

MIDLANDS STATE UNIVERSITY

FACULTY OF SOCIAL SCIENCES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

APPROVAL FORM

The undersigned certify that they have read and recommend Midlands State University to accept a dissertation entitled: **Land Suitability Analysis from Space for Crop Farming: The Case of Ward 36, Mberengwa District in Zimbabwe** by **Hove John (R103505M)** in partial fulfilment of the requirements of a BSc Honours degree in Geography and Environmental Studies.

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ABSTRACT

Vegetation Condition Index (VCI), a function of Normalised Difference Vegetation Index (NDVI) forms a very critical model for climate modelling, detecting crop yield productivity and yield prediction. It approximates the weather (rainfall) component in NDVI value and allows quantifying the impact of weather (rainfall) on maize crop. The thrust of this research study was to detect land suitability potential for maize crop based on VCI-drydekads in Mberengwa District, Ward 36 in view of recurrent food insecurity in this study area. Maize crop performance is a function of critical variables which include rainfall and soil nutrients. A test of the relationship between average VCI and remotely-sensed seasonal rainfall was performed using an empirical regression model. A significant relationship ($p < 0,05$; $R^2 \times 100 > 80\%$) for all the five sample growing seasons was observed between mean VCI and remotely-sensed rainfall amount. Subsequently, VCI was used to detect maize crop land suitability by calculating the number of VCI-drydekads under rain-fed maize Land Utilisation Type (LUT) along with soil analysis in Geographic Information System (GIS). Results showed that Ward 36 experienced the worst maize crop failure based on the subdued VCI (%) and the high number of VCI-drydekads experienced and soil constraints hence factor rated currently not suitable (n1) and marginally suitable (s3) respectively subject to Food and Agricultural Organisation (FAO) land suitability guidelines. Based on FAO land suitability framework, VCI and soil maps which were generated for Ward 36 exposed severe limitations in terms of subdued rainfall totals and pedological constraints that yielded exceedingly high VCI-drydekads. This apparently disqualified its land suitability potential for maize crop production (LUT). The study therefore recommends that Agricultural Research and Extension Services (AREX) should evaluate the feasibility of relying on maize crop judging by the results of this research and advise resettled A1 farmers accordingly on the best diversified investment farming such as drought-tolerant varieties like sorghum and millet. Government should consider allocating bigger plots to A1 farmers for commercial livestock production (LUT) such as cattle, sheep and goats under subsidised loan schemes, inputs, technical support, and establish potential market network.

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DEDICATION

I dedicate this dissertation to my lovely wife Norlene Hove.

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ACRONYMS AND ABBREVIATIONS

AMESD	African Monitoring of the Environment for Sustainable Development
DBMS	Data Base Management System
EMS	Electromagnetic Spectrum
<i>et al</i>	et alia
FAO	Food and Agricultural Organisation of the United Nations
Fig.	Figure
FTLRRP	Fast Track Land Reform and Resettlement Programme
GCP	Ground Control Point
GIS	Geographical Information Systems
GRSI	Geo-Information and Remote Sensing Institute
GPS	Global Position System
ICRISAT	International Crops Research Institute for the Semi-Arid-Tropics
ILWIS	Integrated Land and Water Systems
MVC	Maximum Value Compositing
LSA	Land Suitability Analysis
NDVI	Normalised Difference Vegetation Index
NIR	Near infra-red
P	Probability
R ²	Coefficient of determination
R	Red
r	correlation coefficient
RS	Remote Sensing
SPOT	Systeme Pour l'Observation de la Terre, The French designed earth observation satellite systems
TAMSAT	Tropical Agricultural Meteorology using Satellites
VCI	Vegetation Condition Index
QGIS	Quantum-Geographical Information System
UTM	Universal Tran verse Mercator
SIRDC	Scientific and Industrial Research and Development Centre
µm	Micrometer (10 ⁻⁶ of a meter)
<	Less than
>	More than

Definition of Terms

Land: Is delineable Earth's terrestrial surface, the characteristics of which embrace all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area, including those of the atmosphere (climate), the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present human settlement patterns, to the extent that these attributes exert a significant influence on present and future uses of the land by humans (Sombroek and Eger 1996).

Land Quality (LQ): Is a complex and unmeasurable existing attribute of land/environmental quality which has a fundamental bio-physical property that has a substantial effect on the choice of land use. Moisture availability, total radiation and nutrients availability are such examples (FAO, 1993; Rossiter and van Wambeke, 1995).

Land Characteristic (LC): Is a simple attribute of the land that can be directly measured or estimated in routine survey in any operational sense, including remote sensing for application as a means of describing land qualities. Classical examples mean rainfall (mm), sunshine (hours), soil nutrients (pH) (FAO, 1993; Rossier and van Wambeke, 1995).

Land-Use: Is a broad and generalised description of the land utilisation such as dry-land cropping of maize.

Land Utilisation Requirement (LUR): Is a condition (physiological, conservation and management) of the land necessary for successful and sustained implementation of a specific Land Utilization Type (FAO, 1993; Rossiter and van Wambeke, 1995).

Land Utilization Type (LUT): Is a kind of land use described or defined in a degree of specific detail greater than that of land-use indicating the products, management specifications (technologies). In the context of rain-fed agriculture, a land utilization type involve annual dry-land cropping based on groundnuts with subsistence maize, by small-holders with low capital resources, using cattle drawn farm implements, with high labour intensity, on freehold A1 farms of 5-10 ha (FAO, 1993; Rossiter and van Wambeke, 1995).

Land Use Planning (LUP): According to GTZ, 1995 land use planning is an implementation -orientated process for reaching decisions on a sustainable, environmentally sound, socially desirable, and economically appropriate form of land use, based on dialogue and a balance of interests among all participants.

Factor Ratings: Are sets of values which indicate how well each land use requirement is satisfied by a particular condition of the corresponding LQ; the suitability of the LQ for a specific land-use (FAO,1993).

Land Quality Indicator (LQI): Is the relationship between land-use and sustainable development which expresses the vital condition of the environment relative to its sustainable land-use. Examples include; mine dumps, deforestation, overgrazing, siltation (FAO, 1993).

Land Evaluation: Is the assessment of land performance and its production potential when used for a specified purpose, involving the execution and interpretation of surveys and studies of land forms, soil, vegetation, climate and other aspects in order to identify and make a comparison of potential kinds of land use in terms applicable to the objectives of the evaluation qualitatively or quantitatively (Bouma, 2000).

Physical land evaluation: Is an evaluation based only on physical factors that determine whether a LUT can be implemented on a land area, and the nature and severity of physical limitations or hazards such as low rainfall and soil degradation.

Economic land evaluation: Is an evaluation of suitability based on some economic measure of net benefits, should a given LUT be implemented on a given land area such as promoting food security.

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CHAPTER ONE: INTRODUCTION

1.1 Background to Study

The suitability of a given piece of land unit is its natural ability to support a specific crop production purpose. Land-use suitability analysis aims at identifying the most limiting factors of a particular crop production, appropriate spatial pattern for future land uses according to specific requirements or predictors of some activity (Collinset *al*, 2001). According to FAO methodology (2005), this is strongly related to the land qualities such as moisture availability, total radiation, erosion hazard, and flood hazard which are not measurable. As these qualities derive from the land characteristics such as rainfall (mm), sunshine (hours), slope angle (degrees) and length (metres), soil texture (coarse or fine), nutrients (pH), which are measurable, it is advantageous to use these values to study the suitability. Thus, the land characteristics parameters are used to work out land suitability.

The GIS-based land-use suitability analysis has been applied in a wide variety of situations including ecological approaches for defining land suitability/habitat for animal and plant species (Store and Kangas, 2001), suitability of land for agricultural activities (Cam bell *et al*, 1992; Kalogirou, 2002) and environmental impact assessment (Moreno and Seigel, 1988). Smallholder cropping systems in Southern and East Africa are based predominantly on maize, the staple food which accounts for about 50% of the total calories consumed (Mashingwani, 1983). Land suitability analysis is a prerequisite to achieving optimum utilization of the available land resources. Zimbabwe's economy is agro-based and heavily dependent on weather in particular rainfall, soil type and temperature. In areas where rainfall is erratic and inadequate, agricultural productivity becomes highly correlated to weather. Lack of knowledge on best combination of bio-physical and climatic factors that suit production of maize has contributed to the poor production in smallholder A1 farmers in the resettled areas of Zimbabwe. Maize yields have remained far below their agronomic and genetic potential. Maize (*Zea mays*) is Zimbabwe's principal source of food and livelihood (Anderson, 1993; Mushayi, 2001; Wiebe, 2001). The efficiency of calorie production per hectare assumes greater importance as cropping land becomes more sustainable for farmers (Boyce, 2005).

Failure to undertake sustainable land suitability assessments has resulted in massive food insecurity in Zimbabwe's resettled farmers. In the aftermath of the FTLRRP in Zimbabwe, food aid has become a permanent feature in the country. The question is why recurrent poor harvests given the massive tracts of land being utilised by resettled farmers? Therefore there is an urgent need to adopt land practices that are most rational and sustainable so as to improve on food security. The United States Agency for International Development (USAID) defines an area as food secure "when all people at all times have both physical, social and economic access to sufficient food to meet their dietary needs for a productive and healthy life" (Freund, 2005). In 2005, FAO reported that twenty four countries, Zimbabwe inclusive in Sub-Saharan Africa were facing exceptional food emergencies. Famine in Sub-Saharan Africa has been attributed to crop failure partly due to poor land suitability assessments which undermines the incomes of the already very poor (Mellor, 1987; Low, 1991).

In this regard, GIS and RS technology offers a dynamic tool for multidimensional process of land suitability analysis. RS provides landscape information from an overhead perspective synoptically, repetitively and objectively. It is an important source of spatial information such as land use/land cover status using vegetation indices such as NDVI and VCI (Groten, 1993; Perveen *et al.*, 2007). GIS is a powerful tool for geo-environmental analysis and appraisal of natural resources. It allows the user to integrate data bases generated from various sources including RS on a single platform and analyse them efficiently in a spatial-temporal domain. Suitability analysis of croplands helps to ensure that land resources are used in the most productive and sustainable ways. Different crops require different land types and growing conditions.

Optimizing maize production can be achieved through sustainable agriculture. The concept of sustainable agriculture involves producing quality products in an environmentally sound and economically efficient way (Addeo *et al.*, 2001), ensuring optimum utilization of the available natural resource for efficient maize production. In order to comply with these principles of sustainable agriculture, the farmer has to grow the crops where they suit best and for which initial prerequisite conditions is to carry out land suitability analysis (Nisar Ahmed *et al.* 2000). Suitability is a function of crop requirements and land characteristics (Mustafa *et al.* 2011). Matching land characteristics with the crop requirements gives the suitability. Therefore suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (FAO, 2005). Land suitability analysis has to be

carried out in such a way that local needs and conditions are reflected well in the final decisions (Prakash2003).

This study uses NDVI and VCI as surrogate measure of maizecroproduction, satellite rainfall estimates and soil analysis for smallholder A1 farms located in natural region 4, a critical semi-arid agricultural region of Zimbabwe. The main objective of the study is to analyse land suitability for maize crop through the use of an empirical regression model in which rainfall amount is the independent variable and VCI is the dependent variable from 2000-2012 farming seasons.

