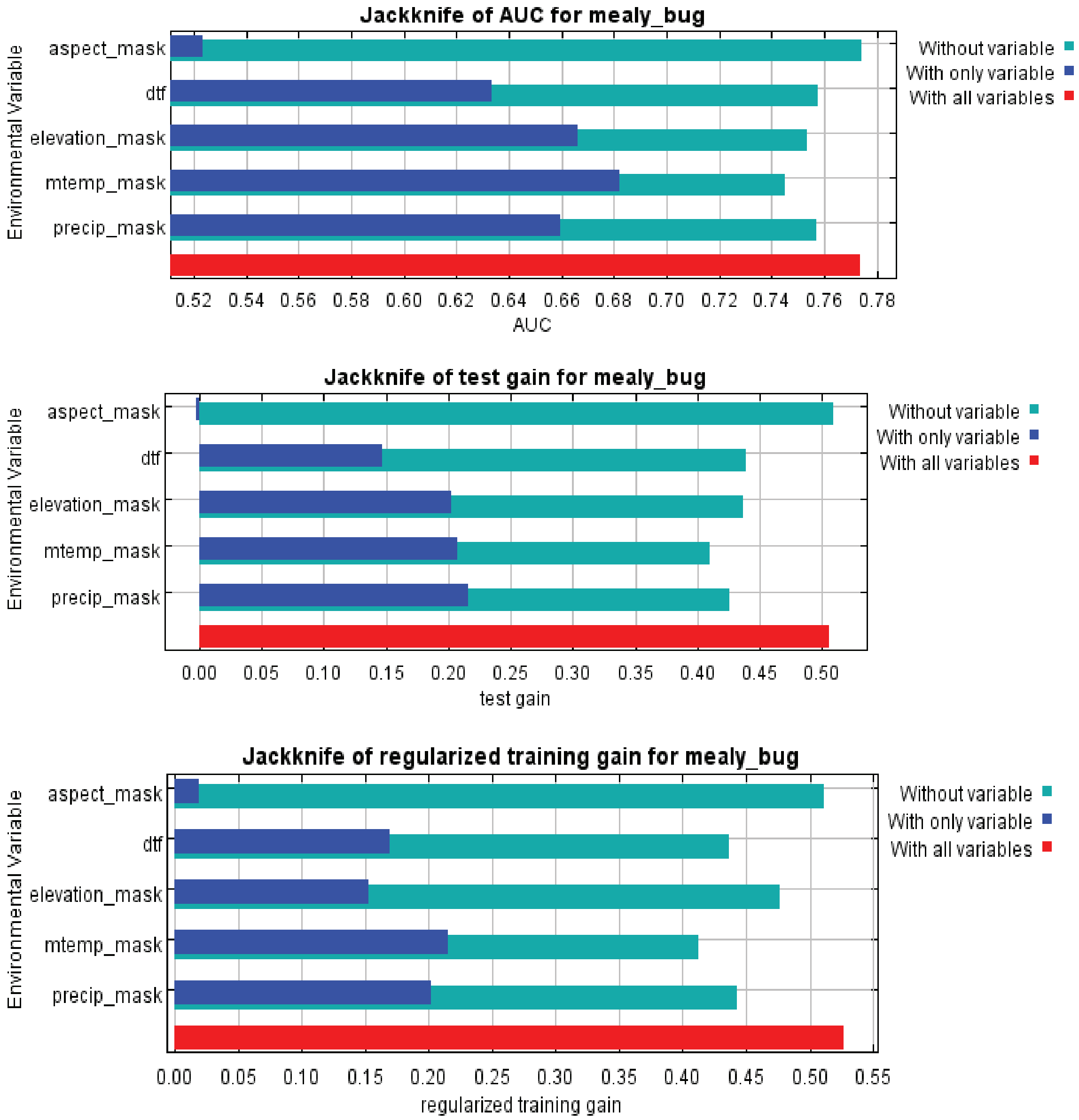


Figure 4.11 : Jackknife Test of AUC (top), Regularized Training gain (middle) and Test gain (bottom) for variable importance for MaXent model for CSSV

5 DISCUSSION

5.1 Introduction

The results discussed in the previous chapter (4) which indicate the possibility of applying GIS to map the spatial distribution of CSSV disease, the establishment of relationship between environmental variables and the prevalence of CSSV and the determination of potential sites of risk using MaXent to expedite the eradication of CSSV disease was affirmed. Other areas of importance that could enhance the eradication procedure were also established. These included the types of cocoa grown in the study area, and age class of cocoa.

