Master Thesis in Geographical Information Science nr 132

A Case Study to develop and test GIS/SDSS methods to assess the production capacity of a Cocoa Site in Trinidad and Tobago

Pritam Kumarsingh

2021

Department of

Physical Geography and Ecosystem Science

Centre for Geographical Information Systems

Lund University

Abstract

Trinidad and Tobago is heavily dependent on the oil and gas sectors. However, the sector has been in decline over the last 20 years. Diversification of the economy by improving the contributions to the economy from other sectors is becoming more challenging but essential to economic growth. Cocoa (*Theobroma cacao*), one of the premium resources available, could potentially expand and contribute more significantly to the National GDP. However, production has also declined from 3000Mt in 1981 to 300Mt in 2015.

New large-scale investments would be necessary for the revival of the industry and to improve the output. This requires that the investors assess potential sites to maximise production and develop a cost/benefit analysis to devise management and mitigation plans given the risks involved in cultivation. The purpose of this study is to develop and test a Spatial Decision Support System (SDSS) using Multi-Criteria Analysis (MCA) and Geographic Information Systems (GIS) and other methods to estimate the production capacity of an existing cocoa growing site containing approximately 4,458 Hectares. The study examines the interrelationship among soil and climatic factors and their effects on crop production. MCA is used to weight each of the factors which are determined by experts in the field. The weights applied to each factor are tested for the subjectivity in judgement using the Analytical Hierarchical Process (AHP) which uses a Consistency Index. These weights are then applied to each factor and analysed using GIS methods to calculate the productive capacity of the study area. This area is regarded as a historically high yielding site. The results show that the site is suitable for cocoa production where moderate production is 45.8% and high production is 46% while no production is possible in 8.2% of the site.

Preface

This thesis is in partial fulfilment of the Master’s in Geographic Information Systems offered by the Department of Physical Geography and Ecosystem Science, , Lund University in Sweden.

Acknowledgements

I wish to thank my supervisor Ms. Cecilia Akselsson for her guidance and assistance throughout the project. I also wish to thank Ms. Karin Larsson for providing her invaluable support and insightful comments. I also wish to thank Dr. Bheshem Ramlal of the Department of Geomatics Engineering and Land Management, The University of the West Indies and Professor Pathmanathan Umaharan of the Cocoa Research Centre. I wish to acknowledge the contributions made to this project by the farmers and to Mr. Joseph Sampson especially whose passion for the cocoa industry remains immeasurable.

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List of Acronyms and Abbreviations

AHP	Analytic Hierarchy Analysis
CEC	Cation Exchange Capacity
CI	Consistency Index
CR	Consistency Ratio
CRC	Cocoa Research Centre
DEM	Digital Elevation Model
EIA	Environmental Impact Assessment
EMA	Environmental Management Agency
ET	Evapotranspiration
ET_C	Crop Evapotranspiration
ETo	Reference Surface Evapotranspiration
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GPS	Global Positioning Systems
ICCO	International Cocoa Organization
ICG	International Cocoa Genebank
ICS	Imperial College Selections
IDW	Inverse Distance Weighting
LGP	Length of the Growing Period
MCA	Multi Criteria Analysis
MCDA	Multi Criteria Decision Analysis

MCE	Multi Criteria Evaluation
MCFCSL	Monserrat Cocoa Farmers Cooperative Society Limited
PET	Potential Evapotranspiration
Pmax	Principal Eigenvalue
R	Rainfall
RI	Random Consistency Ratio
SDSS	Spatial Decision Support Systems
TSH	Trinidad Selected Hybrids
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WLC	Weighted Linear Combination

1 INTRODUCTION

1.1 Background

1.1.1 Historical Perspective

Cocoa production in Trinidad and Tobago was introduced during the Spanish occupation of the islands in 1525. The industry developed mainly in the 1800s when the original Criollo variety, through hybridization with the Forastero variety, created the Trinitario hybrid (Bekele, 2003). Trinidad and Tobago developed the industry during this time to become one of the leading exporters in 1830, producing 20% of the global output (Bekele, 2003). The sector significantly contributed to the national economy and was the main agricultural export product between 1866 and 1920. Matelot, once an isolated underdeveloped region in East Trinidad, contributed to the economy through the introduction of the cocoa industry. The locality attracted labour and settlers from the islands of the West Indies and flourished (Morton- Gittens, 2011). The emancipation of the slaves and changes to the earlier plantation system led to contracts for small 10 acre farms and an abundant labour supply. The areas that were cultivated include Matelot, Sangre Grande in East Trinidad, the Gran Couva area in Central Trinidad, the Moruga district in South Trinidad and the hillside areas of Tobago (Bekele, 2003). The implementation of fiscal policies such as price stability and an increased demand for the product largely contributed to the success of the sector (Johnson, 2012).

The decrease in the production of cocoa, price fluctuations, labour competition from the resurgent sugar industry and the introduction of the oil sector made the cocoa industry unsustainable since the 1930s (Bekele, 2003). In order to revive the industry, research institutions were set up with a mandate to identify disease-resistant cocoa beans in the 1930s.

As a result the Imperial College Selection (ICS) was chosen as the best suited variety to the climatic conditions and resistant to diseases. Additional policies included the subsidization of farmers but yet again the uncertainty associated with labour and market factors forced the industry into stagnation (Bekele, 2003).

The establishment of the Cocoa Research Unit in 1930 which later became the Cocoa Research Centre (CRC), and the Cocoa and Coffee Board in 1961, resulted in ground breaking genetic research being undertaken in Trinidad and Tobago. The sector enjoyed the successes until the 1960s when drought conditions and Hurricane Flora decimated the crops. Despite changes to policy, returns on investments have been poor, and the industry remains largely dormant (Spence, Sukha, Persaud, Waldropt-Ferguson, Maharaj, & Gordon, 2011).

Trinidad and Tobago is one of twenty-three (23) countries designated as an exclusive fine and flavoured producer of cocoa beans (Cocoa and Coffee Organization, 2016). The CRC manages the International Cocoa Genebank, Trinidad (ICG,T) and boasts of international recognition and funding. This gives Trinidad and Tobago the added advantage of germplasm research. Varieties are represented by a unique number and some of the clones produced as the Trinidad Selected Hybrids (TSH), such as the 919, 1076, 1095, 1102, 1220 and 1188, are considered high yielding and disease resistant (Bekele, 2003). This exclusivity secures a higher, more stable price since the demand for chocolate is increasing globally, particularly in developed countries. While the majority of the global output is bulk cocoa, only 5% produced are fine and flavoured (Spence, Sukha, Persaud, Waldropt-Ferguson, Maharaj, & Gordon, 2011).

1.1.2 Potential for development

The distinction between fine and flavoured cocoa and bulk cocoa is a genetic and flavour difference. The Cirillo and the Trinitario varieties are considered fine and flavoured while the Forastro is designated as bulk cocoa. Moreover, the pulp and waste of both types can be used for the production of fertilizers, mulches, food products and soaps which can provide additional industries that benefits the national community. Fine and flavoured cocoa has the advantage of being the preferred product for chocolatiers (Sukha, 2003). While there is a growing market for fine and flavoured cocoa, organic cocoa production is gaining popularity and increasing in demand (ICCO, 2006). Organic cocoa represents only 0.5% of global production (Neptune &

Jacques, 2008) and is produced through agro-ecological factors which integrate the ecology with agriculture practices, biodiversity, soil conditions and biological activities thereby dissuading the use of synthetic material (ICCO, 2006). The limited market share of organic cocoa is due, in part, to its costly international certification process (KPMG, 2012). International certification provides advantages that maintain premium prices based on acceptable environmental and industry standards. Certification incentivises cocoa production as farmers are able to access funding. However, the costs to achieve the standards can be prohibitive for the smaller farms but more beneficial to shared costs through cooperatives (KPMG, 2012). The demand for fine and flavoured cocoa and its value added products present the opportunity for the establishment of downstream manufacturers which can improve the industry and earn foreign exchange for the islands.

1.1.3 Economic Challenges

The oil and gas industry contributes 40% of the National Gross Domestic Product (GDP) (Central Bank of Trinidad and Tobago, 2016). However, in recent times the industry has declined. The lower energy prices are no longer just a function of global output but faces competition from the demand for alternative fuels (Bloomberg, 2014). The dependence on the oil and gas sector is pronounced and the onset of Dutch Disease has presented the critical need for diversification into the non-energy sector (Spence, Sukha, Persaud, Waldropt-Ferguson, Maharaj, & Gordon, 2011). Dutch disease is the effect of the dominance of one commodity while diminishing the value of other sectors. In addition to the decrease in energy prices, the production of oil and gas fell substantially. Oil fell from 100,000 to less than 80,000 barrels a day, while gas production fell by 6.9% to its lowest historical levels (Central Bank of Trinidad and Tobago, 2016). This resulted in increasing deficits and lower employment. The non-energy sector also suffered decreases as the economy declined. The uncertainty of the energy sector and the general impact on the overall economy critically demonstrate the need for diversification (Anatol, 2009). The cocoa industry historically contributed to the GDP, however, despite being considered a 100% fine and flavour producer, cocoa production fell annually. Figure 1 shows the comparative production rates from 1981 to 2015 declining from 3,145 Mt 352 Mt in 2015 (Bekele, 2003).

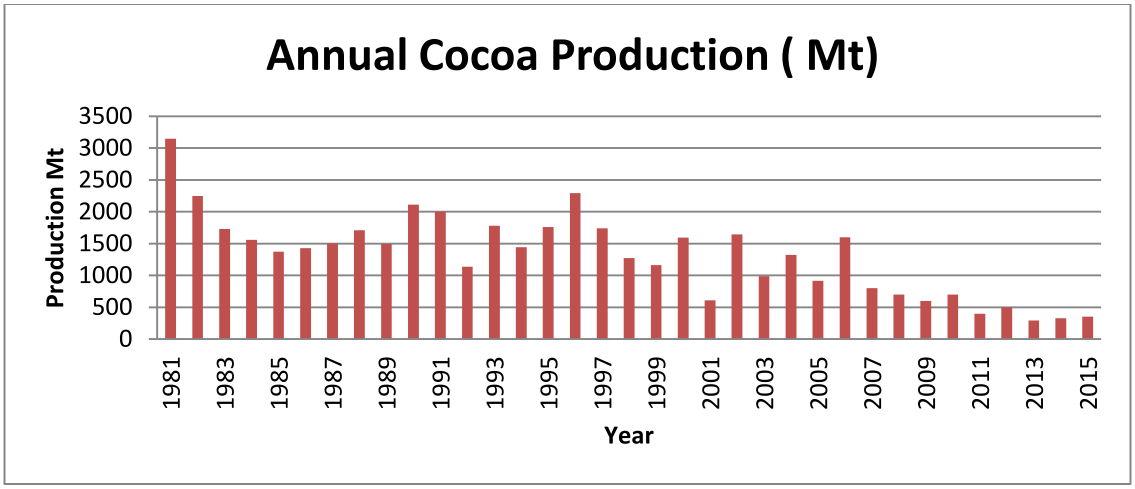

Figure 1: Cocoa Production levels (Metric tonnes) in Trinidad and Tobago from 1981-2015

Compared to other agriculture crops, cocoa and other beans contributions to exports are lower than vegetables and fruits with cereals as the main contributor. Figure 2 shows the agriculture exports for the period 2000 to 2015.

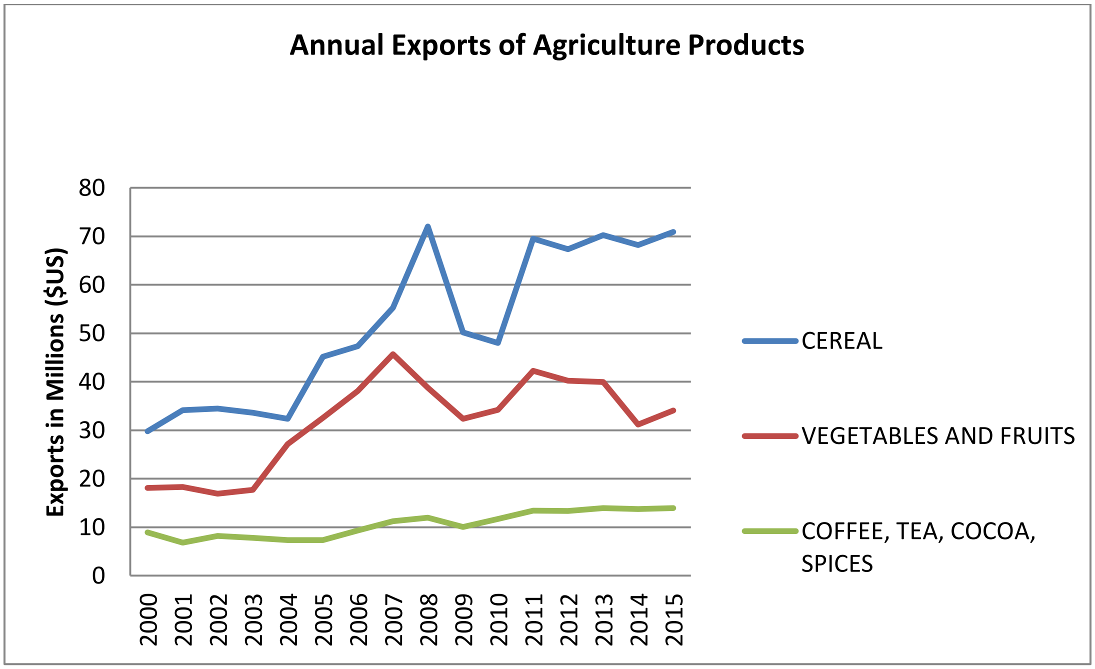

Figure 2: Exports of Agriculture Products ($US million) from Trinidad and Tobago from 2000 to 2015

Total contribution of the agriculture industry is less than 1% of total GDP for Trinidad and Tobago (Ministry of Agriculutre, Trinidad and Tobago, 2008).

1.2 Statement of the Problem

Attempts at reviving the cocoa industry have been unsuccessful due to production-related factors and increasing uncertainties arising from historical and current issues. One such factor is the ad hoc utilisation of land (Armstrong, 2008). The development of the cocoa industry depends on the availability of land. Spence et al. (2011) recommend that 25,000 acres or 101 square kilometres are required for the industry to impact significantly on the national GDP. However, the developable landmass in Trinidad and Tobago is limited given the size of the country at 5131 square kilometres, a population density of 249 persons per square kilometre and a national policy to ensure that 40 to 50% of lands be retained for forest, vegetation and protected areas (Armstrong, 2008). Much of the land space is prone to flooding as a result of inconsistent planning and development and a lack of enforcement of applicable laws. Finding the balance between economic yield, competing for land space and environmental protection is, therefore, posing significant challenges going forward (Armstrong, 2008).

Large scale investment opportunities must be guided and influenced by data that supports the return on investment for any profitable venture (Kerzner, 2001). Inherent in agriculture investments are the levels of uncertainty and the complexity of production, harvesting and market fluctuations (Hadekar, Lien, Anderson, & Huirne, 2004). Consistency and quality are primarily dependent on climatic changes and managing risks (Spence, Sukha, Persaud, Waldropt-Ferguson, Maharaj, & Gordon, 2011). Some of the risks associated with cocoa production, such as climate change, forest fires, flooding, inadequate labour supply, and variances in crop yield are difficult to assess given the high level of uncertainty (Johnson, 2012). Prevailing conditions, such as high operating costs and crop management techniques, pose a challenge to attaining premium prices and sustainability in the sector (Spence, Sukha, Persaud, Waldropt-Ferguson, Maharaj, & Gordon, 2011).

Additionally, the productive life of a cocoa farm is approximately 50 years during which time, production decreases with the age of the tree and requires rehabilitation and replanting (Wood & Lass , 1985). These bio-physical factors along with socio-economic and geo-political changes impact the sustainability of cocoa production in Trinidad and Tobago. Optimization of the land space to achieve profitable yield through mitigation against these endogenous and exogenous factors has been challenging. Traditional crop management techniques have not been able to achieve the potential yields of the farms. Farms typically yielded between 400kg/ha. and 700kg/ha. for a 3m x 3m planting density. However, increased production is possible if different non-traditional crop management techniques are adopted. Farmers are reluctant to introduce new systems due to higher costs and consider the investment risky due to their age (Maharaj, Indalsingh, Ramnath, & Cumberbatch, 2003). Greater attention to the effects of environmental conditions on the physiology of cocoa trees through an adaptation and mitigation strategy will increase efficiency and boost production (Lahive, Hadley, & Daymond, 2018).

These factors are spatially interrelated and affect production in different ways. The complexity of these relationships can be difficult to analyse and this creates an uninformed decision making process. The challenge lies in providing a platform which meaningfully analyse large complex datasets which simulates reliable outcomes so that decision making is more effective.