1.2 Problem Statement

Food security through investing in productive crop farming requires research on the factors that hinder or promote its success. Major parameters include rainfall exceeding 850mm for maize per season and fertile soils. Maize forms the main cultivated crop for the bulk of small-scale subsistence farmers in Mberengwa District. During the FTLRRP in 2000, the government allocated land in an attempt to enhance food security among vulnerable landless farmers under A1 model in the vast Cold Storage Commission, Costas and Mapuma Ranches in the area. Allocation of land was done without undertaking land suitability analysis on such factors as rainfall and soil fertility potential. Prior Resettlement programme, Cold Storage Commission, Costas and Mapuma Ranches were utilised under a viable commercial cattle ranching scheme because the area receives marginal rainfall totals between 450-650mm annually which hardly support crop farming such as maize. The period from 2000 to present has been characterised by severe recurrent agricultural drought with poor crop yields compromising food security in the entire Ward 36. Land degradation is evident through unauthorised gold panning within and adjacent derelict mines as people strive to supplement scanty food-crop reserves. Uncontrolled deforestation on already unproductive soils undermines environmental integrity. Mtshingwe River has massively degraded and silted as a result of unsustainable land practices. This research study therefore seeks to undertake a land suitability analysis for maize crop farming from 2000-2012 using remote sensing indices (NDVI and VCI) in semi-arid Mberengwa Ward 36. Such information may result in informed decisions on the principle of land sustainability by farmers, government, Agricultural, Technical and Extension services and policy makers on food security in the Ward.

1.3 Objectives of the study

1.3.1 General Objective

To analyse Land suitability for crop farming from 2000-2012 in semi-arid Mberengwa Ward 36 using remote sensing indices (NDVI and VCI).

1.3.2 Specific Objectives:

- To test the relationship between average Vegetation Condition Index (VCI) and seasonal rainfall amount (2000-2012).
- To detect land suitability potential for maize crop based on VCI-dry-dekads (2000-2012) and Soil map analysis.
- To produce land suitability maps for maize crop (2000-2012).

1.4 Research Hypothesis

In this study we hypothesize that:

- There is a significant relationship between Vegetation Condition Index (VCI) and remotely-sensed rainfall amount.
- VCI derived dry-dekads are indispensable to detect land suitability potential.
- Multi-temporal remotely-sensed vegetation and rainfall data provide tools to map the suitability cropping conditions.

1.5 Justification of the study

Resettlement in Zimbabwe has political, economic and social benefits in terms of returning land to the landless in order to alleviate poverty and enhance food security. However, the success of resettlement was constrained by a number of limitations during implementation. The shortage of qualified land use planners, resettlement officers, land managers, land economists and land evaluators within the ministry made the implementation of the land reform process difficult (Werner, 2002). This has resulted in lack of proper land evaluation in the country, and it is regarded as a contributing factor to unsustainable environmental practices for the area's natural resources.

The basic premise of GIS suitability analysis is that each aspect of the physical landscape has intrinsic characteristics that are in some degree either suitable or unsuitable for the activities being planned. Furthermore, GIS has the capability of presenting data in both tabular and map format. This is very useful for decision making for policy-makers, land use planners, farmers and government since the information in tables can be associated with location (Walford, 1995). It is further expected that the findings of this study will be made available to relevant ministries, development agencies, research and teaching institutions as well as the private sector investment. To enhance food security, a concept composed of anti-hunger elimination goals and sustainable food systems, it is envisaged that by undertaking land suitability in Mberengwa Ward 36 the optimal maize crop conditions can be identified to mitigate recurrent food shortage in the Ward. The rationale for selecting the study area was based on the need to justify land suitability for maize crop farming in the aftermath of land reform in 2000. This also serves to equip the local community with knowledge on sustainable land use, minimise land degradation and promote environmental integrity. Therefore in order to produce an ideal suitability assessment in Mberengwa Ward 36, there is need to analyse the relationship between remotely sensed rainfall and VCI as well as NDVI under Zimbabwe environmental conditions.

In this study SPOT-Vegetation (NDVI) and TAMSAT data was used because it is acquired on daily basis for any location in Africa free of charge to generate VCI and rainfall parameters respectively.

1.6 Map and Description of the Study Area

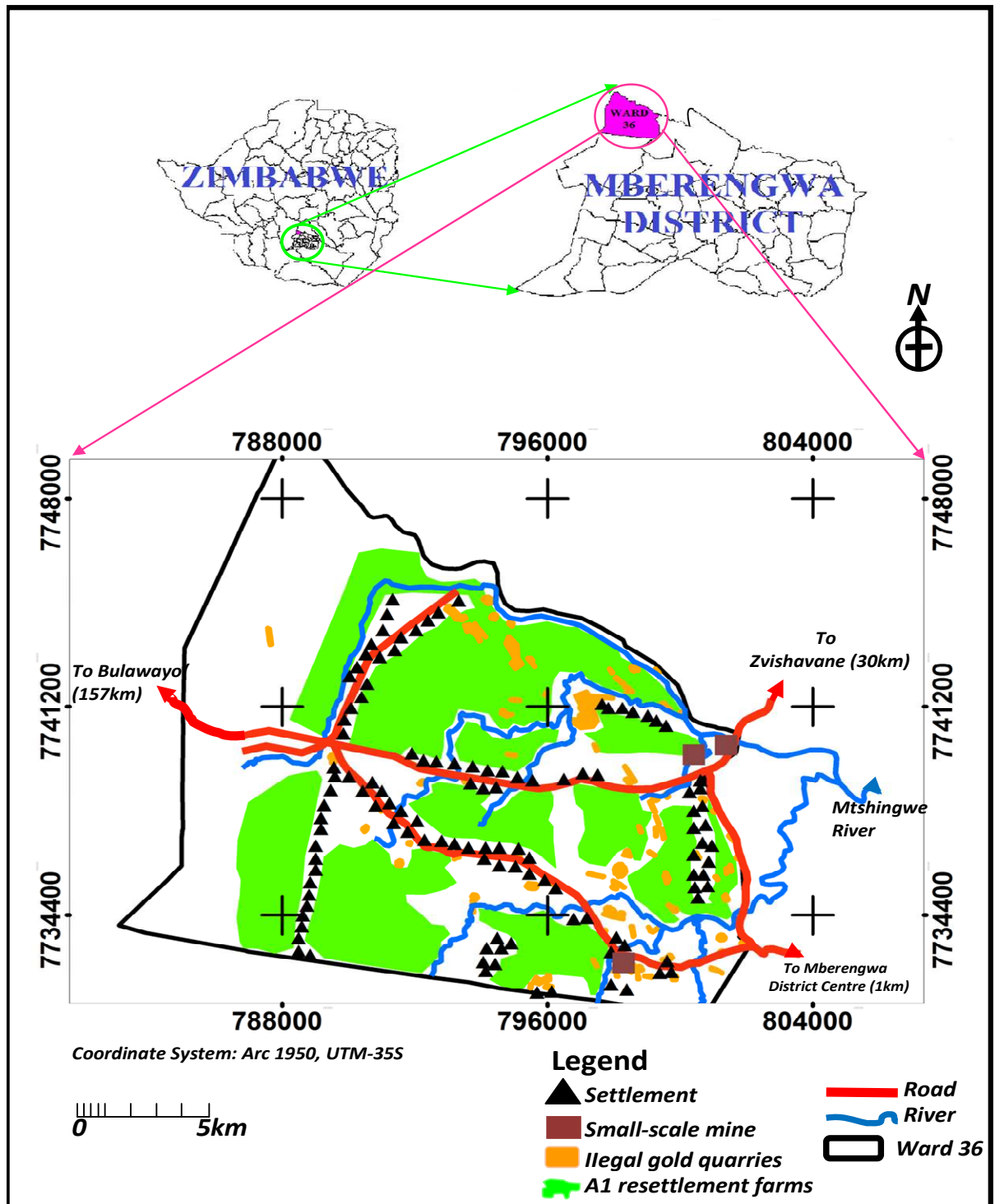


Figure 1.1: Location map of Ward 36 A1 resettlement farms, Mberengwa District.

1.6.1 Physical Description of the Study Area

Mberengwa District is located in the Midlands Province of Zimbabwe. It is 132 km south-east of Gweru and 30 km south-west of Zvishavane between latitude $20^{\circ} 29^1$ S and Longitude $029^{\circ} 55^1$ E at an altitude of one thousand six hundred and thirty-seven (1637) metres above sea level. Mberengwa lies in natural region four (4) of Zimbabwe's agro-ecological zones where annual rainfall is usually between four hundred to six hundred millimetres (450- 650 mm). Temperatures range between $25-30^{\circ}\text{C}$ with minimum temperatures experienced during the winter season (Gambiza and Nyama, 2000; Chenjeet *al*, 1998). The soils in the area are not uniform throughout, but vary from loamy sands to fersiallitic soils which dominate the northern part of the District. Mberengwa is a mountainous area with predominantly middle veld grazing, though there are pockets of flat land with a mixture of Miombo woodlands and thorny Acacia species. The area forms a drainage catchment for most tributaries that flow into rivers like Ngezi and Mwenezi cascading to Runderiver to the East and Mweneziriver to the south respectively.

1.6.2 Socio-Economic Description of the Study Area

Mberengwa District has 87085 males and 99079 females representing a total population of 186164 from the preliminary report Census (2012). Average household size is five people. Provincial growth rate (%) (2002 – 2012) show that Midlands had 1%, with a population density of thirty-three (33) people per square kilometre. Mberengwa district is an economically vibrant district with mining industries such as the Sandawana mine for emeralds, Vanguard and C-mine for gold respectively and the now dysfunctional Buchwa and Inyala mines for iron ore and chrome respectively. There is also significant gold panning prevailing in some of the district's major rivers like Ngezi and Mtshingwe along with small-scale fishing from these rivers which form an important socio-economic activity within Mberengwa Ward 36. Agriculturally, the district depends on subsistence rain-fed crop farming in maize, groundnuts, round-nuts and millet along with potential livestock production particularly goat, sheep and cattle ranching.

Most women are vendors selling fruit produce and operate flea markets at Mberengwa District centre and Mberengwa turn-off business centre. Vendors travel to Zvishavane town to buy their wares at wholesale price. Some vendors undertake door to door selling of their merchandise within homesteads in the Ward, mining compounds and within the shaky structures where illegal gold panners reside and this contributes to source of income. Vending is further by cross border trade to South Africa and Botswana where the vendors buy goods. Male active population also migrated to neighbouring countries for manual employment which also contributes to remittances back home where the young and the aged population are who cannot undertake productive farming. The farmers also undertake home gardening along the major rivers to supplement fresh produce such as vegetables and tomatoes.

Ward 36 has very limited schools namely: Neta and Zvavashe Secondary, Neta and Chomkondo Primary schools. Most children attend Mberengwa Primary School 10km and Dove Secondary School 12km due east outside the Ward. School dropout is very high as children engage in illegal gold panning activities and some have migrated to South Africa and Botswana in search for employment. This further strain the labour-force required for farming activities.

CHAPTER 2: LITERATURE REVIEW

2.1 Land suitability Analysis (LSA)

The process of matching land utilisation requirements (LUR) and land qualities (LQ) is called land suitability analysis (FAO, 1993). Determining suitable land for a specific use is a quite complex exercise encompassing multiple decisions that relate to socio-economic, bio-physical and institutional aspects hence a consistent and logical approach to well structured LSA is quite important. The entire process of land suitability classification involves the evaluation and grouping of specific areas of land in terms of their inherent suitability for specific land-use. The thrust behind land evaluation is to detect the inherent capacity of a land unit to support a defined land-use for a longer period without deterioration and sustain environmental integrity hence the concept Sustainable Development/Sustainable Land Management (SLM).

