Suitability Analysis of Satellite Remote Sensing Methods to Map Agricultural Land Use Change after Zimbabwe's "Fast Track Land Reform Programme"

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„Thus by their fruits you will recognize them“

A PhD thesis is a lifetime project. It pushes the author to the limit but at the same time, it is this hardness and all the challenges which show how important the support and reliability of persons and institutions are in life.
Therefore, close to the end of my time as a PhD student, I want to express my gratitude to all of you who have helped to shape this work, to you who have motivated me to carry on, and to you who have helped me to pick myself up after I hit rock bottom.
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Acronyms and Abbreviations

AER	Agro-Ecological Region
AIDS	Acquired Immune Deficiency Syndrome
ANC	African National Congress
AVHRR	Advanced Very High Resolution Radiometer
BFAST	Breaks For Additive Season and Trend
BISE	Best Index Slope Extraction
BRDF	Bidirectional Reflectance Distribution Function
BSAC	British South Africa Company
CEC	Cation-Exchange Capacity
CFU	Commercial Farmer's Union of Zimbabwe
DOY	Day Of Year
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization
FAS	Foreign Agricultural Service of the United States of America
FEWSNET	Famine Early Warning Systems Network
FPAR	Fraction of absorbed Photosythetic Active Radiation
FTLRP	Fast Track Land Reform Programme
FWHM	Full Width at Half Maximum
GDP	Gross domestic product
GIS	Geographic Information System
GLOVIS	USGS Global Visualization Viewer
GLP	Global Land Project
GTZ	Gesellschaft für Technische Zusammenarbeit
HANTS	Harmonic ANalysis of Time-Series
HIV	Human Immunodeficiency Virus
IFOV	Instantaneous Field Of View
IGPB	International Geosphere-Biosphere Programme
IMF	International Monetary Fund
ITCZ	Inter-Tropical Convergence Zone
LAA	Land Apportionment Act
LHA	Lancaster House Agreement
LOESS	Clevelands LOcally wEighted regreSsion Smoother
LULC	Land Use and Land Cover
LULCC	Land Use and Land Cover Change
MDC	Movement for Democratic Change Zimbabwe
MDC-M	Movement for Democratic Change Zimbabwe - Ncube
MDC-T	Movement for Democratic Change Zimbabwe - Tsvangirai
MODIS	MODerate-resolution Imaging Spectroradiometer
MOSUM	MOving SUM breakpoint test

MSD	Meteorological Service Department
MVC	Maximum Value Composite
NDVI	Normalized Differenced Vegetation Index
NGO	Non-Governmental Organization
NIR	Near Infrared Red
NLHA	Native Land Husbandry Act
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Production
OECD	Organisation for Economic Co-operation and Development
OPO	Ovamboland People's Organization
PA	Producer Accuracy
PPGIS	Public Participation Geographic Information System
RESTREND	Residual Trend Analysis
RF	Random Forest classification
SADC	Southern African Development Community
SNR	Signal to Noise Ratio
SP	Seasonal Parameter
STA	Seasonal Trend Analysis
SVM	Support Vector Machine
SWAPO	South-West Africa People's Organisation
SWANU	South-West African National Union
UA	User Accuracy
UDI	Unilateral Declaration of Independence
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WFP	World Food Programme
WRB	World Reference Base for soil resources
ZANU	Zimbabwe African National Union
ZANU-PF	Zimbabwe African National Union - Patriotic Front
ZAPU	Zimbabwe African Peoples Union

Abstract

Forced evictions of white commercial farmers in the year 2000 took the Zimbabwean land reform programme to a new level. While international media covered the tragedies of white farmers, the collapse of a state economy and the food shortages in the country, new farmers emerged on former large scale production schemes. At the same time, the Zimbabwean Government officialized the community driven farm take overs and provided legislation and administration through a 'Fast Track Land Reform Programme' (FTLRP). In recent years, there has been a vivid scientific debate on whether new farmers are productive and on whether the FTLRP has been successful or not. But despite the remarkable reception in media and academic work, actual figures are hard to get hold of.

Aiming to provide answers to the often posed question of 'what has happened where after the FTLRP?', the present thesis provides an analysis of geospatial methods to research tenure change and its consequences. It conceptualizes the potential of remote sensing and GIS to contribute to an integrated land reform research, and assesses whether this potential has been fully tapped. An analysis framework for the FTLRP is presented to overcome the apparent lack of spatial research. In order to proof its applicability, three of the proposed spatio-temporal methods are critically examined for their suitability to adequately map outcomes of the land reform: phenology based temporal land use classification, productivity trend mapping, and breakpoint analysis.

A time-series based multi-temporal land use classification approach on Moderate Resolution Imaging Spectroradiometer (MODIS) data was used to analyse trajectories of the agricultural sector. The objective of this approach was to produce a dataset of annual binary crop/non crop maps for former freehold tenure areas, providing spatial and temporal information on Zimbabwe's agricultural production after the FTLRP. However, the well-established and commonly used method of phenology based land use classification does not provide meaningful results. Therefore, after a comprehensive review of limitations of MODIS-NDVI based hard classifications, a relative assessment approach is additionally presented.

As answers to questions of Zimbabwe's national agricultural production after the FTLRP remained unanswered, trend analysis of vegetation was applied for crop area of Zimbabwe's most productive farming region. The results reveal that no correlation between negative production trends and new land tenure types exists. Trends of production are rather characterised by spatial clusters of strong negative trends resulting from operation stops of irrigation schemes.

To map fallow irrigation schemes in Zimbabwe, a hybrid-methodology of "Breaks For Additive Seasonal and Trend" (BFAST) and "Seasonal Trend Analysis" (STA) was introduced. The combination of 'time of peak' calculated with STA, and 'breakpoint of seasonal signal' calculated with BFAST, provides sound results for time and location of abandonment of irrigation schemes which had great impacts on the country's food and export crop production.

It is concluded that temporal classification results based on medium scale resolution data have to be used with great caution and that combination of methods significantly enhances explanatory power of MODIS-NDVI data. By using FTLRP as a case study for the suitability of remote sensing to map tenure induced land use changes, the thesis forms an essential contribution towards integrated land use science.

Zusammenfassung

Vertreibungen und Enteignungen weißer Farmer im Jahre 2000 gaben dem Landreformprogramm Simbabwes eine neue Dimension. Während internationale Medien über Schicksale weißer Farmer, den Zusammenbruch der Wirtschaft und die Nahrungsmittelknappheit im Land berichteten, etablierten sich neue Farmer auf den ehemaligen Großbetrieben. Gleichzeitig reglementierte die Regierung Simbabwes die gemeinschaftlich organisierten Farm-Enteignungen und lieferte mit dem 'Fast Track Land Reform Programme' (FTLRP) den rechtlichen und administrativen Rahmen. In den letzten Jahren wurde eine leidenschaftliche Debatte darüber geführt, ob die neuen Farmer produktiv wirtschaften, und ob das FTLRP erfolgreich war. Doch trotz der hohen Resonanz in Medien und Wissenschaft sind belastbare Zahlen nur schwer zugänglich.

Mit dem Ziel Antworten auf die oft gestellte Frage „was ist wo nach dem FTRLP passiert?“ zu geben, liefert die vorliegende Dissertation eine Analyse raumbezogener Methoden um den Wandel der Landbesitzverhältnisse und dessen Folgen zu erforschen. Sie konzeptualisiert das Potential fernerkundlicher Methoden und GIS einen Beitrag zu integrierter Landreformforschung zu leisten und untersucht in wie weit dieses Potential ausgeschöpft wurde. Um den deutlichen Mangel an räumlicher Forschung zu mindern, wird ein FTLRP orientiertes Forschungskonzept vorgestellt. Seine Anwendbarkeit wird anhand der kritischen Evaluierung dreier Methoden geprüft: Phenology based temporal land use classification, productivity trend mapping, and breakpoint analysis.

Mit Hilfe eines zeitreihenbasierten multitemporalen Klassifikationsverfahrens von Moderate Resolution Imaging Spectroradiometer (MODIS) Daten wurde die Entwicklung des landwirtschaftlichen Sektors untersucht. Ziel dieses Ansatzes war es, einen Datensatz binärer Karten mit den Klassen „Ackerfläche“/ „keine Ackerfläche“ für ehemalige Privatbesitzgebiete zu produzieren, der raumzeitliche Informationen über Simbabwes landwirtschaftliche Produktion nach dem FTLRP enthält. Die weit verbreitete und oft genutzte Methode der phänologiebasierten Landnutzungsklassifikation erzielt jedoch keine zufriedenstellenden Ergebnisse. Deshalb wird nach einer ausführlichen Diskussion der Schwachstellen MODIS-NDVI basierter harter Klassifikationen, ein zusätzlicher, relativer Bewertungsansatz vorgestellt.

Da Fragen zur landesweiten Agrarproduktion Simbabwes nach dem FTLRP immer noch nicht vollständig beantwortet sind, wurde ein Vegetationstrend für das landwirtschaftlich produktivste Gebiet Simbabwes berechnet. Die Ergebnisse zeigen, dass kein Zusammenhang zwischen Produktivität und neuen Landbesitzverhältnissen besteht. Vielmehr sind Trends durch die räumliche Aggregation starker Negativwerte gekennzeichnet, welche von der Aufgabe von Bewässerungsstrukturen verursacht werden. Um die Aufgabe der Bewässerungssysteme zu kartieren, wurde eine Hybrid-Methode aus “Breaks For Additive Seasonal and Trend” (BFAST) und “Seasonal Trend Analysis” (STA) entwickelt. Die Kombination des mit STA berechneten 'time of peak' und des mit BFAST ermittelten 'breakpoint of seasonal signal', liefert zuverlässige Ergebnisse über Zeitpunkt und Ort der Aufgabe von Bewässerungsstrukturen, welche empfindliche Auswirkungen auf die Erzeugung von Lebensmitteln und Exportprodukten hatte.

Es wird geschlussfolgert, dass Ergebnisse temporaler Klassifikationen von mittelaufgelösten Daten mit großer Umsicht behandelt werden sollten und dass die Kombination von Methoden die Aussagekraft von MODIS-NDVI Daten erheblich verbessert. Mit dem FTLRP als Fallbeispiel für die Untersuchung der Eignung fernerkundlicher Methoden für die Kartierung von Landnutzungsveränderungen als Folge von geänderten Landbesitzverhältnissen, leistet diese Arbeit einen wesentlichen Beitrag zu einer integrierten Landnutzungswissenschaft.

I. Structure and concept of the thesis

1 Introduction and goal of the study

Geography as a discipline features a gap which Massey relates to as “one of the most well-established and best-fortified [...] old divides within knowledge [...], that between the 'physical' and 'human' science” (Massey 1999). Indeed is the division into 'physical' and 'human' geography an intensively debated issue among international and German geographers (Harrison et al. 2004, Weichhart 2003). This thesis, with its focus on land use and land cover change (LULCC), is located at the fringe of these two sub-disciplines and while it recognizes the necessary bisection, it does not aim to achieve the impossible by bridging them; something which has also been flagged unnecessary by Weichhart (Weichhart 2008).

It rather draws from both sides and generates knowledge which is important for the 'physical' and 'human' understanding and assessment of LULCC. Its overall goal is to conceptualize, asses, describe, and exemplify the potential of time-series based remote sensing methods and geomatics to contribute to socio-economic and to ecological analysis in land use science. To achieve this, emphasis was put on a very specific case study of changing land use, land management and land tenure: The Zimbabwean 'Fast Track Land Reform Programme' (FTLRP) which started in the year 2000.

Zimbabwe has experienced intense changes of its agrarian structure since its official independence in 1980 (Palmer 1990). Several land reform programs and politically motivated processes have occurred since then, all leading to different settings of land ownership, management and agricultural use (Matondi 2012). The happenings which culminated in the year 2000, are the outcome of a set of different factors which all lead to the dissatisfaction of a large proportion of population concerning unequal distribution of wealth, means of production, power, but also of social participation (Chaumba, Scoones & Wolmer 2003). As a result, farm evictions took place and formed an unseen reorganization of land tenure, change of agricultural production, and introduced a new composition of race and gender of economically active citizen.

It is this part of Zimbabwe's land reform program which has received attention from a broad spectrum of journalists, film makers, politicians, scientists, and members of the civil sector. All in all, the FTLRP can be seen as one of the most prominent redistribution and reorganization of land tenure and agricultural production schemes in recent history, as it is the only “sweeping, regime-sanctioned, confiscatory land redistribution in the world today” (Bernstein 2003). Questions of legitimacy and efficiency make studying this topic a highly political issue, while a lack of reliable data on larger scale is evident in all aspects of the discourse (Scoones 2014a). Studies which research the pathway of evictions, or try to assess the successfulness and the effects of the FTLRP, lack long-term and objective data as the events occurred in an unplanned and erratic manner.

One hypothesis of this thesis is that the unique major countrywide impacts of land reform on land use change, also determined by the FTLRP's sweeping character, offer great connecting factors where spatial methods can be applied. Mapping the abrupt change of land use generates added value and answers specific questions on 'what has happened where' after the reorganization of the Zimbabwean agricultural production scheme. Since decades, remote sensing products offer more than plain land cover products and contribute to an interdisciplinary research of a changing earth surface (Liverman et al. 1998). This thesis is in line with these efforts and exemplifies the importance of space in social research as formulated by Goodchild and Janelle: Location allows to integrate multidisciplinary approaches in general and recognizes three principal questions of social research: human behaviour and resulting processes; their prediction; and respective problem solutions (Goodchild & Janelle 2003). A conceptual framework on land reform assessment demonstrates the suitability of geomatics for integrated research on land reforms, while results of the study on long term and abrupt changes are of immediate benefit to land reform assessors, as they address the lack of information on processes, magnitude, speed and pattern of redistribution. This part of the thesis has proven Fraser's argument of the well-suited inter- and cross-disciplinary character of geography right, which has - in his view - not contributed sufficiently to land reform research so far (Fraser 2008).

Secondly, it is hypothesized that the outcomes of a suitability analysis of different remote sensing methods also contribute to the discipline of land use science, as the study of LULCC lies at its heart. There is a persistent interest among scientists to understand the causes of LULCC, partly because of their indifferent character (Meyfroidt et al. 2013). Various global think tanks on land sciences, such as the Global Land Project (GLP), draw on remote sensing products to generate a profound knowledge of the changing surface of our planet (GLP 2012). Land cover and land use can be defined as the "biophysical attributes of the earth's surface" and "human purpose or intent applied to these attributes" respectively (Lambin et al. 2001), meaning that land cover can be determined by land use, which is a result of human driving forces at different scale from social, economic, political and cultural spheres (Meyer & Turner 1994). The FTLRP is a prime example of a radical change of these spheres and therefore demonstrates the need for interdisciplinary approaches in science to understand the processes restructuring land cover. The thesis meets this demand by critically investigating the suitability of research frameworks and spatial methods for land reform assessment. A detailed description of limitations of MODIS time series forms an integral contribution to the community of applied remote sensing.

The lack of similar studies, combined with a growing number of downloads of publications linked to this thesis - despite their narrow focus -, underpins the importance of integrated conceptual work on applied remote sensing at the fringe of human and physical geography. Old but still important: the concept of “Socializing the Pixel and Pixelizing the Social” (GEOGHEGAN ET AL. 1998) offers room for scientists to scrutinize, challenge, engage and make impact; also today.

2 Structure of the document

This PhD thesis is handed in as a cumulative dissertation. Therefore, three chapters of this document have been submitted to different scientific journals. To guarantee a cohesive thesis, the text is structured in seven MAIN SECTIONS, in which the reader is first provided with an overview (I. MAIN SECTION), followed by contextual background information (II. MAIN SECTION), before emphasis is put on the potential impact, geomatics can have on the discourse on land reform and interdisciplinary land science (III. MAIN SECTION, including article 1). After this conceptional section, a part on the suitability of multi-temporal classification of MODIS data to map changing crop area as a result of land reforms follows (IV. MAIN SECTION, including article 2). Subsequently, the reader is presented a method based on trend and breakpoint analysis to localize changes which occurred after the 'fast track' part of Zimbabwe's land reform (V. MAIN SECTION, including article 3). Finally, a conclusion and outlook to further studies wrap up the thesis (VI. MAIN SECTION). Additional material and references are provided at the end (VII. MAIN SECTION).

The main research questions of this PhD thesis can be grouped into three categories, which are broadly linked to the chapters published or submitted as articles.

Conceptional (first article, chapter 7)

C1) How can land reforms be evaluated?

C2) What contributions can spatial methods make to land reform assessments?

C3) Has this potential been tapped on?

Methodological (second article and third article, chapter 9 and 11)

M1) Are MODIS datasets suited to classify land cover after Zimbabwe’s FTLRP?

M2) Can trend analysis generate information on agricultural production in Zimbabwe?

M3) Is breakpoint analysis an adequate method to locate the changes of Zimbabwean irrigation schemes in space and time?

Thematic (third article, chapter 11)

T1) How did total crop area develop after the FTLRP?

T2) Are there different developments in different land tenure schemes?

T3) Are significant changes of production patterns linked to the FTLRP?

2.1 Chapters published as articles

As described above, two chapters (7,9) of this thesis have been published in scientific journals, one has been submitted (11). As most articles are to be submitted in American English and the thesis is written in South African English, differences might occur throughout the document. Thes published articles are:

Hentze, K., and G. Menz; 2015. **"Bring Back the Land" - A Call to Refocus on the Spatial Dimension of Zimbabwe's Land Reform.** Land 4(2), 355-377.

Abstract: In this article, we argue that research on land reform in the nation of Zimbabwe has overlooked possibilities of integrating geospatial methods into analyses and, at the same time, geographers have not adequately developed techniques for this application. Scholars have generally been captured within the debate focused on the success or failure of the Zimbabwean land reform program, and have neglected to analyze what has occurred where during the process of "fast-track land reform". To date, no extensive national dataset of land ownership change, and the effect of this change on land use planning strategies, has been developed within the scientific community. As a result, most publications, even very detailed and thorough ones, have been based on regional case studies, broad estimates, or on outdated, cross-referenced statistics. To overcome the lack of spatio-temporal data, we propose an analytic framework to map Zimbabwe's fast-track land reform and its country-wide effects. It emphasizes the potential of geographic information systems and satellite remote sensing to provide an objective basis for future studies of the subject.

Keywords: Zimbabwe; fast track land reform program; remote sensing; public participatory geographic information system (PPGIS); geomatics

Hentze, K., Thonfeld, F., G. Menz; 2016. **Evaluating crop area mapping from MODIS time-series as an assessment tool for Zimbabwe's "Fast Track Land Reform Programme".** PLoSONE 11(6), e0156630.

Abstract: Moderate Resolution Imaging Spectroradiometer (MODIS) data forms the basis for numerous land use and land cover (LULC) mapping and analysis frameworks at regional scale. Compared to other satellite sensors, the spatial, temporal and spectral specifications of MODIS are considered as highly suitable for LULC classifications which support many different aspects of social, environmental and developmental research. The LULC mapping of this study was carried out in the context of the development of an evaluation approach for Zimbabwe's land reform program. Within the discourse about the success of this program, a lack of spatially explicit methods to produce objective data, such as on the extent of agricultural area, is apparent. We therefore assessed the suitability of moderate spatial and high temporal resolution imagery and phenological parameters to retrieve regional figures about the extent of cropland area in former freehold tenure in a series of 13 years from 2001-2013. Time-series data was processed with TIMESAT and was stratified according to agro-ecological potential zoning of Zimbabwe. Random Forest (RF) classifications were used to produce annual binary crop/non crop maps, which were evaluated with high spatial resolution data from other satellite sensors. We assessed the cropland products in former freehold tenure in terms of classification accuracy, inter-annual comparability and heterogeneity. Although general LULC patterns were depicted in classification results and an overall accuracy of over 80% was achieved, user accuracies for rainfed agriculture were limited to below 65%. We conclude that phenological analysis has to be treated with caution when rainfed agriculture and grassland in semi-humid tropical regions have to be separated based on MODIS spectral data and phenological parameters. Because classification results significantly underestimate redistributed commercial farmland in Zimbabwe, we argue that the method cannot be used to produce spatial information on land-use which could be linked to tenure change. Hence capabilities of moderate resolution data are limited to assess Zimbabwe's land reform. To make use of the unquestionable potential of MODIS time-series analysis, we propose an analysis of plant productivity which allows to link annual growth and production of vegetation to ownership after Zimbabwe's land reform.

Hentze, K., Thonfeld, F., G. Menz; 2016. **Beyond trend analysis: how a modified breakpoint analysis enhances knowledge of agricultural production after Zimbabwe's fast track land reform.** Journal of Applied Earth Observation and Geoinformation. Submitted.

In the discourse on land reform assessment, a significant lack of spatial and time-series data has been identified, especially with respect to Zimbabwe's “Fast-Track Land Reform Programme” (FTLRP). At the same time, interest persists among land use change scientists to evaluate causes of land use change. Increasing the explanatory power of remote sensing products is key for these efforts. This study recognizes these demands and aims to provide input on both levels: Its focus was to evaluate the potential of satellite remote sensing time-series to answer questions which evolved after intensive land redistribution efforts in Zimbabwe. On the other hand, it investigates how time-series of Normalized Difference Vegetation Index (NDVI) can be better understood with regard to information on impact of land reform on land use change. To achieve this, two time-series methods were applied to MODIS NDVI data: Seasonal Trend Analysis (STA) and Breakpoint Analysis for Additive Season and Trend (BFAST). We linked productivity trends to land tenure and showed that regional clustering of trends is more dominant than a correlation between tenure and trend. Investigation of regional trend clusters revealed that information generated with time-series is limited, but can be enhanced through a multi-method approach which recognizes the most prominent effect of Zimbabwe FTLRP on productivity trend: The abandonment of irrigation schemes with high productivity potential. A conventional trend analysis is not able to recognize this abrupt change of production, but the proposed enhanced breakpoint analysis is applicable to map location and date of operation stop of irrigation schemes in these clusters. We therefore conclude that the careful selection and combination of time-series analysis methods enhances knowledge on Zimbabwe's FTLRP and can overcome known limitations of trend analysis.

Keywords: MODIS, NDVI, Seasonal Trend Analysis, BFAST, Zimbabwe, Fast Track Land Reform Programme, crop area mapping

II. Contextual background

Zimbabwe is a landlocked country in Sub-Saharan Africa, characterized by a diverse natural environment and a rich history. A diversity which challenges uniform time-series based analysis. MODIS - a sensor commonly used for land use classifications - has been described as powerful by some, but also as unsuitable by others to produce products of regional land cover (Herold et al. 2008). An integral part of this PhD thesis was the assessment of this sensors products as the basis for nationwide land use classification approaches in the context of land tenure change. The publication "Evaluating crop area mapping from MODIS time-series as an assessment tool for Zimbabwe's 'Fast Track Land Reform Programme'", contains a section of explicit and detailed argumentation why the heterogeneous land use and climate of Zimbabwe's hinder a classification based on MODIS time-series. Just as the knowledge of Zimbabwe's geographical setting is important to critically evaluate methods of remote sensing, an overview of the country's history is essential to understand the importance of the political issue 'land' which is picked out as a central theme in the publication "Bring Back the Land" - A Call to Refocus on the Spatial Dimension of Zimbabwe's Land Reform. This introductory section therefore aims to provide these overviews as a set of tools to contextualize research topic, methods and results. It does not aim to provide a detailed scholarly piece on Zimbabwe, but shall rather give a general outlook to the heterogeneous physical environment (chapter 3) and the land question of the country (chapter 4), as well as to the basic concepts of mapping land cover and its change (chapter 5).

3 Environmental factors influencing remote sensing of vegetation

3.1 Geographical setting

Zimbabwe is completely situated in the torrid zone, while most of its neighbouring countries -Namibia, Botswana, South Africa and Mozambique-, stretch South of the Tropic of Capricorn. Zambia, bordering Zimbabwe to the north, shares a common history with Zimbabwe because both countries emerged from former Rhodesia as Northern Rhodesia and Southern Rhodesia (later again Rhodesia) respectively.