5.1.1 Identifying the spatial distribution of CSSV disease

Using GIS to model the spatial distribution of CSSV disease by the creation of distribution map, the main objective of mapping the distribution of CSSV disease in the study area was achieved. It emerged from the study that detailed information can be achieved by the use of GIS to explain the phenomenon under discussion. GIS as a tool was used effectively to map the distribution of CSSV for the realization of their eradication.

Identifying the spatial distribution of CSSV through the use of GIS was achieved. It was observed that presentation of diseased and non-diseased fields with polygons as offered by the Mapping Department of CSSVDCU allowed for the creation of a CSSV distribution map, calculation of total outbreak areas, percentage of outbreaks, and number of outbreaks. The presentation of diseased and non-diseased fields with polygons was seen as a more effective tool than the monthly progress report of the CSSVDCU which is usually presented in a tabular form. (See tables 1 and 2)

It should be observed that the monthly progress report did not permit investigation of different graphical representation of the same data. However, the use of GIS, allowed the flexible use of data (maps) for other graphical representations. The significance here is that GIS as a tool for spatial analysis is multifunctional and can be relied on for varied and complex analysis of spatial phenomena. See figures 4.1, 4.2 and 4.3 for details.

With the GIS approach diverse tools were available to evaluate different strategies in preventing the spread of CSSV. For example, the buffer operation tool may well be used to create zones of specified width around newly replanted fields as stated by L. A. A. Ollennu (2003) to serve as a barrier to prevent CSSV reinfection of newly established fields from diseased fields (Ollenu, 2003). Obiatey (2010) also recommended that buffer zones with immune crops such as citrus and oil palm around new plantings are needed to prevent reinfection. (Dzahini-Obiatey. H et al, 2010).

It also emerged that field data collected with geographical positioning systems (GPS) could not be edited for further analysis. The significance of the use of the GIS approach facilitated cocoa map making and updating of records when they were in digital form to minimize the use of printed maps as data stored and thereby reduced the effects of classification and generalization of the quality of the data.

The applicability of GIS approach expedited analysis of data that demanded interaction between statistical analysis and cocoa mapping. This when applied will limit the stock of cartographic information (paper maps and statistical records) the control programme of CSSV has created over the years. This would also reduce cost of storing data in paper forms (Hard copies) and also make for easy reference.

By the GIS approach the attribute data on cocoa fields for example; number of cocoa fields, sectors and block numbers, outbreak sizes, field locations etc. that are handled separately from spatial data by the CSSVDCU, were kept in the attribute table making data management of CSSV easy. With the flexibility use of GIS in the study, both spatial and attribute data were effectively joined hence maps are quickly and cheaply produced to accelerate control of CSSV.

Presently the method used in mapping diseased and degraded cocoa fields for eradication has yielded little results due to its failure to identify fields with CSSV infection for treatment and owners for compensation. Maps prepared do not have detailed information on infected fields in relation to their owners (individual fields) and boundaries (Thresh, 2003). By the use of GIS the shape files containing non-diseased and diseased fields' areas were calculated to identify number of CSSV in the study region. This proposes that the GIS approach could be used to map individual cocoa fields for treatment and compensation.

To eradicate and monitor diseases effectively, maps are necessary to combine frequency of infection to identify areas of high risk. Hence, CSSV distribution map was generated to identify areas with high prevalence of the disease. By this approach disease control managers can prioritize cocoa sites with high incidence of CSSV for eradication. These high risk cocoa fields could receive special attention from disease managers, or for allocation of funds to eradicate the CSSV disease.

The statistical data on types of cocoa and the age classes were converted into graphs for visualization and easy understanding. For example, types of cocoa and the age classes were displayed with graphs for better understanding. This type of information explained CSSV distribution and implication in the study area. The reason being that available literature proposes that Amazonia and Amelonado cocoa breeds are susceptible to CSSV; therefore abundance of these two breeds may lead to disease outbreak.

Accordingly, the hybrid seedlings that are less infected and develop fewer symptoms than Amelonado and Amazonia types were the official seedlings for replanting schemes to replace trees removed during the cutting out operations. However, the analysis shows that Amazonia cocoa type is densely populated in the study area followed by mixed cocoa type, Hybrid and Amelonado in the study area. See figure 4.5 for details.

Amazonia and mixed cocoa are highly concentrated in the study than the hybrid seedlings which is less infected and develop fewer symptoms. On the district basis the table below shows the type of cocoa and the hectares of land covered in the various districts.