Sustainable land management/development is defined as the combination of policies, technologies and activities aimed at integrating socio-economic principles with environmental concerns. The integration serves to simultaneously: maintain and enhance production (productivity), reduce the level of production risk, and enhance soil capacity to buffer against degradation processes (stability/resilience), protect the potential of natural resources and prevent degradation of soil and water quality (protection), be economically viable (viability) and socially acceptable, and assure access to the benefits from improved land management (acceptability/equity). The definition highlights five pillars of SLM, which are the basic principles and the foundation on which sustainable land management is being developed. Any evaluation of sustainability has to be based on productivity, stability/resilience, protection, viability, and acceptability/equity. This definition and five pillars has been field tested in several countries, and they were judged to provide useful guidance to assess sustainability (Smyth and Dumanski, 1993).

LSA is an inter-disciplinary field encompassing complementary information from diverse domains namely soil science, meteorology, hydrology, crop science, environmental economics and management which all utilise the advent of GIS and RS technologies (Prakash, 2003). GIS and RS technologies are robust in handling such continuous variables that differ in nature like soil attributes and climatic parameters through overlay analysis in

spatial modelling. Essentially, land suitability deals with information variables in various scales of measurement like interval, ordinal and nominal data in a GIS environment. Land suitability is a component of sustainability evaluation of a land use. Suitability together with vulnerability measures the sustainability of a land unit. The sustainable land use should have maximum suitability and minimum vulnerability (de la Rosa, 2000).

2.2FAO land evaluation framework

The natural resources of the third world were systematically mapped in the 1950-1970s, the era of reconnaissance land resources surveys. The need arose for means to interpret these surveys in terms of land use potential. By 1970 many countries had developed their own systems of land evaluation such include the 1965 Zimbabwe Soil Classification System (Thompson, 1965) and Natural Regions and Farming Areas of Zimbabwe (Department of Conservation and Extension Services, 1983). This made exchange of land information difficult since no standard models existed for easy interpretation and analysis land resources. Essentially, there was a clear need for international consultation to achieve some form of standardization. The FAO Framework for land evaluation was developed and has proved to be one of the most reliable and widely used methodologies currently in the domain of land resources and agricultural development. Furthermore, it has fundamentally influenced many land evaluation methodologies developed since 1976 (FAO, 1993).

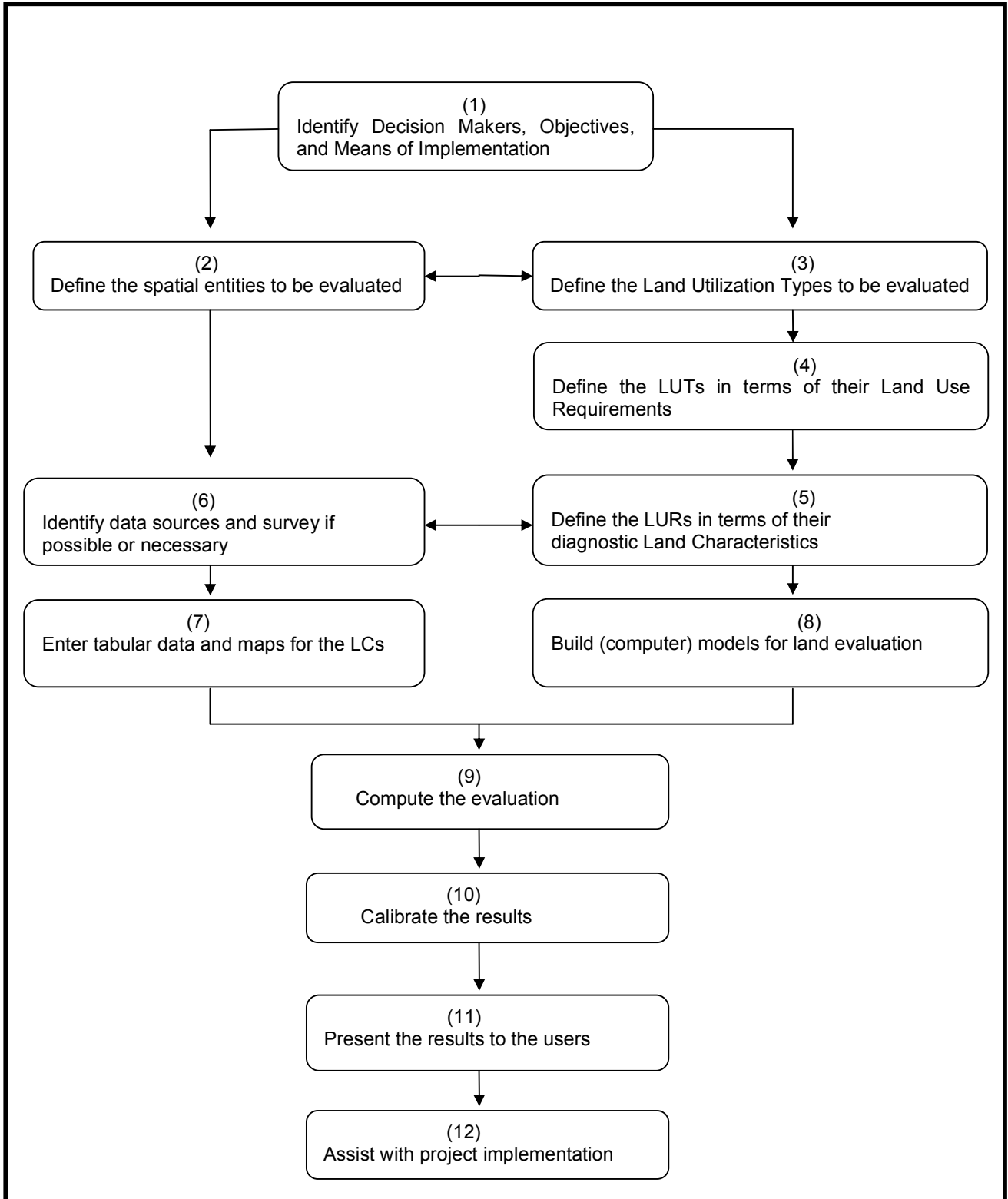
In light of this background, LSA emerged as a link to various kinds of natural resource survey (soil survey and crop yield interpretation, agro-climatic analysis, soil and vegetation productivity indices, water resources appraisal) with technological aspects involving computerized land evaluation systems in GIS together with economic and social analysis (Sombroek *et al*, 1995). Factor ratings by FAO Framework on land evaluation are grouped into land suitability orders and classes for which two guidelines determine factor ratings, that is, either yields against inputs or degrees of limitation (suitability). Land Suitability Orders have suitability orders indicating in the simplest form whether land is suitable or not suitable for specified use. Whereas S = Suitable, N = Not suitable for the land use. Land Suitability Classes have suitability classes showing the degree of suitability within an order (Table 2.1).

Table 2.1: Land suitability classes (FAO, 1993).

Order	Class	Description
Suitable	s1 (Highly suitable)	Land having no, or insignificant limitations to the given type of use
	s2 (Moderately suitable)	Land having minor limitations to the given type of use
	s3 (Marginally suitable)	Land having moderate limitations to the given type of use
Not suitable	n1 (Currently not suitable)	Land having severe limitations that preclude the given type of use, but can be improved by specific management
	n2 (Permanently not suitable)	Land that have so severe limitations that are very difficult to be overcome

Land evaluation forms the core of land suitability analysis, a procedure which answers the following questions. For any specified kind of LUT, which areas of the land are best suited? For any kind of land, for which kind of LUR is it best suited? These questions can be answered by going through a systematic procedure of land evaluation for LUT such as rain-fed agriculture, irrigated agriculture, forestry and livestock production. The procedure includes description of potential land use types. For each LUT, determine the requirements such as water, nutrients, avoidance of erosion. Conduct the surveys necessary to map land units and to describe their physical properties such as climate, slope and soils. Compare the requirements of the land use types with the properties of the land units to arrive at a land suitability classification (Table 2.2) (FAO, 1993).

Table 2.2: Land Evaluation Framework (FAO, 1993).



2.3 Land evaluation using Earth Observation

Remote sensing is the art and science of Earth observation of material objects, surface or phenomenon to acquire information (radiometric and spectral) from an overhead perspective, that is, satellites or aerial platforms without actually being in physical contact with it (Lilleland *et al.*, 1994; Lilleland, 2004). The term embraces a number of observation or sensor techniques ranging from; photography, multi-spectral, thermal and hyper-spectral sensing. It is based on the principle that terrestrial objects reflect or emit radiation in different wavelengths and intensities depending on specific conditions. Aircraft, spacecraft, satellite or ship may be used for this purpose equipped with recording devices such as camera, laser, radar, sonar and seismograph. With advancements in information technology, RS is prominently being carried out using digital processes. However, non-digital methods can also be employed depending on specific needs (Rolf *et al.*, 2000). The remote sensing process is carried out in the following stages: data acquisition, data processing and analysing (typically involves radiometric and geometric correction, image enhancement, geo-coding, filtering, band transformations), data fusion, data interpretation, data utilization. It may also involve input of data (scanned topographic maps, DBMS, GPS) into a GIS (Walford, 1995).

2.4 Merits of Remote Sensing

Remote Sensing is a relatively cheap and rapid method of acquiring near-real time information over a large geographical area. It is the only feasible and practical way to obtain data from inaccessible regions, as the Antarctica, Amazon forests (Rolf *et al.*, 2000). Remote Sensing makes it possible to measure energy (such as ultra-violet, infrared, microwave) at wavelengths that cannot be resolved by human vision. Scientific advancements have resulted in use of RS in a variety of disciplines such as agriculture, cartography, meteorology, forestry, hydrology and geology. It also provides robust method of constructing base maps in the absence of detailed land surveys. RS data is easy to manipulate with the computer, and combine with other geographic data layers in the GIS. Satellite remote sensing can be programmed to enable temporal resolution on object or area under study and enables generation of up-to-date information and continuous acquisition of data (Bakker *et al.*, 2000). RS provides accurate data for information analysis and the data is of a broader coverage and good spectral resolution. It also enables continuous acquisition of spatial data serving a large archive of historical data for modern decision planning.

2.5 Demerits of Remote Sensing

Remotely sensed images are indirect samples of the phenomenon, so must be calibrated against reality. Apparently, calibration is never precise; a classification error of 10% is excellent. RS images must be corrected geometrically and geo-referenced in order to be useful as maps which may pose problems to technically incompetent human personnel (Boyce, 2005). Distinct phenomena can be confused if they appear uniform to the sensor, leading to classification error for example: artificial and natural grass in green light, however these can be easily distinguished by near infrared light. Material phenomena meant not to be measured (for the application at hand) can interfere with the image and must be accounted for. Examples that interfere with land cover classification are atmospheric pollutants, water-vapour, and sun versus shadow (Bakker *et al*, 2000). The resolution of satellite imagery may be too coarse for detailed mapping and for distinguishing small contrasting areas. The rule of thumb is that a land use must occupy at least 16 pixels (picture elements, cells) to be reliably identified by automatic methods. However, latest satellites models such as Geo-eye, IKONOS, World-View 2 and Quick-bird invented with sub-metre resolution are capable of high data volume at detailed mapping scales.