Situated between the Rivers of Limpopo and Zambezi, the country has a size of 390,757 km^2 ("The World Factbook, Zimbabwe" n.d.) and is home to approximately 13 million inhabitants which are very unevenly distributed throughout the country (Zimbabwe National Statistics Agency 2014). Eight rural and two urban provinces form the administrative divisions. Prominent are two major geographical stratifications of the country: One is the gradient of agro-ecological growth conditions, commonly referred to by six agro-ecological regions (AER, compare Figure 9.1, page 69), the other is the division into state, communal and private land tenure regimes (compare Figure 4.1). The growth conditions expressed in AERs are a result of physical factors which are given attention to in this chapter, the division into property regimes are relicts from colonial and apartheid rule, broached by the following chapters.

3.2 Geology

Petters characterized the African Geology by dividing its phenomena grossly into cratons and mobile belts whereby the former are considered as "stable parts of Precambrian crust which have not been deformed or metamorphosed since Early to Middle Proterozoic times". Mobile belts, on the contrary, have metamorphed more recently during the African orogeny (Petters 1991).

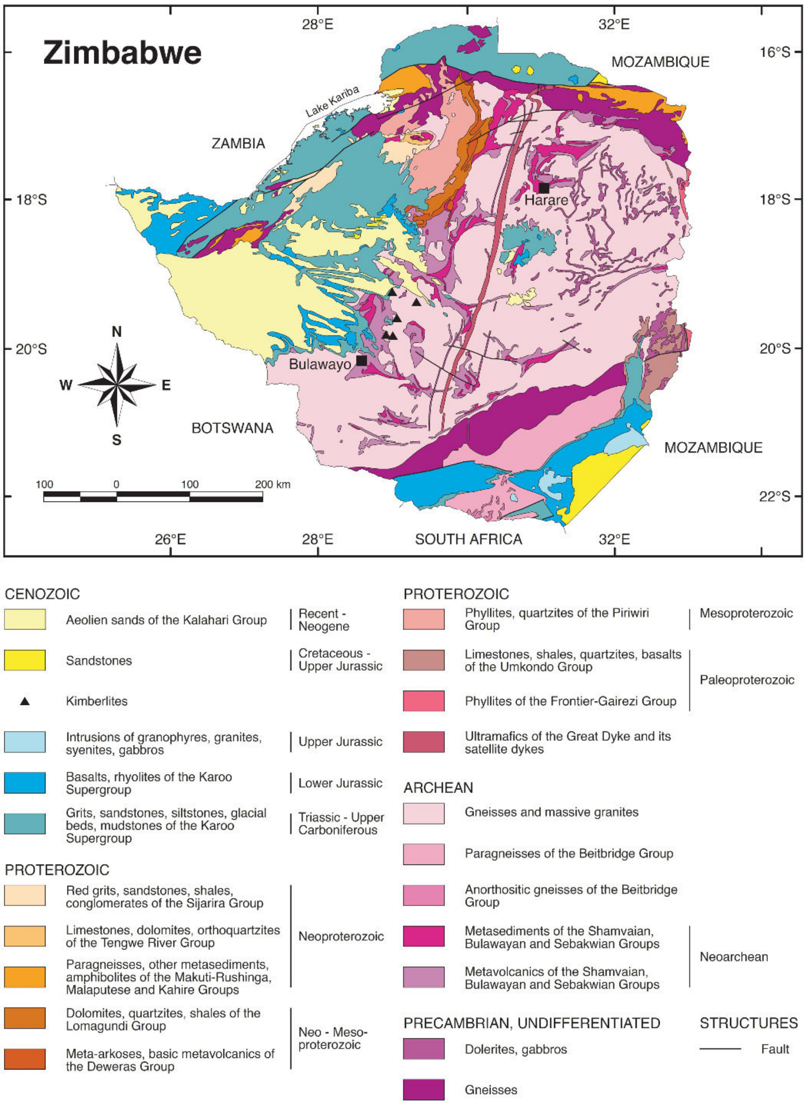

Figure 3.1: A geological overview of Zimbabwe (Schlüter 2006).

Zimbabwe's geological basement is formed by the Zimbabwe Craton, a part of the bigger Kapvaal Craton, which stretches from South Africa over Namibia and Botswana to Zimbabwe. Belonging to the archean groups (shades of purple in Figure 3.1) it is characterized by high metharmorph archaic rocks (Schulze 1993). Igneous and metamorphosed igneous rocks account for more than 65% of Zimbabwe's bedrock, more than half of it are granites or granitic rocks (Nyamapfene 1991). After the Bulawayan orogenesis, sediments of the Shamvaian Group were deposited in isolated sinks (Buchholz 1995) Most of them however surface in Eastern Zimbabwe (Schlüter 2006), making the region between the Limpopo mobile belt in the Southwest and the other younger cover rocks in the north-eastern part of the country an important reservoir of mineral resources such as gold, chrome and nickel (Schulze 1993).

The central part of the country is surrounded by younger cenozoic formations (shades of blue and yellow in Figure 3.1). Western Zimbabwe's geology is characterized by poorly consolidated sandstones and sands (Schlüter 2006), forming the Northern part of the Kalahari. Kalahari Sands and Karroo Sandstones account for 25% of the area not covered by igneous rocks (Nyamapfene 1991). To the North, the Zimbabwe Craton is bordered by the Zambezi mobile belt followed by the adjacent Zambezi escarpment fault (Schulze 1993). The Southern Gneiss is adjacent to the Save-Limpopo Basin floored by the Limpopo mobile belt (Chinoda et al. 2009).

A very prominent feature of Zimbabwe's geology is the Great 'Dyke' a linear feature of 480 km length and an average width of 8 km (Wilson 1982). It has been built in the Proterozoic Eon (shades of brown in Figure 3.1) and is a rich source of several ores. In fact, the Great 'Dyke' should not be considered as a dyke in the true sense and rather be referred to with inverted commas as Wilson suggests. It is accompanied by various satellite dykes (Wilson 1982) and a result of intrusive magma, which surfaced during the consolidation of Gneisses. Sharp edges of altering adjacent bedrocks are the reason for clearly visible different soil and vegetation composition around the Great 'Dyke', especially where toxic serpentine are surfacing (Nuding 1999). In general, a strong relationship between geology and soils can be stated for Zimbabwe.

3.3 Soils

Zimbabwe's agriculture has to struggle with tropical and subtropical soils which are generally characterized by low agricultural suitability and difficulties in maintaining fertility. As van Straaten states: “most of the soils in Zimbabwe are nutrient deficient and are degrading at rapid rate” (Van Straaten 2002). They are indeed mainly sandy, have low mineral contents and are prone to erosion and loss of nutrients (Stocking 1986). Their sandy proportions are altering from coarse sands, where soils developed on the widely distributed granites, to fine sands which are predominant in the Kalahari fraction (Thompson 1965).

In general, Zimbabwean soils are immature and reflect the bedrock, of which the above mentioned granitic is the most dominant. The lesser common Greenstonebelts are parent material for much more fertile soils (Van Straaten 2002), because ferromagnesian minerals in these mafic rocks lead to more clayey soils (Nyamapfene 1991). Ultramafic rocks on the other hand form toxic soils, due to higher levels of heavy minerals besides magnesium. They inhibit plantgrowth in the most southern and western part of the country as well as on Great 'Dyke' and its satellites (Nyamapfene 1991).

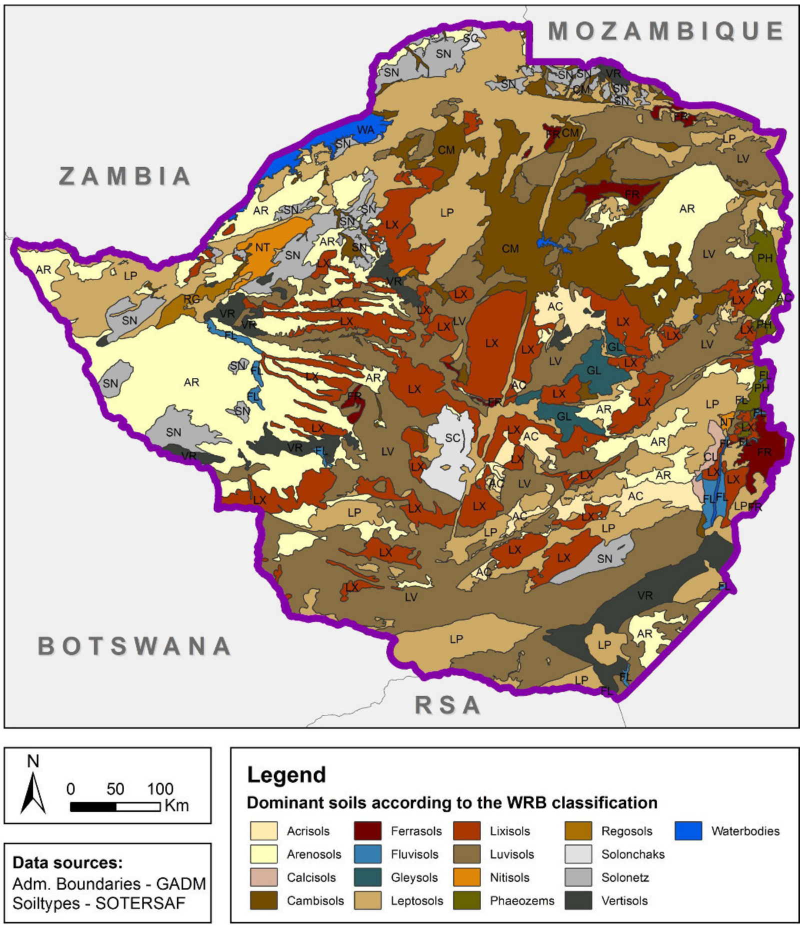

Figure 3.2: Soilmap of Zimbabwe, based on WRB.

To conclude, the parent material can be considered as the most influential soil forming factor of the country's soils. This explains the strong correlation between the geological map (Figure 3.1) and the soil map of Zimbabwe (Figure 3.2) whose most prominent classes (according to the FAO WRB system) shall be quickly outlined:

- *Arenosols,* found in the Western part of the country, are sandy soils formed either by residual material from in-situ weathering, or by alluvial deposition. Their utilization requires stabilizing protection measurements and carefully applied fertilization (IUSS 2006). The Kalahari with its aeolian material represents the biggest sand body in the world.

- *Cambisols,* are modest developed soils still reflecting the bedrock, in Zimbabwe mainly the granitic craton. Despite their relatively young age, Cambisols are globally considered as relatively fertile soils. In the tropics however, their nutrient supply and cation-exchance capacity (CEC) is low but still higher than those of neighbouring Acrisols and Ferrasols (IUSS 2006).
- *Leptosols* can serve as further examples for the less developed soils of Zimbabwe. They are shallower than Cambisols and prominent on steep mountainous area or gravelly underground. Because of their high relief energy and low developed horizons, Leptosols are prone to erosion and can only sustain grazing or forest plantations (IUSS 2006).
- *Luvisols* in the subtropics are also a sign for short landscape evolution. However, they are characterized by soil forming factors, especially lessivation. This leads to higher CECs in the B-horizon and a generally fertile soil of good agricultural value (IUSS 2006).
- *Lixisols* are strongly weathered soils with high accumulations of clay in the subsoil formed mainly on African bedrocks rich of quartz, such as the Zimbabwean craton. Their CEC is relatively low and plant nutrients are scarce. A permanent agricultural usage requires well managed fertilizing and protection of the erodible top layer (IUSS 2006).

3.4 Climate

The climate of Southern Africa is influenced by tropical and subtropical anticyclonic circulations as well as perturbations of these. Dominant are however the semi-permanent subtropical high pressure cells (Tyson & Preston-Whyte 2000) and the moving Intertropical Convergence Zone (ITCZ). The South Indian Anticyclone and the South Atlantic Anticyclone, parts of the southern discontinuous high pressure belt, are determining the seasons by moving north and southwards. These cyclic movements are of yearly (South Atlantic) and half yearly (South Indian) character (Tyson & Preston-Whyte 2000).

Arid conditions in the western part of the region are a reason of the Benguela current and the relatively stable north-south moving South Atlantic anticyclone. The zonal shifting South Indian anticyclone on the other hand leads to higher precipitation and a differentiation of summer and winter rainfall on the eastern side of the subcontinent (Spinage 2012).

3.4.1 Seasonality of Zimbabwe's Climate

Zimbabwe’s climate is therefore characterized by the movement of ITCZ-influenced circulations. During the austral winter, stable layers are caused by sinking masses of stronger trade winds and are hindering convection. In summertime, the trade winds become weaker due to low pressure areas over the land surface and lead to unstable conditions favouring convective currents (Nuding 1999). Four seasons are differentiated by the Meteorological Service Department of Zimbabwe (MSD) according to precipitation and temperature - a concept which dates back to before the Zimbabwean independence (Patterson 1970):

- *Rainy season*
  Mid-November to mid-March, with the hottest day temperatures in the course of the year: 26 °C - 36 °C.
- *Post rainy season*
  Mid-March to mid-May, moderate temperatures (23°C to 31°C) with diminishing rainfall.
- *Cold dry season*
  Mid-May to mid-August, with day temperatures falling to 20°C to 29°C.
- *Hot dry season*
  Mid-August to mid-November with hotter day times from 26°C to 36°C and occasionally rains, especially towards the end of season.

The climograph (Figure 3.3) for Harare emphasises the distinct rain-drought pattern which is an important limiting factor for the country's agriculture. Sufficient rainfall for cropping can only be expected between October and April, so fields have to be irrigated for a second harvest.

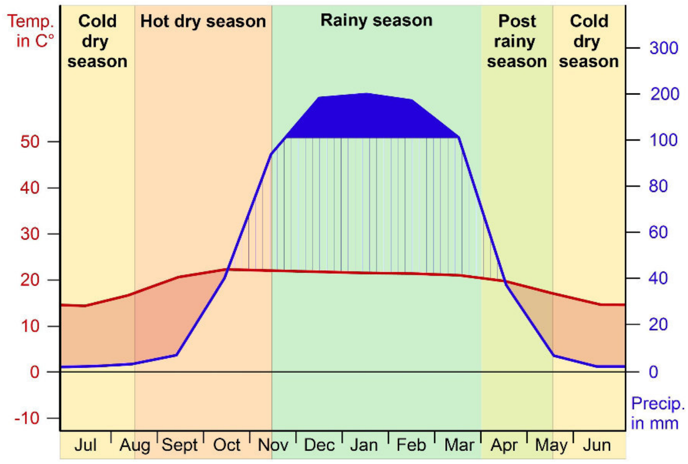

Figure 3.3: Climograph for Harare (Data WMO), indicating the four seasons (according to MSD).

3.4.2 Spatial characterisation of Zimbabwe's climate

With its high altitudes, the Zimbabwean relief endows the country with a moderate climate, resembling features of subtropical latitudes. It is also determining the country's spatial distribution of mean precipitation.

The spatial heterogeneity of Zimbabwe's climate is mainly characterized by a west-east increment of yearly precipitation (Figure 3.4). The Eastern part experiences in contrast to the rest of the country precipitation throughout the year (NYAMAPFENE 1991). The mountainous areas of Nyanga and Chimanimani, as well as the Eastern Highlands enclosed by them, do not only receive more rainfall from summer westerlies by condensing rising air. Their high altitudes also invert the drier east trades during winter months and lead to an orographic rainfall pattern which causes higher rainfalls in the mountainous areas and a dry leeward side in the South-East of Zimbabwe (NUDING 1999). The variability of rainfall events rises from east to west, corresponding with the decreasing annual precipitation.

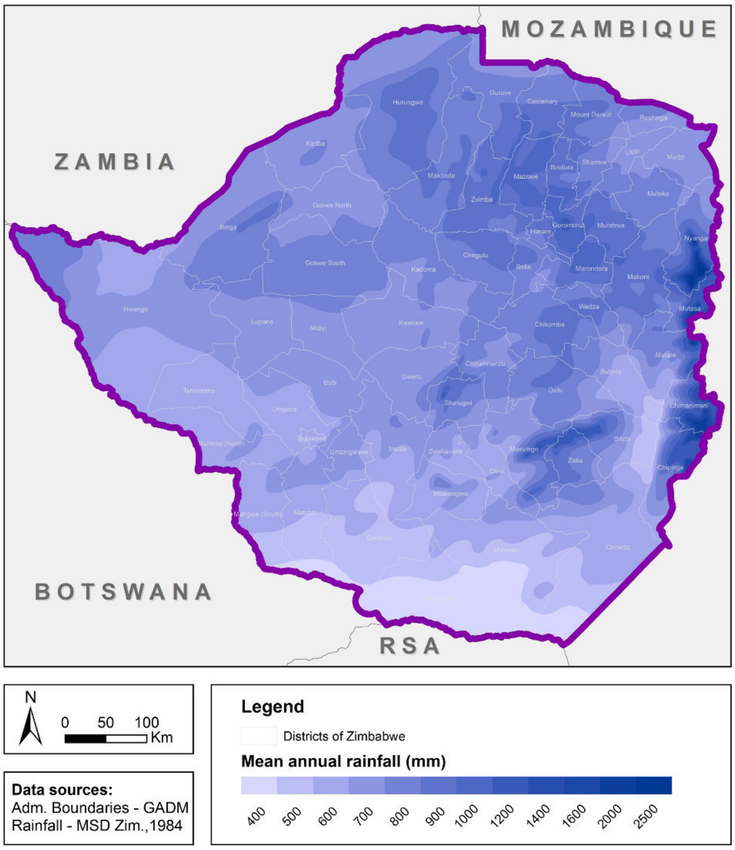

Figure 3.4: Map of Zimbabwe's mean annual rainfall, based on data from MSD Zimbabwe.

3.4.3 Climatic variations

Another distinct feature of the local climate besides its spatial heterogeneity and the course of the year is its high inter-annual variability. The country's location close to two oceans and between dynamic anticyclonal circulations exposes Zimbabwe and the region of Southern Africa to frequent irregular climate anomalies. Most prominent and of significant impact is the El Niño Southern Oscillation phenomena (ENSO). Teleconnections associated to the Pacific Phenomena lead to altered pressure cells and significant shifts in rainfall patterns. Various studies have shown that warmer sea-

surface temperatures of the Agulhas system lead to dryer conditions in Southern Africa and can even be considered as the main reason for severe droughts in the past (Holmgren et al. 2001). Matarira refers within this context to the El Niño event of 1982/83 which caused a 60% decrease of rainfall on 75% of the regions land surface (Matarira 1990). La Nina events on the other hand leads to increasing rainfalls
In addition to the ENSO phenomena and alterations over the Indian Ocean, Reason et al. stress a broad range of influential factors for regional climate variability. They consider the Atlantic circulations and variabilities of great importance for rainy seasons (Reason, Landman & Tennant 2006) and relate the early onset of summer rains in Zimbabwe and neighbouring countries to altered anticyclonic ridging from the Atlantic to the Indian Ocean (Reason et al. 2006).These anomalies add to the difficulties the agricultural sector of Southern Africa is facing anyway (like conflicts, depths, infrastructure and HIV/AIDS) as O'Brien and Vogel state in their call for an improved climate forecast (Vogel & O'Brien 2003).

3.5 Natural vegetation

One possibility to describe Zimbabwe's vegetation is the use of common local vegetation classes which can be further differentiated by a set of key species. Although other authors make use of the altitudinal gradient to classify the country's vegetation (especially by referring to Highveld and Lowveld vegetation) (Nuding 1999) (Wolmer 2007), or simply describe it as woodland of different species composition (Spong, Booth & Walmsley 2003), this more detailed approach will be presented in this chapter.

3.5.1 Overview of Zimbabwe's vegetation

Broadly outlined however, the Highveld encompasses a dense vegetation at heights above 1350m, forming the most southern tip of the African Miombo Woodland. Lower altitudes are covered with *Terminalia* and *Burkea* compositions. The Lowfeld is dominated by Mopane throughout, apart from Kalaharisands covered by *Baikiaea* and heavy soils covered by *Acacia* species (Cole 1986). Cole pointed out that these plant groups are widespread in the region and can be associated to the geomorphology of Southern Africa (compare Figure 3.5).
These geomorphic vegetation groups can be also related to the broad moist and dry savanna differentiation by Huntley. He distinguished savannas according to the properties of their underlying soils and the received amount of precipitation leading to structural and floristic significances. A method which allows to group the dominant genera of Zimbabwe: *Brachystegia*, *Julbernardia*, *Burkea* are woody plants of moist savannas; *Acacia*, *Commiphora* and *Colophospermum* of dry savannas (Huntley 1982).

In Southern Africa, different grass-wood compositions are usually classified by their respective tree-grass relationship, which is determined by climate, soil quality and geomorphology as 'bottom up factors' and by herbivory and fire as 'top down factors' (Venter, Scholes & Eckhardt 2003). This method of classification will be elaborated in the following section.

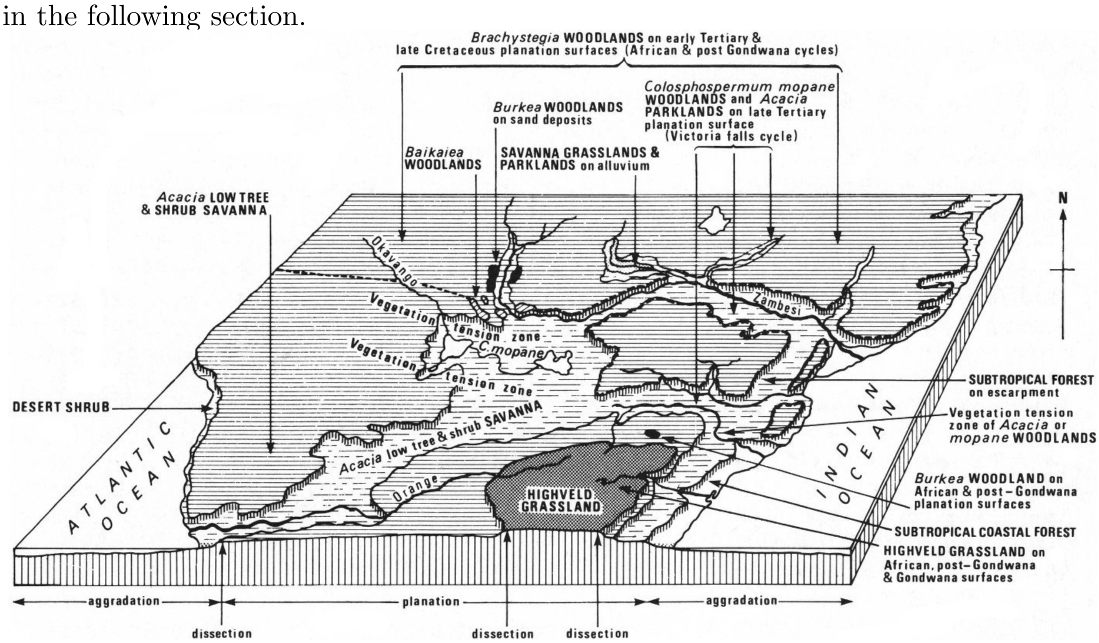

Figure 3.5: Relationship between vegetation and geomorphology in Africa *(Cole 1986).*

3.5.2 Regional ecosystem types of Zimbabwe

1963, Cole has presented a widely accepted characterisation of African and Australian savannas which explicitly focusses on their patchy composition instead of “latitudinal zoning” (Cole 1963). The separation of classes is achieved by the above mentioned comparison of portions of tree- and grass cover. Her primary categories, presented in Table 3.1, are of structural, physiognomical and floristical nature and are the result of an attempt to harmonise different mapping categories of savannas. Just as other contributions - also on Zimbabwe's neighbouring countries (Weare & Yalala 1971)- , the attempt was inspired by the ground breaking specialist meeting on Phyto-Geography of the C.S.A. in Yangambi, Belgian Congo in 1956.