Table 5.1 : Depicts types of cocoa and the hectares of land covered on district basis

District	Amelonado (ha.)	Amazonia (ha.)	Hybrid (ha.)	Mixed (ha.)
Essam	-	18,909.20	318.61	922.42
Juabeso	-	6,707.65	3,607.97	2,433.92
Boako	61.32	6,344.86	1,138.98	494.79
Sefwi/Bekwai	-	147.15	4,952.46	5,960.64
Enchi	103.72	3,905.37	281.18	6,961.83
Akontombra	3,531.94	1,594.92	244.14	2,459.70
Dadieso	5.16	1,969.29	144.45	7,584.99
Dunkwa On-Offin	-	7,760.65	2,494.16	7,047.48
Tarkwa	100.35	2,654.75	560.59	2,993.75
Sekondi	1,034.00	979.36	1,683.77	799.81
Wasa- Akropong	1,502.93	6,646.22	1,949.41	471.19
Samreboi	3,044.12	5,306.86	3,126.67	7,050.00
Asankragwa	2,797.65	2,194.14	2,061.86	8,412.98

Note: areas with the sign (-) means no data was recorded for that type of cocoa.

In relation to age class of cocoa in the study region, the (B) and (C) classes of cocoa which are between fifteen to thirty years and over thirty years are highly concentrated, followed by (B) and (A) classes of cocoa.

Table 5.2 : Age class of cocoa and the hectares of land covered on district basis

District	Class A (ha.)	Class B (ha.)	Class C (ha.)	Class D (ha.)
Essam	199.59	2,199.11	17,745.33	6.20
Jabeso	585.51	5,065.19	6,564.54	534.30
Boako	1,114.91	1,391.35	5,507.81	25.88
Sefwi/Bekwai	1,004.46	6,385.96	3,669.83	-

District	Class A (ha.)	Class B (ha.)	Class C (ha.)	Class D (ha.)
Enchi	159.43	1,834.11	9,258.55	-
Akontombra	282.51	323.07	6,632.50	592.62
Dadieso	71.72	1,466.32	7,759.95	405.91
Dunkwa On-Offin	1,731.41	4,276.94	11,273.21	20.73
Tarkwa	809.28	1,857.35	3,466.71	176.10
Sekondi	745.08	1,268.57	1,990.59	492.70
Wasa- Akropong	974.53	959.49	5,770.00	2,865.73
Samreboi	1,799.90	4,836.51	10,768.14	1,123.10
Asankragwa	975.30	4,267.16	8,962.89	1,261.28
Total	10,453.63	36,131.13	99,370.05	7,504.55

In totality the region is highly populated with the (B) and (C) age class of cocoa with the highest class in Essam and Dunkwa On-Offin districts. This information on cocoa types and age classes could explain the spatial distribution of CSSV in the western region and the reason for present prevalence of the disease. For example the districts with high concentration of (B) and (C) class of cocoa were noted with large outbreak areas. However, prompt action need to be taken as a result of the high concentration of Amazonia cocoa breed and aged cocoa fields in the study area to avert CSSV disease outbreak.

Furthermore, the study revealed contradictions in the spatial and monthly report on CSSV activities. For example, the number of diseased fields recorded in the monthly report did not coincide with that in the shape files. The attribute table was partial; dates for data collection, diseased / non-diseased field sizes, X and Y coordinate were all omitted. Field data collected were not edited to enable effective analysis.

Using GIS approach the irregularities were rectified by the use of the repair geometry tool which was used to edit the data. The calculate geometry tool was used to calculate the area of diseased / non-diseased fields, number of outbreaks and X, Y coordinates. This indicates that the GIS approach can be relied upon for effective mapping of spatial distribution of CSSV.

5.2 Establishing relation between environmental Variables and CSSV Incidence

The essence of this segment was to establish the relationship between environmental variables and the prevalence of CSSV disease as an objective. Available literature proposes that the selected environmental variables influence the distribution of CSSV in the study area; however cocoa is not cultivated in relation to the variables influencing CSSV distribution by farmers. This situation is worsened by the failure of Technical Officials of the CSSVDCU to educate farmers on the need to do so. However, it has been proven that these environmental variables including: Temperature, precipitation, elevation, and distance to forest significantly influence the incidence of CSSV. See pages 33, 34 and 35 for details.

As a result of the influence of the environmental factors, statistical and overlaid analysis was carried out to determine the contributions of the preselected variables to the distribution of CSSV occurrence. The overlay analysis was to identify the exact locations with influence of the environmental variables. This proposes that the GIS approach used provide a mechanism to digitally pinpoint a location on earth, view the location on a map, and use the location and ancillary data in spatial analysis(Holcombe *et al.*, 2007).