Multi Criteria Analysis (MCA) is one of the methods used to analyse the effect of the factors in relation to production. This is a weighted method used to determine how each factor relates to others. The weights are applied based on the level of influence of each factor on any particular outcome. Geographic Information Systems (GIS) allows for multiple, complex spatial and non-spatial data to be stored, manipulated and analysed through computational platforms and can be used as part of the MCA to provide the decision maker with the tools required to analyse the effects of the factors on production.

1.3 Research Questions

The central research question of this project is as follows: **What data driven methods can be implemented to assess the production levels of a cocoa site?**

The following research sub-questions are examined:

1. What are the criteria for optimal cocoa productivity?
    a. How do climatic conditions affect cocoa production and yield?
    b. How do soil properties affect cocoa production?
2. What GIS/MCA methods can be used to develop an SDSS for the cocoa industry to inform management decisions?
3. What is the estimated production capacity of the study site based on prevailing soil and climate conditions?
4. How does the model compare to historical assessment of the site?

While cocoa production is affected also by other risks including pests, diseases and forest fires, this project is limited to the influence of soil properties, topography and climatic conditions.

1.4 Purpose of the Study

In order to improve decision-making and precision farming techniques, traditional approaches to cocoa production must be re-examined and refined based on modern, innovative, and technologically-enabled methods (Hadekar, Lien, Anderson, & Huirne, 2004). The purpose of this study is to develop and test a Spatial Decision Support System (SDSS) using Multi Criteria Analysis (MCA) and Geographic Information Systems (GIS) methods to enhance the assessment of an existing site's production capacity which can be used to guide decision making. The SDSS will enable the decision-makers to adjust crop management techniques to improve production.

The study will estimate the yield of a site consisting of 4,458 Hectares located within the Gran Couva district in Central Trinidad based on site-specific climatic and soil characteristics.

This site was chosen since it is the largest and most commercially active cocoa site in Trinidad. The study area shown in Figure 3 is historically known to be the most suitable area for cocoa production in Trinidad and Tobago. All other sites are mostly abandoned or not commercially active and consist of less than 1000 acres.

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The objectives of this research project are:

- To develop criteria which measure the effect of soil and climate conditions on cocoa production through experts' preferences to determine the influence of each factor on production using a suitable weighting method.
- Use established methods to analyse the experts' relative weighting among the factors.
- Use GIS/MCA methods and supporting systems to analyse the factors of production and establish a Spatial Decision Support System to enhance farmers' crop management.
- To determine the production capacity of a cocoa producing site in Central Trinidad based on the developed weighing method and combining the layers using GIS methods.

The hypothesis is that investors and farmers can use an MCA/GIS model to examine the interrelationship among large, complex physical and chemical datasets to provide an estimate for the productive capacity of a cocoa site, and make informed site specific decisions on crop management techniques, mitigation and revenue projections to improve production and quality over time.

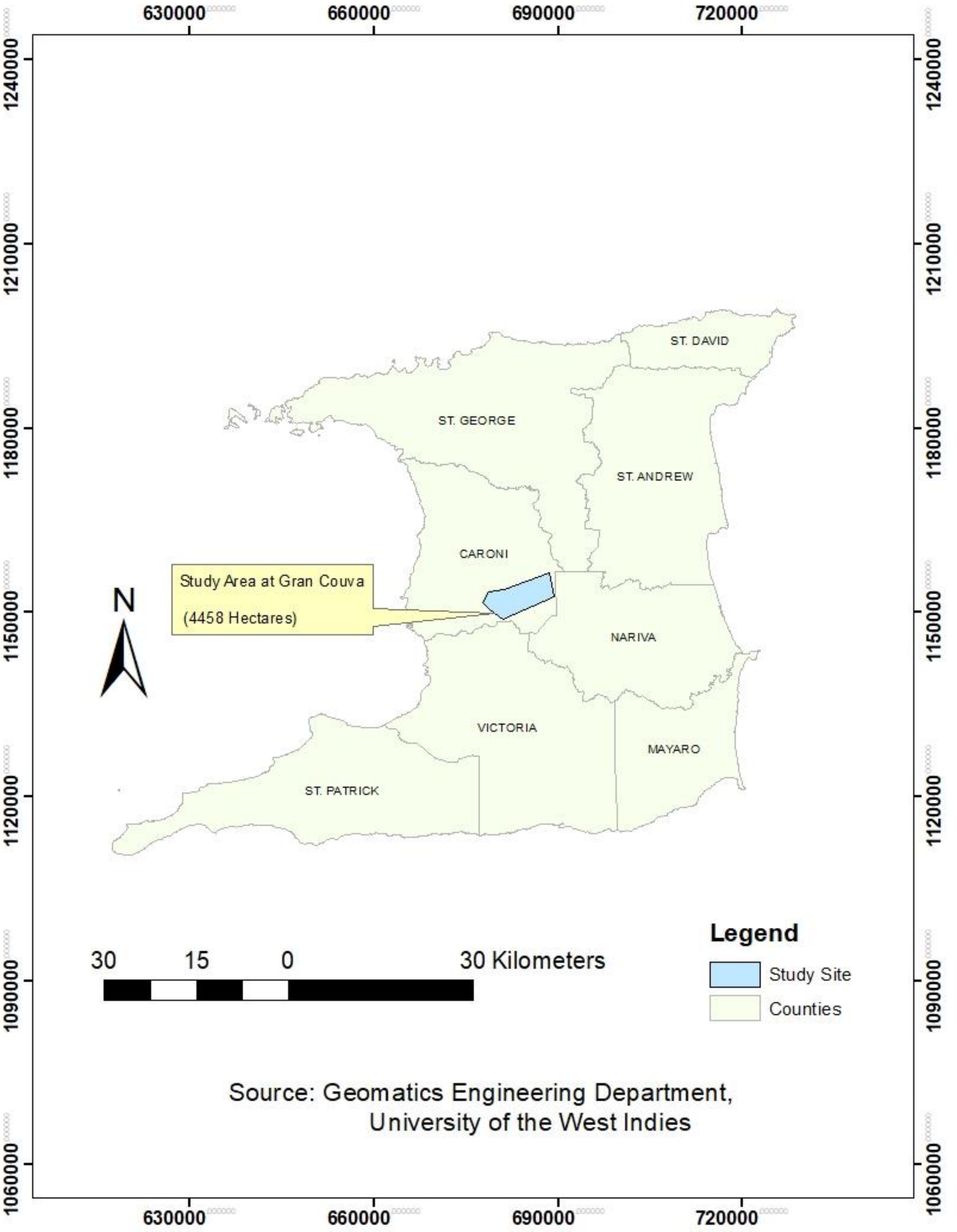

Figure 3: Location of the study area at Gran Couva containing 458 Hectares of commercially active cocoa site in Trinidad and Tobago

1.5 Climate

Trinidad and Tobago is considered a suitable location for cocoa production given its geography, soil type and climate. The twin-island state lies on a Latitude of 10^0 40' and Longitude – $61^0$31' which falls within a favourable region for cocoa production (Lass & Wood, 1985).The Köppen-Geiger subtype climate classifies Trinidad and Tobago as a tropical monsoon climate. This type of climate system provides an annual dry and wet period. This climate classification is defined by a monthly mean temperature > 18^oC and the driest months has a precipitation of < 60mm. The "dry" season extends from January to April while the "wet" season commences in May and ends in December. The annual rainfall is estimated as 2150mm (Ministry of Agriculture, 1995).

1.6 Soil and Vegetation

Although Trinidad and Tobago is part of the West Indies, the soil content is different from the volcanic or coral normally associated with the islands (Ahmad, 2011). Trinidad and Tobago's soil profile is related to the proximity to the South American mainland. This is evident in the lithology and the vegetation of the two areas. According to FAO (1995), there are six (6) main soil types in Trinidad and Tobago. These include beach sand, deep hydrophobic soils, deep alluvial soils, terrace soils, intermediate upland soils and high upland soils.

The study site is located in the Central region of Trinidad on the hilly area of the Central Range which is a mountainous area known as the Monsterrat Hills. The land is undulating, sparsely populated and contains approximately 500 cocoa fields ranging from 5 to 10 Hectares and 156 hectares of protected forests. Chenery (1952) categorised the topography of Central Trinidad into five (5) areas including the Central Range. These five (5) topographical areas are swamps, Northern Plains, The Northern Peneplain, The Central Range, and the Naparima Peneplain. The Monsterrat Hills are located at an elevation of 274 metres above sea level (Wood & Lass , 1985). The soil is characterised by the drainage, texture and nutritional content which are considered suitable for cocoa cultivation (Ahmad, 2011). The soil is typically free draining, and the humic soil acts as a buffer during the "dry" season while the texture allows for the root zone to access the inherent nutrient content. The texture is characterised by the composition of clay, sand and silt. The conditions are considered ideal for bananas and cocoa plantations which requires soil to accommodate the lateral roots (Chenery, 1952). The soil names are derived from the geographic location where it is typically displayed (Chenery, 1952; Ahmad, 2011). The location also consists of the Brasso and Monserrat soil series which is more dominant on the Central Range. Both the Brasso and Monsterrat soil series have a high composition of clay. Brasso soil is dark brown humic clay, but the drainage is described as imperfect. The texture decreases with depth, but the nutrients are considered suitable for cocoa production. Monsterrat soils are yellowish-brown in colour which gets lighter as depth increases owing to the presence of fine and coarse sand particles. The topsoil is highly humic in nature and the soil nutrient levels are favourable for cocoa production.

The internal drainage is free draining and suitable for cocoa production. Figure 4 shows the distribution of the soils within the area.

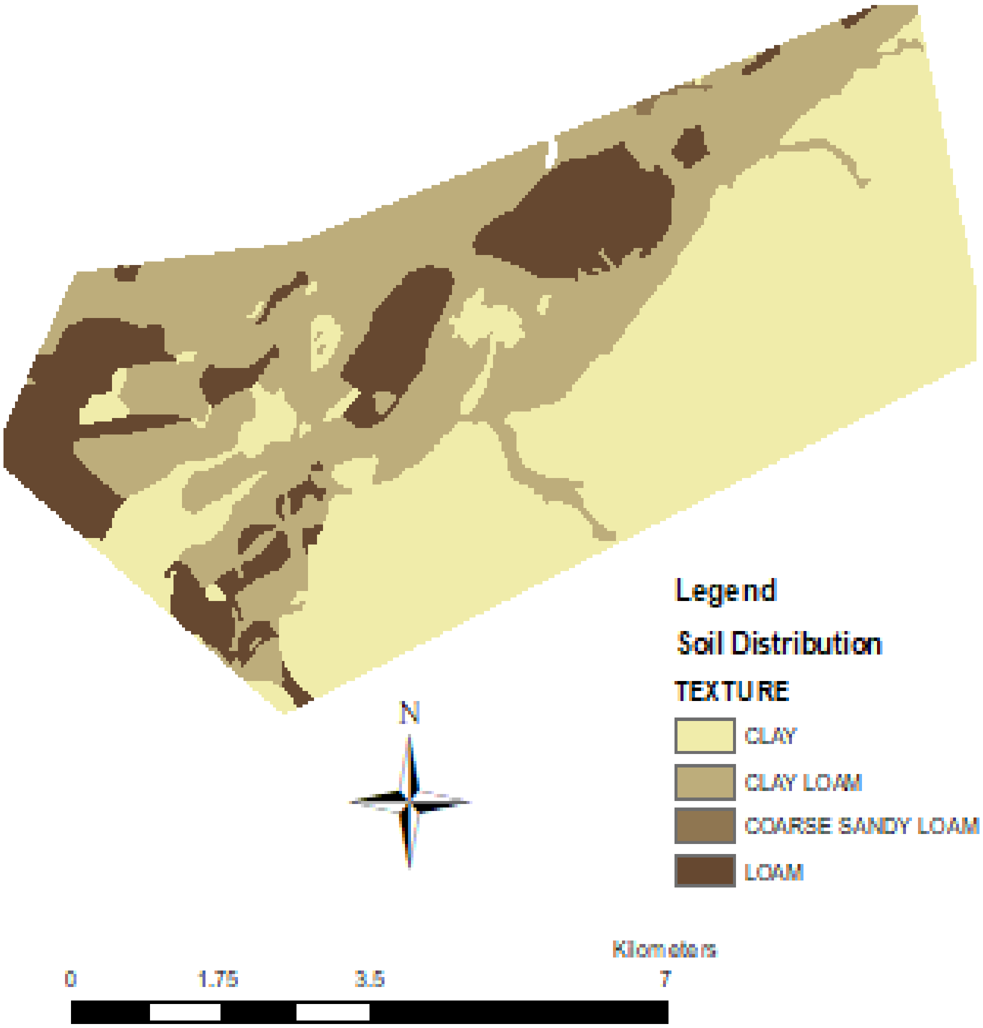

Figure 4: Soil Distribution Map of the Study Area, Gran Couva, Central Trinidad

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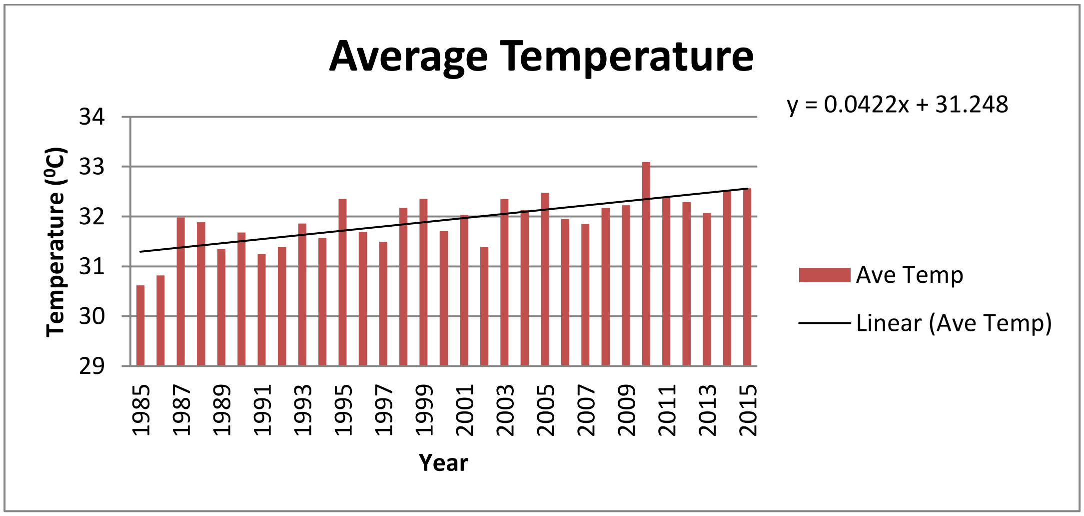
2 APPLICATION OF A SPATIAL DECISION SUPPORT SYSTEMS IN COCOA PRODUCTION

2.1 Theoretical Background

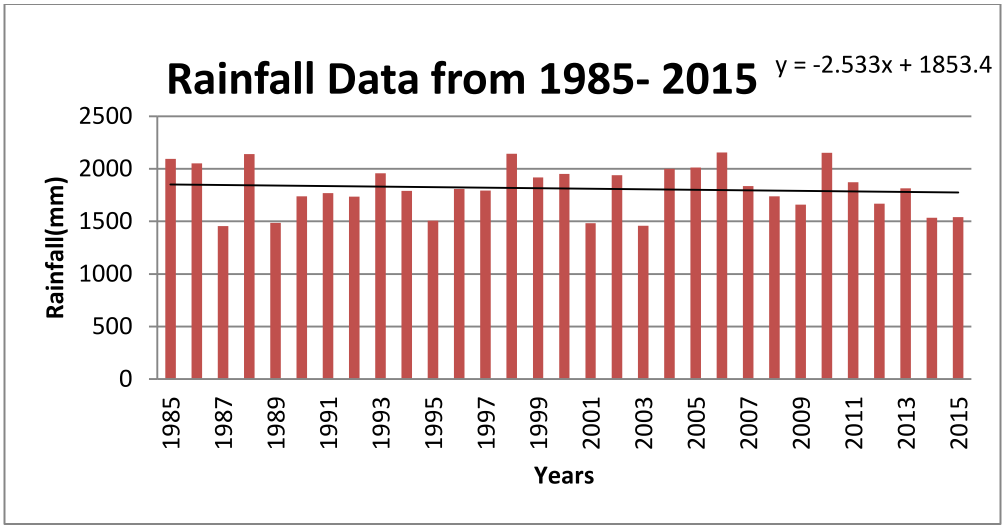
2.1.1 Climate Factors

Crops are affected by prevailing conditions in precipitation, temperature and humidity. Climatic changes can affect the plants ability to produce. Change in temperature and rainfall over time, can make projections for harvesting difficult if threshold values or a range of values suitable for the crops are exceeded. This occurs because climate changes can alter the biophysical process of photosynthesis (Brown, Poggio, Gimona, & Castelazzi, 2011). These changes occur in rainfall, temperature, humidity, and evapotranspiration which change crop production, ecology and land suitability (Knox, Huford, Hargreaves, & Wall, 2012). The indirect changes in soil water balances, increase waterlogging, and drought conditions can potentially create changes in pests, diseases, and crop suitability (Knox, Huford, Hargreaves, & Wall, 2012). Water logging can create the environment for diseases such as Phythophthora which is soil borne pathogen caused by high moisture in cocoa (Wood & Lass , 1985) . Rainfall affects the crops' ability to transfer nutrients to the plant from the soils, while temperature increases affect the rate of evaporation which hinders the effects of rainfall in nutrient transfer. Water limitation severely affects cocoa production (Lahive, Hadley, & Daymond, 2018). Humidity is the measure of water vapour in the atmosphere which affects the environmental conditions for crop growth and pollination. High humidity can also increase the risk for Black Pod and Phythophthora in cocoa (Lawal & Emaku, 2007). During the flowering phase of cocoa production, wind speed can affect production since it can remove the flowers from the plants (Wood & Lass , 1985).