Table 3.1: Five primary categories for the classification of savannas (Cole 1963)

Category	Description of Vegetation
Savanna woodland	Deciduous and semi-deciduous woodland of tall trees (more than 8 metres high) and tall mesophytic grasses (more than 80 cms. high); the spacing of the trees more than the diameter of canopy.
Savanna parkland	Tall mesophytic grassland (grasses more than 80 cms. high) with scattered deciduous trees (less than 8 metres high).
Savanna grassland	Tall tropical grassland without trees or shrubs.
Low tree and shrub savanna	Communities of widely spaced low growing perennial grasses (less than 80 cms. high) with abundant annuals and studded with widely spaced low growing trees and shrubs often less than 2 metres high.
Thicket and shrub	Communities of trees and shrubs without stratification

To a certain degree, Coles categories can be related to the mapping units shown in Figure 3.6. This map is based on a comprehensive vegetation map depicting the area of the international research project “Flora Zambesiaca” (WILD & GRANDVAUX BARBOSA 1967a) The accuracy of the potential vegetation has been proven by various authors later on (WOOD CONSULTANTS & IMPACTO 2002), who partly highlighted the present suppression by anthropogenic land use (KANSCHIK 1999). It can be seen as one of the most detailed sources on potential vegetation which has unfortunately never been updated (GOYDER 2013).

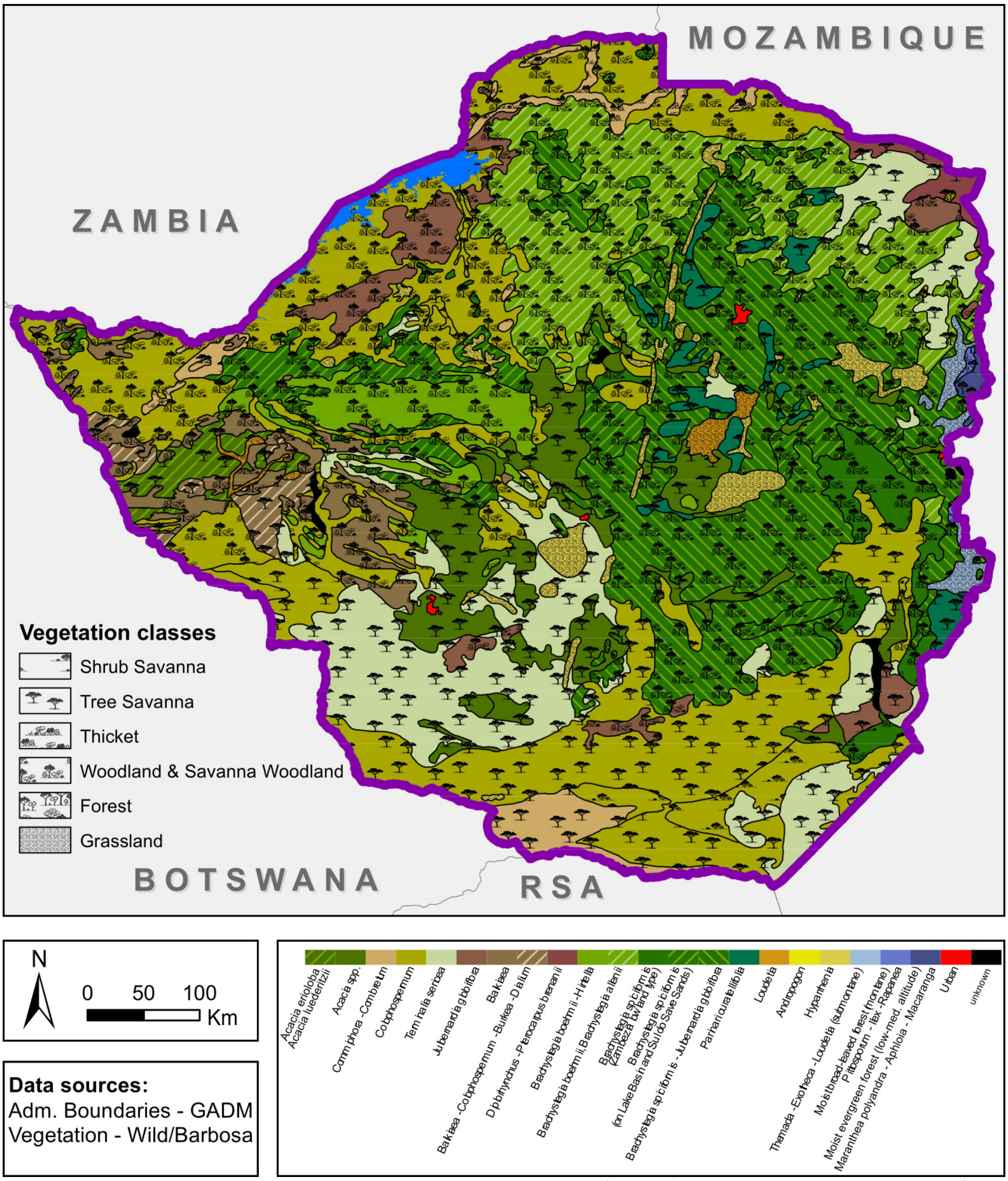

Figure 3.6: Natural vegetation of Zimbabwe, adapted from (WILD & GRANDVAUX BARBOSA 1967b).

The “Vegetation Map of the Flora Zambesiaca area” groups various key species in six vegetation categories from grassland to forest:

Grassland

Four different grassland types can be found in Zimbabwe: dominated either by *Andropogen*, *Hyperrhenia*, *Loudetia* or *Themeda*, *Exotheca* and submonate *Loudetia.* However, just like with woody plants, these genera are often associated with each other, for instance *Loudetia* with *Hyparrhenia* (Reynolds & Batello 2005). Grasslands usually describe areas with a tree and shrub cover of less than 10 percent (Scholes & Hall 1996), in Zimbabwe, they are limited to the central part of the country, the extent of the 'great dyke' and the Eastern Highlands. Edaphic conditions and altitude are the main reasons causing the sparse grassland patches in the region. Species of *Andropogen* for instance are tolerant to heavy minerals of ultramafic rocks (Kanschik 1999), *Loudetia* species are common on poor soils around wetlands (Hoare n.d.).

Shrub savanna

Shrub savannas in Zimbabwe are dominated by *Colophospermum mopane* and can be mainly found in the leeward region of the Eastern Highlands. In all parts of the country, they are enclosed by *Colophospermum* tree savanna while lacking high trees themselves. A circumstance which could be explained by underlying clay-rich vertisols whose dynamics of cracking and churning often limit the growth of trees (Mekonnen et al. 2006). The low available water capacity due to good water holding properties of clay is another growth limiting factor.

Tree savanna

According to Scholes and Hall, savannas are - in contrast to woodlands - characterized by a tree cover of 10 to 50% (Scholes & Hall 1996). By description and reference pictures, the term “tree savanna” can be compared to Coles “savanna parkland” (Cole 1963), although this author generally associates only *Acacia* to savanna parkland. The “Flora Zambesiaca” map however lists twelve genera of trees which form tree savanna types in various combinations: *Terminalia, Combretum, Commiphora, Colophospermum, Baikiaea, Burkea, Colophospermum, Dialium, Diplorhynchus, Pterocarpus, Acacia, Lonchocarpus and Parinari.* Together, they cover almost half of Zimbabwe's surface and form a distinct floristic contrast to the Miombo woodland, whether they are referred to as “tree savannas” or as “woodland” themselves. Usually, tree savannas are delimited to woodlands because of lower rainfall rates caused by low altitudes as shown in Figure 3.5. In addition, soil characteristics are prohibiting denser growth of woody plants; *Parinari ssp.* for instance are dominant where near surface water tables are preventing “woodlands” to grow (Cole 1986).

Thicket

Continuous thicket areas are only found in the Northern and Western part of the country. They are limited to uniform riverine vegetation and rocky outcrops as well as steep slopes. *Commiphora* and *Combretum* grow in these patches not favoured by woodland genera on the one and tree savanna on the other hand.

Woodland

The other prominent vegetation structure besides "tree savanna" is "woodland", which is formed by *Brachystegia* species in various combination and dominance, *Julbernardia, Colophospermum* and *Baikiaea*. Scholes and Hall define woodlands as areas with 50-100% canopy cover. Although their gramineous layer can be sparse, it is always significant (Scholes & Hall 1996). Higher altitudes and lower latitudes lead to more rainfall and more favourable conditions for woody plants, allowing denser woodland vegetation to grow. The range of *Brachystegia* and *Julbernardia ssp.* corresponds with the extend of the well-known Miombo woodland, which covers an extensive area of Eastern, Central and Southern Africa. In fact, the term "Miombo" describes *Brachystegia* in a number of vernacular dialects of the region which emphasises the importance as key species (Backéus et al. 2006). Lower altitudes and precipitation as well as less favourable soils sustain the Mopane (*Colophospermum*) and Teak (*Baikiaea*) woodlands. These Genera compositions are similar to "tree savanna" communities.

Forest

As sketched in the climate section above, the high altitudes of Eastern Zimbabwe sustain unique afromontane grasslands and moist forest communities. The latter can be characterized as broad leaved forests (*Pittosporum, Ilex* and *Rapanea*) and evergreen forests (*Maranthes, Aphloia* and *Macaranga*). All genera are limited to areas of high rainfall and altitude or exposed habitats such as rocky outcrops.

4 The origin of Zimbabwe's land question and land reform

Land is not only a resource of natural and economic value but also of great cultural importance. In the last 20 years, land reform and land tenure reform were more prominent in the political discourse on the African continent as ever before. Important to note is that disputes over land date back to way beyond the colonial time and continue today in manifold shape (Manji 2006, Moyo 2011). Especially in Southern Africa's civil societies and politics of the day, land plays a central role. This chapter highlights the role of land in Zimbabwe and its neighbouring countries and touches on reasons which lead to the various calls and efforts to restructure land tenure and ownership in Zimbabwe and its neighbours Namibia and South Africa.

4.1 The importance of land and its ownership in Zimbabwe

As the recent (international) media coverage of Zimbabwe's land reform has shown, land is a very sensitive topic in the region of Southern Africa. Impacts of the FTLRP have spilled over to neighbouring countries and resulted in manifold receptions among different stakeholders, pressure groups and individuals (LAHIFF & COUSINS 2001). The emotions are deeply rooted in the legislation and administration during colonial and apartheid times as well as in the resulting historical pathway of the distribution of agricultural land. On top of that, land in the region touches many aspects of governance, politics, economy, reconciliation and people's daily lives. Figure 4.1 shows the inequality of land ownership in Zimbabwe before it gained official independence in 1980. Various measures of systematic oppression and skewed tenure politics in the past contributed to the fact that half of the country's productive land was owned by about 6000 white owned farm business, while the black majority of farmers made a living on the other half. The Utete report of the Government of Zimbabwe numeralized the white owned land with 15.5 mio hectares, land worked on by 8500 small scale black farmers with 1,4 mio hectares, and the communal areas with 16.4 million hectares which were cultivated by 4.5 mio. Farmers (UTETE 2003).

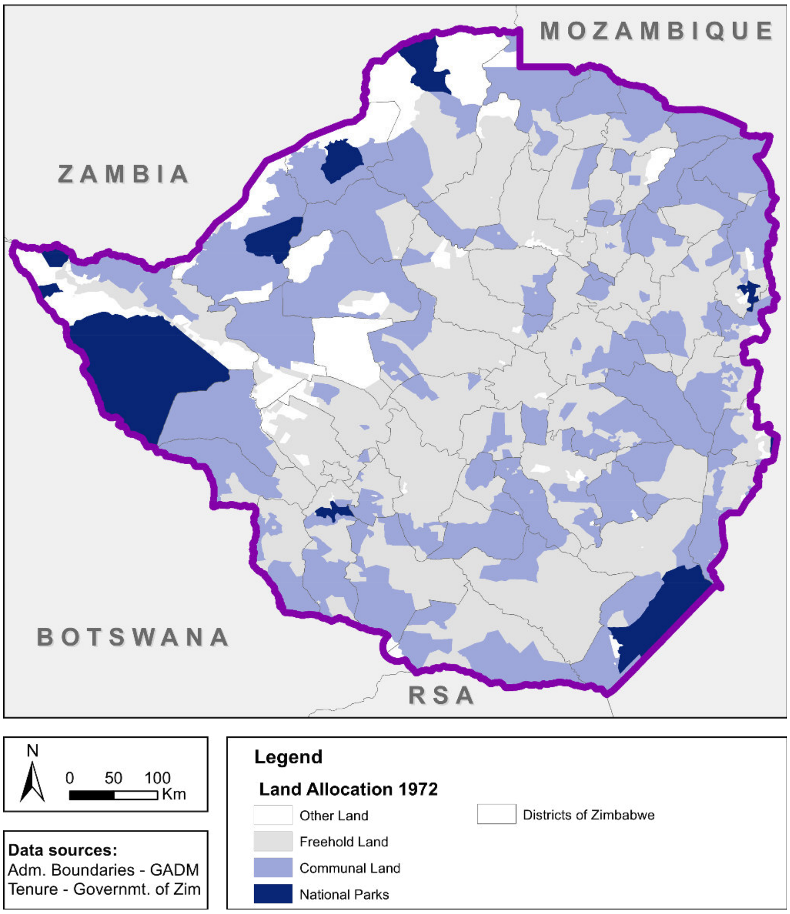

Figure 4.1: Land allocation in Rhodesia before official independence in 1980.

Moyo addressed the variety of aspects of tenure and their interwoveness by calling for a *historical*, *economic* and *political* research framework (MOYO 2005). In the following, five conceptional aspects of land ownership will be presented. They provide a broader understanding than the three fields Moyo mentioned and give insight into the complex setting of different factors which complicate the unequal distribution of land in the region. All of them influence each other and are strongly linked to the historical setting of the region. The call for land redistribution in the region can, as Murray and Williams state, "only be understood in the context of the history of conquest and dispossession, of territorial segregation and political exclusion, of generations of state control, of the movement of people and the socio-economic conditions of their lives" (C. MURRAY & WILLIAMS 1994).

It is important to remember that the here referred groups, such as the "white farmers", are in no ways homogeneous groups with similar views, history and political involvement (HODDER-WILLIAMS 1983). On the other hand, black individuals cannot be seen as beneficiaries of land reform per se. Farm workers for instance form a large group of black indigenous suffering from the new pattern of land distribution and production (HARTNACK 2005). Furthermore, it must be pointed out that all over in Southern Africa, customary tenure forms an integral part of land ownership management. Nevertheless, it is often not recognized as 'de jure' by governments, other regulations of the commons are mostly neglected (ALDEN WILY 2008). Therefore, 'tenure' in this thesis refers to as tenure in the legal sense, recognized, formulated and reformed by the government.

While arguing about the distribution of agricultural land in Southern Africa, it is very difficult to avoid to fall into the traps presented in this section. Remote Sensing as a politically neutral method bears therefore great opportunities to assess the spatial patterns of landownership and reform. It is essential however, to keep in mind that results and publications of the research can also be used for political manipulation within the discussion of land tenure and land reform in Zimbabwe.

4.1.1 Racial aspect of landownership

To understand the importance of land in Zimbabwe and the hot debate around the redressing of unequal ownership, one has to be aware of the strong racial tensions it comprises. In actual fact, land in the region is the embodiment of disparities between black and white in Southern Africa's former settler colonies (MOYO 2005). From early settlement until "independent" Rhodesia, race was an issue of land and part of the according legislation (MUTIZWA-MANGIZA 1985). Even years after liberation, the landownership hadn't changed much since colonial and apartheid times. Today, the spatial patterns of landownership in countries such as South Africa, Namibia and Zimbabwe still reflect the racist ideology of apartheid governments and authorities, and impact today's spatial planning (Smith 2002). And simply because the owners of large farms which are acquired during the land reform process are white, and beneficiaries to which the land is redistributed are black, land reform is a sensitive, emotional and race related issue (Moyo 2005). The radical reform of land tenure, linked to changing notions of race, nationalism and identity, has re-emphasized and intensified the racial character of land in the country (Muzondidya 2007). On the other side are arguments related to productivity, to the history of occupation and to land tenure (cf. the following aspects) all closely linked to racial and cultural differences of land owners in the region (Rutherford 2001).

4.1.2 Ideological perception of agricultural production

There is broad consensus about the need of a new balanced ownership of land in Southern Africa, but within the debate on how to achieve this, different stakeholders and opinions can be identified. Their differences often result from race, but also social and economic status. Commercial farmers had, for instance through the 'Commercial Farmers Union' (CFU), much influence on policy makers and still today, they play a central role in the dealing with land reform and shape the picture of how successful farming should look like in the region (Palmer 1990, Rutherford 2001). This roots also in the time of sanctions on Rhodesia, when the white commercial farmer became a "symbol of survival" (Galtung 1967).

Rent seeking of lobbyist groups and the resulting policy have cemented the division of the regional agricultural sector, leading to the large-scale commercial farmer in Southern Africa seen as the prototype of effective land management in the region (Deininger & Binswanger 1995, Rutherford 2004). His engineered and market oriented production stands in stark contrast to the subsistence agriculture practised by most rural Africans, although numerous of large scale farming enterprises of the region are highly indebted. The picture of the small-scale farmer as an unproductive, backward individual, without the capabilities to make economic sound decisions, persists in the context of land use and policy in Southern Africa (Englert 2001a, Kirsten & van Zyl 1998). But there are recent studies and figures which support a different and more nuanced view. They acknowledge the (sometimes higher) productivity of small-scale farmers which account for the majority of grain production worldwide, and also in Zimbabwe's Highlands (Baiphethi & Jacobs 2009, IFPRI 2002), and emphasize the fact that white farmers benefit through subsidies, special loans, veterinary and extension services, and are often still struggling to create profit (LEAD 2005). Moreover, a recent report stresses that large proportions of Sub-Saharan subsidy programmes effectively benefit the large scale and multi-national farming sector (ACBIO 2007).

4.1.3 Political aspects of land

The political connection to land in Zimbabwe was formed by colonial and apartheid history. The liberation struggles of Namibia, South Africa and Zimbabwe were mainly fought around the unequal distribution of land, resources and wealth. For governments of the new independent states, land became one of the most important issues. In 1977, Palmer described land as the "'life-blood' of Rhodesian politics" (PALMER 1977). The political parties which form today's governments of the three countries all emerged from liberation movements: Namibia's SWAPO (South West Africa People Organisation, former SWANU and OPO), South Africa's ANC (African National Congress) and Zimbabwe's ZANU PF (formerly ZANU and ZAPU). Governments of the region draw their post-colonial and post-Apartheid legitimacy from their historical influence, which is strengthened by selective narratives and memories of the liberation war (MELBER 2011). According to Moyo, the land question in these three settler territories remains unresolved because the liberation was only partly concluded, unlike in Mozambique or Angola (MOYO 2005). Also the fact that Zimbabwe's independence struggle was fought by people of the countryside, rather than urban elites like in South Africa, lead to a strong political identification with land as means and source of security, identity and production (HANLON, MANJENGWA & SMART 2013). After independence, Mugabe and relevant authorities glorified land and utilized religious themes to authenticate political claims and secure power (CHITANDO 2005). Terms like "sell out" for political opponents, and "birthright", "heritage" and "soul" as synonyms for land, in the political campaigns of ZANU-PF intensified the politicisation of land (compare Figure 4.2) (MOORE 2003).

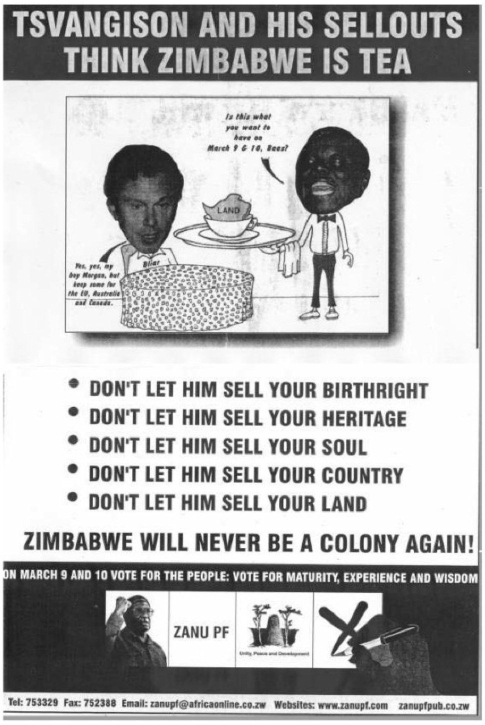

Figure 4.2: Billboard of ZANU-PF election campaign (MOORE 2003)

4.1.4 Economic realities of land distribution

Land in Zimbabwe has always been dominated by accumulation processes caused by strong involvement of the former and today's middle class (Hanlon et al. 2013). The institutionalized inequality in the country lead to vast economic disadvantages for the black majority and small-scale farmers compared to European descendants. Through legislation procedure, black farmers were only allowed to buy land outside of homeland like areas in designated "native purchase areas" while productive farmland was reserved for white farmers with commercial interest (Pollak 1975). Sanctions put on Rhodesia lead to economic policies which aimed to boost local economy and to secure food security. As a consequence, these policies also backed white farmers as they were the key suppliers of goods and jobs in the country, which made them powerful supporters of Ian Smiths minority government (Galtung 1967). While white areas of production were privileged, indigenous Africans experienced various repressions such as registration to monitor movement and taxation, which impelled many to formal labour (Bratton 1979). The overall significance of economic aspects of land becomes visible by the share agriculture contributes to Zimbabwe's exports, which was around 40% before the FTLRP (Sachikonye 2003). It was for a reason that the ZANU-PF chose the slogan "the Land is the Economy and the Economy is the Land" in the year 2000, and that a large proportion of their campaign material always addressed the skewed land ownership and economic situation of many farmers (Moore 2003).

4.1.5 Ecological aspects of landownership pattern

Both, the ideological division of agricultural producers in black communal and white commercial, as well as the unjust land access and ownership are manifested in the ecological discourse about land in Zimbabwe. In Southern Africa the colonial image of the white conservationist individual and the unsustainable black with lack of foresight, is persistent until today. Carruthers exemplifies this by drawing from images, notions and prejudices in the context of nature conservation and the design, establishment, and the management of protected areas (Carruthers 1995). The debate on the 'tragedy of the commons' is closely linked to the perception of traditional land use strategies in Sub-Saharan Africa (Hardin 1968).

Apart from these discourses is the huge gap in population density an undeniable main driving factor of proximate causes of degradation, such as overcropping, overgrazing and unsustainable resource extraction (ABEL & BLAIKIE 1989, DALAL-CLAYTON 1997). Awareness of the severity of nutrient depletion and a shrinking vegetation cover as a result of unequal land distribution was existent long before independence already (WHITLOW 1986). Today, the consequences of skewed population density in Zimbabwe are visible from space with optical sensors through nuances of colour as a direct result of different densities in vegetation cover (Figure 4.3).

Figure 4.3: Screenshot of Google Earth, showing tenure related differences of vegetation density.

4.2 The history of Zimbabwe

Disputes on various levels, often following the influx of different cultural groups, have shaped the history of Zimbabwe. They have been carried out over governance, land, resources and identity. These aspects, together with race, form the central narrative of liberation movements and rhetoric of post-independence leaders (RAFTOPOULOS & MLAMBO 2008). First settlements in today's Zimbabwe date back to 50 thousand years B.C. Before and during the arrival of white pioneers, the area was ruled by a number of well-established kingdoms with diverse histories. The transition of power to whites was accompanied by the unique acquisition and administration of land by the British South African Company (BSAC), established by Cecil Rhodes.

Since independence, ruling elites of Zimbabwe always tried to promote a pre-colonial history of powerful kingdoms and national identity. The reality however was much more differentiated than this concept of 'patriotic history' (NDLOVU-GATSHENI 2011, RANGER 2004). However, the local kingdoms with their regional influence and power are striking features of this time, together with waves of immigration. The growing of an Iron Age settlement to the prominent 'Great Zimbabwe' - a well-documented stone structure, populated by up to eighteen thousand people in its heyday - preceded this period. To understand the land question however, it is important to focus on the time after settlers of European descent have started to farm in the region of today’s Zimbabwe. According to Chitiyo, “the land question in Zimbabwe is both a cause and consequence of Zimbabwe's struggle for liberation” (Chitiyo 2000).