2.6 Interaction of vegetation with the Electro-Magnetic Spectrum (EMS)

When incident solar radiation strikes Earth objects, certain wavelengths of the visible spectrum are absorbed and others are reflected. Chlorophyll in plant leaves strongly absorbs light in the visible wavelength (region) of the electromagnetic spectrum (0.4 to 0.7 μm), for use during photosynthesis (Bakker *et al*, 2000). Green and healthy plants strongly reflect in the near-infrared region of the electromagnetic spectrum (0.7 to 1.1 μm) due to the spongy mesophyll cells but readily absorb in the red region (0.4 to 0.5 μm) of the EMS. Leaf cells have evolved to scatter (i.e. reflect and transmit) solar radiation in the near-infrared spectral region (which carries approximately half of the total incoming solar energy), because the energy level per photon in that domain (wavelengths longer than about 700 nanometres) is not sufficient to be useful to synthesize organic molecules (Rolf *et al*, 2000). The more leaves a plant has, the more these wavelengths of light are affected, respectively. The differential reflectance in these bands provides a means of monitoring density and vigour of green vegetation growth, soil and water characteristics (Fig 2.1) using the spectral reflectivity curves of solar radiation (Gitelson *et al*, 2003). This contrast between responses of the two bands can be modelled by vegetation ratio transformation called NDVI. Subsequent

numerous studies attest to that NDVI is directly related to the photosynthetic capacity and hence energy absorption by plant canopies. Green and healthy vegetation absorbs most of the incident visible light and reflects a large portion of the near-infrared light (Bakker *et al*, 2000). Unhealthy vegetation reflects more visible light and less near-infrared light (Lillelsand, 2004). Other vegetation indices (ratios) derived from the same spectral channels include the VCI, an extension of NDVI, Ratio Vegetation Index (RVI), Difference Vegetation Index (DVI) and the Vegetation Productivity Index (VPI).

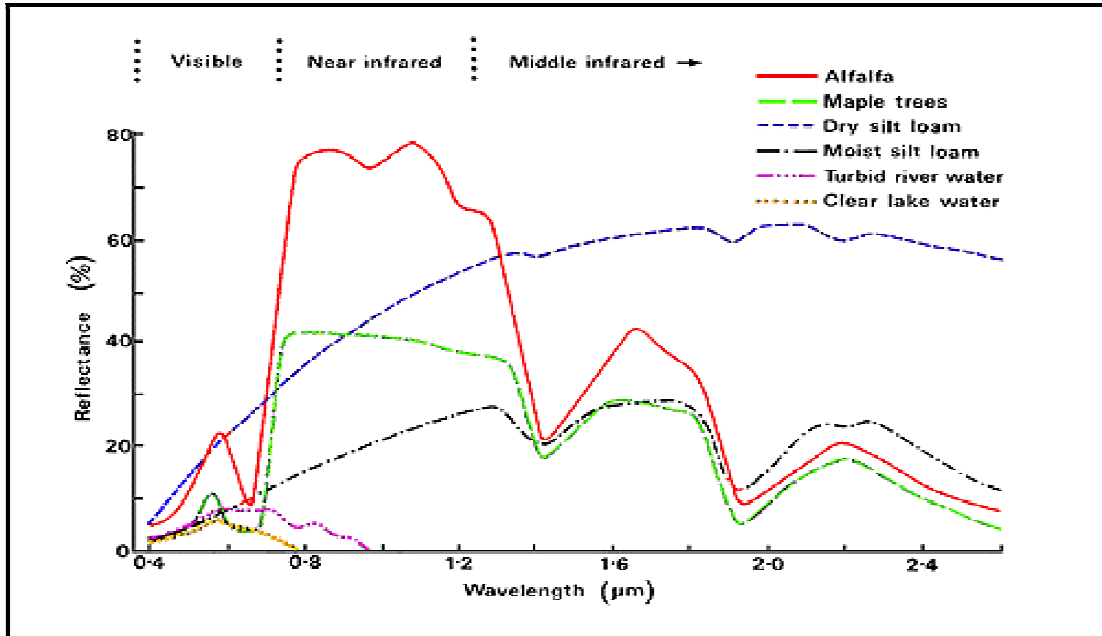


Figure 2.1: Spectral Reflectance Curves (Source: AMESD-SIRDC 2013).

2.7 Relationship between NDVI and VCI

Weather data, particularly rainfall, are currently the primary source of information widely used for vegetation growth monitoring in Southern Africa. Weather data from RS platforms is used to complement rainfall in crop yield assessments (Groten, 1993; Hayes, 1996). The VCI captures rainfall dynamics better than the NDVI particularly in geographically non-homogeneous areas which has essentially supported numerous theoretical and empirical studies of the statistical significant relationship between VCI and remotely-sensed rainfall (Sellers, 1989). VCI as a vegetation growth monitoring algorithm considers separation of the short-term rainfall-related NDVI fluctuations from the long-term ecosystem changes. This is an important procedure because the rainfall signal in an NDVI value is weaker than the ecological one because of atmospheric attenuation. Therefore, weather-related NDVI

fluctuations are not easily detectable, hence the development of VCI which is a function of NDVI defined by the expression: $VCI = 100 \times (NDVI_t - NDVI_{min}) / (NDVI_{max} - NDVI_{min})$, where NDVI, $NDVI_{min}$ and $NDVI_{max}$ are the smoothed weekly NDVI, its multi-year absolute maximum and minimum, respectively. The VCI approximates the weather (rainfall) component in NDVI value. It changes from 0 to 100%, corresponding to the changes in vegetation conditions from extremely bad to optimal. The VCI not only permits the description of land cover, spatial and temporal vegetation change but also allows the quantifying the impact of weather (rainfall) on vegetation. VCI values indicate easily how much the vegetation has advanced or deteriorated in response to rainfall and how far maize crop development is from the potential maximum and minimum defined by the ecological limits. Therefore VCI is an empirical model to calculate dry-dekads (10 day dry period in a month) which is a powerful measure to determine crop development and yield performance in land suitability studies (Kogan, 1995a). Dekadal maps (Fig 2.2) are then generated using VCI model for land suitability classification (Table 2.3) where in most cases a crop mask helps to identify exact study areas.

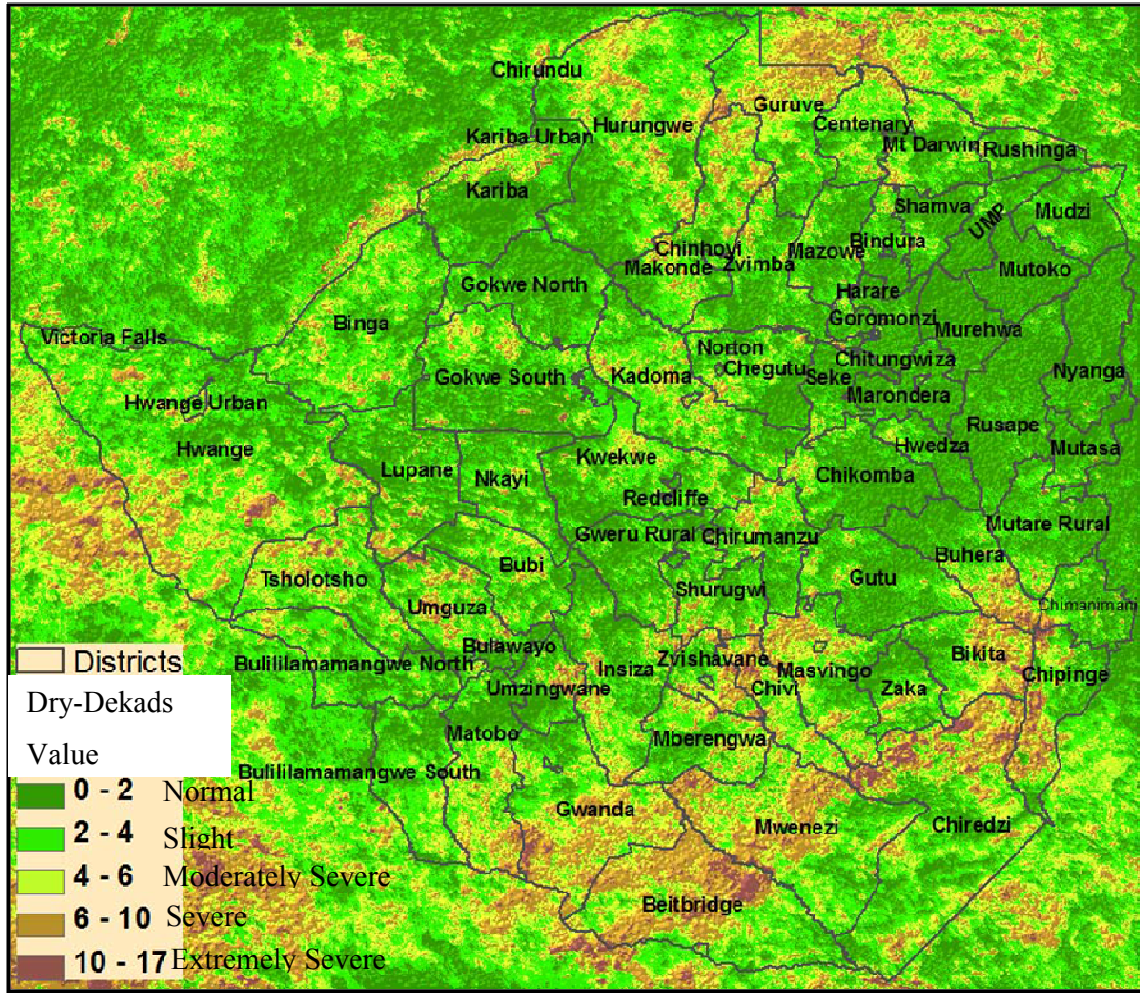


Figure 2.2: Dry-dekadsMap(Source: AMESD-SIRDC 2013)

Table 2:3 VCI-based severity classes (Kogan 1995).

VCI (%)	Vegetation/Crop Severity Class
50-100	Normal to above normal
36-49	Moderately Severe
<36	Complete crop failure

2.8 Critical syntheses of literature: research gap

Previous studies on land resource inventory have been undertaken for suitability analysis using cumbersome manual land surveys and expensive aerial reconnaissance in Zimbabwe. On the basis of topographic, geological and soil base maps evidence attest to dominance of gold claims (C-Mine and Vanguard plants) in Ward 36 and a host of illegal gold excavations in the vicinity because Ward 36 lies along Zimbabwe's Great Dyke belt. Further research surveys prior FTLRRP in 2000 show evidence that Ward 36 sustained a viable commercial cattle ranching scheme as observed by Ndou (2007) in a study on Socio-Economic Impact of the Participatory and Conventionally Implemented Irrigation and Livestock Development Projects in Beitbridge and Mberengwa Districts. This is because the area receives erratic and marginally low rainfall totals (450-650mm) annually and is dominated with poor shallow soils. Ward 36 falls under Agro-ecological region 4 characterised by frequent droughts. It is against this background that the researcher seeks to explore LSA in Ward 36 using near-real time efficient modern Earth Observation techniques utilising archived Rainfall, NDVI and VCI data and Zimbabwe soil map data to ascertain feasibility for maize crop cultivation which forms the bedrock for human livelihoods in this Ward.