The National Climate Change Policy (2011) notes the changes in temperatures for Trinidad and Tobago are consistent with global changes with an increase of 0.6 ^{0}C from 1961 to 1990. The report indicates that there is a projection of increased extreme weather patterns with an expected increase in frequency and intensity in hurricanes (National Cliimate Change Policy, 2011). However, the larger islands, including Trinidad and Tobago, would experience little damage to croplands when compared to the smaller islands. Damages to Trinidad and Tobago croplands is estimated to be less than 1% of the GDP and is likely to be faced with hurricane conditions at least every ten (10) years (Mohan & Stobl, 2017). The rainfall trend during the period 1985 to 2015, shows that the rainfall patterns are decreasing while there is an increasing trend in temperature. Figure 5 shows the average annual rainfall and average maximum temperature for the period 1985 to 2015.Anual Rainfall has decreased from 2100mm in 1981 to 1500mm in 2015. The average temperature has increased fron 31.8 degrees celcius to 32.6 degrees celcius from 1981 to 2015. This data was taken from the Piarco Metereological Station.



(a)



(b)

Figure 5: Annual Average Temperature (Degrees Celsius)(5a) and Rainfall Totals(mm)(5b) for the period 1985-2015. The equation shows a negative trend for rainfall and a positive trend for Temperatures

These changes are likely to adversely affect the agriculture sector. The Environmental Management Agency (EMA) (2011) report projected that the aridity of the soils will be affected by increased temperatures and decreased rainfall. As a result, crop yields are likely to decrease while sea-level rise will affect the croplands near the coastal regions with increased salinity to the soils. Pests and diseases are also expected to increase with changing climates (National Climate Change Policy, 2011). ICCO (2015) identifies several diseases that affect cocoa production. These include Witches' Broom, Frosty Pod Rot, Phythophthora, pod rot and vascular-streak dieback. In recent times, the frosty pod disease spread by the basidiomycete Moniliophthora roreri has caused significant losses to cocoa production in Latin America and South America (International Cocoa Organization, 2015). Some of the pests associated with cocoa are identified in the Forum for agricultural risk management in development (2014) as mirids, cocoa pod borer, ring bark borer, thrips and the cocoa beetle. This type of site-specific analysis is critical for estimating and predicting the proclivity for disease and productivity.

Annual rainfall (R) has been considered as an important factor in cocoa production (Alabi, Sonder, Oduwole, & Okafor, 2012). However, the distribution of rainfall is essentially more important than the average annual rainfall (Lahive, Hadley, & Daymond, 2018). This is because the patterns of rainfall in cocoa growing countries have distinctive annual dry and wet seasons (Carr & Lockwood, 2011).

The Length of the Growing Period (LGP) considers the distribution of rainfall and evaporation rates. This represents the period when plant growth occurs. The LGP is estimated using rainfall and the crop evapotranspiration (ETc). ETc is measured by multiplying the crop coefficient by the referenced Evapotranspiration (ETo). R is the average daily precipitation over a period of one year. ETo, measured as mm day^{-1}, is defined by Allen et.al (1998) as the crop's evaporating demands from crops that are grown in large fields under optimum soil water and excellent management and environmental conditions. It is the ability to achieve full production under specific climatic conditions (Carr & Lockwood, 2011). The crop coefficient is the ratio for the particular crop ETc as observed and a referenced crop under the same conditions (Allen, Perreira, Raes, & Smith, 1998). The referenced crop used by FAO is a grassed surface. The Agro-ecological zones described three (3) phases in the LGP and it is calculated over a period a year. The dry ($ETc/2< R$), intermediate or humid period ($ETc <R< ETc/2$) and the wet period ($R>ETc$) are the defined periods for the LGP. The humid period and the wet period is the LGP. This measure of precipitation, as it relates to other climatic factors by evaluating evapotranspiration, reflects the distribution of rainfall and the weather changes throughout the year (Lahive, Hadley, & Daymond, 2018). This method has been accepted as an unambiguous determination of ET (Allen, Perreira, Raes, & Smith, 1998). In rain- fed agriculture, the LGP provides information so that the decision makers can plan their crop management programme (Thirupathi, Shashikala, & Prabhakar, 2015).

Suitable conditions for cocoa growth include (1) a monthly rainfall distribution where the rainfall is not less than 100mm for a period of three (3) months and the annual rainfall is between 1200-2400mm (Wood & Lass , 1985*).* (2) temperatures ranging from a maximum of 30^{0}C - 32^{0}C to a minimum between 18 – 21^{0}C and (3) humidity between 70% and 100% (Alabi, Sonder, Oduwole, & Okafor, 2012*).*

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2.1.2 Soil Factors and Slope

The potential crop yield of a site is also dependent on the physical and chemical soil characteristics and the accessibility for harvesting on the site. If the slope is challenging during harvesting, then those areas are less efficient than flat or undulating areas. Harvesting is labour intensive and therefore requires significant effort in steep sloping areas (Umaharan, 2017). These areas are also prone to landslips and can be a threat during heavy rainfall (Ramlal & Baban, 2011). The examination of the chosen sites enables decision-makers to analyse the fertilisation needs of the soil and provide an estimate for costing that will facilitate optimal soil nutrient levels and increase production. This project will examine two (2) chemical properties and two (2) physical properties of soil. The chemical properties are pH and Cation Exchange Capacity (CEC) and the physical properties are texture and drainage. The pH represents the level of acidity or alkalinity in the soil. The Cations Exchange Capacity (CEC) is a measure of the soil's ability to hold onto the cations and the values are determined by the clay and organic matter present in the soil (Ajayi, Ololade, Gbadamosi, Mohammed, & Sunday, 2010). The CEC preserves the nutrient levels to prevent the soil from acidification.

Drainage is the soil ability to percolate water to provide nutrients to the roots and can be described as excessive, free, imperfect and impeded (Landon, 1991). Texture describes the physical characteristics of soil based on the particle sizes inherent in the soil type. It is defined by the proportions of silt sand and clay. The soil texture has five (5) attributes. These are clay, clay loam, coarse sandy loam, humic sandy loam and loam (Landon, 1991; Ahmad, 2011). The clay is least suitable for cultivation of cocoa as it binds solidly when wet. Loam is soil which has equal proportions of clay, silt and sand. The different types of loam are based on the dominant particle size within the soil (Wood & Lass , 1985).

Soil properties that were considered as suitable based on literature and experts' interviews, include a pH level between 5.5 and 6.5 (Alabi, Sonder, Oduwole, & Okafor, 2012), a CEC value of above 12 me/100g with a minimum of 8 me/100g, free drainage and a texture which allows for the healthy growth of the lateral roots (Njukeng & Baligar, 2016; Landon, 1991). Although cocoa can be productive over a range of pH values, if the soil is more acidic, the nutrients are less likely to be present; therefore this range was chosen (Alabi, Sonder, Oduwole, & Okafor, 2012). The lower limits should not be less than 4, nor should it be greater than 8 (International Cocoa Organization, 2013; Landon, 1991). Alkalinity decreases mineral levels.

2.2 Development of SDSS

Spatial Decision Support Systems (SDSS) can improve the effectiveness of decision-makers (Sugumaran & De Groote, 2011). The combination of different spatial and non-spatial data using GIS and Multi-Criteria Analysis provides the SDSS with the potential to assess all the elements of the planning and decision-making process. However, GIS as with non GIS processes, have been criticised for limiting public participation which has subsequently improved by the provision of tools that are now accessible to "non-experts" (Maclzewski & Rinner, 2015). The authors also identify the critical nature of GIS-MCDA (Multi-Criteria Decision Analysis) as the ability to provide alternatives based on the decision-makers' preferences and criteria. GIS provides the computational platform for assessment, while Multi-Criteria Evaluation creates an index on which decision making is affected (Alabi, Sonder, Oduwole, & Okafor, 2012).

The complex interrelationship among the components described above in land suitability and risk assessment can be interpreted using technological tools. In addition to storing large amounts of geographic data, Geographic Information Systems (GIS) also provide spatial analysis by combining data layers from different sources which include non-spatial data. These spatial analyses include statistical, geometrical, mathematical and cartographic methods (Huxhold, 1991).

SDSS emerged with the recognition that decision making is heavily dependent on spatially interrelated features (Lowenberg-DeBoer, 1999). Geographical Information Systems (GIS) was developed as spatial data became more available, and the widespread applications made decisions less difficult (Burroughs & McDonnell, 1998). This approach includes data modelling using different data types that examine the interrelationship of various features. This provides the user with the tools for decisions which can prove challenging otherwise because of the complexity involved. However, SDSS modelling is often incompatible if the modeller does not communicate with the end-user. Modelling can also be misunderstood because of the parameters used for weighing factors which may conflict with the end-user and creates disconnect in understanding the output of SDSS. Interpreting the results based on calculations can also be problematic if it is not fully explained to the end-user (Sugumaran & De Groote, 2011). There is the issue of compatibility with other datasets, and this must be investigated prior to development (Lowenberg-DeBoer, 1999).

2.3 Multi-Criteria Analysis

Multi -Criteria Analysis is the application of methods which compare the influence of various factors on an event to evaluate its outcome. A systematic weighting mechanism whereby factors are combined through a priority ranking based on individual influence on a particular event is one way of applying MCA (Maclzewski & Rinner, 2015). The outcome of the event is determined by the value placed on each factor (Alabi, Sonder, Oduwole, & Okafor, 2012).

In GIS, the Weighted Linear Combination (WLC) is a method used to facilitate MCA. It is a method which combines graphical data layers using an evaluation criteria to produce maps which contain information to assist the decision making process. It is used in the analysis of geographic data to perform analysis of spatial phenomena affected by different attributes. Maclezewski (2000) describes a six (6) step for WLC. The first step is to identify the map layers. The second step is to define the feasible alternatives. The third step is to generate the attribute maps. The fourth step is to assign the necessary weights. The fifth step is to combine the attributes with the specific weights through GIS operations and the sixth step is to perform a ranking of the output.

Weights are usually derived from expert knowledge, and this can be done through interviews and/or literature from prior studies. However, assigning weights are subjective and can result in inconsistencies (Maclzewski & Rinner, 2015). One of the techniques that test the consistency of assigned weights is the Analytical Hierarchical Process (AHP). While this system does not remove the subjectivity inherent in the preferences, it tests how each factor relates to each other through a mathematical relationship. This is a system of pairwise comparison of the assigned weights as determined by experts. This method is extensively used in Multi-Criteria Land Evaluation (MCE). The AHP ranks each feature and compare the factors in a rectangular matrix against the other factors (Triantaphyllou & Mann, 1995). The method employs a four step normalization technique and a ranking system which is used to estimate the influence of each factor on an outcome and the consistency ratio between factors. (Triantaphyllou & Mann, 1995).

AHP is developed around the decision-makers' preferences and the order of importance for each criterion. A scale of 1 to 9 is used to determine a pairwise comparison among the factors. The first step is to determine the influence of each factor and put a value to each one. 1 indicates that factor has an equal effect as another factor while 9 is more favourable than the other. As the scale moves from 1 to 9, the odd numbers represent the level of favourability between two factors (Triantaphyllou & Mann, 1995). The values 2, 4, 6 and 8 are values which are intermediate values.

The second step is to formulate a pairwise comparison rectangular matrix. The third step is to normalise and determine the weights or priority vector. This priority vector or the eigenvalue is calculated by dividing the cell value by the sum of the columns, this is then placed in the position of comparison within the matrix. The total of the weights is always equal to 1. The fourth step is to determine the Consistency Ratio (CR), which is defined as follows:

CR = Consistency Index / Random Consistency Ratio;

Where CI = (P_{max} - n) / n -1 ; P_{max} is the principal eigenvalue which is calculated as the sum of the products between each element of the weights and column totals, while n is the number of factors (Estoque, 2011; Triantaphyllou & Mann, 1995). The consistency ratio gives an indication of whether or not the value given should be accepted. If CR <0. 1, then the weight is accepted, if not then the weighting has to be revisited. The values in Table 1 were developed as a random consistency ratio (RI) by Saaty (1987).

Number of factors	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

Table 1:The Random Consistency Ratio(RI) values developed by Saaty (1980) used in the calculation of the Consistency Ratio.

The AHP method is used to test the consistency ratio among the site factors chosen for this project. Additionally, sensitivity analysis can be applied to the weights to examine the behaviour of each factor. This can be done in two ways. Firstly, percentage changes in the experts' preferences can be applied individually to each factor while proportionate changes are applied to the other factors. The second application is to assign a dominant weight to each factor while distributing the difference equally across the other weights.

2.4 Fuzzy Methods to analyse datasets

Fuzzy logic is not probabilistic but rather explores the possibility of an event and that there is a degree of truth, unlike Boolean methods which is definitive and categorises the output into either suitable or unsuitable classifications (Burroughs & McDonnell, 1998). Fuzzy methods therefore do not rule out the possibility of an event occurring on some level as in Boolean methods. The chemical and physical properties of soil can have varying influences on cultivation, growth and production levels. These production levels can be variable but still possible. As such, applying a fuzzy membership function to the attribute contained therein can impact the outcome of a suitability study (McBratney & Odeh, 1997). A fuzzy membership function is derived from criteria set based on expert-based observations and statistical data (Burroughs & McDonnell, 1998). This function can assume different shapes depending on the effect of the attribute on the outcome of an event (see figure 6). While Boolean set theory assigns a definitive value of 1 or 0 to suitability where values of 1 represents suitable areas and 0 represents unsuitable areas, fuzzy membership assigns a function between the value of 1 and 0 which depicts the 'partial truth' or the possibility of partial suitability. Both methods follow classical set theory. Figure 7 shows possible outcomes among three (3) membership functions. While AHP tests the comparative, subjective weighting among the factors, fuzzy methods are used in this project to determine the effects of the attributes contained in each soil factor and LGP. These attributes are both qualitative or descriptive and quantitative.

The choice of fuzzy methods for assessing the attributes contained in the factors is also due to the fact that cocoa can be grown on varying levels of soil properties. Soil varies across Trinidad and Tobago over short distances (Ahmad, 2011; Wood & Lass , 1985; Chenery, 1952).

When the fuzzy membership is applied to a raster dataset, the value of the resultant surface cells can have the value of 1, 0 or between 1 and 0. The value 1 means that the cell is most suitable, 0 means that the cell is not suitable and the cell values in between 1 and 0 means the cell is partially suitable.

While fuzzy membership can be continuous, values can also be discrete. GIS analysis using fuzzy methods requires continuous surfaces. The point data used in the project therefore must be converted to a continuous surface before analysis can be performed. The half way value of 0.5 or average is considered the threshold or crossover value as the condition transitions from one outcome of suitability to another. As the value tends to 1, the more favourable is the outcome.