4.2.1 From colonial time (1890) to Unilateral Declaration of Independence (1965)

As in the whole of Southern Africa, Christian missionaries, merchants and later seekers of concessions, spearheaded an influx of Europeans with various ambitions. All groups were either directly or indirectly supported from western governments, leaders and societal interest groups. They paved the way for colonisation by integrating Shonas, Ndebele and others into European economic principles, judiciary, beliefs, and way of life (Zvobgo 1977). Early settlers encountered over five hundred year old Shona settlements, which resulted from a group of different Shona kingdoms. Ndebele groups arrived later from the South around 1835, together with Boer treks seeking for promised land; both fought against each other about cattle and settlement in various occasions. The Ndebele gained their power based on raids and oppression of Shona settling the region but were also displaced by Boers until they finally founded their capital Bulawayo, the second biggest city of Zimbabwe today (Zvobgo 2009).

The most thorough European influence was the British occupational rule. It started in 1890 with the activities of John Cecil Rhodes, the British imperialist and empire builder (Raftopoulos & Mlambo 2008). In this year, the Pioneer Column arrived from South Africa, consisting of around 200 pioneers and more than twice as much policemen. Rhodes activities in the mining sector and the hope to prospect gold in the Shona region lead to the establishment of the BSAC. Only shortly after, 1893-1894, the 'I. Matabale War' formed the first larger land dispute (also caused by the severe rinderpest eradication), followed by the 'II. Matabele War', or 'I. Chimurenga' 1896-1897 (Morens et al. 2011). For the latter, Shona joined Ndebele in a united uprising against European Settlers, but the different groups were defeated, some of their leaders surrendered, some were murdered (Beach 1979, Burke 1970).

Backed by the Government of Great Britain, the BSAC started concessions and later established a company rule in the region. The Southern part of then named Rhodesia became a self governed colony of the British crown in 1923 (Slinn 1971). It was in this time when the inequality of land governance was cemented by the Land Apportionment Act (LAA) in 1930, drafted by the Carter Commission and passed through parliament headed by Premier Moffat (Chitiyo 2000). It removed the right of 'Natives' to hold commercial land and divided Southern Rhodesia in separate areas for 'Europeans' (commercial land) and 'Natives' (Tribal Trust Land). To achieve a thorough separation, European properties which fell into 'Native land' were included therein and vice versa. Municipalities had to designate areas allowed for 'Natives', outside the 'Tribal Trust Land', black residents could only acquire land in these areas or small 'African Purchase Areas' (ENGLERT 2001a, JENNINGS & HUGGINS 1935). Jennings and Huggins explain that "A Native is defined as any member of the aboriginal tribes or races of Africa, or any person having the blood of such tribes or races, and living among and after the manner of Natives. This means that coloured people, Asiatics, etc., not falling within this category have rights to acquire land in the European Area" (JENNINGS & HUGGINS 1935).

With lack of enforcement, this concept became blurred. The land question was revitalised with the 'Native Land Husbandry Act' (NLHA) from 1951, which addressed the problem of land shortage in overcrowded native reserves, but also sought for a final division of blacks in peasants and proletariats. Core issue was therefore to overcome the fragmentation of the boundaries established by the LAA and to reassure a strong division of tenure (MACHINGAIDZE 1991). It also aimed to create a black middle class to increase crop production and numbers of consumers, as well as skilled workers to back local industry and production under the tightening up of sanctions (DUGGAN 1980). However, instead of relieving pressure, the NLHA fostered anger of local inhabitants, as it broke with traditional rules and introduced upper limits of cattle stocking, and top down decisions on land use and agricultural production (BULMAN 1970). While opposition grew in the rural areas, a new wave of European settlers which escaped the conditions of post-World War II Europe arrived in Zimbabwe, the number of whites rose from around 80,000 in 1945 to over 200,000 in 1960 (UTETE 2003).

4.2.2 From Unilateral Declaration of Independence (1965) to Zimbabwe (1980)

In November 1965, the cabinet of the Rhodesian state passed the 'Unilateral Declaration of Independence' and set itself independent from Great Britain and the Commonwealth. It was a reaction to the unsuccessful bids to gain independence from Britain like Zambia and Malawi. This was however condemned by the United Nations and the general assembly voted with 107 to 2 votes against the recognition of an independent Rhodesia (MCDOUGAL & REISMAN 1968). Economic sanctions were the consequence, which put enormous pressure on Rhodesia's economy and requested a new orientation of internal politics. Being the most comprehensive sanctions of that time, they were implemented gradually and eventually contributed to the breakdown of Rhodesia (MINTER & SCHMIDT 1988). West Germany remained the most important international trading partner of Rhodesia (GALTUNG 1967).

As blacks were represented only partly in the Rhodesian government, some chiefs or traditional leaders were tightly linked to the minority government and oppression of ordinary black citizens continued, a guerilla war was fought from 1964 until independence in 1980. During this time, national and international critique of the racial tenure system intensified. The "Quent Commission of Inquiry into Racial Discrimination" recommended to abolish the land tenure system in 1976. One year later, the Land Tenure Amendment Act was passed which allowed all races to acquire free hold tenure in the commercial areas (Englert 2001a). The 'Rhodesian Bush War' is also known as 'Second Chimurenga', with reference to the 'First Chimurenga' (meaning revolution or struggle) against the BSAC (Suransky 1981). Joshua Nkomo head of Zimbabwe African People's Union (ZAPU) and Robert Mugabe head of Zimbabwe African National Union (ZANU) lead the fight against the white minority regime, which formed under pressure an intermediate unrecognised state Rhodesia-Zimbabwe in 1979. The two leaders also lead a delegation participating at the Lancaster House negotiations which lead to an independent and officially recognized state of Zimbabwe in 1980. Both Unions formed the Patriotic Front and operated from Zambia and Mozambique, mainly financed by Russia and China (Moorcraft & McLaughlin 2010).

The Lancaster House meetings between the interim state Rhodesia-Zimbabwe and the ZANU/ZAPU fraction were mediated by the British Government. Their outcome was the Lancaster House Agreement (LHA) in 1979 which paved the way from the six months old interim state to independent Zimbabwe. It forms a central part of land legislation and reform of the new state of Zimbabwe, as it fixed the negotiated regulations on expropriation of white farmers (Gregory 1980).

4.2.3 From Independence (1980) to economic crisis (1997) and FTLRP (2000)

Despite hopes for a peaceful prosperity, the reconciliation phase after independence did not last long. Internal conflicts over power, as well as disputes between the two PF-fronts let to civil and military unrest especially in Matabeleland. As a consequence, the North-Korean trained Shona speaking 5th brigade committed a massacre and killed ten thousands of Ndebele, displaced hundreds of thousands, and denied them access to food and basic needs (Phimister 2008). In 1988, ZANU and ZAPU merged into ZANU-PF, headed by Robert Mugabe who succeeded various internal power struggles (Moore 2014). He later became President after Canaan Banana under which he served as Prime Minister (O'Brien 2009).

Zimbabwe was everything but a weak state and the administration as well as the centralist government used the strong interventionist character of institutions they inherited after independence to strengthen their own power (Alexander & McGregor 2013). Despite successful programs addressed at the black majority, such as basic education, two governmental decisions can be identified which shackled the state budget and the country's stability: The promise of high pensions for war veterans and

pay rises for public workers as well as the military involvement in the DR Congo's civil war 1998 (McGregor 2002). At the same time, the grip of the International Monetary Fund (IMF) on the Zimbabwean Government tightened as requirements increased until eventually, international loans and payments were suspended (Mlambo 1995). State decisions and the economic crisis lead to a civil unrest mainly lead my unions and later on, the opposition party Movement for Democratic Change (MDC) was founded in the time of a general perception of a failing government. Although it did well in countrywide elections and referendum in 2000, it lacked rural support and widespread influence (Raftopoulos 2006).
With fading power, ZANU-PF took more measures to secure its influence by threatening supporters of opposition and re-emphasizing the struggle for equality and land. In stark contrast to the rhetoric of regaining the land in a 'Third Chimurenga', stands the government's repression of residents, the mystification of liberation to secure power, and the eviction of around 700.000 people in Harare with indirect consequences for over 2 million people. This 'Operation Murambatsvina', officially a program to restore order, has been criticized by the international community and human rights organisations, as it was also directed against MDC supporters (Melber 2004, Vambe 2008).

4.3 Land reform in Zimbabwe

The historic pathway to the nation of Zimbabwe, with its struggle over land, resources and race, together with the long lasting unequal distribution of land ownership, made a redistribution through a national land reform program inevitable. Not only did the independence movements draw their legitimacy from this issue after they came to power; the social, ecological and administrative challenges of the skewed ownership (compare Figure 4.1) demanded a new order of tenure, settlement and land use. Moyo provided the most comprehensive overview of people in demand for land to be acquired by the state. Their heterogeneity of interests and demands underpins the complexity of the subject 'land reform in Zimbabwe':

- Landless young households seeking communal land
- Households in unfavourable areas with small agricultural plots
- Communities with depleting grazing areas
- Households aiming for the small areas with better water supply
- Peasants looking for possibilities to increase production
- People outside of communal areas seeking titles in these areas
- Emerging elites looking for individual titles as investment
- Governmental and NGO structures in need of titles for Community Development projects

- Migrant peasants which are after land to settle down
- Migrant workers from towns retaining titles for secured family production
- Retiring workers looking for land as security
- Foreign migrants seeking places for retirement

As complex as the land question's history in Zimbabwe is the sequence of events redressing the ownership patterns. All in all, over 16,000,000 hectares of agricultural land were redistributed in about 23 years, facilitated by different acts and amendments, farm purchases, compulsory land acquisitions, individual and formal evictions (Moyo 2006).

4.3.1 Land reforms, an introduction

Reforms of land ownership have been carried out all over the world since settlement had to be administrated. From the Ottoman Empire to increase productivity, over the United States of America to re-arrange native ownership, to post-soviet countries in order to break up the kolkhoz production scheme; reasons for and methods of land reform are diverse (Davison 2015, Otis 2014, Wegren 2003). By addressing the aspects of land ownership presented above, land reforms contribute to economic productivity, environmental sustainability, social equity, justification and pacification. The United Nations emphasize the importance of secure tenure as a prerequisite for poverty reduction and food security (UN n.d.). Land reforms are either defined narrowly as means of land provision to landless, or comprehensive as the transformation of an agricultural production (Tai 1974). Often, the terms "agrarian reforms" and "land reforms" are used interchangeably, Jacobs however draws a division and sees agrarian reform as more inclusive with an additional provision of new infrastructure and extension (Jacobs 2013). Land reforms can be state-led or driven by bottom up approaches, in Southern Africa they are carried out by national governments and mainly aim for the redistribution of agricultural land.

Because of the distinct history and character of ownership, state-led land reforms in Southern Africa focus on three broad aspects: *redistribution*, *restitution* and *tenure reform* (Lahiff 2003). These can coexist in land reform programs, although redistribution is mostly at the centre of all programs in the region. This is partly due to the fact that it is the easiest to conduct (depending on the methodology), as there is an increasing complexity among the three aspects, but mainly because its impact is of greatest magnitude and visibility. In South Africa for instance, all three aspects have been addressed in different pace of progress (Carey Miller & Pope 2000).

Land tenure reform comprises the abolishment of acts from the past (such as the LAA and NLHA in Zimbabwe); the regulation of ownership security; the codification of use, control and transfer rights; the legal framework to deal with violations; definition of responsible institutions; and various other aspects of legislation, jurisdiction and enforcement. Its complexity is rooted in its effects on the discussion of citizenship and government in the respective states (Boone 2007).

Land restitution is an important part of the South African land reform, rather than the Zimbabwean, and represents a method to directly redress injustices of the past (Walker 2008). Through 'land claims', people and groups, which were evicted during apartheid time (after 1913) could reclaim the cultural, spiritual, and economic importance of the land they settled on. By providing information on the claimants (individuals, descendants, or communities), the eviction, and the compensation, it was possible to request a restoration of property rights before the dispossession took place. The claim was lodged with the 'Commission on Restitution of Land Rights' (DRDLR n.d.).

Land redistribution, on the other hand addresses the above mentioned problems such as environmental sustainability, overcrowding of former 'Tribal Trust Lands' or 'Homelands', racial disparities and inefficient production schemes, on a broader basis through the redistribution of land from one group to another (Rosset, Patel & Courville 2006). Land redistribution can be achieved in different ways, either through an expropriation program or a less radical non-compulsory market based approach. The latter preceded the FTLRP in Zimbabwe and is still the modus operandi in Namibia and South Africa. Its regional name “willing buyer - willing seller” describes the principle well: If a legal land owner aims his or her property as a willing seller, it must first offer it to a willing buyer, often the state, which would pay the market value of the property, gains its legal status and therefore contributes to a change of ownership pattern (Aliber & Mokoena 2015). The market based approach is favoured by local elites and has often been implemented after negotiation with western donor countries, the World Bank and the IMF (Platteau 1992). There is an own debate on the practicability and necessity of this kind of approach, as it is a costly and lengthy process through a number of reasons. Furthermore, it often does not meet the targets and is not helpful to overcome the division into large-scale and small-scale farmers (Lahiff 2007).

4.3.2 From Lancaster to 1990, the first phase of land reform

After years of war, violent conflict and international sanctions, the conflict parties of the 'Rhodesian War' gathered in England’s Lancaster House to negotiate the framework and conditions for an independent state of Zimbabwe with majority rule. The resulting trilateral LHA formed the basis for independence and included a comprehensive chapter on land reform. The land question almost lead to a drop-out of the ZANU/ZAPU delegation as its visions were fundamentally different to that of other parties, but pressure was high and the 'Patriotic Front' did not want to be responsible for a collapse of talks (Gregory 1980). Heating the debate was the pull-back of the first financial draft by the British Government. Finally, it was agreed that the British would pay for half of the costs of a willing-buyer willing-seller land reform program, while compulsory land acquisition was not allowed apart for land which was underutilized, or of national interest. Expropriation in these cases had to be compensated immediately and with foreign currency (PALMER 1990). Furthermore, the Zimbabwean Government was obliged to stick to this agreement and was only able to implement an own land reform program, which would go beyond resettlement, after 1990. Discussions on large redistribution of land were new that time, as the other settler colonies Namibia and South Africa gained independence and majority rule later. Military disputes in Mozambique and Angola hindered ordered restitution and redistribution after Independence (MOYO 2000).

In the early 1980'ies after independence, the immediate focus of land reform goals was to address the ecological pressure and social injustice in communal areas. The program was also a reaction to the shackled economy and agricultural production, as well as a growing food insecurity of high numbers of internally displaced people (PALMER 1990). Seven aims were formulated: reduced population density in communal areas, higher production of small scale farmers, improved living standards of the marginalized, growth opportunities for landless and jobless, re-cultivation of unused agricultural land, improved infrastructure and economic growth, and secured national stability and progress (KINSEY 1999). Together with these social aims, a general vision of 'growth with equity' was established. This meant a focus on general growth with the idea of social and economic upliftment in the rural areas to avoid conflict of interests between commercial and communal farmer interest groups (ENGLERT 2001b).

Through the 'Communal Land Act' in 1981, the tenure governance which was drafted in the 'Land Apportionment Act' and several subsequent amendments on 'Tribal Trust Land', was overcome. Designated authorities instead of 'traditional leaders' were now institutionalized to govern land rights and use, but this transformation proceeded slowly (COUSINS, WEINER & AMIN 1992).

As agreed on in the LHA, the government passed the Land Acquisition Act in 1985. It formed the cornerstone of the 'willing-seller, willing-buyer' program which was based on constitutional arrangements following the LHA before. With strengthened rights to acquire land, the government sought to speed up the land reform process. But with lack of international support, a successful opposition of white farmers, and tightened hands by an Economic Structural Adjustment Programme, the government fell short of its own set goals and only acquired less than half of the area it sought to redistribute (MOYO 2006).

4.3.3 From 1990 to 2000, the second phase of land reform

After the expiration of the LHA, tensions grew further between the British and Zimbabwean Governments, as Zimbabwe complained about the shortcomings of the market based land reform, mainly costs and duration, and took a more radical path to the redistribution of land (Lebert 2006). The Government of Zimbabwe addressed the land question with a Land Policy Statement immediately in 1990. At the same time, it changed sections 16 of the constitution by adding an amendment which empowered the state organs to carry out compulsory land acquisition for utilized land as well. Compensations to expropriated individuals and corporations could now be paid in local currency and within 'reasonable timeframe' instead of immediately after acquisition. These changes were later passed in a revised Acquisition Act in 1992 to create a statutory basis (Coldham 1993). Resettlement areas were either designed as 'B models', or 'A models' which referred to cooperative or 'village based', a division which resembled the planning of the last decades and missed a break with the pre-independence planning philosophy. Although the cooperative model fitted the ideological vision of the socialist government better, most farmers were resettled in village models (Chaumba et al. 2003).

The government also set an ambitious target to acquire five million more hectares in order to be able to resettle over 100,000 households. Furthermore, it aimed to revise the land tenure regulation in communal areas and to introduce a taxation on land. A change of focus on economic instead on social criteria as in the 1980ies, was in line with the overall aim to integrate more black farmers in the commercial sector (Moyo & Trust 1995). Some argue that the shift to an economic focus of land reform was influenced by lobby groups and a more and more reluctant black elite, which did not see interest in the redistribution of land any more (Englert 2001b). Moreover fell this phase of land reform in the high noon of the IMF and World Bank activities which shaped decisions and policy as they gave loan packages to a vast majority of Sub-Saharan countries (Sahn, Dorosh & Younger 1999). There are several other reasons why the land reform process slowed down several times, a lot of them being of structural nature. As numbers of willing-sellers decreased with the slowdown of white emigration, land which could be acquired became less. At the same time, market prices rose and limited the states capacities in times of economic crises and state deficits, with a national budget controlled by the IMF (Palmer 1990). Recent studies proof that 69% of white owned land has changed ownership since 1980, and the majority got a 'no present interest' certificate which was easy to get and allowed the land to be sold on the free market (Pilossof 2016).

As a reaction of these difficulties, the Zimbabwean Government passed the new Land Acquisition Act in 1992 to again speed up the reform process (Coldham 1993). However, after a change of Government in Great Britain, external funding for land acquisitions declined further as the labour government drew a sharp line to the negotiations of its predecessor. This has strained the relations of the two countries for years and was subject in several campaigns and propaganda related to elections and land, exemplified in the popular song line "the only Blair I know is a toilet" from 2005 which draws a comparison between the British Premier and the Zimbabwean name for pit toilets (Thram 2006). Already before this change, the British were more and more critical towards the growing gap between aims and achievements of resettlements by the Zimbabweans.

4.3.4 The third phase as Fast Track Land Reform Programme (FTLRP)

With the slow proceedings of the market-based redistribution, combined with the perception of ordinary Zimbabweans, and especially war veterans, that they did not benefit from the independence in 1980, discontent grew in large proportions of the Zimbabwean population. It was a time in which the land question was intensified and racialised by the debates on land reform and the international influence on it, as well as by the intense rhetoric of the government and a starting propaganda campaign (Chitando 2005).

Meanwhile, the ZANU-PF faced a growing opposition from unions and the MDC, and having still the majority in parliament, the party drafted a referendum on a new constitution. Civil Society Organizations had organized themselves in 1997 and lobbied as the pro-democratic force 'National Constitutional Assembly' against the power gain of the one party Government in Harare (Dorman 2001, Sithole 2001). A successful turnout of the first national referendum after independence would have allowed the government to acquire land without compensation but also would have empowered its structures and presidency. Linking the emotional debate on land tenure with the centralization of power eventually did not work out for the government. With 53% of votes, the referendum was dismissed, while the majority of voters stated in a survey that they were more concerned about a further empowered, centralist government than the land question. However, only around 30% of all Zimbabweans, mainly inhabitants of the large urban areas, participated at the referendum (Englert 2001a).

After this result, civil unrest started in a more spontaneous than planned manner, dubbed as 'jambanja', which means 'violent argument' in the Shona language (Chaumba et al. 2003). Various interest groups which labelled themselves as war veterans, invaded large scale farms, owned or managed by the white minority. However, the young age and the mobility of a large proportion of invaders, supported the allegations which accused the ZANU-PF of orchestrating parts of the uprising to influence the upcoming election as it was afraid of an MDC landslide victory (Willems 2004). Although Robert Mugabe denied the initiation of the invasions, and while officials did condemn the actions, farm occupations were not ended by the police because of the lack of resources and the fear of a further escalation. Other reports of direct involvement of police forces in evictions exist, despite a high court ruling, which deemed the invasions as illegal. Mugabe labelled the land question 'as something which cannot be dealt with by courts' (Compagnon 2011).

In April 2000, parts of the dismissed referendum were passed by the government. It allowed authorities to buy farmers of their farms compulsory without compensating for the land, but for the investments they made on it. Expropriated farmers plead this amendment in the ongoing negotiations over compensation of farmers affected by the FTLRP. Later, end of 2000, Mugabe passed an amnesty for the crimes committed around the FTLRP except murder, rape and robbery (Fischer 2002).

After farms had changed ownership, state officials started to re-plan the agricultural area in a way which accommodated the new tenure structures. Designated areas of A1 and A2 farming schemes were proclaimed and surveyed as far as possible. The superimposed concept of the two husbandry categories is oriented at the resettlement schemes of the 1980'ies and resemble the vision of commercial successful black farmers but also drew a sharper line to pre-independence tenure administration. Small-hold A1 farmers were granted individual crop area and sometimes common grazing land. Opposed to this 'villagized' model were A2 farms designed as small versions of commercial farms with market integration, business plans (Marongwe 2011).

Although violence over the land question of Zimbabwe and farm evictions have occurred earlier, the de-racialisation has never been as thorough as after 2000 (Chitiyo 2000). After the FTLRP the number of white commercial farmers has reduced from around 6000 to less than six hundred (Pilossof 2012).

5 Technical factors influencing change analysis in remote sensing

To map changes of the earth's surface by means of remote sensing, it is essential to understand the conditions which influence the acquisition process of data. Apart from the spatial heterogeneity of natural growth potential and vegetation in Zimbabwe touched on in chapter 4, properties of change which has occurred and properties of sensors which are used to map the change, have to be considered in a land reform analysis for Zimbabwe (Thonfeld 2014). As they also played a role in the publications linked to this thesis, an overview of these technical factors will be given in the following.

5.1 Aspects of change

LULCC analysis researches the changing Earth's surface, where one land cover type is altered or replaced by another (Lambin & Geist 2008). A common change analysis in remote sensing is the post classification comparison, where two time steps of land use classifications are compared to each other. But analysis of temporal gradients, together with the direct use of indices, forms an integral part of research, as their informative value is much greater than the interpretations of snapshots only. Making use of the multi-temporal space allows to formulate change as vectors which describe direction and magnitude of change, compared to a bi-modal analysis of post classification (Lambin & Strahlers 1994).

Apart from magnitude, as the intensity of change from one land use type to another, change events can be described by their temporal or spatial characteristics. Although the Zimbabwean FTLRP is a manmade change, both patterns are unknown as the happenings were not a centrally and spatially planned process. A main goal of this thesis is to examine different changes of agricultural area, and this section serves as a conceptualisation to categorise the occurred changes.

5.1.1 Temporal nature

In general, three different temporal characteristics of trends can be identified: *abrupt* change, *gradual* change or *periodic* change patterns (Thonfeld 2014, Verbesselt, Hyndman, Zeileis, et al. 2010a). This distinction is important in remote sensing studies, because although the magnitude of change between two time-steps of acquisition might be similar, the pattern, causes and consequences can differ significantly. Abrupt changes are the result of sudden events with great impact on the land cover, such as storms, floods, fires or harvesting. Gradual changes are a result of slowly changing conditions, such as rising temperatures, increasing precipitation, or grazing pressure. Periodic changes result from frequent occurring events such as filling of ephemeral rivers, seasonality of favourable growth conditions, or crop and grazing conditions. In reality, two types of change often occur at the same time and might also influence each other. Gradual trends can experience abrupt changes of their direction, while patterns of periodic changes can be influenced by both abrupt changes and also long term trends of magnitude. Figure 5.1 depicts different changes with their temporal characteristics of occurrence and magnitude.