CHAPTER 3: MATERIALS AND METHODS

3.1 Research Design

Research design defines action plan that guides empirical research in a manner that aims to combine relevance to the research purpose with economy and procedure from the hypotheses to the conclusions and includes steps for collecting, analysing, and interpreting evidence according to pre-determined assumptions, rationale for linking the data to the assumptions, units of analyses and application of standard criteria for interpreting the findings (Yin, 2003). It provides clear guidance to the researcher on how to proceed with the research in terms of variables to study, types of controls, and sampling techniques. In this study, the researcher used the quantitative research design which is capable of establishing the numerical relationship between average VCI and remotely-sensed rainfall amount with rainfall amount as the control variable. Quantitative approach is a research technique in which scientific, concrete, and numerical data can be statistically analysed to ascertain whether results obtained are not by chance factor.

Statistical Package for Social Scientists (SPSS) version 20 and Microsoft excel was then used because these programs can analyse remotely sensed data collected from tests and can perform statistical analyses such as descriptive and inferential statistics and graphical presentation of data to answer the first objective. GIS and RS technologies were used for land suitability analysis. These are important sources of spatial information such as land use/land cover status using vegetation indices such as NDVI and VCI (Groten.1993; Perveen et al. 2007). ILWIS- GIS is compatible digital image open source software for geo-environmental analysis which was used to calculate the number of VCI dry dekads to answer the second objective. ILWIS-GIS was further used for image processing in order to detect land suitability potential for maize crop farming from maps for VCI dry dekads experienced in the Ward for five sample growing seasons. Simple systematic random sampling was done to select the five growing seasons between 2000 to 2012. Finally, image analysis and mapping of maize crop performance was done to answer the third objective.

3.2 Sources of Data

The vegetation and rainfall data used in this study was primarily secondary in nature derived from satellite platform, and ancillary data in the form of 1:50 000 geo-referenced topographic map and Zimbabwe soil map

The researcher used 12 years x 36 NDVI images archived decadal Maximum Value Composite (MVC) from SPOT vegetation sensor from 2000-2012. NDVI was calculated using the equation: $\text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}}$, where NIR is reflected radiation in the wavelengths (0.7-1.25 μm) and R is reflected radiation in the red spectral region (0.6-0.7 μm). NDVI was further used to generate VCI as shown in the equation: $\text{VCI} = 100 \times \frac{\text{NDVI}_t - \text{NDVI}_{\min}}{\text{NDVI}_{\max} - \text{NDVI}_{\min}}$, where NDVI, NDVI_{\min} and NDVI_{\max} are the smoothed seasonal NDVI, multi-year absolute maximum and minimum respectively and NDVI_t is the NDVI for the period under observation. VCI was used in the regression equation: $Y = \beta_0 + \beta_1 X$, where Y (VCI) is the dependent variable, X (rainfall) is the independent variable, β_1 is the gradient of equation and β_0 is the intercept. This model considers separation of the short-term weather-related NDVI fluctuations from the long-term vegetation changes. This is a very important procedure because the weather signal in an NDVI value is weaker than the ecological one. Therefore, weather-related NDVI fluctuations are not easily detectable hence the VCI quantifies the weather impact in NDVI value. The NDVI data is available at the GRSI at SIRDC, Harare. GRSI receives NDVI data on daily basis under the AMESD project headquartered in Botswana.

Rainfall data from the TAMSAT distributed via GEONETCast was used in this study. TAMSAT has archive decadal rainfall data for the entire African continent since 1983 to present. The data was obtained at the GRSI at SIRDC, Harare via website: <http://www.met.reading.ac.uk/~tamsat/rfe.html>.

The researcher used 1:50 000 scanned topographic map for Mberengwa Ward 36 which was geo-referenced in QGIS 1.7.3. An average of 13 GCP was established under a 2nd Order Polynomial transformation type yielding a perfect 0.7 mean error. The study area was digitised and projected to UTM-Zone 35S for six thematic layers: fields, settlements, gold-quarries, rivers, gold-mines and roads. The topographic map was obtained at the SIRDC-GRSI, Harare. Zimbabwe Soilmap analysis in QGIS 1.7.3 was used for maize crop suitability analysis. The map was obtained from Forestry Commission, Harare.

3.3 Data Pre-processing

SPOT Vegetation products were imported using the GEONETCast-AMESD-SADC toolbox plug-in into ILWIS –GIS 3.7.2. The main objective of the toolbox is to allow the users to import datasets relevant to environmental monitoring and management through Graphical User Interface (GUI) in ILWIS 3.7.2 (Maathuis *et al.* 2011a). For SPOT VGT NDVI, a Vegetation-Extract program that allows extraction of S10 MVC NDVI compressed files for certain Regions Of Interest (ROI), Zimbabwe in this case, was used. It converted Hierarchical Data Format files into formats compatible in ILWIS to generate NDVI values. For TAMSAT rainfall data Win-RAR software was used to extract the compressed files, import and process using the TAMSAT post March 2011 operation in ILWIS compatible formats to generate TAMSAT 10day accumulated rainfall Africa.

3.4 Methods

3.4.1 Calculate Maximum-Minimum NDVI statistics to generate VCI

The researcher created seasonal NDVI map-list for dekads 01, 11 and 21 from 2000-2012 chronologically for which a growing season starts from September to April. Then, maximum and minimum NDVI statistics were calculated for each dekad. VCI is a function of NDVI, therefore using the calculated maximum and minimum NDVI statistics, the seasonal VCI was calculated using the formula: $VCI = 100 \times (NDVI_t - NDVI_{min}) / (NDVI_{max} - NDVI_{min})$, expressed as percentage. Then a VCI map-list was produced for: 2001-2002, 2004-2005, 2007-2008, 2010-2011 and 2011-2012. Systematic random sampling enabled one year in between the four sample years and the last sample year was randomly selected because the 2013 sample year was not available. Calculation of average VCI from the VCI-map-list was done. Then the intersection of each average VCI map with Mberengwa Ward 36 raster map and the values were extracted for statistical analyses. The baseline year (2000-2001) was not considered because most farmers were undertaking initial land preparation on their newly acquired plots following the land reform programme: cutting down trees, stumping and burning.

3.4.2 Calculate VCI dry-dekads

From the VCI map-list created threshold values were assigned using the formula $\text{iff}(@1 < 36, 1, 0)$ implying that if a pixel has a value less than 36 it is assigned the value 1 otherwise assign it the value 0 so that a scale value with less than 36% denote complete crop failure, 36-49% show below average crop performance and 50-100% show normal to above normal crop performance. Based on the number of VCI dry dekads calculated, their summation was obtained. The researcher further applied a mask for the cultivated crop area so that all vegetated areas that are not agricultural could not interfere with VCI dry dekads. This is critical to determine the Ward's crop response to rainfall or impact of dry spells. Finally, an intersection calculation of total dry dekads map with Ward 36's raster map was done so as to justify crop farming based on the severity of the number of VCI dry dekads summarised for each map pixel in the Ward.

3.4.3 Calculate Rainfall statistics

In ILWIS-GIS seasonal rainfall map-list for five randomly selected growing seasons: 2001-2002, 2004-2005, 2007-2008, 2010-2011, 2011-2012 for 1st, 2nd and 3rd dekads were created in chronological order and re-sampled to Mberengwa geo-reference and UTM Zone 35S coordinate system. Further, seasonal sum rainfall statistics were calculated using the Map-list Statistics operation. Intersection of each sum rainfall map and Mberengwa Ward 36 raster-map was then done. Rainfall is the key limiting factor in crop production; therefore the researcher extracted the seasonal sum rainfall from the intersection table output for statistical data analysis.

3.5 Image Processing and Analysis

In order to detect land suitability potential for crop farming, the researcher used Mberengwa geo-referenced cultivation-Dry dekad Sum maps created, and extracted the VCI dry dekad maps by running the ILWIS GIS command: `CultDrySum=ifnotundef(Mberengwa-Ward36 rastermap,CultDrySum2001-2001Re-sample)`. The map outputs were displayed and an overlay of Ward 36 shape file was performed. Finally, map layouts were produced showing the magnitude and severity of VCI-dry dekads experienced in the Ward for five sample growing seasons. The map layouts were exported as bitmap compatible for report documentation.

3.6 Soil Analysis

A geo-processing operation by clipping Ward 36 soil classes overlaid on Zimbabwe Soil map in QGIS 1.7.3 to analyse potential soil types for maize crop farming was done. The labels operation was activated to display the dominant soil characteristics and its distribution in Mberengwa-Ward 36. Evidence from the soil map shows that the ward area is a combined entity of soil classes which included kaolinitic (5G) and siallitic (4E) groups and litho-sols (2) which are shallow (< 25cm in depth) to moderately shallow brown or reddish brown clays formed on mafic rocks.

3.7 Statistical Data Analysis

Used Shapiro-Wilk test, mean VCI and Rainfall data was tested for normality. All the data was normally distributed ($p > 0.05$). Therefore, the parametric statistical data analysis was used to establish the relationship between mean VCI and rainfall amount and a graphical presentation illustrates this relationship.

Since the data on mean VCI and rainfall was normally distributed, Pearson correlation coefficient (r) was used to determine the degree of relationship between mean VCI and rainfall amount and given in form of a table.

A regression analysis to compare the relationship between mean VCI and rainfall amount was performed using the regression model: $Y = \beta_0 + \beta_1 X$, where Y (VCI) is the dependent variable, X (rainfall) is the independent variable, β_1 is the gradient of equation and β_0 is the intercept. The main thrust of this study was to determine environmental suitability potential for maize crop farming based on VCI and rainfall amount which was presented in form of graphs, maps and tables.

Chapter 4: Results and Discussion

4.1 Results

4.1.1 Average VCI and Rainfall relationships in Mberengwa District (2000-2012)

Figure 4.1 shows the correlation between VCI (dependant variable) and Rainfall (independent variable). It is observed that there is a significant positive relationship between VCI and Rainfall ($r = 0.950$, $p < 0.05$). Furthermore, it is observed after regression analysis that there is a significant relationship between the VCI and Rainfall ($R^2 = 0.902$, $p < 0.05$). Coefficient of Determination indicates that 90% of VCI can be explained by the variation in rainfall and only 10% of the variability in VCI is due to other unidentified factors.

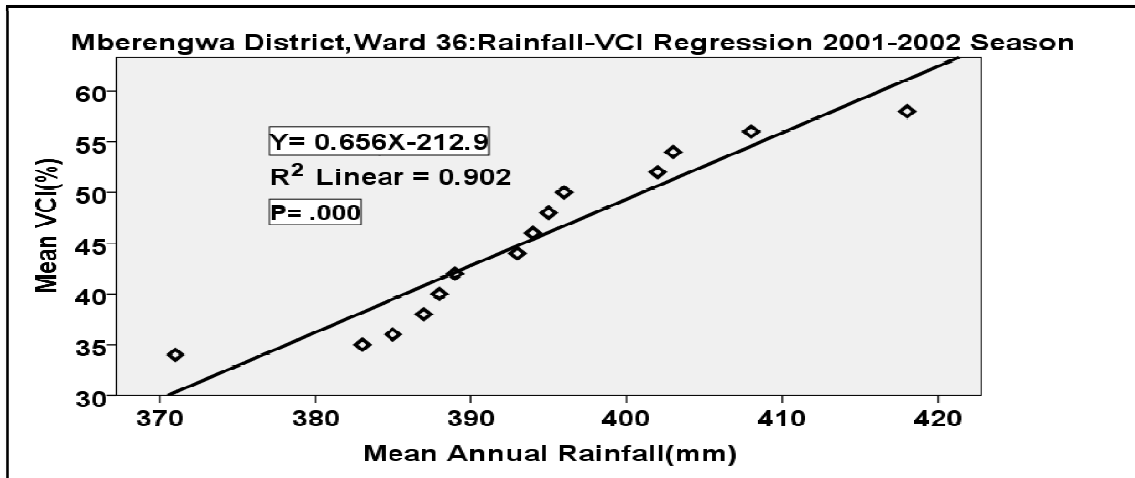


Figure 4.1: Average VCI and Rainfall 2001-2002 Season.