The study found out that; great majority of CSSV had spread to locations with high environmental influence. Areas with high influence of environmental variables can therefore be considered as susceptible to the CSSV disease and therefore less suitable for the cultivation of cocoa. See figure 31, 32, and 33 for details. Nevertheless, precaution to avert disease outbreak can be taken once these locations are identified in such potential cocoa fields. This process led to the achievement of objective number two; to establish the relation between environmental variables and the prevalence of CSSV disease.

5.3 Modelling probable sites for reintroduction of CSSV disease using MaXent

This aspect responds to the third specific objective of modelling the probable sites for reintroduction of CSSV to determine the areas of greatest risk. Environmental variables are known to impact the distribution trend of CSSV. During the study it was observed that the CSSVDCU which is tasked to ensure effective eradication and management of CSSV disease did not have risk maps which could detail potential areas of risk. Thereby the Unit faces the challenge of determining where an outbreak may occur or may move next. However, with the use of MaXent and GIS modelling tools, potential sites of risks were detected leading to the production of CSSV probability map. See figure 4.9. By this procedure the objective number three and the research question were achieved.

AUC of 0.08 indicates excellent model, this proposes that the environmental variables used in modelling the probable sites for reintroduction of CSSV disease offers a strong depiction of the field situation. The environmental variables used showed significant influence in relation to CSSV incidence which is in agreement with other published study (Dzahini-Obiatey*., et al.*, 2010). The results of MaXent output highlight the effects of environmental variables and the prevalence of CSSV disease. The CSSV distribution map did not considerably disagree with the MaXent probability map. This proposes that MaXent can be depended upon to determine the probable risk site of CSSV disease.

The study has demonstrated that, there is significant relationship between the environmental and climatic variables namely precipitation, temperature, elevation, aspect (aspect is circular value 0 is equal to 360 degrees) and proximity to forest and the prevalence of CSSV disease in the study region, leading to the acceptance of the null hypothesis.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The spatial distribution of CSSV was modelled to identify the distribution of CSSV in the study area by the use of GIS to accelerate the eradication of CSSV disease in the western region of Ghana. The distribution map of CSSV pinpoints cocoa fields with high density of CSSV disease for effective and efficient control of CSSV. The geographic areas with the high concentration of CSSV are; Boako, Dadieso, Akontombra, Enchi, Sefwi Bekwai and Jabeso. Relationship was established between environmental variables and CSSV occurrence.

Environmental variables with significant influence on CSSV prevalence when analysed statistically are; temperature, precipitation distance to forest, elevation and aspect. Probable sites for re-establishment of CSSV disease were modelled by the use of MaXent software to identify potential sites of risks to determine the potential pattern of the disease.

6.2 Limitations of the study

Although GIS is considered as an effective tool in the processing and analysis of data gathered during the study, there were issues that could not be dealt with. This situation arose not because of the ineffectiveness of GIS as a tool, but was as a result of scanty information and several inaccuracies given to the researcher by the CSSVDCU staff.

6.3 Recommendations

The following recommendations are made based on the research methods and findings to ensure effective and efficient mapping of diseased and non-disease cocoa fields in the study region.

- The study has shown that the use of GIS is capable of modelling the spatial distribution of CSSV; therefore needs to be integrated in the control process to serve as a tool of intervention in the nationwide eradication programme.
- There is the need to accelerate the eradication of CSSV disease, by the recognition and application of other newly emerging capabilities of GIS to enhance the control and monitoring of CSSV.
- To ensure effectiveness and efficient performance, the CSSVDCU needs to follow the modern trend of mapping and surveying. In this direction the role of CSSVDCU in the eradication programme and the mapping processes becomes effective to aid the Mapping Department in their day to day activities.
- For the CSSVDCU to meet complex challenges of modern trends in mapping, there should be the injection of more qualified staff into the mapping Department.
- Attribute data need to be well organized and used for the preparation of the monthly progress report to eliminate inconsistencies.
- Dates for data collection also need to be recorded to facilitate analysis and comparison of data.
- Boundaries of individual cocoa fields or diseased areas need to be demarcated for effective management of CSSV disease.
- In order to assess the risk of CSSV disease there is the need to produce probability maps using MaXent or other related software to predict potential CSSV abundance.
- There is the need for further study to explore the use of other modelling types to predict CSSV abundance as early warning system.

It is expected that if these measures are effected, the CSSVDCU would be able to improve their efficiency in the eradication of the CSSV processes, and thereby, enhance their influence on the overall development of the cocoa industry in Ghana.

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