It exemplifies that combinations can affect the magnitude of a change (gradual seasonal change), or the temporal pattern of a change (abrupt seasonal change). The latter will be paid attention to in chapter 11.

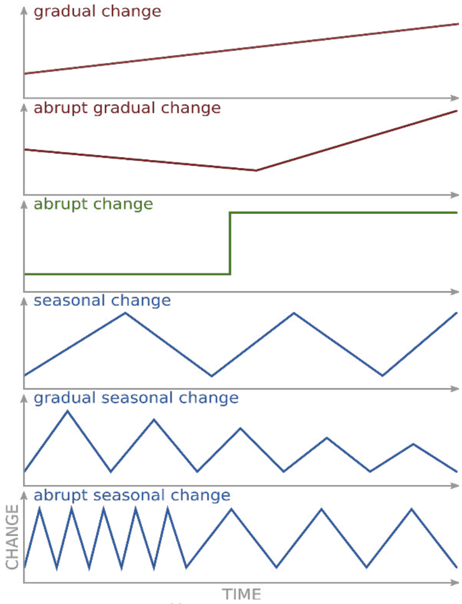

Figure 5.1: Different types and combinations of changes in temporal signals.

5.1.2 Spatial nature

The pattern of the area which changed its land cover is another key feature of change typology, as it contains information of causes and results. Heterogeneous patterns often result from natural occurring changes, as the change events follow random influencing factors. These can be for instance fuel load for fires, or the direction of wind and the age of forests for storm events. Human induced changes however, are characterized by homogeneous patterns as they relate to anthropogenic zoning of landscapes such as farm boundaries, administrative divisions or forest parcels.

The development of spatial character is also characterized by a temporal pattern. These spatio-temporal patterns may allow do draw additional information on driving forces of land use change from direction, growth, magnitude, and area converted by change (Blaschke 2005, Thonfeld 2014).

5.2 Aspects of data acquisition

Remote sensing is about the relation of the backscattered or emitted radiation of the earth and the sensor of an acquisition platform (Lillesand, Kiefer & Chipman 2014). Different criteria have to be considered when the earth is observed by the detector, they can be grouped into sensor and acquisition properties which both determine the remote sensing product.

5.2.1 Spatial resolution of sensor

Important for the detection of land use change is the appropriate spatial resolution, determined by the area represented in one pixel of the sensors product. This 'Instantaneous Field Of View' (IFOV) must be adequate to represent the spatial extent of changes, as mixed pixels do not allow to carry out a change analysis (TURNER 1990). There is always a trade-off between different resolutions, as the spatial resolution impacts the temporal resolution: the larger the area covered by the sensor, the higher the repetition rate of the platform (CHEN ET AL. 1999). Sensors of very high spatial resolution, such as QuickBird with a nadir IFOV of 60 by 60 cm, cannot be used for phenological analysis, because they lack the temporal resolution (XIE, SHA & YU 2008). Their explanatory power is limited to mapping the results of occurred land use changes, rather than the underlying processes, because the low number of acquisition time-steps per year allows a post classification only. Low spatial resolution sensors on the other hand, such as AVHRR with a nadir resolution of 1.1 km ("NOAA Satellite Information System (NOAASIS)" n.d.), have a high repetition rate of acquisition. But their coarse scale products limit their suitability for accurate change analysis as the process on the ground might be too small to be recognized in a IFOV of 1km by 1km. In Figure 5.2, Foody demonstrates the problem of mixed pixels which result from different overlapping backscattered signals (FOODY 2004). Pixel a) shows distinct objects smaller than the resolution scattered in another land cover type, b) a mixture of discrete continuous land cover types, c) the gradual change from one land cover type to another and d) the influence of an object outside of the IFOV. All types of sensors experience these problems at different scale, the coarser the resolution, the greater is the influence of mixed land cover. The sensor MODIS, placed on the Satellites Terra&Aqua, provides a thankful compromise between spatial (250x250m for Vegetation analysis) and temporal (daily) resolution. It is operating since 2000 (ESA n.d.) and its products were used in this analysis.

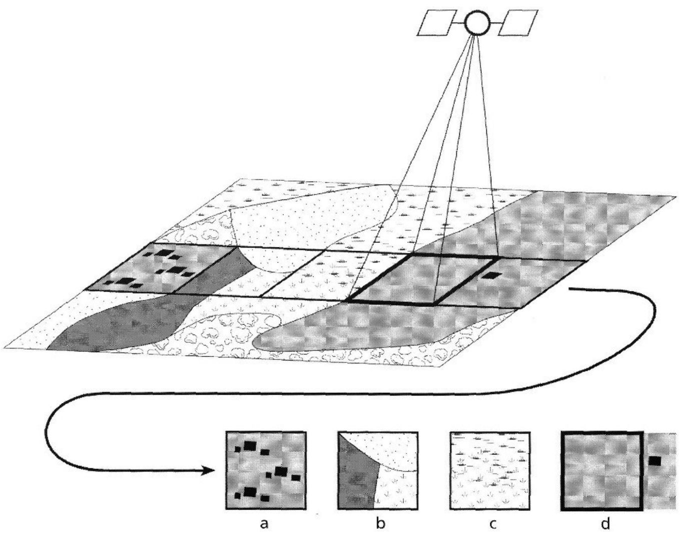

Figure 5.2: Four examples of mixed pixels, adapted from (FOODY 2004).

5.2.2 Temporal resolution of sensor

The temporal resolution is the frequency of data acquisition in a given time, determined by the number of passes of the satellite over the area to be recorded. Temporal resolution is crucial for change detection, as it relates to the temporal characteristics of trends elaborated earlier. The repeating acquisition points might not be of regular character as an increasing number of platforms allow an off nadir acquisition, where the sensor can be directed by tilting. Temporal resolution of a sensor is determined by the interplay of height and speed of the orbit, as well as the swath width, as broader acquisition allows a larger coverage of the surface (Ryerson & Rencz 1999). The higher the temporal resolution, the greater is the explanatory power towards the time and character of change. For analysis of phenology, a high repetition rate at regular time steps is needed to monitor the growth cycle of vegetation (Zhang et al. 2003). Low spatial resolution sensors with long and consistent history of acquisition are the most prominent sources of data for time-series vegetation analysis. The MODIS sensor used for this study, offers data of moderate spatial resolution with high temporal resolution which ensures the coverage of key phenological features such as the green up or senescence. Recently however, Landsat is used more often, after the accessibility to archived scenes and the computation power both improved significantly (Kennedy, Yang & Cohen 2010).

High repetition rates of sensors such as AVHRR and MODIS make it also possible to build Maximum Value Composites (MVC) for improved analysis. MVCs are generated by using the best pixel within a given time period to avoid cloud cover or other influences. The advantages are the higher explanatory power and the reduction of data; the major shortcoming is the loss of the regular temporal character of pixels. Figure 5.3 visualizes this reduction of data for MODIS-Terra images which are taken daily and are composited to 16 day MVCs, as this time is the repeat cycle of the satellite. These MVCs, consisting of pixels from up sixteen different acquisitions, served as the basis for parts of this thesis.

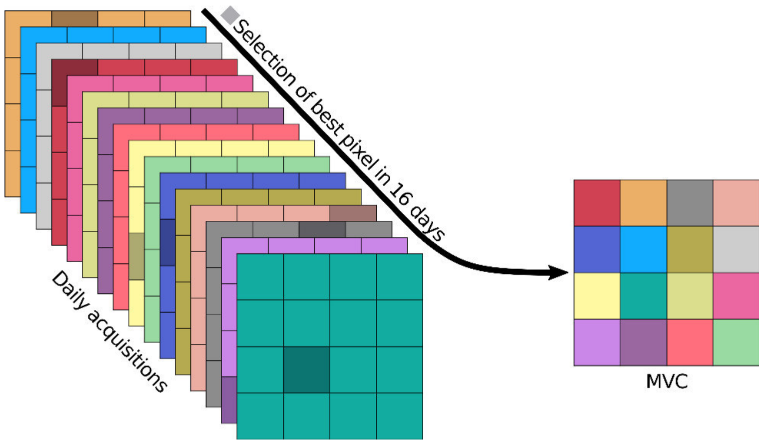

Figure 5.3: Visualization of MVC process for one time step and 16 exemplary pixels.

5.2.3 Spectral resolution of sensor

All objects on the earth's surface are emitting radiation, and more important: reflect emission of the sun. Passive sensors, which do not emit radiation but only record incoming reflection, make use of this backscattering process. Before the reflection, different objects absorb characteristic wavelengths, a principle which allows to draw information on the land surface by analysing the received signal. The fineness of the aperture to absorb backscattered radiation is determined by the number and width of sensor bands and is defined as spectral resolution of sensors. Bands refer to the sensors coverage of the electromagnetic spectrum, as they are characterised by their center wavelength and the Full Width at Half Maximum (FWHM) in nano- or micrometer (Ryerson & Rencz 1999). A band at 555 nm with a FWHM of 10 nm would therefore record radiation from a wavelength of 550 to 560 nm.

The more bands a sensor can use for image acquisition, the more accurate is the representation of the backscattered radiation, as a low number of bands with high FWHM generalize the pattern of the signal. The electromagnetic profile is a heterogeneous curve and can hardly be described with a few number of measurements. This fact is demonstrated in Figure 5.4, where bands of Landsat 7 are visualized with spectral signatures of soil, vegetation and water. The graph highlights the importance of the sensor design, as bands have to be placed at points of highest significance.

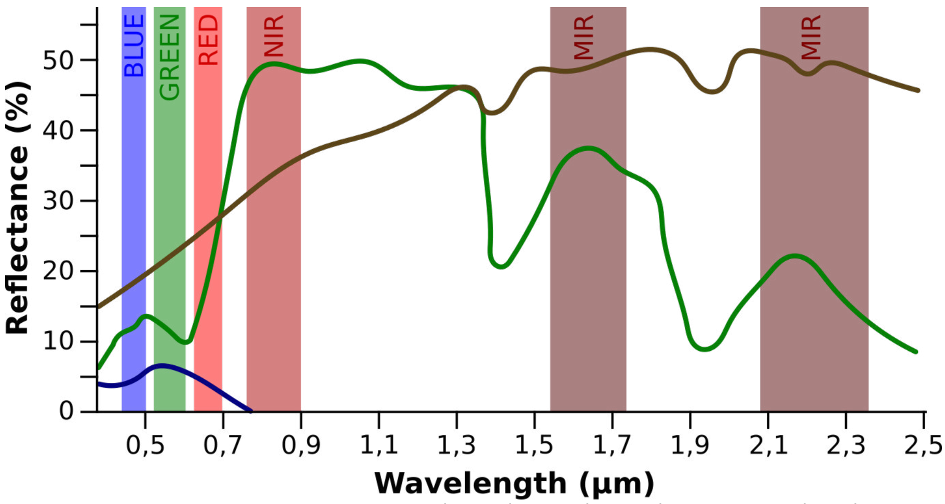

Figure 5.4: Reflectances of Vegetation (green), soil (brown) and water (blue) and their coverage by six Landsat7 bands, adapted from (USGS n.d.).

Important for vegetation measurements are red and near infrared (NIR) bands, as they are sensitive to the red edge, the steep slope of reflection between red and NIR band in Figure 5.4. This significant part of the spectrum relates to the chlorophyll and water content and therefore the vitality of vegetation (Filella & Penuelas 1994). The gap of values between NIR and red bands is used in a number of indices, such as the NDVI, which can be directly linked to vegetation activity (Jackson & Huete 1991). The

MODIS sensor is an important source of data for the calculation of NDVI, which can be accessed as a ready to use, pre-compiled product.

5.2.4 Radiometric resolution

The forth resolution of sensors is measured in depth of data storage capacity, radiometric resolution therefore determines the amount of information in products which can be processed. The higher the radiometric resolution, the finer is the discretion of received energy in the according picture. Common radiometric resolutions range between 8 bit and 16 bit. Besides this technical aspect, radiometric resolution is also determined by the 'Signal to Noise Ratio' (SNR) which describes the sensor's ability to account for extreme measurements (Gao 1993). The SNR is expressed by the mean signal over the standard deviation.

$$SNR=\frac{\mu}{\sigma}$$

SNR is especially important in multispectral image processing and change analysis, as the saturation level influences spatial and spectral resolution at various temporal and spatial scales (Thonfeld 2014). Recently, it has been shown that NDVI has lower signal noise ratio and that soil adjusted indices are more accurate in terms of radiometric resolution, especially in sparsely vegetated area (Ji et al. 2014).

5.2.5 Conditions of acquisition

The quality of remote sensing data largely depends on atmospheric characteristics. As sun radiation travels the atmosphere twice, as emission and as reflection, haze, aerosols and clouds form substantial sources of error (Lillesand et al. 2014). Especially in time-series analysis and change mapping, they have to be taken care of because they change from acquisition to acquisition and influence land use change which makes us of data from multiple time steps (Song et al. 2001). Another factor leading to different acquisition conditions is the inclination of sun in relation to the sensor's angle towards the object. This 'Bidirectional Reflectance Distribution Function' (BRDF) is a complex source of error, as it can be calculated in several dimensions of inclination and rotated angles and is complicated by of NADIR directions of acquisitions (Salomon et al. 2006).

Atmospheric correction, as well as the above elaborated MVC process, account for these conditions. Atmospheric correction is commonly distinguished in absolute atmospheric correction (individual conversion of radiation to reflectance), and relative atmospheric correction (same value represents same reflectance) (Chavez & MacKinnon 1994). MODIS products are offered in different qualities, related to the preprocessing which has been applied. The MOD13Q1 NDVI product used for this research is “computed from atmospherically corrected bi-directional surface reflectances”, which makes it applicable to map land use changes in the context of Zimbabwe’s FTLRP (USGS n.d.).

III. People and pixels: answering anthropogenic questions from space

6 The impact of spatial methods at the fringe of Human and Physical Geography

At least since with the spatial turn in the 20th century, space became an increasingly important factor role in social sciences (Döring & Thielmann 2015). The later occurring automation of spatial methods of landcover analysis, like Geographic Information Systems (GIS) and computerized remote sensing, allowed an even more thorough cross-disciplinary integration of space. Simultaneously, did the spatial turn lead to a growing interest in methods, projects and publications of Human Geography regarding landscape analysis (Thrift 2002). It is the spatial character, combined with the twofoldness of methodology from Human and Physical Sciences which make Geography a powerful contributor to integrated landscape analysis. GIS and remote sensing both have their share in this boost, as Sui emphasizes in his recaption of recent intellectual discourses (Sui 2004). He foresees a domination of these methods and states that "in fact, almost every aspect of natural and social reality that geographers study has, implicitly or explicitly, become computational" (Sui 2004).

Sinton and Lund edited a book which provides a broad overview of disciplines, directly profiting from GIS and its interdisciplinary applicability (Sinton & Lund 2007). And while they emphasize that there is a lack of Geographical thinking in daily lives despite the constant confrontation with maps and spatial data, they assert that GIS fosters the critical thinking of space in all scientific disciplines, simplified by the spatial conceptualization of "Why are things the way they are?" (Sinton & Lund 2007). Automated methods of spatial data research and management meet the growing demand of locational knowledge from research fields like sociology, economics, political science, or archaeology. Meanwhile, they still serve Geologists, Environmentalists and Biologists by developing new concepts and methodologies. By addressing the methodological demand from Human and Physical science, geomatics empower Geography as an interdisciplinary discipline and lobby for the closer engagement of both Physical and Human Geography. According to Campbell, new integrated solutions of geomatics are a welcomed foundation to overcome the "hyperbole" created by "proponents" of 'hard' or quantitative, and 'soft' or qualitative methodology (Campbell 2003).

But has this methodological and conceptional potential of a bi-polar Geography, backed by spatial computation been exploited sufficiently within the analysis of land reforms? With land reforms as reorganisations of the human and physical sphere of landscapes because they influence both, land tenure and land cover? Fraser emphasizes the suitability of Geography for the assessment of land reforms (Fraser 2008). According to him, the discipline addresses the dual character of the research object with its own interdisciplinary nature. He proofs his argument with a number of beautifully crafted research works of Geographers, all contributing to their subject from different spheres. The examples demonstrate the variety of methods and research areas, as land reforms are a global phenomenon. Among them are also methodological contributions with a focus on GIS and remote sensing, and some regional studies on land reforms in Southern Africa (Fraser 2008).

However, if focus is put on the consecutive land reform programs of Zimbabwe, and especially on the FTLRP, the picture is a different one. Although the pathway of the country's reorganisation of land tenure and ownership is one of the best researched; and although the FTLRP has attracted tremendous attention from international media and politics, a lack of data which is generated by other sources than the Zimbabwean Government itself is apparent (Cliffe et al. 2011, Scoones 2014a). As this lack has been formulated by different scholars, the first objective of this thesis was to identify and to quantify the lack of spatial methods in land reform assessments and to provide a possibility to overcome it. The published article of this section therefore lays the foundation of this thesis, as it conceptualizes method and object of research and paves the way for interdisciplinary, computational approaches to study land reforms. To highlight the untapped potential of geomatics, a literature review was carried out, which underpins the argument that the interdisciplinary power of spatial analysis has not been sufficiently made use of within the research on land reform in Zimbabwe.

In a second step, a conceptual overview of land reform assessment criteria was developed and a number of linkages for spatial methods were identified, both from physical and human centered land reform evaluation measures. Finally, a framework of integrated spatial land reform research was conceptualized. Using FTLRP as a case study, this framework highlights the interwovenness of aspects of land reform and at the same time, it highlights the impact geomatics can make by bridging the gap of physical and human science towards an integrated land use analysis.

7 ıBring back the land!ı a call to refocus on the spatial dimension of Zimbabwe—s landreform

7.1 Introduction

Facing screaming injustices of land ownership as a result of Apartheid ideology and legislation, Southern African countries need to address demands of their landless poor and their black majorities, not least because liberation movements have fostered the access to land as one of the key aspects of independence and majority rule (Alden & Anseeuw 2009). The former settler colonies Namibia, South Africa and Zimbabwe have chosen different approaches to land reform in order to redress these imbalances (Adams & Howell 2001): While Namibia and South Africa adhere to moderate, market-based approaches to land redistribution, Zimbabwe's land reform may be viewed as one of the most radical and comprehensive examples in recent world history (Bernstein 2012).

From its inception, land reform in Zimbabwe has attracted extensive and ongoing attention among scholars in a number of disciplines. Research has taken place within different institutions by authors with divergent backgrounds who utilized differing methodologies, and were focused on a variety of study areas, topics, and time periods. Results, conclusions and interpretations of these studies vary widely. Scoones et al. have concluded that bias and misinformation are common in this debate (Scoones, Marongwe & Mavedzenge 2010), despite the tireless efforts of prominent authors such as Moyo, who has published on Zimbabwe's land reform for more than twenty years (Skalnes & Moyo 1990). The lack of comparable datasets acquired through objective quantitative methods is prevalent in the debate and "poverty of data lead to a poverty of understanding" as Scoones concluded in his contribution "Dodgy Data and Measures: Why Good Numbers Matter" (Scoones 2014b). Because of the inherent political character of Zimbabwe's land reform program, its different waves are exposed to an intense scientific debate concerning their success. Recently, authors - notably Scoones et al. (Scoones et al. 2010) and Matondi (Matondi 2012) - have moved away from simply characterizing the reform process as either an utter failure or a complete success and as either right or wrong (Scoones et al. 2010). Instead, focus has been placed on outcomes of the major economic and social reorganization ongoing in Zimbabwe exemplified by the special edition of the Journal of Peasant Studies: "Outcomes of the Post-2000 Fast Track Land Reform in Zimbabwe" (Cliffe et al. 2014). Another example is Mutopos's analysis on gender in resettled livelihoods, which shows increased local agricultural production on land previously considered unfavorable. Therefore, her work can be seen as an example of how data can overcome narratives (Mutopo 2014). Currently, however, an objective and standardized spatial research framework does not exist which characterizes the land redistribution efforts in the whole country from independence in 1980 until today.

In this article, we attempt to highlight the contemporary status and potential of geographical research on Zimbabwe's land reform. Through the introduction of an innovative research framework, we aim to overcome highlighted shortcomings of the debate. After outlining the land question in Zimbabwe and the government's countermeasures in Section 7.2, we elaborate on the need of traceable land reform assessment frameworks (Section 7.3). Subsequently, we put the focus on different aspects of research and document the lack of geospatial methods applicable to the research on land reform in Section 7.4. By presenting regional examples of remote sensing analysis in the region (7.5) and the concept of participatory web-mapping (7.6), we illustrate the potential of both methods for the research on Zimbabwe's land reform before we present a research framework which would add spatial and objective input to the research on land reform (7.7). Finally, we conclude in 7.8 that the elaborated methods of geomatics can address important questions of land reform research.

7.2 Zimbabwe—s Multifarious Land Reform

Land has always been a contentious issue in Southern Africa, from the early recorded history of the region until today. The movement of native Africans to the Southern tip of the continent (MITCHELL & WHITELAW 2005), the expansion of European logistic settlements (GUELKE 1976), the extensive form of local agriculture and the hunt for mineral deposits (PALMER 2011) have all been important factors in provoking demand for and conflict over land in emerging territories and colonies in the region. Following the establishment of independent states with white minority rule, access to productive land was restricted by public law (POTTS 2012). In the former Rhodesia, approximately 50% of the agricultural land was held by 6100 settler families, while the majority of the country's 7,000,000 people lived within the other half (DEININGER, HOOGEVEEN & KINSEY 2004). Among various others, the call for an even distribution of productive land was an important factor for liberation movements and independence fighters to back their support from a large proportion of the region's population. In 1994, Murray and Williams asserted that the call for land redistribution in the region can "...only be understood in the context of the history of conquest and dispossession, of territorial segregation and political exclusion, of generations of state control of the movement of people and the socio-economic conditions of their lives" (COLIN MURRAY & WILLIAMS 1994).

As a reflection of its critical importance, land was an immediate issue following the founding of the independent nation of Zimbabwe in 1980 (SHAVA 2010). After independence, the newly elected government started to implement the national land reform program which is documented in the Lancaster House Agreement, a result of the preceding independence negotiations of the British Government, the Zimbabwe Rhodesia Government and the political and military alliances ZANU (Zimbabwe African Peoples Union), Patriotic Front and ZAPU (Zimbabwe African National Union) (PALMER 1990). As the former colonial power in Rhodesia, the United Kingdom provided foreign currency support to compensate expropriated farmers for their farms, which were usually purchased in an open market through a state pre-emption process.

Palmer, writing in 1990, provided a useful history of land reform in Zimbabwe during the 1980 - 1990 period (Palmer 1990). He describes initial land reform efforts in Zimbabwe as proceeding relatively swiftly and successfully (Palmer 1990). A period of quiet regarding land reform followed this initial process. By the late 1980s, however, land reform had become less efficient and successful. Many of the farms purchased by the government in the initial phase of land reform were easily acquired as they had been left abandoned by their former owners following independence. Transfer of land then became more complex and costly. In addition, the nation entered a period of economic recession, further complicating land reform. The Zimbabwean government also contributed to the perception of a failed land reform by subsequently developing increasingly ambitious and unachievable land redistribution goals. As Palmer emphasizes, the number of households to be resettled by the government was increased nine-fold in the first two years of independence. The slow and costly “willing buyer-willing seller” approach along with the limitations of compulsory acquisition led to disappointing results as the governmental institutions could not achieve their ambitious land reform goals (Palmer 1990).

The Land Acquisition Act was revised in the early 1990’s. While the revised act empowered the government to involuntarily expropriate operating farmlands (with appropriate compensation), this did not accelerate the land reform process (Böhler 2006). The number of resettled households continued to decline each year between 1995 and 2000. When the market-based redistribution approach slowed further, land acquisition strategies changed. In the year 2000 a process called jambanja began. In a more spontaneous than planned fashion, poor rural residents started occupying farms and evicting the white owners. This practice was supported by a shift of executive power from state organs to group movements that ignored respective court rulings which judged the process as unlawful.