Figure 4.2 shows the correlation between the VCI (dependent variable) and Rainfall (independent variable). It is observed that there is a significant relationship between VCI and Rainfall ($r = 0.978$, $p < 0.05$). Further, it is observed after regression analysis that there is a significant relationship between the VCI and Rainfall ($R^2 = 0.956$, $p < 0.05$). Coefficient of Determination indicates that 96% of VCI can be explained by the variation in rainfall and only 4% of the variability in VCI is due to other unidentified factors.

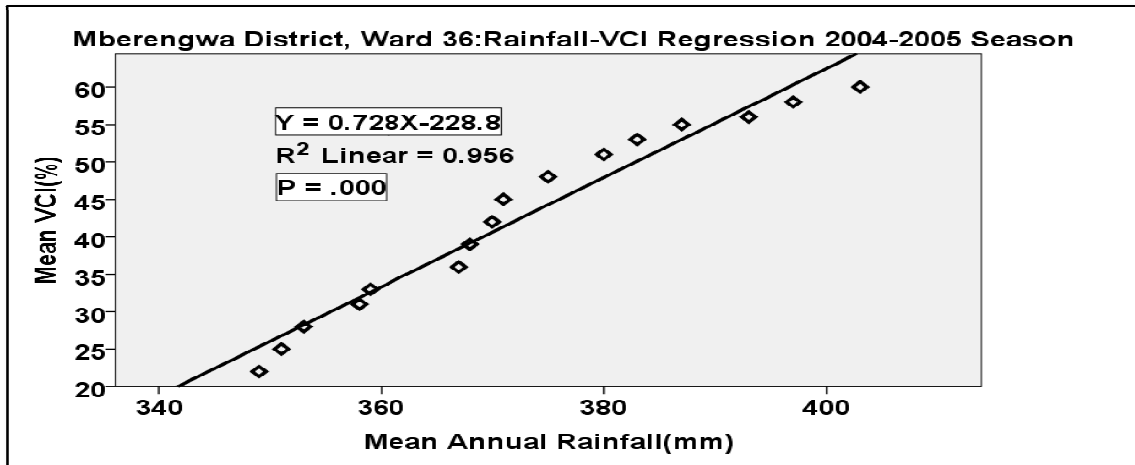


Figure 4.2: Average VCI and Rainfall 2004-2005 Season.

Figure 4.3 shows the correlation between the VCI (dependent variable) and Rainfall (independent variable). It is observed that there is a significant relationship between VCI and Rainfall ($r = 0.912$, $p < 0.05$). Further, it is observed after regression analysis that there is a significant relationship between the VCI and Rainfall ($R^2 = 0.831$, $p < 0.05$). Coefficient of Determination indicates that 83% of VCI can be explained by the variation in rainfall and only 17% of the variability in VCI is due to other unidentified factors.

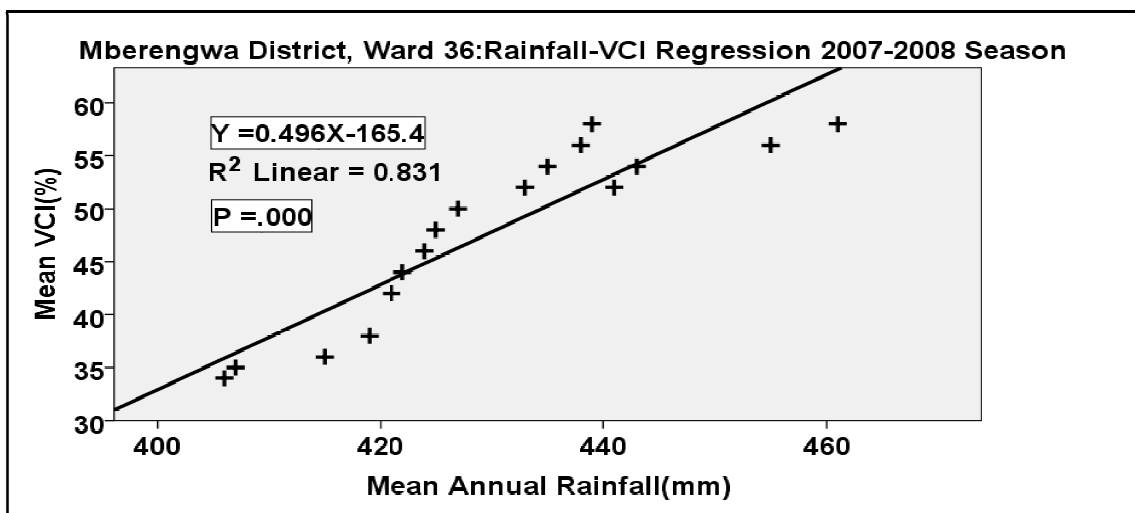


Figure 4.3: Average VCI and Rainfall 2007-2008 Season.

Figure 4.4 shows the correlation between the VCI (dependent variable) and Rainfall (independent variable). It is observed that there is a significant relationship between VCI and Rainfall ($r = 0.987$, $p < 0.05$). Further, it is observed after regression analysis that there is a significant relationship between the VCI and Rainfall ($R^2 = 0.974$, $p < 0.05$). Coefficient of Determination indicates that 97% of VCI can be explained by the variation in rainfall and only 3% of the variability in VCI is due to other unidentified factors.

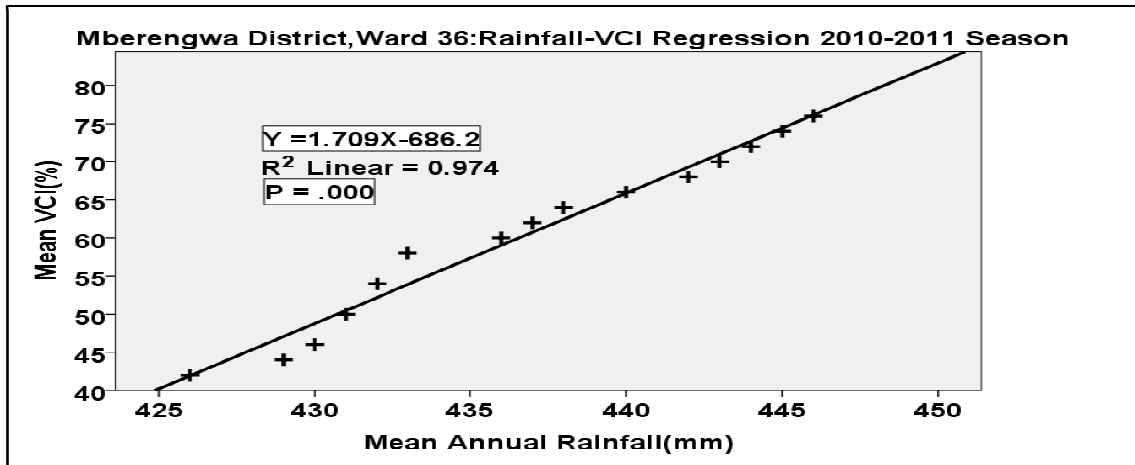


Figure 4.4 Average VCI and Rainfall 2010-2011 Season

Figure 4.5 shows the correlation between the VCI (dependent variable) and Rainfall (independent variable). It is observed that there is a significant relationship between VCI and Rainfall ($r = 0.973$, $p < 0.05$). Further, it is observed after regression analysis that there is a significant relationship between the VCI and Rainfall ($R^2 = 0.946$, $p < 0.05$). Coefficient of Determination indicate that 95% of VCI can be explained by the variation in rainfall and only 5% of the variability in VCI is due to other unidentified factors.

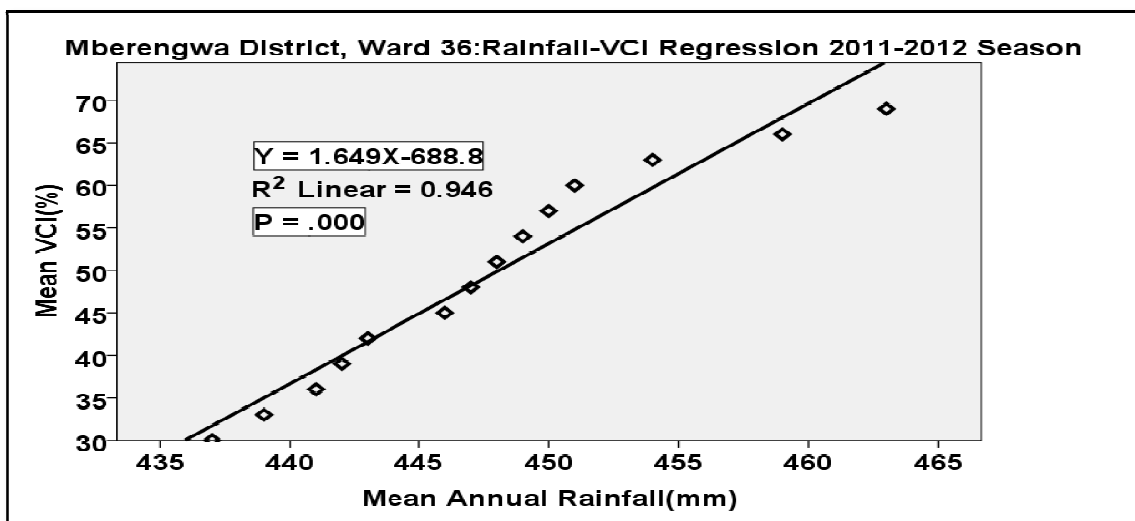


Figure 4.5: Average VCI and Rainfall 2011-2012 Season.

4.1.2 Detection of land suitability based on VCI-drydekads from 2000-2012

In Figure 4.6, a maximum of 13 VCI-derived drydekads were experienced which represent 54% of the total (24) dekads measured against a maximum of 399mm per 1km² pixel received for the 2001-2002 growing season. VCI-drydekads are a function of rainfall hence the observed high number of drydekads is attributed to recurring marginally low rainfall totals.