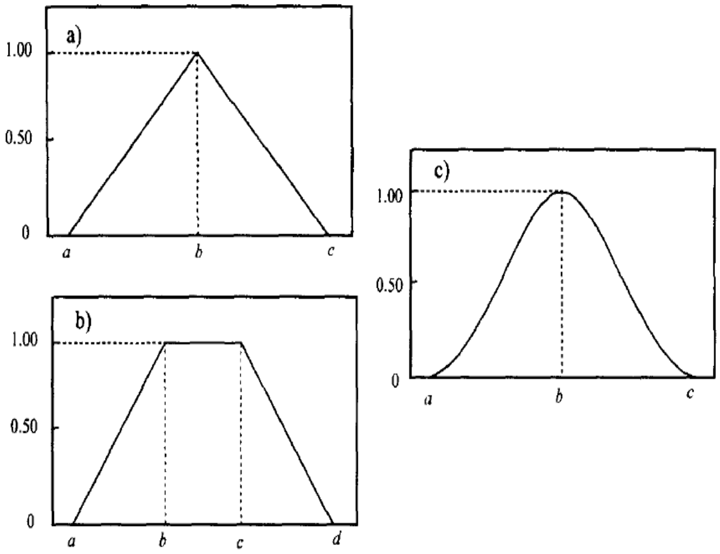

Figure 6: Examples of fuzzy membership. a and b are linear transitions. c is a parabolic function. The shape is determined by the parameter values

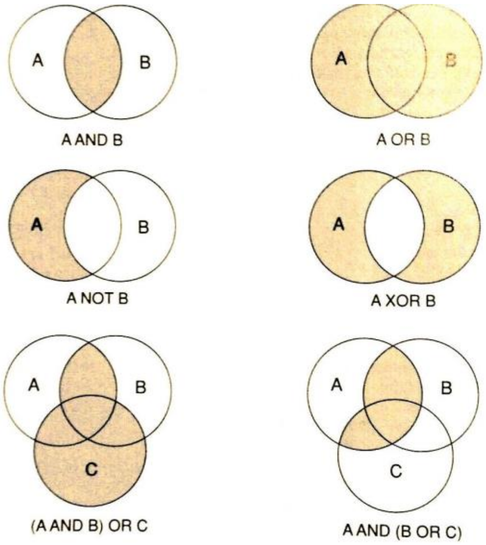

Figure 7: Notation for combining Boolean and fuzzy membership functions. A,B and C each represent membership functions and the coloured area are possible outcomes.

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2.5 Interpolation method for point data

Interpolation is the method used to convert a discrete dataset into a continuous surface which is necessary so that un-sampled areas can be analyzed (Burroughs & McDonnell, 1998). There are several methods used to interpolate data. Inverse Distance Weighting (IDW) is one such method.

IDW is a local deterministic method based on the spatial proximity of data points to each other. Observations are usually either in regular grids or sampled in a random, irregular manner (Burroughs & McDonnell, 1998). The interpolation places a value on un-sampled locations based on the neighbouring points to create a continuous surface. The value given is influenced by the distance of the neighbouring points. The continuous surface can then be classified into the categories set in the criteria. This surface is usually used to produce raster data which is a gridded cell with different values determined from the interpolation.

The value z of an attribute in the dataset is weighted using the formula as given by Burroughs & McDonnell (1998) below:

$\hat{z}\ (x_0) = \sum_{i=1}^{n} \Lambda.\, z(x_i)\ ...$ *Equation 1*

And $\sum_{i=1}^{n}(\Lambda_i) = 1$ *Equation 2*

Where Λ_i is the weighted value and are given by $\emptyset d(x, x_i)$ on the condition that

$\emptyset d \rightarrow\ measured\ value\ as\ d\ \rightarrow 0; given\ by\ e^{-(d)}$ and $e^{-(d^2)}$

Ø (d) has the predictive form;

$\sum_{i=1}^{n} z(\ x_i\ ) .\, d_{ij}^{-r} / \sum_{i=1}^{n} d_{ij}^{-r}$ *Equation 3*

Where $\boldsymbol{x_j}$ are the points to be interpolated and $\boldsymbol{x_i}$ are the data points. As $\boldsymbol{d} \rightarrow \mathbf{0}$; $\emptyset(\boldsymbol{d}) \rightarrow \boldsymbol{\infty}$, it means that the data point coincided with the interpolated point and the value remains the same for the interpolated point (Burroughs & McDonnell, 1998). Given the low density of points, the IDW method gives more influence to the closest points (Bruss, et al., 1996).

2.6 Examples of GIS in Agriculture

There are several studies that explore the use of GIS in agriculture production and sustainability. Alabi et. al (2012) demonstrate the use of GIS and Multi-Criteria Analysis in the cocoa industry in West Africa. The study combines the biophysical factors, climatic data and socio-economic data to determine the areas of cocoa production sustainability in West Africa. The factors were combined based on expert advice that determined the weight of each factor and then used WLC to combine the factors. The report stressed the importance of consistency provided by the experts and declared that the GIS multi-criteria approach was effective in land evaluation.. Additionally, the study was able to identify expansion zones for cocoa cultivation (Alabi, Sonder, Oduwole, & Okafor, 2012). While this study is applicable to the objectives of this project, the study used Boolean set theory and map algebra to combine the datasets.

Nguyen et al (2014) used GIS and Multi-Criteria Analysis (MCA) for sustainable land evaluation at a regional scale. This study combined the agro-ecological features with environmental impacts and socio-economic data using mathematical functions to derive suitability maps. This involved a scoring method and fuzzy membership theory to determine the importance of the effect of each characteristic and divided the components into both constraints and factors. However, the choice of fuzzy membership still carries some uncertainty and subjectivity. This can be minimized by applying algorithms from land sample points i.e. defining membership functions from empirical data (Nguyen, Verdoodt, Tran, Delbecque, Tran, & Ranst, 2014).

Brown et al. (2011) assessed the suitability of soils in Scotland using spatiotemporal climate data through a vulnerability index to measure the risks associated with climate change and projected the effects of climate change on soil wetness to 2050. The study concluded that suitability will improve for grasslands and arable lands in some areas in East Scotland but unsuitability will increase in South West Scotland. The data compares the precipitation and potential evapotranspiration (PET) using the FAO56 method while soil change was derived from the IPCC assessment method (HadRM3/HadCM3 model) using base data from 1961- 1990 to project data to 2050. This study also shows the potential changes that can occur from climate change through predictive mapping. This can assist decision-makers to assess the possible mitigation needed over time and assist in planning and policy development. In the local context, policy changes will be required for developing the cocoa industry (Spence, Sukha, Persaud, Waldropt-Ferguson, Maharaj, & Gordon, 2011).

Seegobin et al. (2018) developed a hierarchical suitability map for cocoa production based on soil, slope, soil fertility, soil texture, soil drainage, and the USDA soil classification. The study used a suitability index using the Length of the Growing Period and four (4) edaphic factors for evaluation. The data was achieved by examining soil samples from six (6) cocoa growing districts across Trinidad and Tobago. The study concluded that the main areas of Gran Couva, Santa Cruz and South Trinidad are likely the areas that are most suited for cocoa production. However, the study noted that the soils best suited for cocoa production were used for other land uses. The study concluded that climate effects were most critical in the assessment of the sites (Seegobin, Rostant, Ramlal, Persad, & Umaharan, 2018). While this study is similar to the project goals, the scoring of the individual factors does not consider a mathematical relationship for the attributes but rather a scoring and ranking system. Their study used a ranking system between 1 and 5 for suitability where 5 is the most suitable and 1 is the least suitable. The weights were combined using the Weighted Overlay tool in ArcGIS.

3 RESEARCH METHODOLOGY

3.1 Model Development

The methods chosen were derived from available site-specific data. As such the Multi-Criteria Analysis (MCA) is limited to climate data presented as LGP and four soil characteristics presented as pH, CEC, drainage, texture and slope. Land use data include forests, roads and rivers. All of the data were point datasets. Climate data covering the 30 year period from 1985 to 2015 were used to generate the LGP. This data included daily rainfall, temperature and humidity averages. The LGP was calculated using the CROPWAT 8 software which computes the evapotranspiration rates using the FAO(56) equation (see Appendix 4). Soil point data from twenty four (24) stations were used to develop the soil surfaces needed while eleven (11) stations were used for the LGP surface (see Table 2). Each soil factor was separated and extracted from the soil database to create new geographic point files. The next step was to derive continuous surfaces for each soil attribute using the IDW interpolation method. Each dataset was then categorised using fuzzy methods derived using the limiting values discussed in Chapter 2 (see Appendix 2). These values were derived from both literature and experts' interviews (see Appendix 6). When the fuzzy datasets were completed, each was multiplied by the priority weight. Each priority weight for each factor was tested for consistency using the AHP method before acceptance of the values. The assigned weights were then multiplied by the prepared datasets and combined by summing the resultant datasets.

The slope data was derived from a point file which was used to generate a surface and converted to a Raster format. The same applied to the land use data which were removed from the analysis as no production is possible in these areas. By multiplying the summed resultant datasets to the land use data, the roads, river and forests were removed from the final calculation for production.

This was done by assigning these areas the value 0. The remaining areas were then classified based on the fuzzy values which correspond to the level of production. The estimates for production were then calculated by multiplying the final raster by areas. Each classified area is multiplied by the values estimated for that particular production classification. These were then totalled to get the production capacity for the study area.

The data was compiled from 1: 25000 vector datasets using a UTM Zone 20 WGS 84 map projection. The standardized datasets were provided by the University of the West Indies as shown in the table below. The perimeter coordinates were provided by the Monsterrat Cocoa Farmers Cooperative Society Limited (MCFCSL). Although some of the ownership is not part of the MCFCSL, they are also cocoa-growing communities. The perimeter polygon was digitized based on the information provided. The datasets used for this project are described in table 2 below.

Dataset	Description	Feature	Datatype	Source
Cation Exchange Capacity	Soil Data	Point	Vector	Soils Department, Ministry of Agriculture
pH	Soil Data	Point	Vector	Soils Department, Ministry of Agriculture
Drainage	Soil Data	Polygon	Vector	Department of Geomatics Engineering and Land Management, University of the West Indies
Texture	Soil Data	Polygon	Vector	Department of Geomatics Engineering and Land Management, University of the West Indies
Land Capabilities Map	Soil Data	Polygon	Vector	Department of Geomatics Engineering and Land Management, University of the West Indies
Rainfall	Climate Data	Point	Database	Water Resources Agency/ Department of Geomatics Engineering and Land Management, University of the West Indies/ Metereological Office, Piarco
Temperature	Climate Data	Point	Database	Meterological Office, Piarco/www.wunderground.com
Humidity	Climate Data	Point	Database	Meterological Office, Piarco/www.wunderground.com
Wind	Climate Data	Point	Database	Meterological Office, Piarco/www.wunderground.com
Rivers	Land Use	Polyline	Vector	Department of Geomatics Engineering and Land Management, University of the West Indies
Roads	Land Use	Polyline	Vector	Department of Geomatics Engineering and Land Management, University of the West Indies
Forest Reserve	Land Use	Polygon	Vector	Department of Geomatics Engineering and Land Management, University of the West Indies

Table 2 : List of datasets used for the project. This consists Soils, climate and land use data

3.2 Data Preparation

The point data were converted to a continuous raster surface by interpolation. The Inverse Distance Weighted (IDW) is chosen for the point datasets for pH, CEC, LGP and DEM. Bruss et al. (1996) compared the interpolation methods in soil data and suggested that there is no significant difference in approach for interpolation among kriging, nearest neighbour, IDW and splines.

This interpolation was done using 11 points for analysis for the climate data and 35 points for the soil data with a resolution of 10m. The eleven (11) climate data points were within close proximity of a 10km radius from the site which is considered an effective spatial range for changes in rainfall patterns (Gonzalez-Hidalgo, Brunetti, & de Luis, 2011). Three (3) stations, the San Juan, San Pedro and San Antonio Estates, were within the study area (see Figure 8). A 10m cell resolution was chosen for interpolation. This also represented the standard cell size used in the analysis of all raster datasets as this was considered after oral communication with experts, to be the most accurate to discern calculated changes. The DEM is a point file was interpolated as described above, to exclude areas that are unsuitable for production. The LGP values for each point was calculated and interpolated as described above.

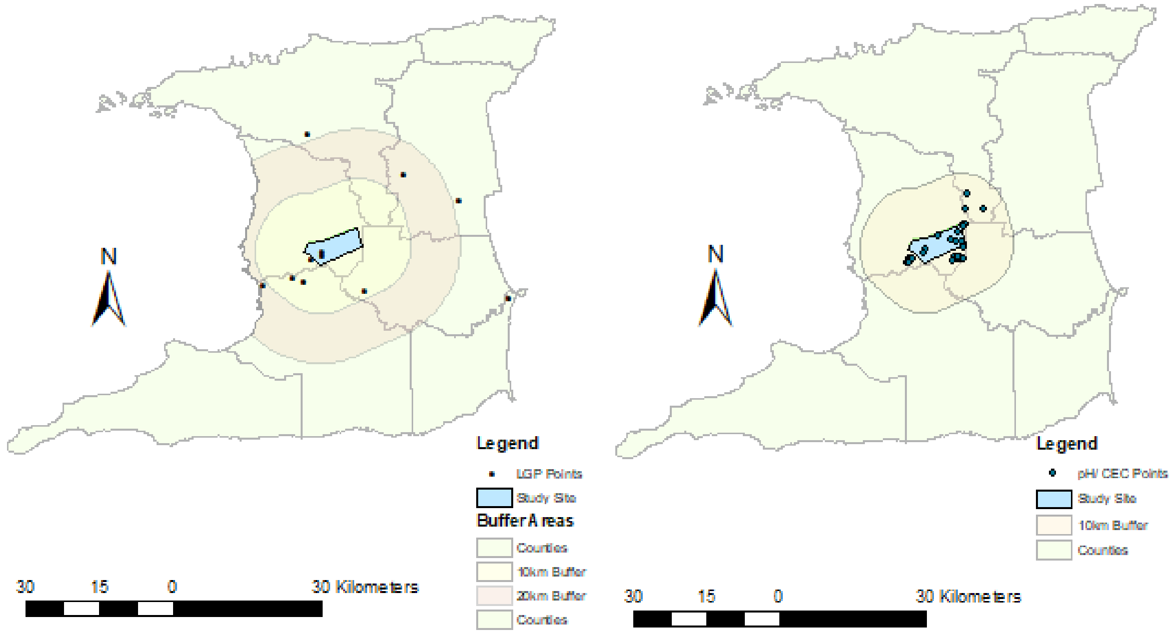

Figure 8: Maps showing point distribution for Length of the Growing Period(LGP)and soil. The buffers for the LGP are 10 km and 20 km. The buffer shown for the soil data is 10 km

3.3 Data Collection and Acquisition

Seegobin et al. (2018) acquired the soil data using a handheld +/-5m accuracy GPS referenced to the WGS 84 UTM projection system for each sample. The dataset used in this project contained 24 soil point data which were used in the interpolation. These samples were each analysed at the Soil and Land Capability Unit of the Research Division, Ministry of Food Production. The pH values were obtained using a pH meter, while the soil properties such as Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium were all analysed using procedures outlined by Landon (1991) (Seegobin D. , Rostant, Persad, Ramlal, & Umaharan, 2018).

The phosphorus levels were determined using the Troug's Extraction and Molybdenum Blue Method. The potassium levels were determined using a Flame Photometer, while the calcium and magnesium levels were determined using an Atomic Absorption Spectrophotometer. The Nitrogen and Carbon/ Nitrogen ratios were extracted from published data (Seegobin D. , Rostant, Persad, Ramlal, & Umaharan, 2018). The CEC is calculated from the sum of the bases in milliequivalent/ 100g or meq/100g. The dataset provided is a point shapefile from which the pH and CEC levels are derived. The choice of the methods is outside the scope of this project.

The soil attribute data was provided by the Geomatics Engineering Department of the University of the West Indies as a point shapefile based on field observation. The drainage and soil texture data were taken from the land capability dataset as a polygon dataset.

The rainfall data were collected from validated 11 stations within spatial proximity of 10km from the study site. This was available through a collaborative effort to verify, validate and compile climate data by the Geomatics Engineering Department of the University of the West Indies, the Meteorological Service of Trinidad and Tobago and the Water Resources Agency for the period 1985- 2015. The temperature, humidity and wind were provided by the Piarco Meteorological Services.

3.4 Vector to Raster data

All polygon datasets used in the analysis were converted to raster datasets with a resolution of 10m using the features to raster operation in ARCGIS 10. These datasets include soil texture and drainage datasets.