Jambanja can be translated as “violence” or “angry argument”. The term cannot be characterized easily and should, according to Chaumba et al., be understood as a combination of top-down influences, including efforts of Zimbabwe African National Union-Patriotic Front (ZANU-PF) cadres to maintain power; individual interests and communal desire for land, compensation and righteousness (Chaumba et al. 2003). Besides a number of possible reasons, some observers have linked the initiation of farm evictions with the loss of support for the ZANU-PF and President Robert Mugabe (Hammar 2008), but also cite the increasing resistance of white farmers to a constitutional election (Pilossof 2012). Mr. Mugabe and his government had to defend their stand in the debate on the constitutional referendum in parliamentary elections 2000 and in presidential elections in 2002. Along with growing opposition among the Movement of Democratic Change (MDC), a lack of popular support became obvious.

The constitutional referendum, which included the legalization of uncompensated farm expropriation, was defeated (Chaumba et al. 2003, Makumbe 2002).
After the defeat of the constitutional election, large numbers of people (notably including war veterans) began moving on to white owned farms. This process was seen by ZANU-PF as a way to mobilize support for its authority as well as for the land reform program (Human Rights Watch 2001). A new set of legal definitions, included in new evictions acts and other legal amendments, followed this uncoordinated process and turned the new de facto ownership into de jure ownership. Through a new ambitious spatial planning process which took place during 2000 and 2001 (but did not meet specific preset goals), the disorder of jambanja was turned into an official governmental policy called the "Fast Track Land Reform Programme" (FTLRP) of Zimbabwe (Chaumba et al. 2003).
Redistributed farms in Zimbabwe were split and categorized according to a dualistic scheme which has its roots partly within the agricultural planning from around 1950 (Scoones et al. 2010). "A1" farms were designed as smallholder farms, while "A2" farms comprised larger small scale commercial farms. Other models such as a model "D" for pastoral use were also defined, but were not applied in practice (Palmer 1990). Common grazing and settlement areas were allocated to some "A1" farms which were then referred to as "villagised" models. For "self-contained A1" model on the other hand a complete segmentation of an entire agricultural area into individually owned plots took place (Cliffe et al. 2011).
Considering Zimbabwe's land ownership history in terms of time, space, participants, aims and strategies, it is understandable that the FTLRP is subject to heated public, scientific and political debate. Obtaining reliable socioeconomic, demographic and environmental data relevant to the history and ongoing events involved in the Zimbabwean land reform process is problematic. This makes arriving at an overall judgment regarding the abrupt and disordered process FTLRP extremely difficult. To elaborate general difficulties of land reform assessments beyond the historical and political context, the following theoretical chapter presents a lineup of reasons which contribute to divergent judgments of success on land reform. These divergences can be harmonized, if accurate data is existent.

7.3 Examining Land Reforms

A major reason for difficulties in land reform assessments is the heterogeneity and the contradictoriness of assessment criteria. Some of these criteria are: the pace of redistribution; the improvement of living conditions for beneficiaries; quantitative agricultural production metrics; type and quality of agricultural products; adequacy of compensation of the dispossessed; the security of land tenure; access to land; the effectiveness of administration; the legality and legitimacy of the land reform process, and; land degradation and land use change characteristics. Additional complexity is introduced by contradictions among some of these aspects.

To visualize this complexity of land reform assessment criteria, we structure a selection in Figure 7.1. We sorted examples of criteria and related them to one of seven broad aspects of success first. In a second step, we structured the success criteria according to their temporal location within the process of land reform which we split into the initial situation, the processes of expropriation and redistribution and finally the outcome of the process.

Criteria are therefore distinct in terms of their aspect of success and in terms of the time-step they are applied to. If an assessment of land reform would solely focus on questions of efficiency, it could determine the crop production per area either before or after the land reform. To evaluate the efficiency of the process of expropriation or redistribution, the assessment could determine the speed of both processes.

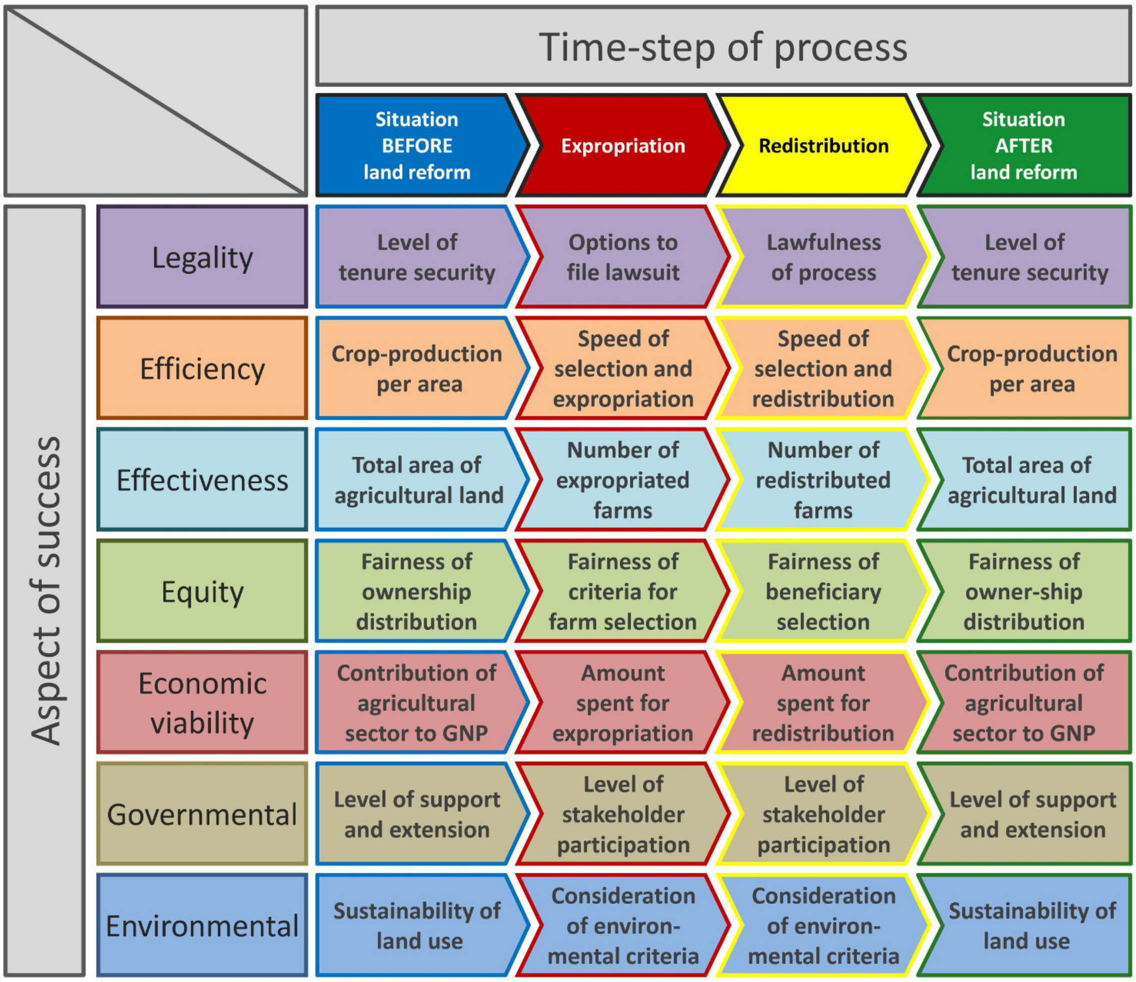

Figure 7.1: Structured overview of multidimensional land reform assessment criteria.

Through this temporal and thematic sorting of the selected criteria, their incomparability becomes explicit by two characteristics:

First, criteria of success are often a snapshot at a specific time-step within the process of land reform and do not describe the whole process or its outcome. Assessing the fairness of expropriation criteria alone may not provide a comprehensive judgement of the overall fairness of a land reform because the resulting distribution of land after the reform could still be unfair.

Second, the seven different aspects of success are thematically not related to each other. While land can be distributed more equitable after the land reform (a criteria of equity), tenure security might be low (a criteria of legality) (MATONDI & DEKKER 2011). Although more land could be cultivated following the land reform (a criteria of effectiveness), the production outcome could still be less than before (a criteria of efficiency) (MOYO & NYONI 2013).

A *third characteristic* is not illustrated through our structuring, but is still apparent after a closer look: Criteria are also differing in terms of their scale. Therefore, land reforms can be assessed on different levels of administration: While the agricultural production of redistributed households might be better than on their previous plots, the overall national production might still be low (KINSEY 2004).

These three factors contribute to contradictory views on the success of land reform in Zimbabwe and emphasize the need for a systematic context and for objective methods of data acquisition to evaluate land reform projects. Authors often neglect this variety of arguments and keep narrow foci. Studies which focus on the design of multi-facetted research frameworks with objective and traceable methods to acquire data however are rare. An exception is Deiniger (DEININGER 2009), who provides a general overview of land policy and reform evaluation but without spatial aspects. A comprehensive framework and an applicable methodology for the analysis of this subject are still needed to overcome the lack of data.

Another reason which contributes to disparities in debates on success is the way success criteria are defined. They can be formulated internally by the participating institutions using specific programmatic goals, or they may be derived from external, even universal, criteria. The Organisation for Economic Co-operation and Development (OECD) therefore distinguishes performance measurements, where a process is simply assessed against its stated goals, and process evaluations which include a whole set of examinations of aspects such as policy instruments, service delivery and management practices (OECD 2003). This applies to the FTLRP as well: Marongwe describes an episode of the Zimbabwean government ignoring and failing its own internal land reform criteria for beneficiary selection by favoring elites rather than landless persons as land recipients in areas around the capital city of Harare (MARONGWE 2011).

The heterogeneity of criteria in terms of the seven aspects of success and the perspective of definition bear the risk that these criteria are used selectively. Cousins and Scoones emphasize that not only the definition of success, but also the political view of contributors, largely determines research approach and results (Cousins & Scoones 2010). Their extensive synopsis provides a detailed analysis of diverging land reform criteria in different analytical frameworks (Cousins & Scoones 2010). The authors contrasted approaches to land reform assessment among six socioeconomic paradigms: neo-classical economics, new institutional economics, livelihood perspectives, welfarist approaches, radical political economy and Marxism. As an example, they detail the narrative of productive large commercial farms and unproductive small communal farms. The contrasting views on good management, productive agriculture and adequate land use, which are enshrined in the dual character of local agriculture, exemplify how tenuous and debatable the assessments of land reform are: Some authors see large market based industrial farms (often owned by descendants of European settlers) as the paradigm of productive agriculture. Others focus on the advantages of alternative, regionally adapted models of African small scale agriculture (Sender & Johnston 2004). Both groups judge the transformation of large farms to smaller farms - often in villagised models - differently according to their ideological background.

Another conspicuous example of criteria selection being the reason for different views in the discourse on land reform success is the published debate that has arisen between Hanlon and Hawkins. Both are economists and have criticized each other in different publications for the use of incorrect success criteria. Hanlon views the reform process as a success, due to increased farmland under production and numbers of people working in the agricultural sector (criteria of effectiveness in Figure 7.1). Hawkins counters with “...the success or otherwise of land resettlement in Zimbabwe cannot be judged by how many people are on the land now, but by what is produced, what incomes are earned and whether the economy as a whole benefitted” (Hawkins n.d.)(criteria of efficiency in Figure 7.1). Murisa, a Zimbabwean researcher, on the other hand counters that production criteria as such are not relevant and emphasizes the importance of criteria of equity (Figure 7.1): “No one ever argued that this (the new way) is a more productive form of farming, but does it share wealth more equitably? Does it give people a sense of dignity and ownership? Those things have value, too” (Polgreen 2012).

These debates which have their roots in the differing backgrounds of authors and the heterogeneity of criteria weaken the discourse on the FTLRP. From his 2010 analysis of opposing factions of land reform research, Southall concluded that it is premature to formulate judgments regarding the success of land reform (Southall 2011).

The opposed views on land reform and the acute debate on its success exemplify the need for accurate data that has been mined with traceable, politically neutral methods. Cousins and Scoones concluded furthermore that assessments of viability “...must embrace heterogeneity, complexity, and competition in relation to multiple objectives... multiple scales... and multiple contexts...” (Cousins & Scoones 2010). Geospatial methods such as remote sensing and Geographic Information Systems (GIS), are possible solutions to deliver this additional information on the redistribution process and its effects. The data source of remote sensing, satellite or aerial imagery, can be seen as a politically neutral source of information. The processing methods are reproducible and traceable and the generated results are statistically significant at multiple scales.

A closer look at success criteria of land reform evaluation reveals that many of them have a spatial character. This underpins the suitability of geospatial methods to fill data gaps in land reform research. Since these methods can deliver countrywide data on key questions which are consistent in terms of space and time, they can be seen as an important contribution to overcome “dodgy data” which lead, according to Scoones, to the “poverty of understanding” (Scoones 2014b). Before we analyse this potential of geospatial methods, we focus on the current stay of geographical research in the following analytical chapter to demonstrate to which degree this potential has been neglected.

7.4 The Current Status of Contemporary Research on Zimbabwean Land Reform - From A Geographical Perspective

Although land, its use and tenure are questions of significant spatial relevance, the geographical perspective is generally absent in the discourse on land reform. Cliffe et al. cite this deficiency in their comprehensive review of the FTLRP in Zimbabwe. It became evident to the authors that, while consensus exists regarding the actuality and nature of agricultural change in Zimbabwe, the location and magnitude of change are in dispute and are seen in many different ways (Cliffe et al. 2011). Magnitude and location however, are subjects that can be adeptly and accurately addressed within a spatially explicit methodology.

Within the discipline of Geography on the other hand, its potential to enhance understanding of remaining questions on land reforms has been identified already. In his 2008 review “Geography and Land Reform”, Fraser called for a more systematic contribution by geographers to research about land reform after he emphasized its explicitly spatial character (Fraser 2008). Geographical contributions to land reforms, especially the Zimbabwean land reform, however, remain inadequate, principally due to the lack of theory and methodology needed to contribute meaningfully to this research.

We must emphasize our conviction that research on land reform has not been biased in any direction; it has not been systematically in error; nor has it omitted any of the seven criteria aspects presented in Figure 7.1. Rather, we acknowledge that the process of land redistribution in Zimbabwe has been one of the most extensively studied and thoroughly discussed land tenure and administration reorientation exercises ever conducted.

However, we carried out a review of published material that underpins our argument of a lack of spatial research within the discourse on land reform. To highlight the lack of spatial input to research, we reviewed articles listed in four principal scientific databases: Web of Science, Science Direct, Google Scholar and JSTOR. Using specific key words as search parameters, our aim was to quantify spatial aspects included in journal articles dealing with Zimbabwe’s land reform. To the initial search keywords “land reform” and “Zimbabwe”, we added the terms “GIS” or “remote sensing” in a second and third round to explicitly focus on these geospatial methods. These parameters were applied to title and abstract and, where possible, to the complete text of all references in the databases. No further filtering, such as date of publication, was applied to include all listed publications. The comparison of the different search results, shown in Table 7.1, illustrates that very few publications address spatial questions of land reform and do not add spatial data sets to the debate.

Table 7.1: Absolute hits of quantitative literature review for respective parameters and databases.

Web of Science	***“Topic”***	--
“*land reform*” and “*Zimbabwe*”	124	--
“*land reform*” and “*Zimbabwe*” and “GIS”	1	--
“*land reform*” and “*Zimbabwe” and “remote sensing*”	0	--
Science Direct	***“Title, Abstract, Keyword”***	***“All Fields”***
“*land reform*” and “*Zimbabwe*”	23	566
“*land reform*” and “*Zimbabwe*” and “*GIS*”	0	41
“*land reform*” and “*Zimbabwe*” and “*remote sensing*”	0	44
Google Scholar	***“Allintitle”***	***“Full Text”***
“*land reform*” and “*Zimbabwe*”	89	14400
“*land reform*” and “*Zimbabwe*” and “*GIS*”	0	766
“*land reform*” and “*Zimbabwe*” and “*remote sensing*”	0	449
JSTOR	***“Abstract”***	***“Full Text”***
“*land reform*” and “*Zimbabwe*”	18	1264
“*land reform*” and “*Zimbabwe*” and “*GIS*”	0	29
“*land reform*” and “*Zimbabwe*” and “*remote sensing*”	0	26

In addition to the literature review that utilized methodological keywords, the most recent journal articles on land reform in Zimbabwe were further examined. Using the search parameter “land reform” and “Zimbabwe”, a maximum of 25 articles were selected from each database.

Having identified the publications that included maps and spatial tables, we then segmented them into two generic groups: publications with maps and spatial tables containing original or primary data; and publications with maps and spatial tables containing data derived from other sources. Maps showing climate data sourced from weather services for example, were considered as maps without original content, as were maps which represented study areas. Products from mapping exercises, remote sensing analyses or any other method of visualizing study results were considered as maps or tables with new or original content. Table 7.2 details the results of this grouping.

Table 7.2: Proportions of publications with or without, with cited or created spatial maps and tables.

All Databases	***n* = 67**	**No Spatial Table**	**Cited Spatial Table**	**New Spatial Table**
no map		38	13	1
cited map		7	5	
new map		2		1
Web of Science	***n* = 22**	**No Spatial Table**	**Cited Spatial Table**	**New Spatial Table**
no map		15	3	
cited map		1	1	
new map		1		1
Science direct	***n* = 23**	**No Spatial Table**	**Cited Spatial Table**	**New Spatial Table**
no map		10	4	
cited map		5	4	
new map				
Google Scholar	***n* = 16**	**No Spatial Table**	**Cited Spatial Table**	**New Spatial Table**
no map		8	5	1
cited map		1		
new map		1		
JSTOR	***n* = 6**	**No Spatial Table**	**Cited Spatial Table**	**New Spatial Table**
no map		5	1	
cited map				
new map				

As an additional method to evaluate the methods of current land reform research, we chose to analyze a scientific conference on the topic which took place in March 2013 and which was organized by leading South African research institutes and universities. Titled "Land Divided", this symposium attracted approximately 350 international participants ("LAND DIVIDED" n.d.). We chose this gathering of the foremost scholars and institutes, because this conference may be viewed as one of the most significant scientific events of the region concerned with the land reform research.

"Land Divided" produced 129 discussion panel contributions; 10 dealt with the Zimbabwean land reform. We analyzed the abstracts from these 10 contributions, attempting to identify any that included possible spatial perspectives. Only a single presenter referenced existing maps, which were used for field research. All other presentations were from a non-spatial background, most commonly focusing on politics or sociology. Further, in an attempt to obtain a more general overview of the presented research methodologies, we examined the abstracts of all conference contributions (except plenary lectures). It became evident how extensive and diverse the current debate on land reform is, as it was difficult to segregate the methods described in these contributions into meaningful categories. They were grouped as shown in Table 7.3. This review revealed that spatial questions generally were not addressed on the conference. Only 2 out of 82 contributions included any spatial component, and none had a methodological spatial focus. A conclusion in the conference synthesis report states: "...presentations...highlighted data gaps, poor information management, weak monitoring and evaluation of land reform and poorly targeted agricultural support services" (DE SATGÉ 2013).

Table 7.3: Grouped methods mentioned in all abstracts of the "Land Divided" conference 2013.

Method (If Mentioned)	No Spatial Focus	Spatial Focus
Photography	5	
Secondary Data	1	
Household/farm survey (partly with interviews)	11	
Economical survey/analysis	3	
Institutional analysis/policy analysis/analysis of interaction of different actors	12	
Macro-financial analysis	1	
Ethnographic/long study field work	7	
Interview	1	
Historical analysis	8	1
Legal analysis /court case analysis /claims	13	
Local case studies	10	1
Action-research	1	
Statistical/demography	1	
(Non scientific) Literature	4	
Productivity Analysis	1	
Survey/questionnaire	1	
Totals	**80**	**2**

This corresponds with our analysis that makes clear that spatial aspects and evaluations of the Zimbabwean land reform are not significant in the current scientific literature. Very few recent publications provide new spatial aspects of Zimbabwe's land reform, although spatial data sets can serve as independent and objective sources for further debate. Spatial data may prove critical in addressing the problem mentioned in Section 7.2: the ambiguous and confusing set of land reform objectives, events, and participants that produce discord in assessments of land reform. Therefore, we will present the potential of remote sensing and GIS to contribute to the research on land reform in the following two chapters.

7.5 The Potential of Remote Sensing to Contribute to the Research on Land Reform

In general, spatial methods have great potential to create added value in social research. Goodchild and Janelle emphasize this by giving two main arguments for the consideration of space in social research: *first*, location provides possibilities to integrate multidisciplinary approaches, and; *second*, location adds to the three principal questions of social research: human behavior and resulting processes; their prediction; and problem solutions (Goodchild & Janelle 2003).

Remote sensing in particular, can answer a number of questions on land reform which are related to agriculture. This suitability is rooted in the characteristics and determinants of agricultural production: Unlike other forms of economic production, the seasonal spatial patterns of agriculture are influenced by physical and human impacts and their effects are directly expressed on the land surface as variances over large proportions of the agricultural area (Atzberger 2013).

Satellite products have been used for decades to conduct a broad variety of significant vegetation analyses (Sellers et al. 1992) since Tucker and his colleagues emphasized the linkage between spectral reflectance and vegetation greenness in the 1980s (Tucker 1980). From that time, critical issues related to agricultural production have been at the center of remote sensing research: Analyses of biomass, crop acreage estimates, and yields/area. In addition to these quantitative, spatially explicit data, satellite imaging provides temporal continuous data sets over long-term acquisition periods. This is important, because time series data sets for long-term analyses have not been available for land reform research. In her 2008 work documenting economic successes of Zimbabwe’s land reform, Zikhali states that a temporal comparative analysis of land reform is not possible due to a lack of continuous chronological data (Zikhali 2008).

In the past, remote sensing based monitoring of vegetation has proven to successfully answer general agricultural questions in Southern Africa in a cost effective, standardized and spatially explicit manner. Some of these questions are at the heart of the debate regarding success criteria of land reform. These critical agricultural issues include for instance the evaluation of farm value (Ganzin et al. 2005) as the basis to assess equity (Figure 7.1) and the updating of the conventional concept of Zimbabwe’s agro-ecological zones (Mugandani et al. 2012) as an improved mechanism to answer questions of economic viability (Figure 7.1).

To further elaborate the potential of remote sensing, we will present a range of studies which demonstrate that this method can resolve important spatial issues directly related to Zimbabwe’s agriculture. To structure our descriptive review of remote sensing studies for land reform research, we chose spatial success criteria of the aspects efficiency, effectiveness and environmental sustainability (as shown in Figure 7.1). For these, we present current shortcomings in research and successful remote sensing applications to overcome these.

7.5.1 Efficiency of Land Reforms - Crop Production per Area

Despite divergent views on the success of Zimbabwe's land reform, there is general agreement regarding official agricultural production data: Annual national agricultural yield figures are often inaccurate and, although they are compiled on a regional basis, the spatial accuracy of these data is questionable. Several studies have described the weaknesses of statistical surveys and institutions in Zimbabwe (Government of Zimbabwe & United Nations Country Team 2010, Scoones et al. 2011). In recent years, agricultural production data has not been collected by the Zimbabwe government despite the assistance of relief agencies including the Famine Early Warning Systems Network (FEWSNET), the Zimbabwe Vulnerability Assessment Committee (ZimVAC) and the World Food Programme (WFP) (Frayne et al. 2012). Even data gathered by these organizations is of low accuracy, and their lack of spatial integrity is criticized. For instance because comparisons of agricultural production in favorable areas with production in unfavorable areas are viewed as impossible (Scoones 2014b).

Researchers and experts - Active principally in fields of food security, investigation and action - often utilize data aggregated to province level (Brown 2008). To generate reliable local data on agricultural efficiency and production, researchers must carry out time and cost intensive household surveys (Zikhali 2008, ZIMVAC 2013). An example of a more detailed survey is the presidential "Utete-report", which lists statistics on land allocation by province level (Utete 2003). However, the process of redistribution, as well as the spatial precision and traceability of methods could be enhanced by the use of geomatics.