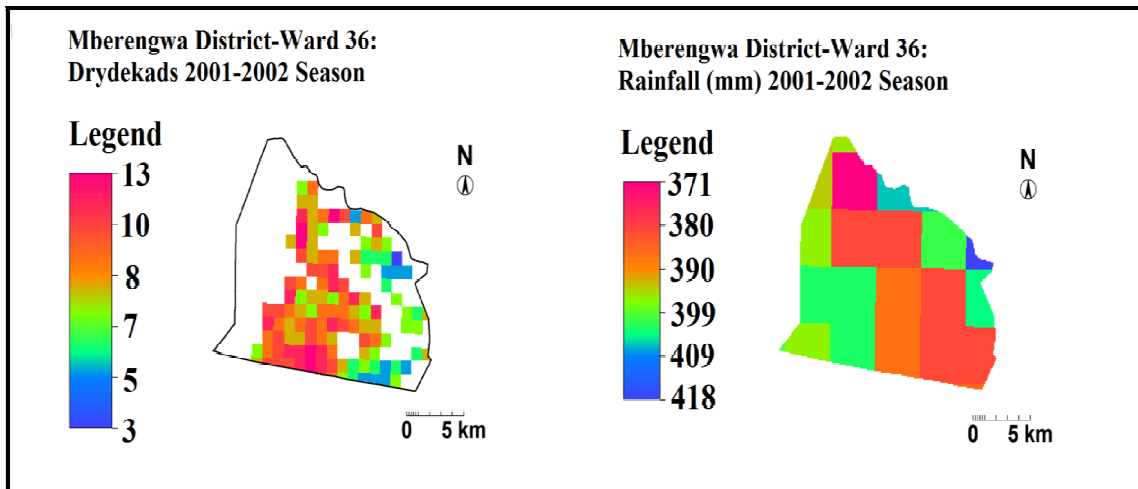


Figure 4.6: Drydekads-Rainfall relationship 2001-2002 Season.

In Figure 4.7, a maximum of 19 VCI-derived drydekads were experienced which represent 79% of the total (24) dekads measured against a maximum of 388mm per 1km² pixel received for the 2004-2005 growing season in Ward 36. VCI-drydekads are a function of rainfall hence the observed high number of drydekads is attributed to marginally low rainfall totals.

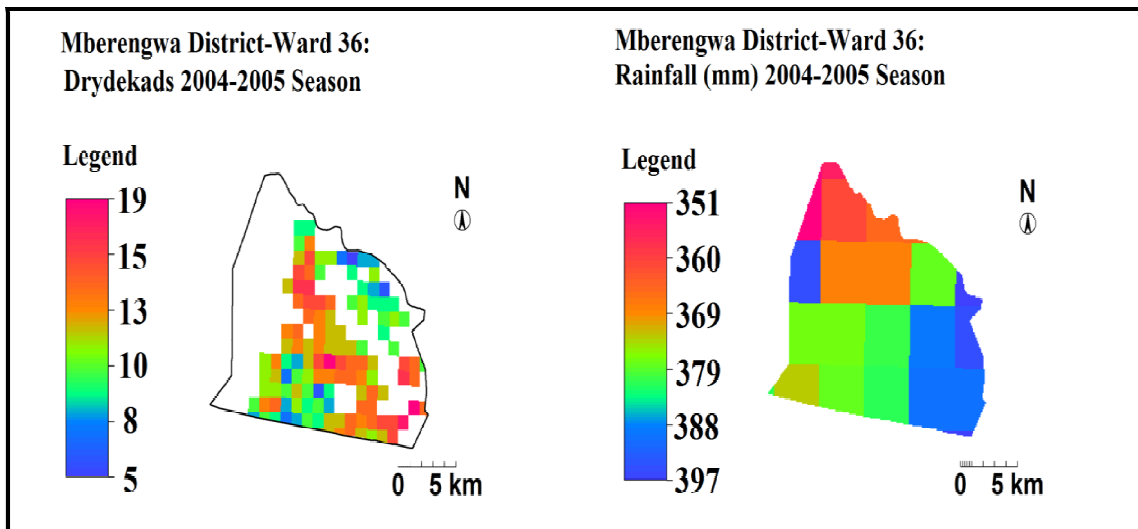


Figure 4.7: Drydekads-Rainfall relationship 2004-2005 Season.

In Figure 4.8, a maximum of 12 VCI-derived drydekads were experienced which represent 50% of the total (24) dekads measured against a maximum of 414mm per 1km² pixel received for the 2007-2008 growing season in Ward 36. VCI-drydekads are a function of rainfall hence the observed high number of drydekads is attributed to recurring marginally low rainfall totals.

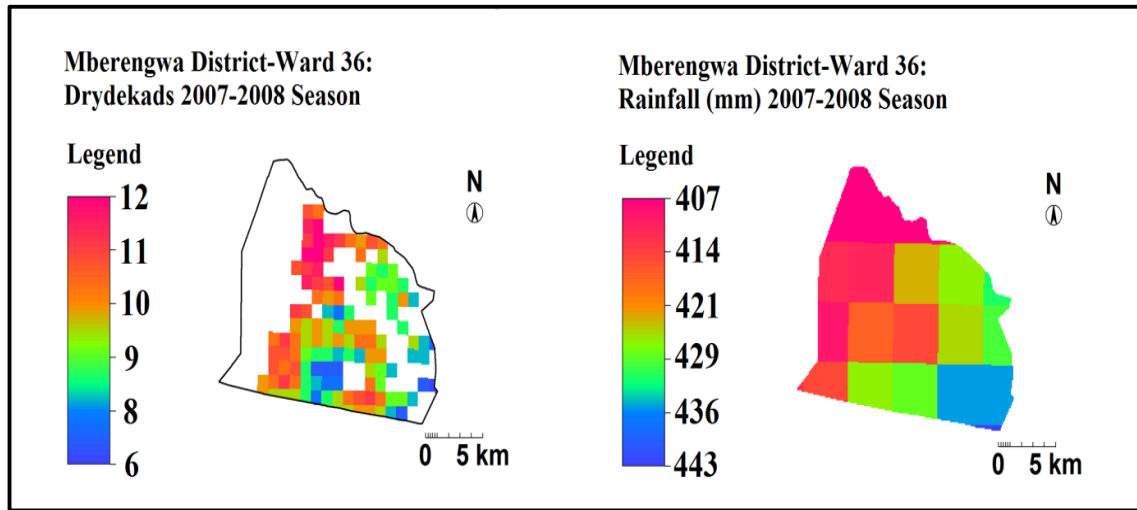


Figure 4.8: Drydekads-Rainfall relationship 2007-2008 Season.

In Figure 4.9, a maximum of 14 VCI-derived drydekads were experienced which represent 58% of the total (24) dekads measured against a maximum of 438mm per 1km² pixel received for the 2007-2008 growing season in Ward 36. VCI-drydekads are a function of rainfall hence the observed high number of drydekads is attributed to marginally low rainfall totals.

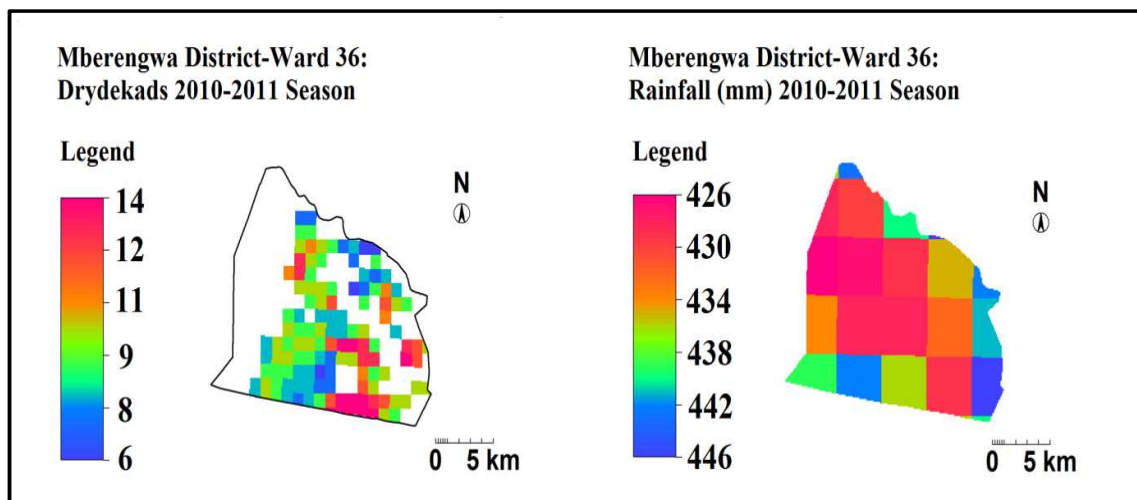


Figure 4.9: Drydekads-Rainfall relationship 2010-2011 Season.

In Figure 4.10, a maximum of 16 VCI-derived drydekads were experienced which represent 67% of the total (24) dekads measured against a maximum of 458mm per 1km² pixel received for the 2011-2012 growing season in Ward 36. VCI-drydekads are a function of rainfall hence the observed high number of drydekads is attributed to recurring marginally low rainfall totals.

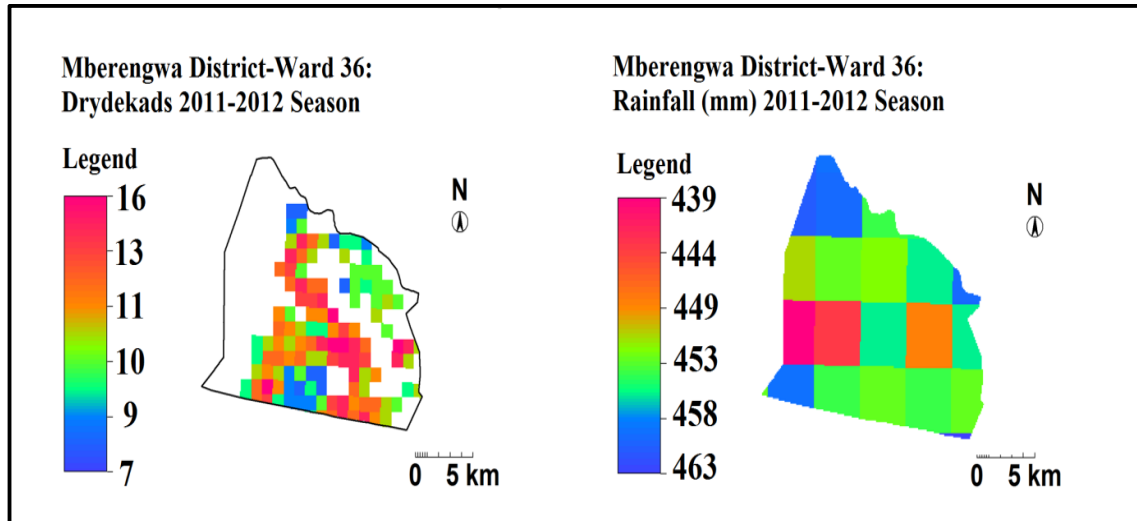


Figure 4.10: Drydekads-Rainfall relationship 2011-2012 Season.

4.1.3 Soil Analysis

The results from soil analysis based on Zimbabwe Soil map show that Ward 36 is a combined entity of soil different classes. It includes kaolinitic (5G) characterised by moderate to strong leached coarse-grained soils, siallitic (4E) groups which are shallow to moderately shallow brown or reddish clays formed from basic rocks and litho-sols (2) which are shallow (< 25cm in depth) to moderately shallow brown or reddish brown clays formed on mafic rocks (Fig 4.11).