3.5 Determination of Fuzzy Membership and Weighting Criteria

3.5.1 Fuzzy Modelling

Linear transitions are assumed for pH since cocoa can be grown on a range from 4 to 8 (Njukeng & Baligar, 2016). The values are chosen as described in the criteria in the literature review. While cocoa can be produced on a wide range of pH values, acidity decreases the availability of Phosphorus (P) but increases iron (Fe), Manganese (Mn) Copper (Cu) and zinc (Zn). This potentially can increase the level of toxicity in the soils. Increased pH above the threshold values are alkaline and presents mineral deficiencies (Wood & Lass , 1985). The value of 8 was used as the threshold. Equation 4 below was used for the pH values.

$$\mu(X) = \begin{cases} 1 & b \le x \le c \\ \frac{d-x}{d-c} & c \le x \le d \\ \frac{x-a}{b-a} & a \le x \le b \\ 0 & otherwise \end{cases}$$

Equation 4

The parameter values used for pH are shown in table 3 and the shape of the fuzzy membership based on the equation is shown in figure 9 below:

Parameter	pH Fuzzy Values
a	4.5
b	5.5
c	6.5
d	8

Table 3 : Parameters for pH values

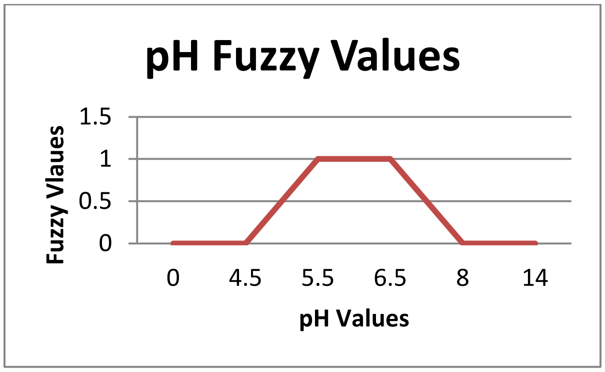

Figure 9: pH Fuzzy Membership Values. The shape assumes a linear transition

The CEC value of 12meq/100g was used as for full suitability (Njukeng & Baligar, 2016). Higher CEC values are considered necessary for cocoa production. The cations in the soils are from calcium (Ca), Magnesium (Mg), potassium (K and sodium (Na). Lower levels can lead to a nutritional deficiency in Ca and Mg (Jiska, Slingerland, Maja and Giller, Ken, & van Vliet, 2015).

Equation 5 shows the membership function chosen for CEC was as follows:

$$\mu(X) = \begin{cases} 1 & x \geq b \\ \frac{x-a}{b-a} & a \leq x < b \\ 0 & otherwise \end{cases} \qquad \textit{Equation 5}$$

Figure 10 shows the graphical representation of the CEC membership and Table 4 shows the parameters.

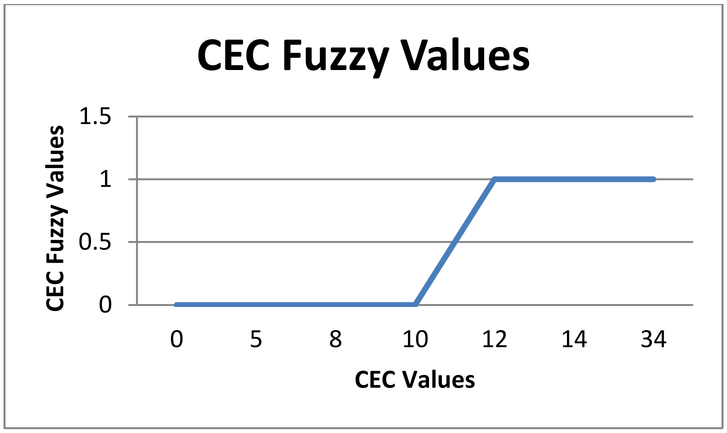

Figure 10 : Graphical Representation of the Cation Exchange Capacity (CEC) membership function

A lower value of 8 was chosen as a reference marker, since productivity is still possible (Wood & Lass , 1985).

PARAMETER	CEC Value (meq/100g)
a	8
b	12

Table 4: Fuzzy values for the CEC factor(meq/100g)

The texture must be able to contain moisture and adequately accommodate the roots which assist with propagation (Wood & Lass , 1985). The loamy soils is acceptable and given one (1) while the others are weighted based on the moisture capacity (Seegobin D. , Rostant, Persad, Ramlal, & Umaharan, 2018). The fuzzy membership values for the texture and drainage were both derived from the ratios given in Seegobin et al. (2018). See Table 5.

Drainage		Texture	
Description	Fuzzy Value	Description	Fuzzy Value
Free	1	Loam	1
Imperfect	0.5	Clay	0.4
Impeded	0	Clay Loam	0.8
		Humic Sandy Loam	1
		Coarse Sandy Loam	0.6

Table 5:Fuzzy Parameters for drainage and texture factors. These are discrete values

The climate data were combined to calculate the Evapotranspiration (ETo). The ETo was calculated as a monthly average over the 30 year period for each station by using the CROPWAT 8.0 software. CROPWAT 8.0 is a Food and Agriculture (FAO) software designed as a decision support tool for farmers. The software calculates the evapotranspiration rates for crops and generates records for irrigation and crop management climate and location data. The calculation for evapotranspiration utilizes the Penman Monteith equation. The software is used as a management tool to calculate irrigation schedules and requirements for crops and calculates reference ETo from daily, monthly and decade climate input.

The crop evaporation (ETc) specific to cocoa is calculated using the formula ETc = k * ETo, where k is a crop evaporation constant which in this case was 1.05 (Seegobin D. , Rostant, Persad, Ramlal, & Umaharan, 2018). The constant k changes for each of the stages of plant development. These stages are the initial stage, the crop development stage and the end season stage. The value for cocoa at the development stage is 1.05 for both the development and end stages (Allen, Perreira, Raes, & Smith, 1998). This was then plotted graphically for each station against the monthly rainfall data for each station to attain the LGP. The values for minimum temperature, maximum temperature, wind and sunlight hours were taken from the Meteorological Service for the same period 2000 – 2015. Figure 11 shows the derived fuzzy values for the LGP and the equation used to derive the classifications is the same as equation 4 as used for the pH values. LGP also transitioned similarly and the parameters were derived based on the distribution of rainfall where production is affected by a three (3) month period of dry conditions and an upper value exceeding 340 days where the risk of diseases is more likely to occur (see Table 6) .

Parameter	LGP Fuzzy Values
a	275
b	302
c	323
d	340

Table 6: Fuzzy parameters for Length of the Growing Period(LGP) (days)

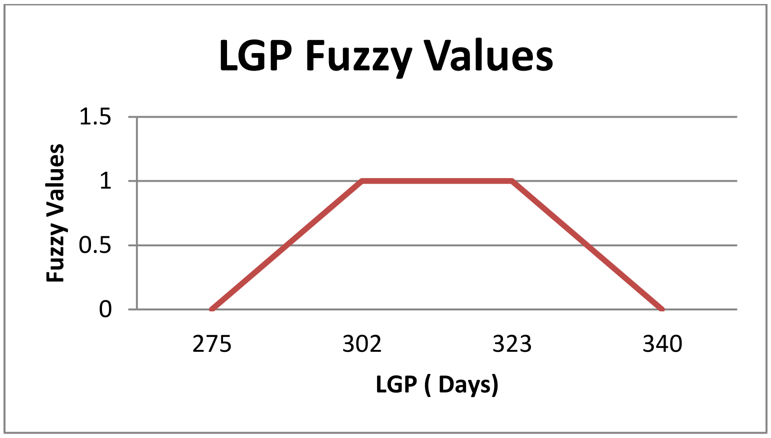

Figure 11:Graphical Representation of Length of the Growing Period(LGP) Fuzzy Values (days)

3.6 Multi-Criteria Analysis for Soil and LGP Factors

The value of the weights selected reflects each factor's relationship in comparison to the others. In this case, LGP was considered the essential factor followed by of the CEC and pH (Seegobin D. , Rostant, Persad, Ramlal, & Umaharan, 2018; Alabi, Sonder, Oduwole, & Okafor, 2012). Drainage and texture are less significant than either the pH or CEC hence the differences in value (Seegobin D. , Rostant, Persad, Ramlal, & Umaharan, 2018; Alabi, Sonder, Oduwole, & Okafor, 2012; Jiska, Slingerland, Maja and Giller, Ken, & van Vliet, 2015). The cultivation methods allows for mixed soils to provide for drainage to accommodate roots for nutrient uptake. CEC is ranked higher than texture and drainage because of the importance of organic matter for pod development (Wood & Lass , 1985; Jiska, Slingerland, Maja and Giller, Ken, & van Vliet, 2015). The pH value is also more detrimental to production as higher pH levels affect the formation of the leaves because of a lack of Fe, Zn and Cu (Landon, 1991).

The AHP method is used in the project to test the consistency of the values chosen for the weighting of each factor. This method is used to assess the subjectivity on the values chosen by the experts. The weights were chosen between 1 and 9, which compares each of the five (5) factors in relation to the level of importance. The following matrix was developed based on the AHP weighting methods (see Table 7). The weights were confirmed in an interview with the Cocoa Research Centre (CRC) representatives. The interview was both a structured and unstructured interview which determined the influence of the factors. The interview also allowed the interviewee, who is an expert in the field of cocoa production to present an understanding of the risks associated with cocoa production and management of the fields. This was an essential component since it provided a realistic insight into the current management techniques of farmers. Interviews with the farmers were unstructured and used to determine their opinions on farming techniques as well as their observations on the effect of climate and other risks. This type of questionnaire was chosen so that the farmers are not restricted in their responses and allowed the flexibility in their responses.

	LGP	pH	CEC	Drainage	Texture
LGP	1	3	3	7	7
pH	1/3	1	1/3	5	5
CEC	1/3	3	1	5	5
Drainage	1/7	1/5	1/5	1	1
Texture	1/7	1/5	1/5	1	1

Table 7: Analytic Hierarchy Process (AHP) weighting matrix for all factors

While the AHP process is a computation matrix for determining the consistency between weights, the sensitivity analysis provides the level of quantitative and qualitative variability that each factor provides in the output. This analysis is important in the verification and validation process of the results and presents the opportunity to observe the behaviour of each factor. The analysis manipulates the weights of each factor and simulates different models with outputs which can be validated and refined accordingly.

Sensitivity analysis was done two (2) ways for this project. The one-at-a-time (OAT) method was applied as a percentage change to the priority weighting as defined by the experts and then as the dominant weight for each of the factors. In the first instance the weight was applied in 5% increments ranging from -20% to 20% to each of the experts' preferences. A total of eight model runs were conducted for each factor and the changes in the productive capacity from one classification to another was calculated (see Appendix 3).

By applying these increments the other weights are proportionally weighted based on the equations below. The notation is taken from (Chen, Yu, & Khan, 2010).

$$W(F_m , pc) = W(F_m , 0) + W(F_m , 0) \times pc ; \qquad 1 \leq m \leq n \qquad \text{Equation 6}$$

Where $W(F_m , pc)$ is the new weight for the base factor and $W(F_m , 0)$ is the initial chosen weight for the factor. The weights are distributed for the other factors using the following

$$W(F_i , pc) = (1 - W(F_m , pc) \times (W (F_i , 0)/ (1 - W(F_m , 0)) \qquad 1 \leq I \leq n ; i \neq m \qquad \text{Equation 7}$$

Where $W (F_i , 0)$ is the initial weight preference of factor i.

The second method applied weights which were not based on the experts' preferences but rather simulations through weights applied to one factor while keeping the other factors evenly distributed. The simulations include equal weighting of 20%, then 40% and 60% for each of the factors (Zavadskas, Turskis, Dėjus, & Viteikienė, 2007).

3.7 Slope and Land Use Analysis

The DEM was treated as a Boolean operation where the slopes are generated and classified as either acceptable or unacceptable. These are assigned 1 or 0, where 0 represents the unacceptable areas i.e. slopes that exceed 40% and 1 where the slopes are below 40%. These values were selected based on the need for forest cover and conservation areas that are at risk for both erosion and harvesting impracticality (Ramlal & Baban, 2011). The Boolean method was chosen because although cocoa can be grown on various slopes, the recommendation for harvesting is less than 40% (Umaharan, 2017). The values above 40% are impractical and will require erosion controls. These values were used in the study as advised during oral communication with the experts. These areas were removed from further analysis on yield and as such, treated as a BOOELAN operation. The road dataset is a line dataset and is also not considered as part of the analysis for yield and is also removed from the analysis in a similar manner. Roads, rivers and forest reserves were not considered for yield in the analysis and were removed from the calculations using BOOLEAN constraints a value of 0 represented areas which are not used in the analysis.

3.8 Weighted Linear Combination Method

Each of the rasters produced was then multiplied by the respective weights. This applies the influence as a measure to each factor. The weighted outcome for each factor was then summed using the ArcGIS operations that preserve the minimum value of each of the factors. This means that this is the least value of each factor under which productivity is possible (Alabi, Sonder, Oduwole, & Okafor, 2012). The resultant raster was then multiplied by the Boolean rasters described above to remove the roads, rivers and the land use.

Given that the fuzzy values ranged from 0 to 1, where 0 represent no production and 1 as the most productive areas, two crossover points of 0.5 and 0.75 as changes in the level of production. Values between 0- 0.5 are low production and 0.5- 0.75 as moderate production and 0.75- 1 as high production areas. The results were reclassified to demonstrate the good, moderate and poor categories for production levels (see Appendix 1). The site productivity was determined based on the expected yield from each category. The expected yield from suitable areas is 1 tonnes/ ha, while moderate areas can yield 400 kg/ha and poor areas can yield less than 250 kg/ ha (Maharaj, Indalsingh, Ramnath, & Cumberbatch, 2003). These figures are given based on historical figures and a tree cultivation matrix of 3m x 3m which is the typical matrix used on cocoa estates in Trinidad. The resulting areas for each category were multiplied by the estimated yield to approximate production. Figure 12 below shows the method flowchart used in the GIS analysis.

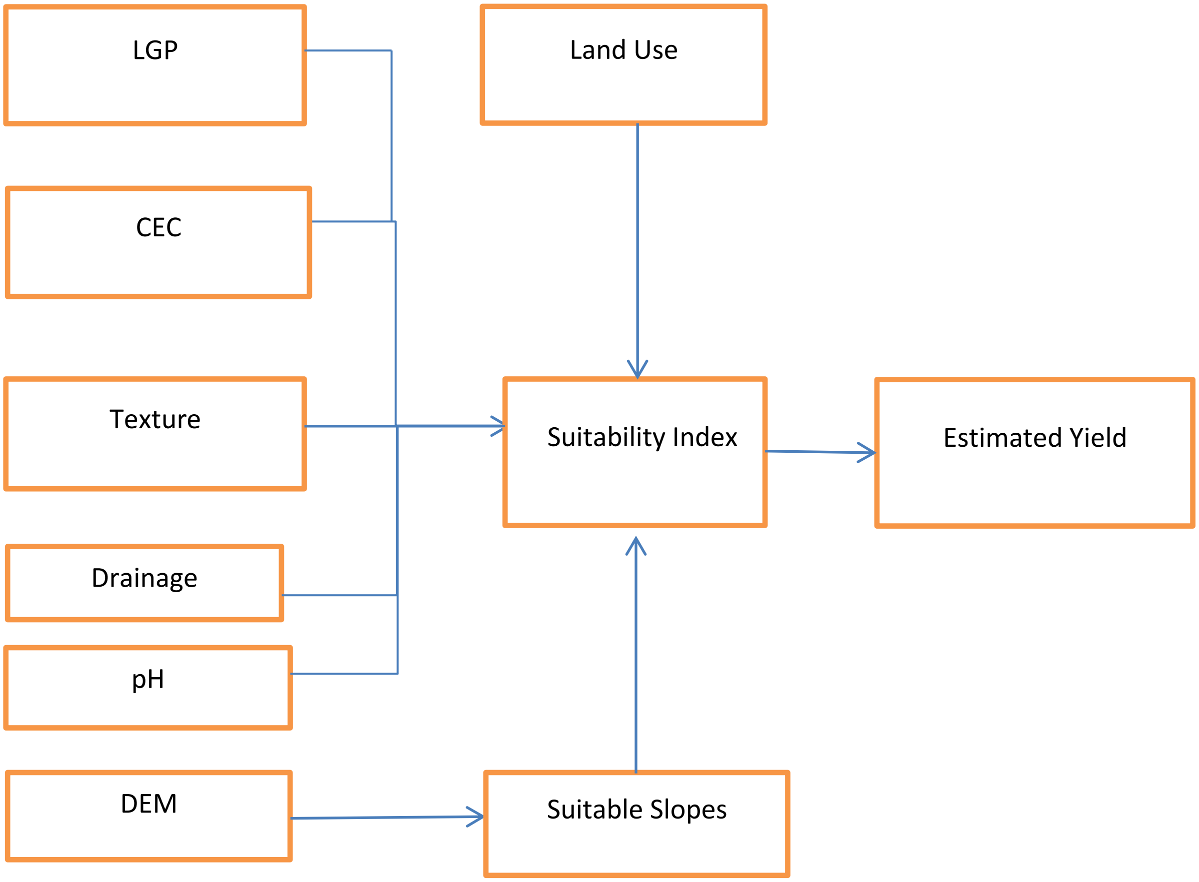

Figure 12: Flowchart of method sequenced in the Geographical Information System(GIS) analysis.