Used adeptly, remotely sensed data can provide spatial and temporal continuous crop production figures countrywide. The relation between luminous and thermal reflectance and plant growth, and its application through the derived Normalized Difference Vegetation Index (NDVI) are well understood and have been applied for decades (Tucker 1979). In 2009, Funk and Budde described a phenology adapted NDVI analysis technique to generate reliable and spatially explicit crop production figures at regional scales for Zimbabwe (Funk & Budde 2009). For this, they used data of the Moderate Resolution Imaging Spectroradiometer (MODIS). Although their focus was primarily on the creation of a province level food security dataset, rather than on a compilation of a high resolution spatially explicit map, the authors demonstrate that remote sensing based on MODIS data is suitable for crop production analysis in Zimbabwe.

Their study methodology is based on the onset of crop growth phases that allows the correlation of spectral reflectance signals to key crop vitality. Assuming and computing a one-month interval between rainfall and crop growth, the authors concluded: "When combined with the high repeat rate and high resolution of MODIS and reliable production statistics for training, these techniques allow us to accurately track crop production from space" (Funk & Budde 2009).

7.5.2 Effectiveness of Land Reforms - Total Area of Agricultural Land and Key Crops

The actual area planted with certain key crops is critical information required to assess land reforms and to monitor changes in agricultural production. Currently, however, capabilities to measure agricultural areas are lacking and therefore reliable figures are unavailable. Spatial inventories in Zimbabwe are scarce and traceable spatial research designs for a national analysis have yet to be developed. As is the case with crop production issues, information regarding agricultural area is currently compiled through household surveys. Most of these assessments are performed for individual districts only, and are not extensible to different environmental settings (Moyo et al. 2009). Examples are the extensive statistics by Moyo and Nyoni and Scoones (Moyo & Nyoni 2013, Scoones et al. 2010), which present data on province level acquired from secondary sources and household surveys. Moyo and Nyoni explicitly mention the limited capacity of state statistical offices while quoting them in their work (Moyo & Nyoni 2013).

Based on the NDVI-relationship elaborated above, methods of geomatics can accurately collect figures of agricultural productive area with high temporal and spatial resolution. Data acquired by MODIS for instance are effective at stratifying African agricultural landscapes or segmenting crop/non-crop areas at high validated accuracy levels and have been used successfully in different agro-ecological regions (Vintrou et al. 2012). Sibanda and Murwira have furthermore demonstrated that NDVI-time series of MODIS can be used to effectively differentiate key Zimbabwean crops such as cotton, sorghum and maize (Sibanda & Murwira 2012). Maize, cotton and sorghum express divergent reflectance values during the "green-up" growth phase, and thus can be discriminated by their individual temporal NDVI-profile in MODIS time series.

Despite the low spatial resolution of MODIS (250 meters), Sibanda and Murwira could proof through imagery of higher resolution and through local field surveys that their discrimination method shows good classification results in small scale farmer environments (Sibanda & Murwira 2012). This is important for a satellite based research on Zimbabwe's FTLRP because farm and field sizes decreased significantly following land reform, as fields were subdivided and a more heterogeneous agricultural production system began (Scoones et al. 2012). Although the authors did not extend their research to a national scale and they did not couple their results to the FTLRP explicitly, their work confirms the applicability of remote sensing and the sensor MODIS to map changes in crop area as consequences of Zimbabwe’s land reform events.

7.5.3 Environmental Sustainability of Land Reforms - Sustainability of Land Use

The close link between land tenure and sustainable use of resources becomes apparent in the degradation of land in Southern Africa, especially in its more arid regions. Despite the vivid equilibrium debate around the role of grazing on degradation (Rohde et al. 2006, Scoones 1992), there is evidence that the concentration of indigenous populations has led to a high demand for natural resources in former “communal areas”. Because of this significant linkage between land tenure and sustainability in the region (Clover & Eriksen 2009), the success of Zimbabwe’s land reform can be measured according to its impact on degradation in transferred farm lands and former communal areas.

Traceable data on degradation is also important, because the partly political discourse on productive farming systems elaborated on in Section 7.3, also affects the debate on degradation. The dualistic notion of land tenure, defining white/commercial land as “productive” and black/communal land as “unproductive”, resulted in a set of divergent judgment factors of human impact on degradation. It has led to early records of environmental degradation (Whitlow & Surveyer 1989) which also have to be seen politically motivated (Munro 2003).

Land degradation may be measured by loss of Net Primary Productivity (NPP) and as NPP can be directly linked to NDVI values, remote sensing offers effective methods to determine land degradation at multiple spatial scales (Bai et al. 2008). In Zimbabwe, this technique has been applied at local scales to determine forest and vegetation changes linked to land tenure change and the FTLRP (Mapedza, Wright & Fawcett 2003, Matsa & Muringaniza 2011). A national scale NPP change analysis can be used to map land degradation “hot spots” for the entire country (Mambo & Archer 2007) and furthermore help to differentiate between the direct effects of human activity and generalized climate impacts. This holds potential for overcoming the impasse that exists in the “grazing vs. climate” nexus and therefore the “commercial vs. communal” nexus in the region (Mambo & Archer 2007).

From remote sensing studies on the socio-ecological link of land reform at local scale, Chigumira concludes for instance that vegetation cover change is driven more by land use alteration and household strategies following land reform then by climate (Chigumira 2010). Prince et al. successfully mapped human induced land

degradation in Zimbabwe on a national scale, using the methodology of local net production scaling where NDVI values of pixels are compared relatively to overall NDVI values of their land use class. However they did not explicitly link their results to the land reform process (Prince, Becker-Reshef & Rishmawi 2009). Despite the feasible ways to connect land tenure, land use change and degradation, no approach of a nationwide spatial correlation of land reform and degradation currently exists.
The above presented, NDVI based remote sensing studies show that methodologies to answer agricultural questions related to land reform exist. The potential of remote sensing to evaluate success criteria of land reform research is therefore evident but has to be proven by a well designed research framework.

7.6 The Potential of Web-Mapping as A Tool to Retrieve Spatial Information on Land Reforms

To benefit from the positive impacts of spatial input on social research presented by Goodchild and Janelle (Goodchild & Janelle 2003), a strategy is needed to link the results of remote sensing to human activities reliably. At the same time, simplifications of cause and effect between tenure and land use change have to be avoided (Lambin et al. 2001). Although remote sensing is able to detect changes in land use patterns, it is not able to relate them to land reform events that have occurred in Zimbabwe. The innovative concept Public Participatory Geographic Information Systems (PPGIS), provides good solutions to establish this spatial socio-ecological link. PPGIS is a mechanism to enable diverse members of the community to contribute their relevant knowledge as spatial data. Mining land tenure and land use change information this way can minimize the necessity for time consuming and costly in situ land ownership change mapping based on household surveys or site visits (Dunn 2007).
By definition, participatory approaches to GIS seek to involve in the mapping process non-experts who have detailed knowledge of local conditions such as land use strategies. This approach has been successfully applied in a number of different environments, mostly in the field of land tenure and resource mapping (Rambaldi et al. 2006). A principal reason for participation is to include in the process indigenous or local residents, who have often been ignored or marginalized in previous programs. By participating in the mapping effort, a broad range of individuals can contribute in a variety of ways (Sieber 2006). E-participation focuses on the participation of larger groups, not bounded within a geographic area. Through online tools and Web-GIS, forms of participation expanded (Dragićević 2004), because Technologies of the second generation internet technologies offer numerous opportunities to engage large groups of people to share their geospatial knowledge through interactive applications (Goodchild 2007).

A well-designed online spatial questionnaire therefore provides a solution to map the land use and land tenure changes of the past by drawing on local knowledge of people. Such maps would overcome the lack of spatial information on expropriation and redistribution. By easily sharing geospatial data, people from an international diaspora, who were affected by land reform events, can share their knowledge on expropriated farms through an online tool that associates their information with spatial location. The dataset on farm evictions could first be used by itself to analyze a number of assessment criteria presented in Figure 7.1, including efficiency (speed of expropriation), or effectiveness (total area of expropriated farms) and general spatial patterns of redistribution. Secondly, the PPGIS can be used to mine information on previous land use strategies. This dataset can then be used to validate the land use datasets based on remote sensing. Figure 7.2 details an example of one element of an online participation tool on Zimbabwe’s land reform. Here, participants can enter the details of a change they allocated previously to an identified farm through a web-map application.

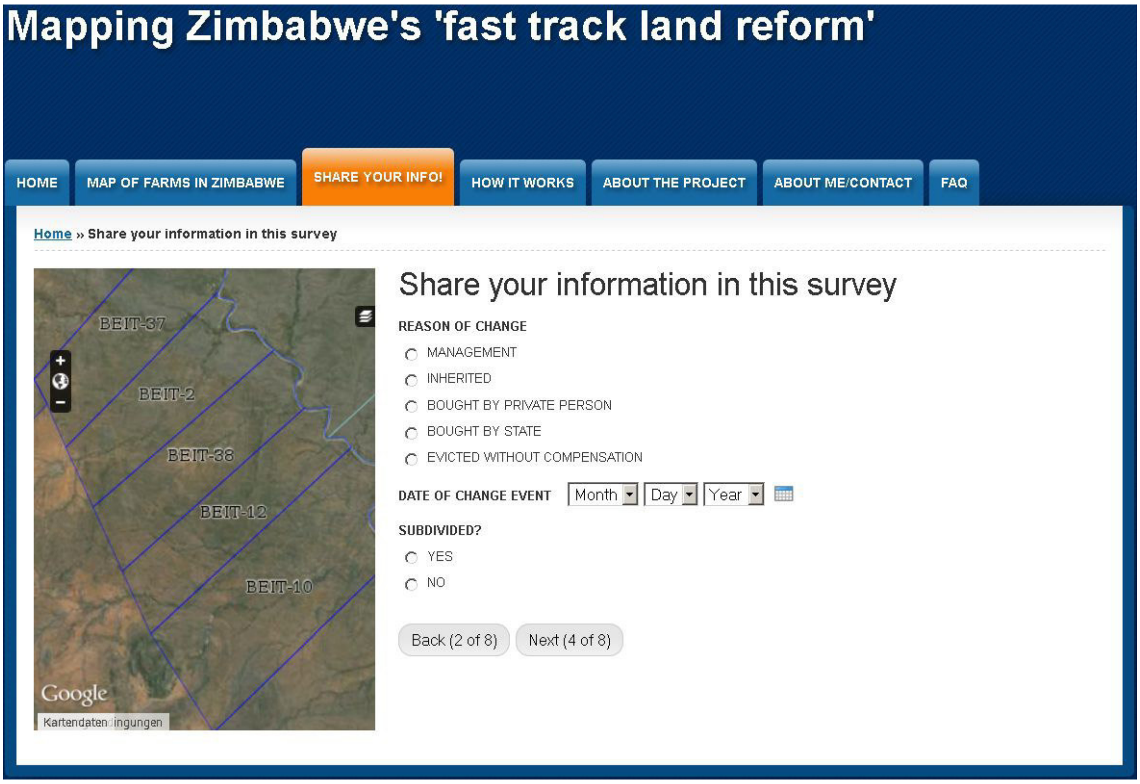

Figure 7.2 Screenshot of mapping portal.

7.7 A Methodological Framework for the Spatial Research of Land Reform

Considering the huge potential of remote sensing and PPGIS to answer various questions surrounding land reform presented above, we are convinced of that

Zimbabwe's fast track land reform program and its effects can be mapped on a national basis. To make use of this potential, we present here a framework for mapping the national reorganization of land tenure and its effects. By combining the spatiotemporal strength of both methods, we attempt the first spatial explicit comparison of agricultural production among different tenure regimes.

This spatial correlation has to be treated with care because numerous studies have concluded that simple regressions between land tenure and land cover change, or even agricultural productivity, have to be drawn with great caution. Changes in agricultural management and production are the result of a combination of various factors (Moyo et al. 2009). For too long, however the lack of agricultural data of has prevailed in the discourse on success of land reforms in Southern Africa. Agricultural figures have been selectively cited, have been "guessed after various factors" (Oya 2010) by officials and are compiled from considerably underfunded institutions. Conversely, in their 2007 review of interdisciplinary spatial-temporal studies of African land use change, Guyer et al. conclude that the remote sensing community has not sufficiently considered the linkages between the "natural and human worlds" (Guyer et al. 2007).

The analytic structure proposed in Figure 7.3 must be tested for its applicability as well as its facility to link Guyer's "natural and human worlds". It is characterized by three elements of spatial-temporal analysis: localization, characterization and comparison. All elements will be worked on "in the natural world" by remote sensing and "in the human world" by the PPGIS approach. The following sections describe the steps and methodological approaches in detail.

7.7.1 Localization of Change Events

The first challenge of land reform mapping involves the spatial characterization of the anthropogenic variables of land ownership and land management. The second requires the correlation of land ownership/management with the physical world of land use and land cover. Important political and collective decisions, which lead to changes in land tenure must be accurately fixed in time and space, this will be accomplished through the PPGIS approach. In our research framework, an interactive web portal will be utilized to account for ownership changes of demarcated farms. Here, participants are asked to provide general information, such as name and size, on farms they recognize and identify on an associated detailed web map. In a second step (see Figure 7.2), respondents will be asked to provide the reason for ownership change and the date of change, as well as to provide information regarding whether or not the specified entity has been subject to subdivision (Hentze n.d.). As a result, expropriations of farms are mapped spatially and temporally.

Time series remote sensing data will be used to locate physical land use changes. The Breaks for Additive Seasonal and Trend (BFAST) analysis method offers distinct advantages in time series analyses by decomposing reflectance values into trend, seasonal and remainder constituents. This allows identification of abrupt changes in land use over the course of several years and they can be separated from regional trends and seasonal change patterns of vegetation. Changes in cropping patterns can therefore be located with an automated spatial approach because of their changing reflection patterns, which are not associated with either general or seasonal trends (Verbesselt, Hyndman, Zeileis, et al. 2010a).
By spatially correlating evicted farms with land use change events, land reform effects can be estimated countrywide. The results can be used to identify volatile land use "hot spots" where changes can be attributed to a variety of factors, including lack of investment and operating capital, deficient knowledge base, and labor shortages. This change analysis process can then serve as a basis for further studies.

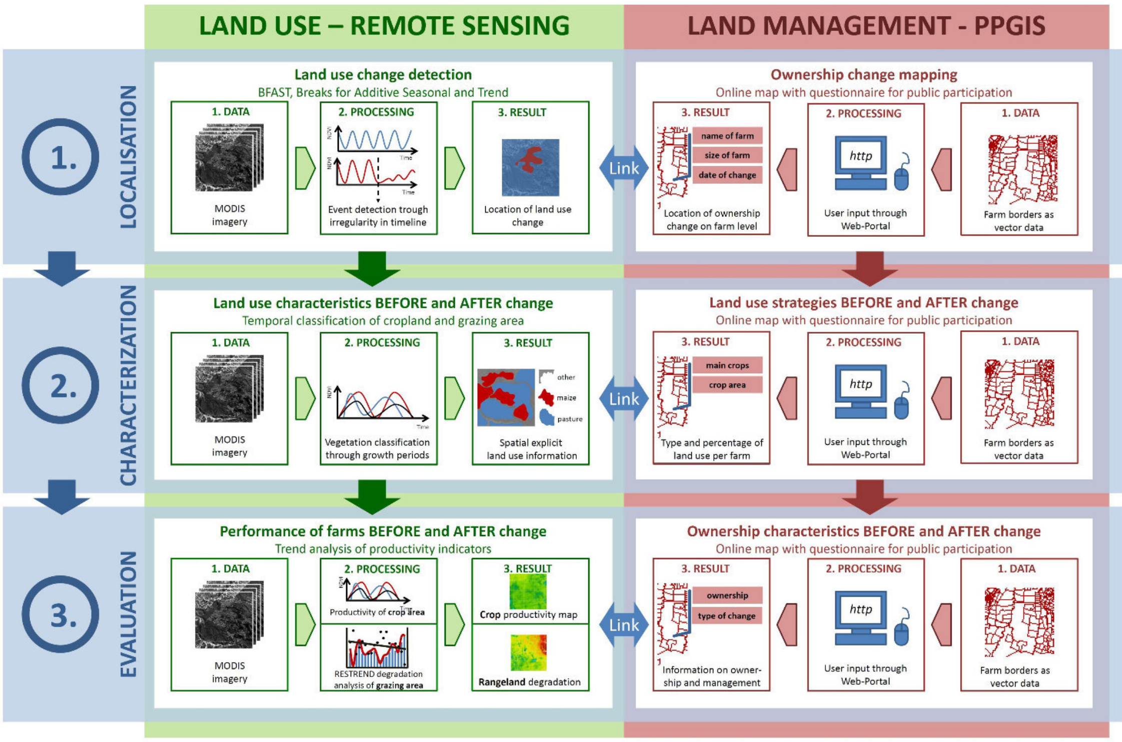

Figure 7.3: Research framework: linking land use change and ownership change by means of remote sensing and public participatory geographic information system (PPGIS).

7.7.2 Characterization of Change Events

After locating and correlating land use and land tenure change events, the proposed framework aims to characterize these changes. The online survey tool will be used to acquire information on changing land use strategies. Participants will be prompted to enter information on crops in production both before and after ownership changes and, if possible, also estimate the planted area and grazing area for each farm. These cropland and grazing area specifications will serve as primary information on land use strategies of changing ownership and management; they will also provide data for use in verifying the accuracy of the satellite based analysis.

To characterize the land use change, we propose a temporal crop masking and classification methodology based on MODIS data. As shown above, temporal classification has been applied in various contexts and provides reliable crop type identification and crop production area calculations. With this method, crop types (and grazing land) can be accurately identified and mapped on an annual basis due to the characteristic reflectance values of different plant types in different growth phases (SIBANDA & MURWIRA 2012).

The resulting annual land cover data sets will capture periods before and after changes in land tenure. Through the applied spatial correlation, these data will provide critical information on the effects that these changes have on land use and allow visualization of their spatial dimension. Change maps can also provide information that is of immediate use for land use planning and management analysis.

7.7.3 Evaluation of Situation before and after Change Event

Finally a comparison of plant productivity before and after the mapped and characterized change events will be performed. This will be limited to a comparison of harvest and biomass per area and is not meant to provide a thorough evaluation of land reform because of the complexities surrounding the determination of success of land reforms discussed previously in 7.3. The online survey will provide information on farm ownership both before and after the change event. In addition, users can specify the reason for ownership change to associate the type of change event with the effects on land use productivity and sustainability.

By using MODIS data, the framework will assess the potential of these data to directly associate changes of crop production with change events of Zimbabwe’s land reform. Furthermore, an analysis of grazing land degradation will be carried out through the application of a Residual Trend Analysis (RESTREND). The RESTREND method compares residuals of NDVI values with a long-term trend, and allows separation of observed episodes of diminishing plant health and production from long term trends associated with or caused by climatic conditions. Applications of MODIS and RESTREND have demonstrated the utility of this approach to differentiate between human induced and natural degradation at regional scales (K. . WESSELS ET AL. 2004). We will implement and test this procedure to identify and characterize vegetation degradation in southern Africa rangeland environments.

Any comparison of pre- and post- land reform agricultural production levels must be performed carefully and two important factors must be considered: (1) the varying causes of land use change or degradation, and; (2) the lack of sufficient, multi-temporal, medium resolution image coverage. The FTLRP was implemented in Zimbabwe beginning in the year 2000. The year 2000 is also the earliest date for which MODIS data products are available which makes a comprehensive temporal comparison based solely on MODIS data impossible. Correlation of early land reform events can only be accomplished by performing a regional spatial comparison of redistributed farms with non-transferred neighboring farms throughout the course of the following years. This method would allow evaluation of whether or not the potential productivity of a given agricultural unit is fully realized.

7.8 Conclusions

We have presented a quantitative literature review that has shown the evident lack of spatial-temporal datasets among current research regarding Zimbabwe’s Fast Track Land Reform after we described the complexity of land reform assessment criteria. We argued that the debate over the success or failure of land reform in Zimbabwe is confused by the absence of data which is comparable and which sources are traceable. We elaborated further that adding a spatial context to the land reform process could help to overcome this current lack of data as well as to encourage rationality, objectivity and consistency in the land reform debate.

Geographic methods of GIS and remote sensing provide answers to spatial questions related to land reform success. We have described how these technologies support multi-temporal analyses focused on the process related character of land reforms and enable or accelerate the transition from qualitative to quantitative research. Geospatial time series analyses allow investigators to characterize different land use change processes as either episodic or continuous and to differentiate farming systems as functioning in either stable or dynamic modes of agricultural production. To link social and political change with physical land use change for the first time on national scale, we introduced an innovative analytic framework which combines time series analysis methods and Public Participatory GIS.

We hope that our approach can motivate spatial researchers for a stronger engagement in the land reform debate and that it contributes to an improved national dataset of changes in land ownership and land use.

IV. Resolutions of pixels: challenging popular methods of land use classification

8 A critical reflection of the suitability of remote sensing products

The III Main Section of this thesis has emphasized the suitability of spatial methods and the unique set of tools Geomatics provide for the assessment of land use status and processes. But it has also shown the apparent lack of geospatial contributions to land reform research which leads to room for engagement.

Aim of this Main Section is therefore to critically evaluate time-series analysis of remote sensing data as a spatial method to provide answers to the often posed question of 'what has happened where?' during the land reform program in Zimbabwe. As elaborated above, remote sensing is a powerful method which is extensively used for spatio-temporal land cover characterization. However, at the same time, there are a number of limitations which are often neglected in the light of colourful maps and graphs.

The reproduction of common remote sensing methods with little questioning of their applicability and validity - especially in mapping of land cover and its change - has to be viewed in the context of the power discourse around maps. As in other disciplines, Geographers and spatial scientists do well in questioning methodology and results with regards to their immanent power, formulated by Foucault (Foucault 2007). Harley regards maps as part of the family of value-laden pictures and emphasizes how they are perceived as dichotomous entities ("true" vs. "false", "accurate vs. inaccurate") which are based on "scientific integrity" (Harley 2009). This scientific integrity is rooted in the power of the cartographer, perceived by the reader. Often, what is depicted on a map is believed to be there in reality - static and discrete - without questioning the soundness of map creation (Wood 2010). But maps are only a synthesis and presentation of data. The "exploration" and "generation" of data, as well as the "confirmation" of methods remain hidden and have to be reproduced in research articles (Crampton 2001).

In contrast to this 'perceived truth', remote sensing methods face a real problem of inaccuracy, determined by the resolution of the sensor (temporal, spatial, spectral, radiometric) and the applicability of method (Comber et al. 2012). Critical evaluations elaborating on the shortcomings of remote sensing are few, but there are authors which do point out the lack of accuracy and of usability for specific research questions. Heumann for instance exemplifies the serious limitations of remote sensing for the discipline of conservation, such as the fact that products are often not suitable to be linked with research questions on the ground; and that studies "omit detailed accuracy assessments", meaning that they fail to reproduce the hidden processes of map creation as described above (Heumann 2011). He links this omission to the gap between remote sensing and the disciplines which make use of the remote sensing products (Heumann 2011). Both aspects are addressed in the following published chapter. It stresses the applicability of a common and often reproduced method on a very specific research question. Furthermore, it provides details on the methodology and the accuracy assessment applied in the research. The critical evaluation of land cover characterisation of a heterogeneous semiarid area by time-series analysis revealed that accuracies are too low to be of any significant contribution to a scientific discourse on land reform assessment in the region.

Three limitations could be identified, which also have been formulated in the context of remote sensing based studies in climatology: "short span of satellite datasets", "bias with instruments", and "uncertainties in retrieval algorithms" (Yang et al. 2013). These shortcomings are also immanent in the commonly used vegetation index products of MODIS. While they correlate well with above ground biomass and its phenological character, a practical application is limited (Huete et al. 2002). MODIS started to operate in 2000, which does not allow long term analysis based on its products (ESA n.d.). Especially for the study of FTLRP, this is a major shortcoming as farm occupations started in 2000 (Cliffe et al. 2011). Although MODIS has a much better resolution than its longer operating predecessors such as the AVHRR, the resolution of 250 by 250 meters hinders a correlation to human activities. Recently, more and more authors try to overcome the resolution dilemma with image fusion if the data availability from sensors with higher spatial resolution is sufficient (Walker et al. 2012). Finally, the study could profit from validation data which is limited in Zimbabwe. With MODIS in general, missing validation data is a drawback as most studies operate on large scale which make comparative measurements on the ground impossible (Zhang et al. 2003).