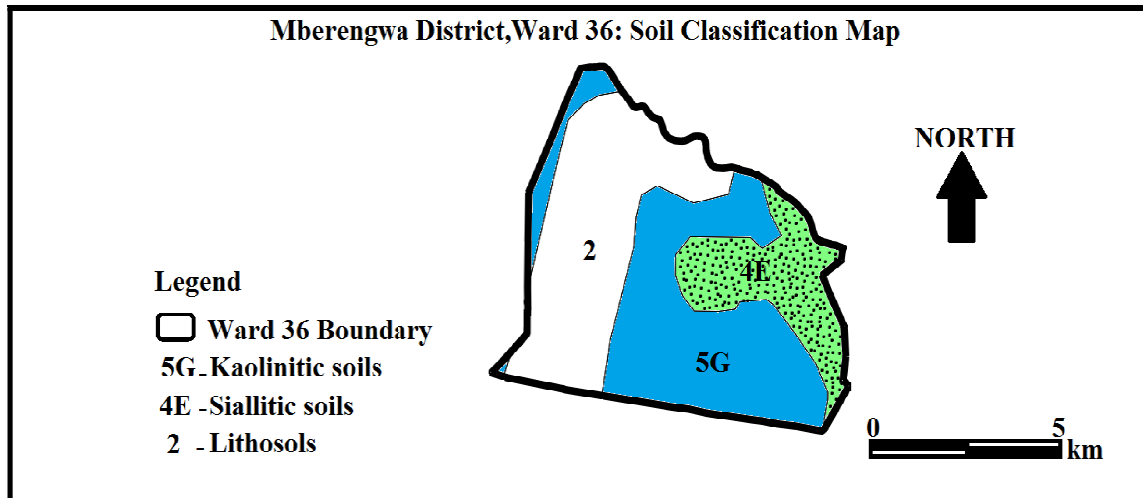


Figure 4.11: Ward 36, Clipped Soil Map of Zimbabwe (Source: Pedology and Soil survey Section, 1979).

4.2 Discussion

4.2.1 Interaction between mean VCI and remotely-sensed Rainfall from 2000-2012

Comprehensive analysis of the results for all the five sample growing seasons in this research study indicate a strong positive relationship ($r > 90\%$; $R^2 \times 100 > 80\%$; $p = .000$) between VCI (response variable) and Rainfall (predictor variable). Numerous empirical and theoretical studies support this observation involving VCI and remotely-sensed Rainfall relationship (Kogan and Unganai, 1998). However, since land suitability is a function of both agro-climatic and agro-edaphic as principal land qualities (LQs), results show subdued land characteristic (LC) ranging between 351mm to 463mm rainfall which is not conducive for potential maize crop production as it requires $> 750\text{mm}$ rainfall per season. These satellite rainfall results complement the modelled ground-based rainfall thresholds for agro-ecological regions of Zimbabwe (Table 4.6). The subdued VCI and rainfall trend indicate that LUR (physiological) for maize crop does not match this rain-fed LUT in Ward 36 as justified by recurring poor rainfall totals since 2000. Based on the number of VCI-drydekads (Fig 2.2) (AMESD-SIRDC, 2013), all five sample growing seasons suffered at least 6 to 19 drydekads yielding moderately severe to complete crop failure hence factor rated permanently not suitable (n2) according to FAO land suitability framework (Fig 2.2).

According to Kogan (1995), VCI threshold between 0-35% denote complete crop failure, 36-49% denote moderately severe crop failure and 50-100% denote normal to above normal crop performance. Results based on VCI (Fig 2.9) show that all five growing seasons experienced moderately severe to complete crop failure measured against low rainfall totals less than 463mm. Sample observations for the five growing seasons show spatial variation in rainfall intensity in the entire Ward 36. Land pixels may register high number of VCI drydekads with a corresponding high rainfall on a specific dekad. This can be attributed to heavy rains subsequently followed by dry spells and inconsistent rainfall intensity, distribution and frequency. The season 2004-2005 typical had this situation where pixels at maximum of 19 drydekads tally with the seasonal maximum rainfall of 397mm. Although this constitute the seasonal maximum rainfall, the crux of suitability is on how sustainable is this magnitude? This scenario gives the LC (rainfall-mm) a factor rate of permanently not suitable (n2) according to FAO land suitability potential. Therefore, Mberengwa, Ward 36 cannot be

relied upon for maize crop rain-fed LUT. Physical land evaluation for the five sample growing seasons justify the limitations posed by LCs (rainfall amount and soil nutrient potential) along with Economic land evaluation where the thrust of promoting food security has been compromised owing to unsustainable land practices such gold quarries (Fig 1.1) within cultivated areas. Evidence from this study support earlier researches that have identified this area as potentially viable for cattle ranching because of marginally low seasonal rainfall totals <450mm. The subdued rainfall totals are insufficient to sustain photosynthetic capacity for maize crop production within 0.5.0-0.60 μ m green band of Visible spectrum hence the characteristic low VCI.

Table 4.1: Natural Farming Regions of Zimbabwe: Adapted from Gambiza and Nyama, 2000 and Chenjeet *al*, 1998.

Natural Region	Type of farming	Rainfall Characteristics
1	Specialised and Diversified-Fruit production, dairy farming	Annual Rainfall >2000mm
2	Intensive –suitable for cash crops, maize, market gardening	Moderately high annual rainfall 750-1000mm
3	Semi-intensive-better for cash crops like tobacco	Moderate rainfall 650-800mm
4	Semi-extensive-subject to drought and severe dry periods. Suitable for drought-tolerate varieties, cattle ranching	Low annual rainfall total 450-650mm
5	Semi-arid-Not sustainable for any farming except commercial cattle ranching	Virtually< 450mm

4.2.2 Detection of land suitability potential based on VCI- based drydekads 2000 to 2012

VCI-based drydekads model detects possible land pixels at risk of low agricultural production (Fig 2.2) (AMESD-SIRDC 2013). Precise analysis of results in this study with the aid of a crop mask show that 2001-2002 season Ward 36 experienced extremely severe maize crop failure with 13 dry-dekads at maximum, 2004-2005 season experienced complete crop failure (write-off) with 19 dry-dekads at maximum, 2007-2008 season experienced extremely severe maize crop failure with 12 dry-dekads at maximum, 2010-2011 season experienced severe maize crop failure with 14 dry-dekads at maximum and 2011-2012 experienced extremely severe maize crop failure with 16 dry-dekads at maximum respectively. For all five sample growing seasons, it is observed that Ward 36 experienced the worst maize crop failure based on the degree of VCI (%) (Table 2.3) and the number of VCI-drydekads experienced hence factor rated n2 subject to FAO land suitability guidelines.

The higher the number of VCI-drydekads measured against total twenty-four dekads is indicative of food insecurity due to inconsistent rainfall patterns in the area hence falls short to yield the potential land suitability for this rain-fed LUT. With regards to FAO (1993) factor ratings of land evaluation, degrees of limitation give guidelines to determine the suitability(s) or not suitable (n) classes. Accordingly, Ward 36's potential for sustainable maize crop suitability is compromised by dominance of litho-sols < 25cm which are shallow to moderately shallow brown or reddish brown clays formed on mafic rocks, moderately to strong leached coarse-grained kaolinitic soils and siallitic soils which are shallow to moderately shallow brown or reddish clays formed from basic rocks based on evidence from the clipped Zimbabwe Soil map (Fig 4.11). All the three soil types hardly support sustainable maize production hence factor rated marginally suitable (s3) according to FAO model on land suitability classes (Fig 2.2). Ultimately, Land Quality Indicators (Pierriet *al* 1995) in the form of extensive degraded gold quarries, deforestation and derelict mines attest to limitations observable that Ward 36 is subjected to that compromise its potential for land suitability.

4.2.3 Land suitability mapping 2000-2012

Based on Rainfall-VCI-drydekads land suitability potential maps generated in Fig 4.1.2, observed results from these parameters answered the last objective. Maize crop development as influenced by rainfall amount led to two critical observations governing cropping conditions in Ward 36. Firstly, a subdued 463mm of rainfall at most was received for the entire five sample years for which critical analysis show that this rainfall amount had a spatial coverage in masked area which apparently is of no agricultural activity. Secondly, severe VCI-drydekads are confined largely within poor and shallow 5G (kaolinitic soil class).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this study spatial analysis to identify land suitability potential was done. The land suitability problem was structured to fit into the framework of decision-making. The 1976 FAO land suitability framework for agricultural crops with regards to suitability classes from not suitable to highly suitable giving emphasis on the crops' unique climatic, topographic and soil parameters is valid. The researcher, equipped with such guiding decision-making principles, utilized RS and GIS platforms to simplify the complexities surrounding land suitability analysis in Mberengwa District, Ward 36 and drew these conclusions:

Firstly, the study tested whether there was a relationship between average VCI and remotely-sensed rainfall amount. Comprehensive analysis of the tests indicated a strong positive relationship ($p < 0.05$) between these variables for the five sample years. Therefore, VCI can be predicted reliably from rainfall hence can be a good measure of maize crop productivity.

Secondly, based on VCI-drydekads, the researcher observed that the average maximum number of VCI-drydekads for the five year sample period was calculated to be 62% against average minimum number of VCI-drydekads of 23%. Apparently, a comprehensive analysis of VCI-drydekads and soil potential show that Ward 36 posed a myriad of limitations due to low rainfall totals and poorly developed soil nutrients. Results showed that Ward 36 experienced the worst maize crop failure based on the subdued VCI (%) and the high number of VCI-drydekads experienced and soil constraints hence factor rated currently not suitable (n1) and marginally suitable (s3) respectively subject to Food and Agricultural Organisation (FAO) land suitability guidelines. As a way of detecting land suitability potential for maize crop these variables were very useful in this study. For more advanced spatial land suitability studies, Multi-Criteria Evaluation model can readily be adopted.

Thirdly, land suitability mapping in Ward 36 at coarse resolution offered reliable results between a corresponding high number VCI-drydekads and subdued rainfall totals although very high resolution images from Quick-bird, Geo-eye or even 30m Land-sat images could yield better analysis. Clipped Ward 36 Soil map was examined and further exposed the limitations of nutrient status for the three different soil entities under maize crop cultivation.

5.2 Recommendations

- Government through Specialist and Research services from ICRISAT and local universities should evaluate the significance of crop farming in Ward 36 as current evidence of recurrent food deficit point to a mismatch between the ideals of land reform and food security status.
- Agricultural Research Extension (AREX) should evaluate the feasibility of relying and promoting maize crop judging by the results of this study and advise resettled farmers accordingly on the best diversified farming such as drought-tolerant varieties like sorghum and millet.
- Government should consider the prospect of constructing a mega-dam for irrigation purposes to boost maize yield for food security in view of recurrently marginal rainfall totals.
- AREX should advise farmers to adopt short-seasoned varieties like R403 and SC513 to counter the effects of limited rainfall.
- Government should allocate bigger plots to A1 farmers for commercial livestock production (LUT) such as cattle, sheep and goats under subsidised loan schemes, inputs, technical support, and establish potential market network.

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Appendices

Appendix 4.1: VCI-Rainfall Regression 2001-2002 Season

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.950 ^a	.902	.894	2.622	.902	110.244	1	12	.000

a. Predictors: (Constant), Rainfall (mm)

Appendix 4.2: VCI-Rainfall Regression 2004-2005 Season

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.978 ^a	.956	.953	2.689	.956	306.584	1	14	.000

a. Predictors: (Constant), Rainfall (mm)

Appendix 4.3: VCI-Rainfall Regression 2007-2008 Season

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.987 ^a	.974	.972	1.874	.974	479.365	1	13	.000

a. Predictors: (Constant), Rainfall (mm)

Appendix 4.4: VCI-Rainfall Regression 2010-2011 Season

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.987 ^a	.974	.972	1.874	.974	479.365	1	13	.000

a. Predictors: (Constant), Rainfall (mm)

Appendix 4.5: VCI-Rainfall Regression 2011-2012 Season

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.973 ^a	.946	.941	3.042	.946	209.269	1	12	.000

a. Predictors: (Constant), Rainfall (mm)