4 ANALYSIS OF RESULTS

4.1 Soil Analysis

Figure 13 shows the soil texture distribution on the study site. The texture raster indicates that the largest soil types are clay (48%), clay loam (36%) and loam (15%). The other texture type was insignificant. The site drainage distribution was 9.3% free, 63.2% imperfect, and 27.5% impeded (see Figure 14 & 15). This suggests that the texture within the area is generally suitable while the drainage is moderately suitable.

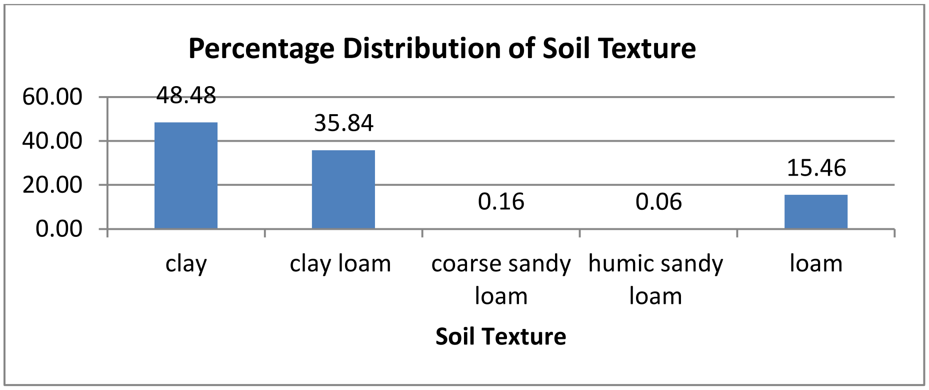

Figure 13: Distribution of soil texture on the study area (%)

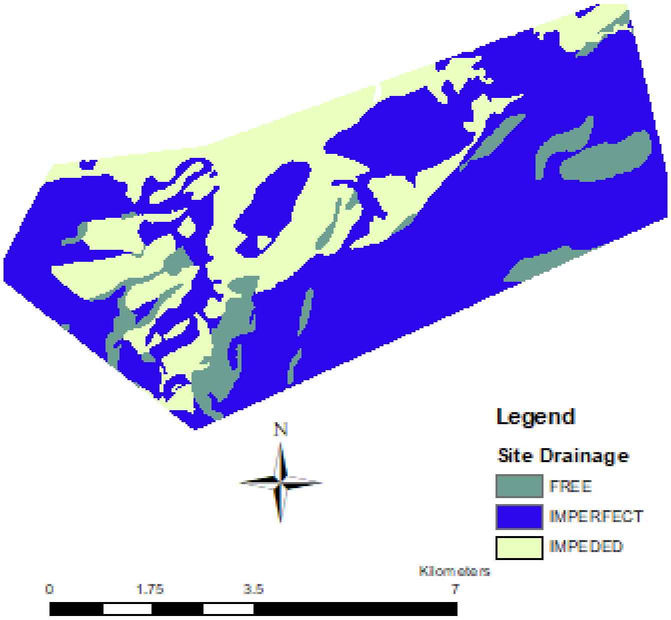

Figure 14: Map showing drainage distribution. This shows that the drainage is mostly imperfect

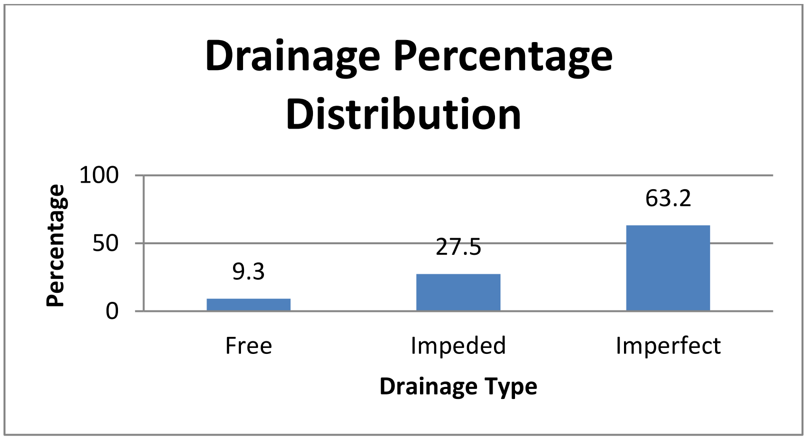

Figure 15: Graphical distribution of drainage areas (%)

The pH levels were generally at acceptable values for cocoa production as shown in Figure 16. 67.3% of the site was within the acceptable range between 5.5 and 6.5 while 1.3% was between 5.5 and 4 and 31.4% was between 6.5 and 8 (See Figure 17). There were no areas which fell into the unacceptable range. The CEC values fell within the acceptable range for the entire site (see Figure 18). The values ranged from 18 to 34 meq throughout the site (See Figure 19).

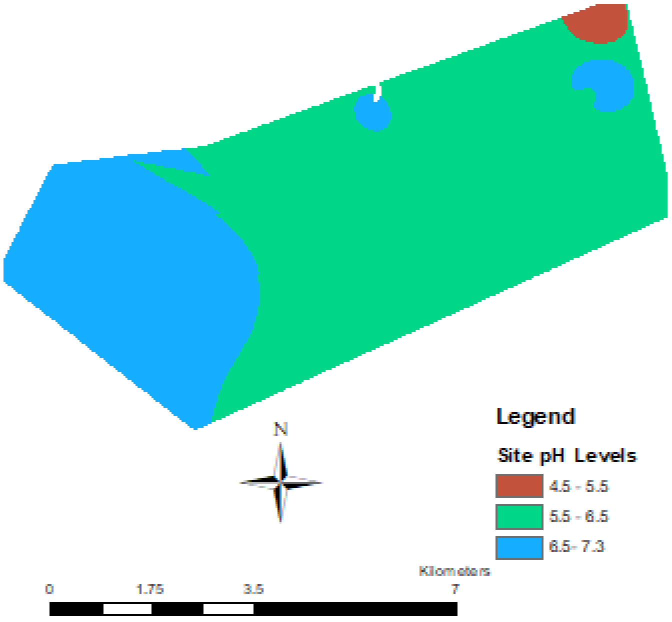

Figure 16: Map of pH distribution

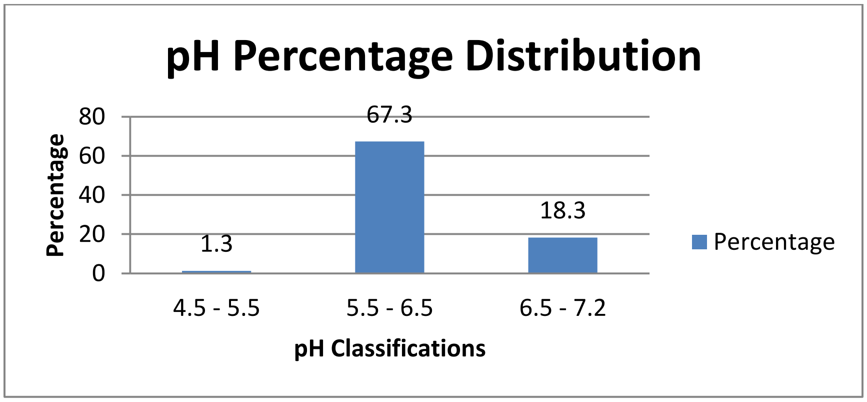

Figure 17: Graphical Representation of the pH distribution (%)

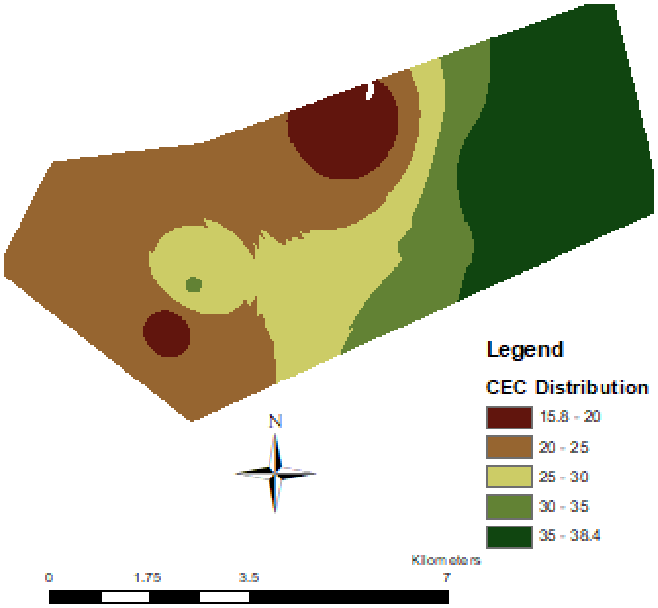

Figure 18: Map of the Cation Exchange Capacity (CEC) distribution (in meq)

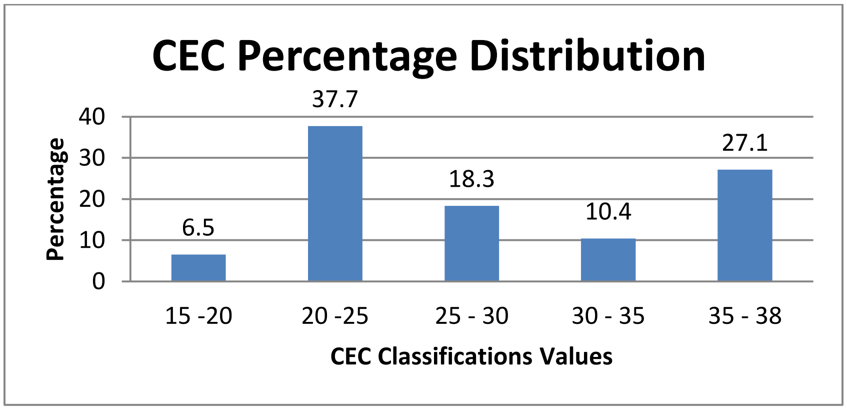

Figure 19: Graphical distribution of the Cation Exchange Capacity(CEC) values (%). All areas are favourable for cocoa production

The slopes did not exceed the 40% limit, which was considered as unusable. It was not necessary to be considered in the analysis since no areas will be excluded. Figure 20 shows the slope classification over the site area.

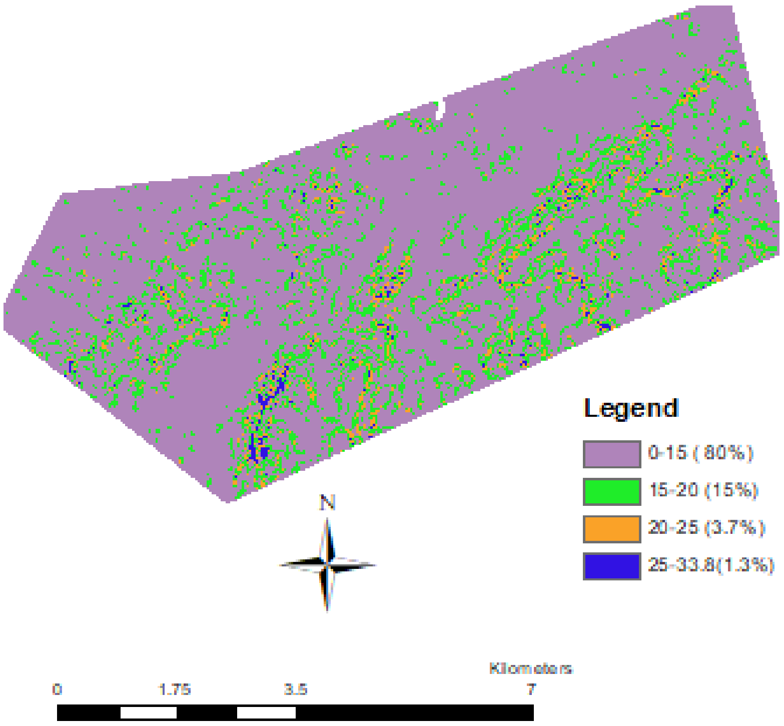

Figure 20: Map of slope classification and the percentages. No areas exceeded the threshold of 40% slope

4.2 Climate Analysis

The ETc values ranged from 3.3 mm day^{-1} to 4.59 mm day^{-1}. The months of February through May were the driest period annually while the humid period occurred during the months June to October and the wet period from October to January. The LGP values decreased from the East to the West based on the interpolation. The difference in LGP calculated between the minimum and maximum over the site was 28 days spanning approximately 12km in an East West direction. The distribution is shown in Figures 21 and 22. Based on the long term trends in rainfall and temperatures a 10% decrease in LGP will result in a decrease in climate suitability of the site based on the fuzzy classification values. The 30 year average shows favourable conditions for cocoa production as 32% favourable, 42.5% moderate and 25.5% unfavourable. Applying a 10% or one standard deviation negative change shows an increase in unfavourable areas to 58.4% and decreases in moderate and favourable conditions to 35.9% and 5.7% respectively. These changes represent the vulnerability to changes in weather patterns.

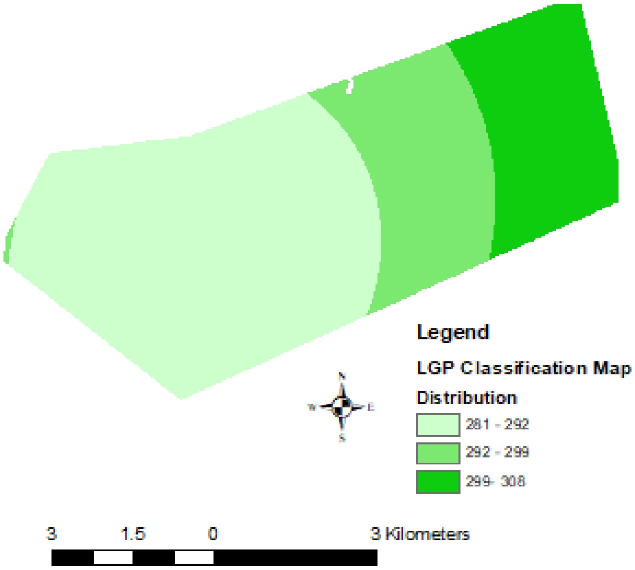

Figure 21: Map showing the Length of the Growing Period LGP distribution (in days)

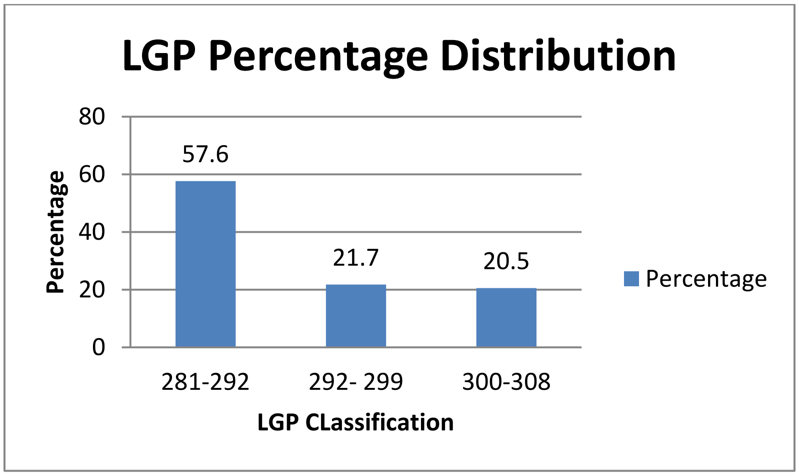

Figure 22: Graphical distribution of the Length of the Growing Period(LGP) (%)

4.3 Land Use

The area covered by roads was 2.8% of the total land area, while the forest reserves covered an area of 3.2% of the site. Rivers accounted for 2.1% of the total area. The extent of the area that was not considered as productive totalled 377 Ha. The communities' data was not used in the analysis since it represented less than 0.01% of the total area (See Figure 23).

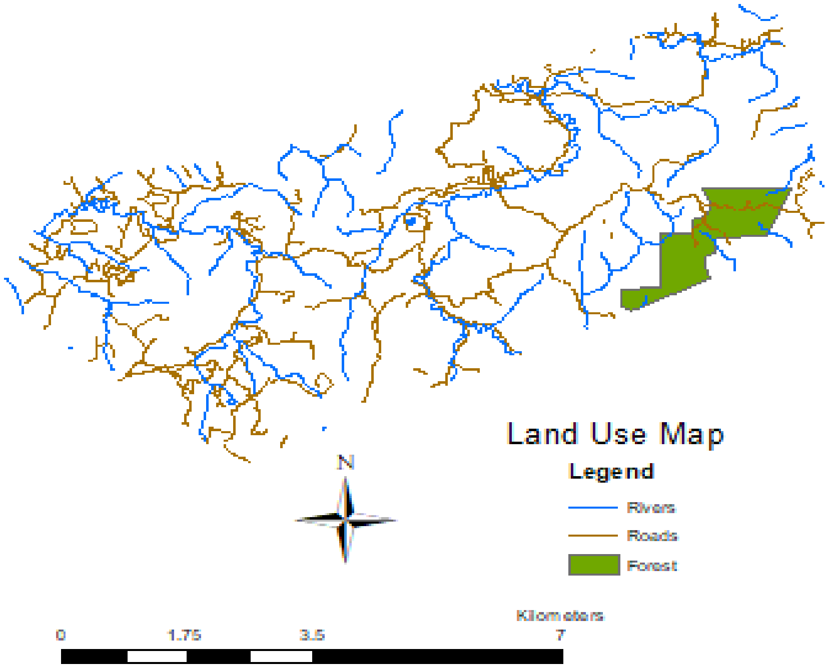

Figure 23: Map of Land use distribution where production is not possible. This represents 8.3% of the total area

4.4 AHP Application

The normalized matrix was derived from Table 7. This was achieved by dividing each cell in the matrix by the sum of each column. When the criteria or priority weights are determined, the consistency between the factors is then compared. The priority weights are calculated as the average of the total of each row.

	LGP	pH	CEC	Drainage	Texture	Total	Priority Weighting
LGP	0.51	0.41	0.63	0.37	0.37	2.29	0.46
pH	0.17	0.14	0.07	0.26	0.26	0.90	0.18
CEC	0.17	0.41	0.21	0.26	0.26	1.31	0.26
Drainage	0.07	0.03	0.04	0.05	0.05	0.25	0.05
Texture	0.07	0.03	0.04	0.05	0.05	0.25	0.05
	1	1	1	1	1	5.00	1.00

Table 8: Priority weighting determined from Analytic Hierarchy Process(AHP) analysis

Each Priority weight is multiplied by the specific column in the original matrix as shown below. The value of Pmax, CI and CR is calculated from the table. Since there were five (5) factors, the value of 1.12 was used based on the RI scale in Table 1.

Criteria Weights	0.46	0.18	0.26	0.05	0.05		
	LGP	pH	CEC	Drainage	Texture	Total	Total*CriteriaWeights
LGP	0.46	0.54	0.78	0.35	0.35	2.48	5.42
pH	0.15	0.18	0.08	0.25	0.25	0.91	5.09
CEC	0.15	0.54	0.26	0.25	0.25	1.45	5.53
Drainage	0.06	0.04	0.05	0.05	0.05	0.25	5.12
Texture	0.06	0.03	0.05	0.05	0.05	0.25	5.12
Total	0.90	1.33	1.22	0.95	0.95	5.34	26.28

Pmax = 5.34 CI = Pmax – 5/ (5-1)= 0.08 CR= C.I./1.12 = 0.07

Table 9: Results of applying the Analytic Hierarchy Process(AHP). The calculation shows C.R.<0.1 which indicates the weights can be accepted.

The value of C.R.< 0.1 and therefore the priority weighting is within the acceptable range.

4.5 Sensitivity Analysis

The results of the sensitivity study are shown in Tables 10 and 11. In the first analysis, the LGP high production areas increased as the weight decreased and decreased with increasing weights while introducing low production areas with increases of 15% in weight. The incremental changes for the LGP for high production were the largest of all the factors. Drainage and texture had similar changes but the incremental changes for each increment were lower than 2% percentage points. CEC and pH had trends with decreasing high production with decreasing increments and increased with increasing weights.

Percentage change in weights	Production Levels										
	LGP			pH		CEC		Drainage		Texture	
	Low	Moderate	High	Moderate	High	Moderate	High	Moderate	High	Moderate	High
-20		27.9	63.8	50.2	41.5	58.2	33.5	45.5	46.2	44.7	47.0
-15		33.6	58.1	49.6	42.1	57.6	34.2	45.7	46.0	45.1	46.7
-10		38.9	52.9	48.0	43.7	56.9	34.8	45.9	45.8	45.5	46.3
-5		42.7	49.0	46.8	44.9	56.2	35.5	45.6	46.1	45.6	46.1
0		45.8	46.0	45.8	46.0	45.8	46.0	45.8	46.0	45.8	46.0
5		52.3	39.4	44.7	47.0	54.6	37.1	46.5	45.3	46.5	45.3
10		55.3	36.4	43.7	48.0	53.5	38.2	46.2	45.5	46.4	45.3
15	0.8	56.3	34.6	42.9	48.8	52.1	39.6	46.6	45.1	46.7	45.0
20	2.1	56.9	32.8	41.9	49.9	50.5	41.2	45.9	45.8	46.9	44.8

Table 10: Table showing the incremental changes in weights for each factor as percentages

The second analysis showed that when equal weights are applied, there are no low production areas with moderate production areas 58% and high production areas 33.7%. When the higher weights were applied, low production classes are introduced for all factors except CEC. The CEC factor influenced the output for high production rate more than any other factors (See Table 11). Figure 24 shows the comparable distribution among the weighted factors.

Factors					Production Levels (%)			
LGP	pH	Drainage	Texture	CEC	None	Low	Moderate	High
20	20	20	20	20	8.3	0	58.0	33.7
40	15	15	15	15	8.3	0.4	65.0	26.4
60	10	10	10	10	8.3	4.1	60.6	27.1
15	40	15	15	15	8.3	0	29.1	62.6
10	60	10	10	10	8.3	0.05	2.0	89.7
15	15	40	15	15	8.3	18.0	65.2	8.6
10	10	60	10	10	8.3	25.9	57.4	8.5
15	15	15	40	15	8.3	0.1	67.2	24.4
10	10	10	60	10	8.3	1.1	64.6	26.0
15	15	15	15	40	8.3	0	28.1	63.8
10	10	10	10	60	8.3	0	0	91.7

Table 11: Table shows the percentage distribution of the areas for each classification of production. The weights are given as a percentage.

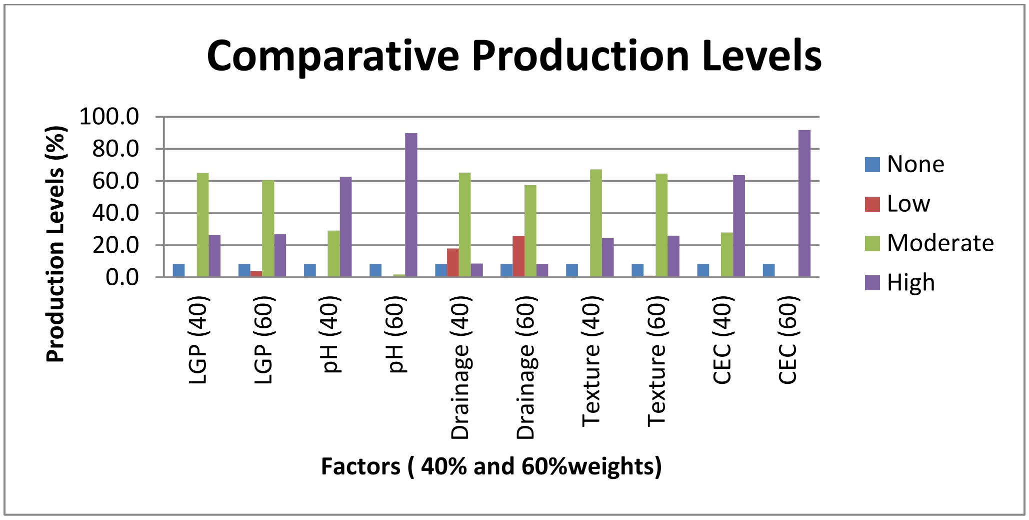

Figure 24: Comparable distribution of production levels (%)

4.6 Weighted Linear Combination Application

The resultant fuzzy values were combined and summed with the resulting values. The yield of the site was then estimated based on the areas given in the classification. The fuzzy values were classified as low, moderate and high. The distribution is shown in Figure 25. Figure 25 shows the unclassified resultant map and Figure 26 shows the classified map.

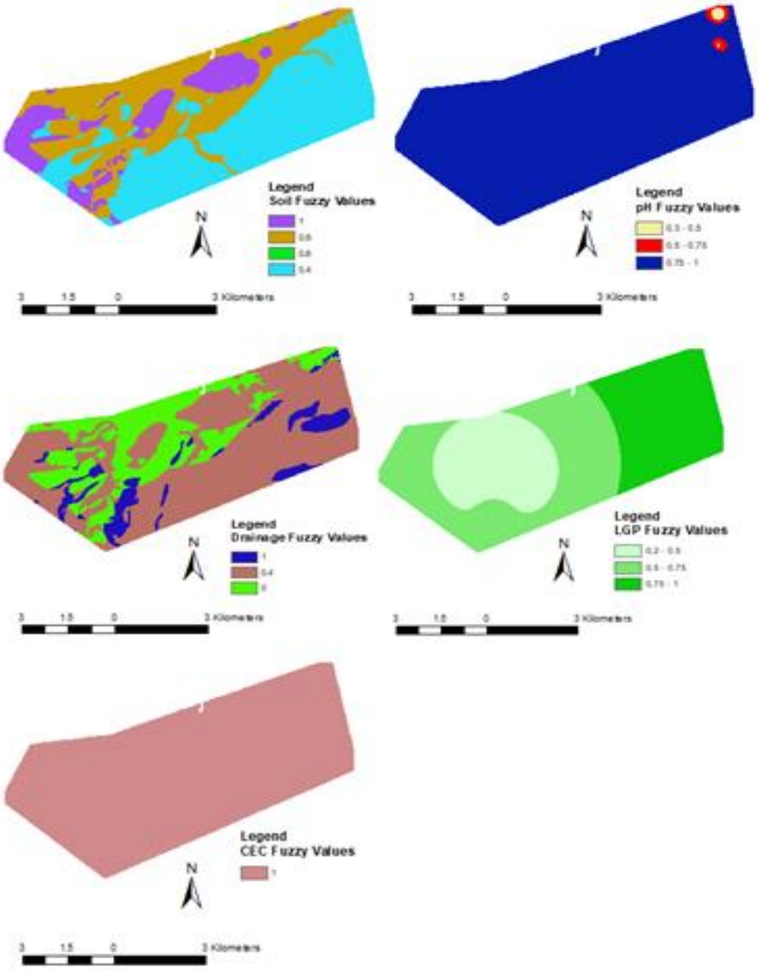

Figure 25: Fuzzy values distribution for each factor

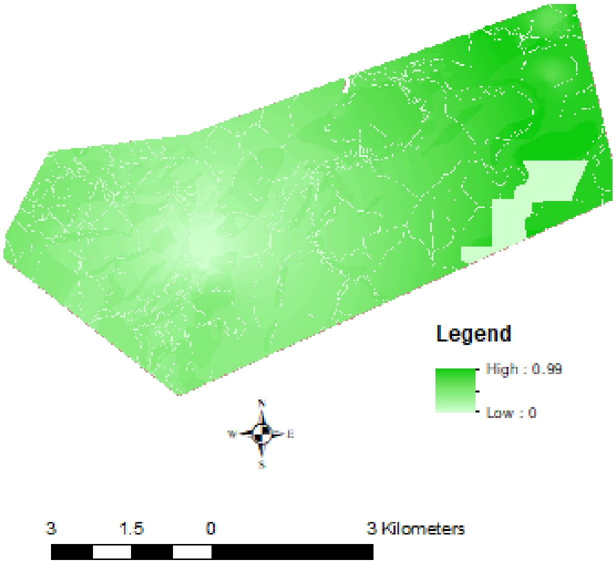

Figure 26: Map showing unclassified production levels of the study

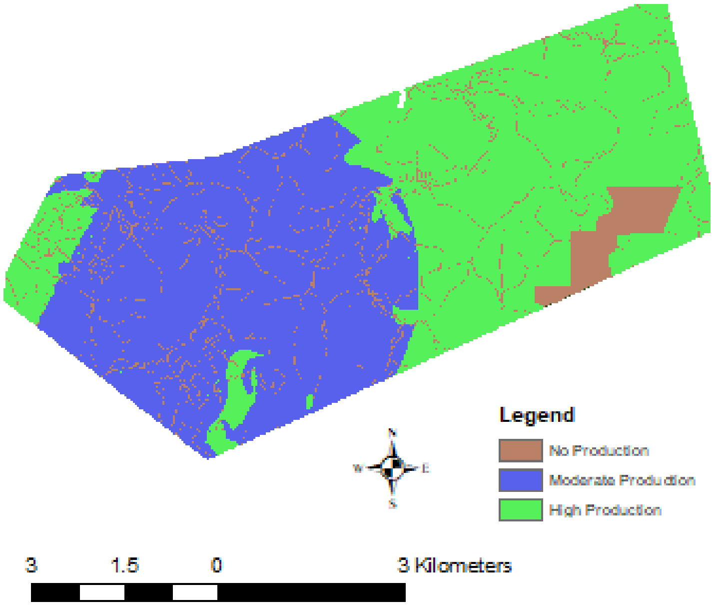

Figure 27: Map of classified production levels of the study area

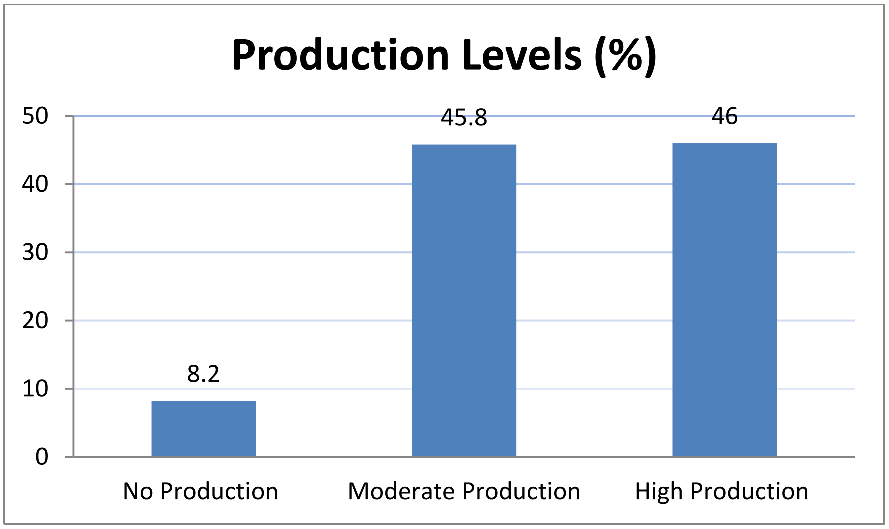

Figure 28: Percentage production Levels(Mt)

Figure 28 shows production distribution in the resultant raster dataset for each classification of production. 0 represents no production. This shows that the areas of no production are 8.2%, moderate levels 45.8% and high levels are 46 %.

Based on the classification, the estimated potential yield estimates for the site based on the 3m x 3m cultivation model is 2,700 Mt This is calculated on the moderate yield of 400kg/ha. and high yield of 1 Mt/ ha for the low density spacing (Maharaj, Indalsingh, Ramnath, & Cumberbatch, 2003). The site actual production averages around 200 Mt annually.

5 DISCUSSION AND RECOMMENDATIONS

5.1 Analysis

The results showed that the site is generally satisfactory for cocoa production based on the MCA /GIS methods as suggested by historical literature on site suitability. However, optimal levels of production have not been achieved.

Based on the climate model and IDW interpolation, a 1% change in the criteria for the LGP can impact the production especially at the pod development stage. Increasing temperature and less rainfall increases the chances of longer dry periods which makes irrigation critical (Sofoluwe, Tijani, & Baruwa, 2011). A distance of 10-20km to give an effective fine spatial resolution for rain stations is suggested. (Gonzalez-Hidalgo, Brunetti, & de Luis, 2011). While the interpolated points met this criteria, the geographic distribution of the points may present bias in the estimation since the distances from each other determines the cell value at any point on the surface. Rainfall in Trinidad and Tobago can be affected by a complex system which influences localised spatial variability (Getis, 2008). These include convective and orographic rainfall (Smith, 1979), while temperature variability is difficult to measure in the absence of reference stations (Stone, 2014). Given the sensitivity of the LGP values and the changes in phenology in cocoa, empirical weather data at regular intervals can create a more accurate predictive model to adopt a site specific irrigation strategy (Maharaj, Indalsingh, Ramnath, & Cumberbatch, 2003).

The data availability for the soils was more readily available for the factors presented in the study with 10 points within the site and the remaining 14 points within 2km of the boundaries of the site. These points were the verifiable data point for soil analysis. The distribution of the points showed that additional data within the site is necessary for variability and further examination.

The experts' preferences for weighting showed that there was agreement among the literature and experts. Although there is a level of subjectivity, finding appropriate values will require empirical data spanning many years given that full production of cocoa occurs within 4 to 8 years after cultivation (Merry, 2017). While there exist study based evidence to support the fuzzy values for pH and CEC, drainage and texture are assigned discrete values and based on experts' judgement. The cultivation method during planting allows for soil mixes including organic matter which allow for root access to nutrients which assist drainage. High water tables, groundwater and aquifers also contribute to nutrients to the plants enabling water balances, while the CEC values are well within the acceptable ranges generally in Trinidad (Merry, 2017)

While the AHP method accepts the consistency among the values, the subjectivity can only be removed by empirical evidence for greater accuracy (Mu & Pereyra - Rojas, 2017). The two (2) sensitivity analyses show the changes from high to moderate areas and low areas. The changes in the weights based on the experts' preferences revealed less than 2% change for all factors except the LGP which had a larger weighting compared to the others. In the second analysis, this introduced low production for drainage and texture as the areas are more varied across the site. This presents the opportunity to further simulate and investigate the model to reflect the interrelationships and improve the model's accuracy (Al Mashreki, Bin Mat Akir, Rahim, Md Desa, Lihan, & Haider, 2011). It also provides the opportunity to separate the factors individually and correlate with production to improve the indices (Chen, Yu, & Khan, 2010).

Trials to improve production in East Trinidad challenged traditional management techniques (Maharaj, et al., 2011). These trials initiated closer planting spacing for three TSH varieties. These trials increased production to 1500Mt/ ha. in East Trinidad. When compared to the study site, the difference in production during the trials demonstrated that a planting density of 1.8m x 1.8m was higher yielding although the yield per plant was lower the increased number of plants from 748 and 1495 to 2990 trees per hectare. The increase in production was attributed to crop management which included field sanitation, plant nutrition and pollination enhancement through improved microclimates. However, the cost of operations increased for the farmers (Maharaj, Indalsingh, Ramnath, & Cumberbatch, 2003). Rehabilitation requires several management decisions including the choice of clones which often depends on the biophysical nature and the soil profile of the fields since clones can be disease or drought resistant.

This will also dictate the spacing of the trees and an estimate of the return on investment. Since the maximum revenue derived from the estates occur after eight (8) years, intercropping is an essential component and the changes in soil fertility through the uptake of nutrients must be monitored for deficiencies and the application of fertilizers. Cocoa plant physiology and genotype also determine the rates of production (Maharaj, et al., 2011). Data availability limited the analysis for the complexity of production which must consider genotype, age, organic content and nutrient levels (Lahive, Hadley, & Daymond, 2018). Plant phenology is also heavily dependent on the site specific microclimates rather than broader environmental conditions (Sofoluwe, Tijani, & Baruwa, 2011). Importantly, wind speed for the flowering stage and the conditions necessary for the midge population will affect the pollination of the trees.

5.2 Further Studies

Other soil factors that are significant for cocoa production include the soil depth, which provides the ability to accommodate the roots of the trees and the organic content required (Carr & Lockwood, 2011). A soil diagnostic tool which can highlight the nutrient requirement can be implemented for more specific and accurate application of fertilisers and irrigation (Alabi, Sonder, Oduwole, & Okafor, 2012; Wood & Lass , 1985). Cadmium in the soils is also one of the major problems for cocoa. Any location that is selected must be tested for the levels of cadmium and its impact on the cocoa pods since this affects the quality required for international standards (Umaharan, 2017).

Soil loss is also another consideration over time. Soil loss occurs as a result of the erosions of sloping land (Haan, Barfield, & Hayes, 1994). The site map shows that the rivers and the tributaries that are part of the region can also cause leaching and the spread of heavy metals and pathogens. Adjacent activity also must be carefully monitored in terms of pest migration and diseases. Land clearance causes the migration of pests towards cocoa estates and increases the risks of crop losses (Merry, 2017). This requires that neighbouring activity is monitored through temporal analysis which is possible through GIS methods.

5.3 Project Limitations

Sufficient yield data was unavailable for the site and as such, the actual yield could not be compared directly with the project estimation. Additionally, the yield data did not account however, for the ages of the trees, the type of bean and the spacing of the trees. The assumption was that the conditions remained relatively stable annually. Record on risks such as forest fires, pests and diseases were not available for consideration but could have influenced the yield in any given year.

Qualitative data was challenging as many of the farmers were reluctant to provide details on the farms. There were three (3) respondents, all of whom indicated that labour challenges, pests and climate were their primary concern for the future. All respondents indicated that they do not use fertilisers nor exercise any pruning to any significant levels on the field. Testing is also not done regularly, and their yields are below 250kg/ ha.

6 CONCLUSIONS

A computer enabling environment is able to store large amounts of both geographic and attribute datasets. The MCA/AHP methods demonstrate the ability of GIS to assess the feasibility of a site and engage both potential investors and farmers, in decision-making processes. This assessment provides the user with an expectation of the site in terms of yield and changing conditions. The methods also enable flexibility to manipulate scenarios and establish outcomes based on simulations. This allows for a qualitative and quantitative analysis of the site which can include other datasets including socio-economic data, land use data and assist in Environmental Impact Assessments (EIA). Since rehabilitation may require a change in flora and fauna, carbon sequestration and other sensitive environmental impacts can be assessed. Adaptation and vulnerability are two (2) factors that must be managed for a long term, viable risk-adverse venture. Improving the study would require both qualitative and quantitative datasets as clusters for a better representation. Records of production, changes in soil nutrients and localized micro climates can enhance the study to produce more accurate results where a comparison between outcome of the model and the actual production can be assessed and modified accordingly.

The project meets the objectives of testing and developing a model for climate and soil suitability and highlights the need for active data collection and records. Despite the lack of data, the project is able to produce results which guide both the planning and implementation process.

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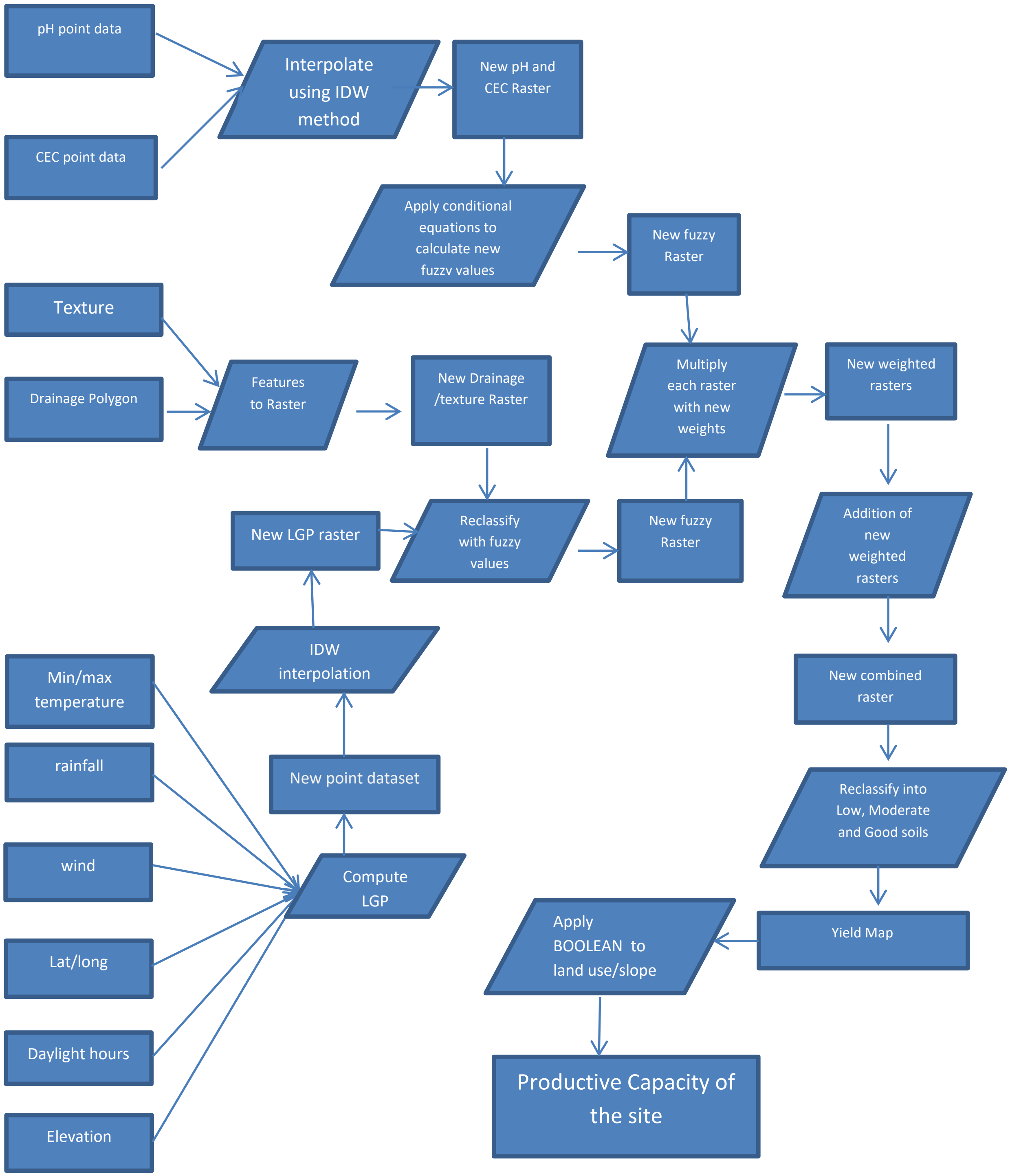
Appendix 1

Analysis Process



Appendix 2

Fuzzy Conditional Equations (CEC, pH and LGP)

CEC

```
Con(("cecrast" > 10) & ("cecrast" < 12), ("cecrast" - 10) / (12 - 10), Con("cecrast" <= 10, 0,1))
```

pH

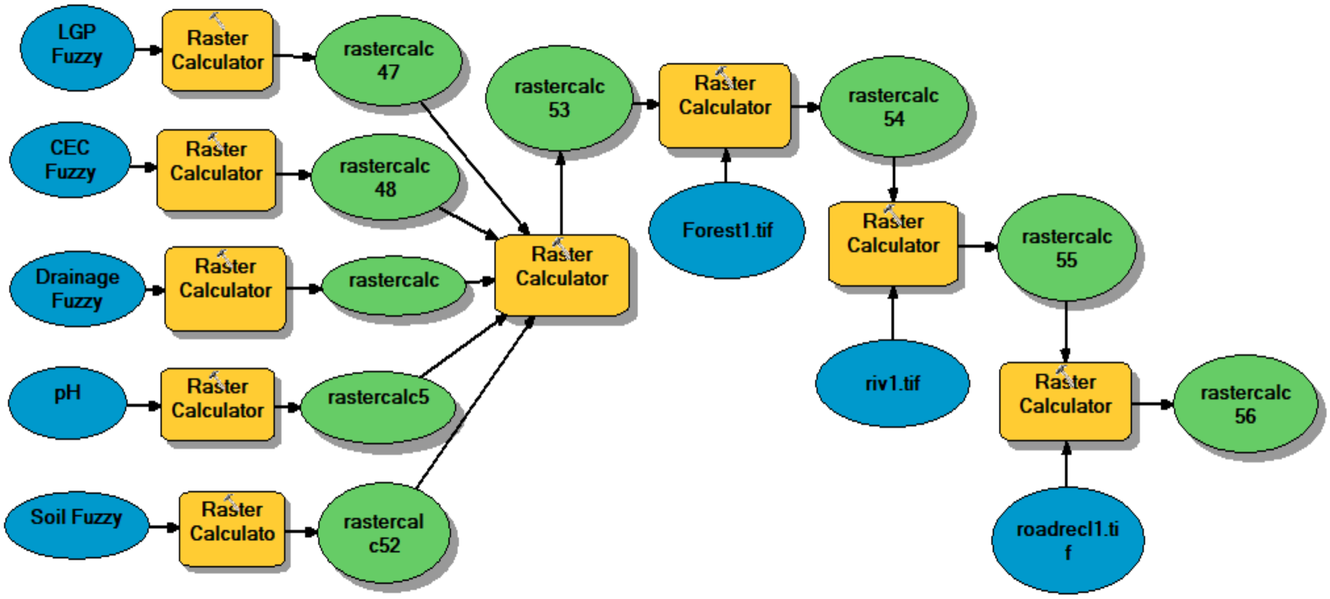
```
Con(("IdwpH" >= 5.5) & ("IdwpH"<= 6.5), 1,Con (("IdwpH" > 6.5) & ("IdwpH"  <= 8), ("IdwpH" - 6.5) / (8 - 6.5),Con (("IdwpH"  >= 4.5) & ("IdwpH" < 5.5), ("IdwpH" – 4.5) / (5.5 – 4.5), 0)))
```

LGP

```
Con(("LGP" >= 302) & ("LGP"<= 323), 1,Con (("LGP" > 323) & ("LGP"  <= 340), ("IdwpH" - 323) / (340 - 323),Con (("LGP"  >= 275) & ("LGP" < 302), ("LGP" - 275) / (302 - 275), 0)))
```

Appendix 3

SENSITIVITY ANALYSIS MODELBUILDER



Appendix 4

FAO (56) PENMAN- MONTEITH EQUATION

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

R_n is the net radiation

G is the soil heat flux

$(e_s - e_a)$ represents the vapour pressure deficit of the air

ρ_a is the mean air density at constant pressure

c_p is the specific heat of the air

γ is the psychrometric constant

r_s and r_a are the (bulk) surface and aerodynamic resistances

Appendix 5

Interview with cocoa farmer

QUESTIONNAIRE

Project overview:

This project is a thesis, which is part of the fulfilment of the MSc. in Geographical Information Systems at Lund University, Sweden. The project objectives include the development of criteria for cocoa production. The criteria will identify the issues that directly affect production and will be weighted according to the influence of each component to provide a Multi Criteria Analysis. The questionnaire will seek to get assistance through the experience of farmers and experts involved in cocoa production to provide the information required for the project.

NAME OF FARM: ___________________________

LOCATION:_________________________________

Date:______23/05/2017_______________

1. What is the size of the farm?

☐ <5 Acres ☐ 5 – 10 Acres ☐ 10- 50 Acres ☐ > 50 acres – 80 acres

2. What type of cocoa is grown?

____

3. What are the ages of the tree?

☐ Less than 5 Years ☐ 5 to 20 years ☐ 20 to 50 years ☐ Greater than 50 years – 54

4. How many trees do you have under cultivation?

____

5. What spacing do you use?

☐ 6 ft. x 6ft. ☐ 8ft. x 8ft. ☐ 10ft. x 10ft. ☐ Greater than 10ft. x 10ft. – 7.5 x 7.5

6. Do you replant trees? If yes, when last did you replant?

____

7. How many labourers do you employ?

____

8. How often do you fertilize?

____

9. What fertilizer do you use?

____

10. What is the yield from the crop annually?

____

____

11. What do you consider the main risk factor that affects the crop yield?

____

____

12. Do you prune your trees? ☐Yes ☐ No How often _________

13. Do you irrigate the field? If yes, please state how often and the method you use.

☐ Yes ☐ No No irrigation, contract – very necessary

If yes indicate the method used __________________.

14. Are you at risk for fires? If yes, describe the areas that are most prone to fires.

☐ Hills ☐ Valleys ☐ Close to access roads ☐ Other

15. What measures do you have in place to deal with a forest fire?

☐ Fire traces- ☐ Wind breaks ☐ Other

16. How do you think you can improve yield and quality?

☐Fertilization ☐Irrigation ☐ Pest control ☐ Disease control ☐Pruning

☐ Harvesting

17. Have you been affected by pests and diseases? If Yes, please give specific types.

Thank you

Appendix 6

EXPERT QUESTIONNAIRE

Cocoa Research Centre, Trinidad and Tobago

Project overview:

This project is a thesis, which is part of the fulfilment of the MSc. in Geographical Information Systems at Lund University, Sweden. The project objectives include the development of criteria for cocoa production. The criteria will identify the issues that directly affect production and will be weighted according to the influence of each component to provide a Multi Criteria Analysis. The questionnaire will seek to get assistance through the experience of farmers and experts involved in cocoa production to provide the information required for the project.

Date:___________________

1. What criteria (values or range of values) would you apply to cocoa production to achieve optimal yield :

2. What is the estimated optimal yield per hectare given the conditions in Trinidad and Tobago?

---

3. How would you weight the effect of each climatic factor on cocoa production?

SOIL FACTORS

4. How would you weight (in order of changes of significance), the soil conditions for cocoa production?

Using a range between 0 – 1, please weight the following in order of significance. The total of all weights must total 1.

- pH ____
- CEC ____
- Drainage ____
- Texture ____

Thank you for your participation

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