Given these shortcomings, together with the problem of unquestioned reproduction of methods, care has to be taken when remote sensing products are used as the basis for further studies. The aim of this reflection is not to deem all remote sensing studies as inaccurate and all research efforts on coarse-scale data as futile, but rather to re-emphasize the importance of validation and of applicability for specific research questions in regional settings. It sets the context for the negative results presented in the following chapter. They have been published to contribute against the positive bias in scientific publishing which limits international research (Granqvist 2015).

9 Evaluating crop area mapping from MODIS as an assessment tool for Zimbabwe's land reform

9.1 Introduction

After Independence in 1980, Zimbabwe had to redress its screaming injustice in wealth and land ownership. More than half of the country's arable land was held by less than 7,000 commercial - often white - farmers, while the majority of the population was concentrated on the other, overall less productive half (Deininger et al. 2004). The newly elected democratic government started a carefully arranged land reform program which aimed to redistribute commercial farmland, but it did not meet its self-set ambitious goals (Palmer 1990). As one consequence of the perception of a failed land reform program, numerous heterogeneous groups of people started to invade commercial farms and to disseize their owners in the year 2000 (Chaumba et al. 2003). In the following period, the agricultural sector of Zimbabwe experienced drastic changes. The consequent vivid debate about whether or not this almost fifteen year-old Zimbabwean "Fast Track Land Reform Programme" (FTLRP) was successful, has still not come to an end (Hanlon et al. 2013, Scoones 2014b). Controversy is ongoing whether overall goals of the program have been met or not and which goals outweigh others. A general challenge in land reform assessments lies within the fact that redistribution processes can be evaluated with different criteria (Cousins & Scoones 2010, Hentze & Menz 2015). Among the discussed measures, the state of national agricultural production patterns recognizes significant attention. But up to date, spatial explicit, objective, and country-wide datasets on the spatio-temporal development of agricultural area in Zimbabwe are rare (Fraser 2008). Throughout the discourse on the success of Zimbabwe's land reform, a general need of reliable, spatial data becomes apparent. A systematic literature review carried out in a previous study reveals a significant lack of recent representative statistical and quantitative spatial data in scientific publications from all research perspectives (Hentze & Menz 2015). Authors themselves highlight the absence of spatial data on relevant issues connected to the FTLRP (Cliffe et al. 2011) which can be linked to untapped potential of innovative geospatial methods (Hentze & Menz 2015).

Remote sensing analysis offers a number of different approaches to deliver spatial, reproducible data on land use and land cover (LULC) and its change. For more than three decades, various methods of remote sensing have been developed to determine plant conditions and vegetation characteristics. Indices such as the Normalized Difference Vegetation Index (NDVI) relate reflectance values to vegetation cover or above ground biomass by making use of the specific relationship between the ratio of red and near-infrared reflectance and plant status (Tucker 1979). It allows determination of the fraction of photosynthetic active radiation (FPAR) from remote sensing data and hence to calculate information on plant cover such as the Leaf Area Index (LAI) while taking background, atmospheric, and bidirectional effects into account (ZHANG ET AL. 2003). NDVI and other indices have successfully been applied to gather agricultural information at different scales (FUNK & BUDDE 2009, TUCKER 1980). Among these methods, time-series analysis has been used extensively to map plant production and LULC information. Applied in different regional contexts, time-series analysis has shown promising results in differentiation of land cover types such as cropland and, under specific conditions, also different crop types using measures of phenology (LUNETTA ET AL. 2010, WARDLOW & EGBERT 2008). This has been successfully proven in Southern Africa and also in Zimbabwe (SIBANDA & MURWIRA 2012). Phenology describes the seasonal plant cycle and its characteristic stages such as green-up onset, peak of greenness, start of senescence, or length of vegetative season (VIÑA ET AL. 2004). As different plants have distinct phenological characteristics, they can be identified and classified according to these temporal measures which have to be acquired throughout a phenological cycle.

We argue that this potential of remote sensing has not been tapped sufficiently to deliver input into the assessment of Zimbabwe's land reform. The goal of this study was to evaluate whether time-series analysis as a method of spatio-temporal mapping is capable to determine changes in Zimbabwe's agricultural area which took place after the FTLRP between 2001 and 2013. It therefore aimed to fill the previously identified gap of spatial objective data within the discourse on the success of Zimbabwe's land reform.

Recent work on time-series and FTLRP has assessed productivity within an agricultural area extracted from external land use datasets (BROWN 2008, FUNK & BUDDE 2009, USDA n.d.). We tested whether coarse-scale, multi-temporal data can be used to classify LULC and its changes occurring as a consequence of the FTLRP in Zimbabwe. If crop area could be mapped on a yearly basis with a reproducible method, an important aspect of land reform assessment could provide meaningful objective input to a highly politicized discourse (HENTZE & MENZ 2015). Changes and volatility of land use in former commercial farmland were to be mapped because titles and mode of agricultural production shifted drastically in this region.

For Zimbabwe, with malnourishment being prevalent in many parts of the country (OLIVIERI ET AL. 2008), spatial accurate information on agricultural production and fallow land is key. More accurate information would not only lead to better assessments of the FTLRP, but could also indicate areas where farmers are in need of extension services, training and financial support. This has been formulated as central to improve nationwide productivity of redistributed farm areas (OWENS, HODDINOTT &

KINSEY 2003). LULC information has been identified as one of the most important variables for a variety of societal aspects in a recent Global Earth Observation System report (BATTRICK 2005).
Within the current study, emphasis was put on the ability of Moderate-Resolution Imaging Spectroradiometer (MODIS) NDVI imagery and derived phenological parameters to map cropland area over twelve agricultural seasons in thirteen years (2001-2013) with explicit focus on redistributed farmland. MODIS offers several advantages for these efforts: In addition to the robustness to cloudiness, an analysis using one methodology applied to one sensor at regular acquisition dates avoids incomparable results due to different acquisition dates or small study areas. Existing LULC datasets for the region have been based on labor intensive Landsat classifications; updates of cropland distribution would require the manual processing of several cloud free scenes per year.

Our specific research questions were:

- How accurate can time-series analysis of MODIS data map Zimbabwe's redistributed agricultural area?
- Can MODIS data be used to map changes and volatility of agricultural area in the time frame 2001-2013?
- Can the generated spatial products be linked to information on land tenure to correlate information on LULC change with information on tenure change?

9.2 Study area

Zimbabwe, bordered by the rivers Limpopo (South) and Zambezi (North) and a mountain range in the east, is a landlocked country in the torrid zone with a size of 390,757 km^2 and about 13 million inhabitants (ZIMBABWE NATIONAL STATISTICS AGENCY 2014). The country's agro-ecological conditions are characterized by contrasting climatic and soil conditions. The average rainy season lasts for about 4 months (November - March), limiting the access to qualitative satisfactory optical remote sensing data of high resolution. During the austral winter, stable air layers are caused by sinking masses of stronger trade winds and hinder convection. During the rainy season, trade winds become weaker due to low pressure areas over the land surface and lead to unstable conditions favouring convective currents (NUDING 1999). However, droughts are regular experiences and form one of the many obstacles of newly resettled farmers in addition to the instability of markets as a consequence of economic recession. Generally, the fertile and climatic favourable tsetse-free highland with highly suitable areas for crop production can be distinguished from the less productive lowland (Potts 2012). Freehold commercial farmland was situated on these fertile areas, whereas communal areas for indigenous people were found on less fertile land. Precipitation ranges from 400 mm to 2,500 mm with a south-west to east gradient (Vincent, Thomas & Staples 1960). Elevation in the eastern mountains ranges up to 2,500 m above sea level, while the central plateau, known as 'Highveld' has an approximate height of 1,200 m above sea level. With parent material being the most important soil building factor, soils are characterized by low nutrition values and rapid degradation (Van Straaten 2002). They are a major limiting factor for agricultural production and natural plant growth, main soils groups include *Arenosols*, *Cambisols*, *Leptosol*, *Lixisols* and *Luvisols (IUSS 2006)*. The vegetation of Zimbabwe is partially comprised of grassland (*Themeda*, *Hyperrhenia*, *Loudetia*), thicket (*Combretum*) shrub-savanna (*Colophospermum*), and afromontane forests (*Pittosporum*, *Maranthes*). Much of the country is covered by tree-savanna (*Terminalia*, *Burkea*, *Baikiaea*) and miombo woodland (*Brachystegia*, *Julbernardia*) (Wild & Grandvaux Barbosa 1967a, 1967b).

Zimbabwe can be stratified into six different agro-ecological regions. They are related to climatic and soil conditions and therefore indicate the suitability for rainfed agriculture (FAO 2006). To avoid negative impact of different climatic conditions, we restricted our analysis to agro-ecological region II (AERII, see Figure 9.1) which is situated at the northern part of the 'Highveld' and highly suitable for crop production. This zone is also characterized by a heterogeneous land tenure pattern including different types of resettlement schemes, communal areas and large scale commercial farming, allowing a

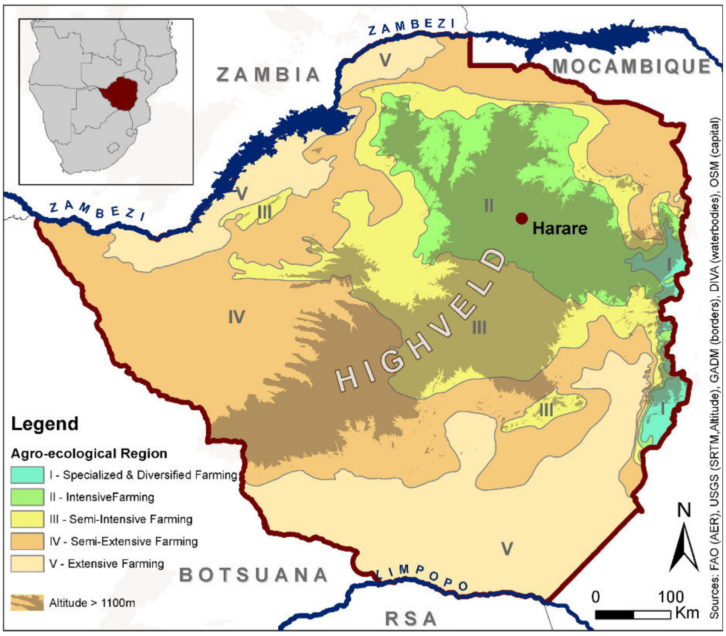

Figure 9.1: Agro-ecological regions of Zimbabwe.

spatial correlation of land tenure and classification results. Our study was restricted to redistributed former freehold land within AERII.

With more than 20% share, agriculture forms a major contributor to the national GDP ("The World Factbook, Zimbabwe" n.d.). In the past, Zimbabwe underwent a number of political and socio-economic changes in addition to the thorough land reform program: As Rhodesia from colonial style-rule by British South Africa Company (BSAC) to self-declared independence, later from guerrilla war to official independence and majority rule as Zimbabwe (Mlambo 2014). Twenty years after independence, the country was hit by an economic recession and hyperinflation. Currently, in 2016, the economy has partly recovered under 'the government of national unity' which followed the 'Global Political Agreement' and was formed in 2009 by the three major parties ZANU-PF, MDC-T and MDC-M. The dollarization and abolishment of the Zimbabwean Dollar in 2009 lead to further stability (Coomer & Gstraunthaler 2011).

9.3 Low Resolution Multi-Temporal Data as a Basis for LULC Classification

The increasing demand for LULC information on regional scales is one driver of the growing number of coarse-scale remote sensing-based classifications (Herold et al. 2008). These datasets are often based on multi-temporal imagery which are acquired with high repetition rates. Products of multi-temporal imagery such as NDVI are available in continuous intervals which allow the analysis of phenological information, since regular NDVI and reflectance values can be used to construct curves which represent the phenological activity of the land surface. Well-established methods to interpolate the data include the Harmonic Analysis of time-series (HANTS), Best Index Slope Extraction (BISE), function-based curve fitting approaches or smoothing of temporal signal such as the Savitzky-Golay filtering (Pan et al. 2015). These methods generate continuous, temporal time-series profiles on a per pixel basis which can be analyzed and described through a set of specific parameters.
Classifications of multi-temporal satellite based information form the basis for a majority of global LULC datasets. Hence, time-series can be considered as an extensively explored, applied, validated, and improved method of remote sensing analysis. Global LULC datasets, such as IGPB-landcover (Loveland et al. 2000), MODIS (Friedl et al. 2002), or GlobCov (Bartholomé & Belward 2005) are widely used in studies of different fields, often with the assumption of accuracy and applicability for the specific research question. However, critical reviews and efforts to assess comparability of results have shown that global LULC datasets have to be treated with great caution, and that methods of specific datasets incompletely match

research designs and questions (Moody & Woodcock 1994, 1995). Fritz et al. provide a detailed comparison of global and regional land cover maps with an explicit focus on the agricultural domain in Africa (Fritz, See & Rembold 2010). They have compared 16 national figures (including Zimbabwe) for agricultural area from different datasets with FAO statistical data. Table 9.1 shows their results with figures of deviation which exemplify that also MODIS, with its relatively high spatial resolution, has strong limitations for global applications.

Table 9.1: RMSE of cropland area comparing different land cover products to national[1] FAO statistics

Land cover type	RMSE(km²)
GLC-2000 minimum[2][43]	21,064
GLC-2000 maximum	76,802
SAGE[44]	25,109
MODIS minimum[45]	27,787
MODIS maximum	36,504

[1] For Botswana, Burkina Faso, Central African Rep., Chad, Eritrea, Gambia, Lesotho, Mali, Mauritania, Morocco, Namibia, Rwanda, Senegal, Somalia, Togo, Zimbabwe
[2]"Maximum" and "minimum" refer to in- or exclusion of mixed classes

As a consequence, datasets have to be chosen with care and criteria for selection have to be made explicit. Also, caution has to be applied to the interpretation of LULC classes of global datasets, because they often follow different classification schemes (Figure 9.2). Especially, classes with mixed ground cover, for example Savannahs, are extremely inconsistent in terms of variables such as ground cover threshold. Low producer and user accuracies for these LULC types are reported for different classification schemes (Herold et al. 2008). A major source of inaccuracies is the fact that global products have to stratify land surface characteristics over large areas of different latitude, altitude, and climatic regimes which leads to heterogeneity and low significance of classes.

Other limitations of global products arise from sensor specifications. The Advanced Very High Resolution Radiometer (AVHRR) data is popular for its long availability time frame and its consistent quality. However, its spatial and spectral resolutions lead to difficulties in classification accuracies (Figure 9.2a). With a ground resolution of 1x1 square kilometres, AVHRR datasets face problems of mixed pixels. More recently, especially for smaller scale regional analysis, imagery from MODIS is used, because it combines suitable temporal, spectral and spatial resolution (Zhang et al. 2003). The sensors of Terra and Aqua have been operating since 1999 and 2002, respectively (ESA n.d.) and show major improvements compared to previously-used systems, such as sensitivity to crop area. Pittman et al. conclude from their global cropland mapping based on MODIS, that crop NDVI phenology varies greatly on global scale and that regional studies based on this sensor will lead to improved results (Pittman et al. 2010).

For the discrimination of agricultural land, several studies using MODIS show promising results on a global and regional level (Friedl et al. 2002). In Zimbabwe, nationwide production anomalies (Funk & Budde 2009), yield predictions (Kuri et al. 2014) and also hard classifications of crop type were carried out successfully using time-series analysis (Maguranyanga, Murwira & Sibanda 2014, Sibanda & Murwira 2012). Acknowledging this potential of multi-temporal data and analysis, but also the limitations in contexts of specific research questions, we tested the suitability of MODIS data for crop classifications as an FTLRP assessment tool in a clearly defined study area with rather homogeneous climatic conditions and land tenure.

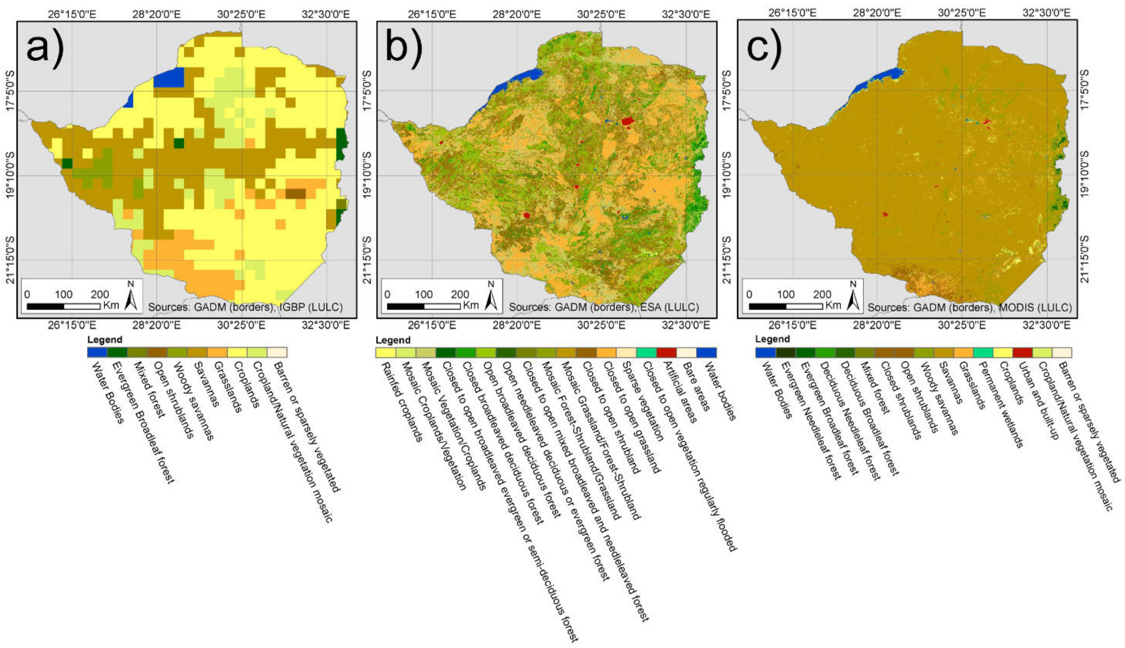

Figure 9.2: Comparison of different LULC classifications and class definitions: (a) IGBP, 1993, (b) GlobCover, 2009(c) MODIS13Q1, 2014 (Band1).

9.4 Data and Preprocessing

Five type of spatial datasets were used for this regional cropland mapping: MODIS NDVI (1) and RED/NIR (2) composites for a time-series analysis for the whole study period of 12 seasons (2001-2013); Landsat scenes (3) for construction of endmembers based on supervised classification; as well as an external LULC data set (4) providing further information as input and validation data. Additionally, we made use of Google Earth imagery (5) to verify different calculation results.

9.4.1 MODIS data

To cover the entire area of Zimbabwe, we mosaiced four tiles of the MODIS product MOD13Q1 (h20v10, h21v10, h20v11, h21v11) which we acquired through the United States Geological Survey (USGS) reverb tool (NASA n.d.). MOD13Q1 is a 16-day maximum value composite (MVC) product of different vegetation and quality indices, and spectral bands, with an annual sequence of 23 scenes per calendar year (USGS n.d.). The NDVI layer (1), as well as RED (4) and NIR (5) were extracted and reprojected from Sinusoidal (SR-ORG:6965) to WGS84 (EPSG:4326) and clipped to a rectangular extent on a pixel based method to avoid spatial shifts (Figure 9.3). We did not extract the quality layer (3) since we applied filtering at a later stage, a method of removing noise in time-series (Wessels, Bachoo & Archibald 2009). For a better overview of the interannual spatio-temporal conditions within the study area and period, and also to adjust TIMESAT calculations, an average NDVI year was produced. Therefore, we calculated the mean for each of the 23 time steps based on the information from thirteen years. To avoid generalization, the data was not used for data gap filling. Missing or faulty scenes were replaced with mean values from preceding and subsequent scenes

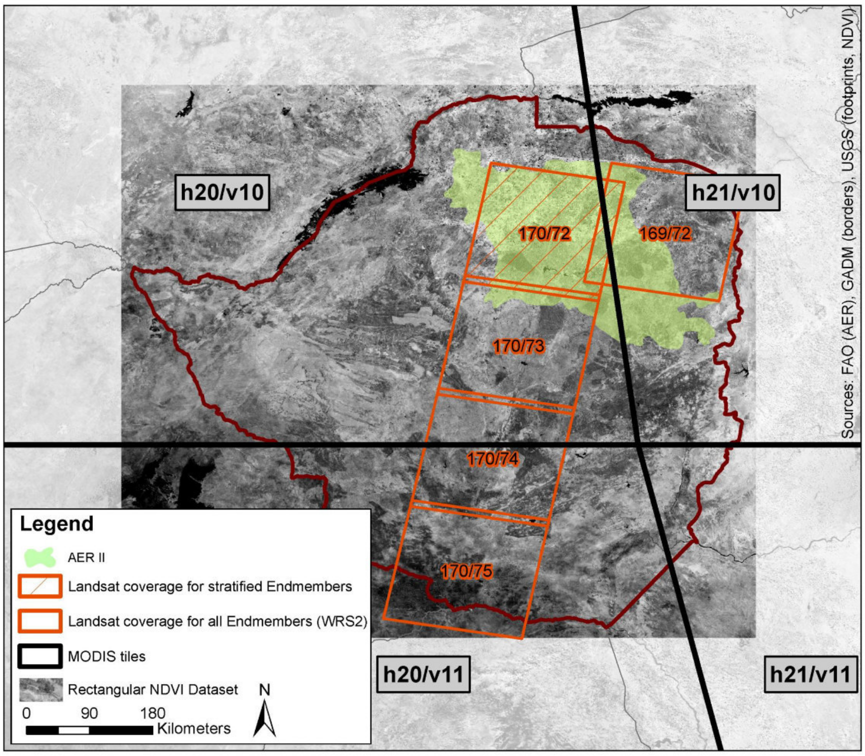

Figure 9.3: MODIS and Landsat tiles used in this study. Landsat tile used for the creation of agro-ecological stratified endmembers is highlighted. The rectangular NDVI dataset represents the extent of the NDVI dataset.

9.4.2 Landsat data

Landsat imagery was accessed through EarthExplorer and GLOVIS from USGS (USGS n.d., n.d.). To retrieve the reference data for MODIS LULC classifications, we chose a year with high coverage of Landsat scenes (Level1) for two day-of-year (DOY) time steps, representing the rainy season in February and the dry season in September. We downloaded all scenes regardless of cloud cover and set a maximum deviation of 8 days from the mean DOY acquisition date of the acquisition clusters to consider the scenes as one time step. For this year, 2005, we mosaiced all scenes with all bands for both time steps, resulting in two almost country-wide datasets. We used these mosaics for general orientation and extracted 5 cloud-free scenes (Figure 9.3) for the creation of training and validation datasets (Section 9.5.3).

9.4.3 Auxiliary spatial data

As an additional source of information for training and validation of classifications, the regional SADC (Southern African Development Community) LULC data set was acquired and clipped to the national boundary from the GADM database of global administrative areas (GADM n.d.). This data set was produced by different institutions and based on different data sources. For Zimbabwe, the data was published by the local Forestry Commission, together with the German Technical Cooperation (GTZ). Landsat Scenes were interpreted manually and resampled to coarser scale, the production date was specified as 1997 (CSIR 2016). To account for the large time lag, the SADC LULC data set was only used for contextualizing and cross-checking of classification results and input parameters.
Land tenure data for the region was acquired from the Foreign Agricultural Service of the United States of America (FAS). This data classifies farm structures in communal, freehold and state land and provides additional information on land holdings after the land reform program. It was considered as accurate in other studies (USDA n.d.).

9.5 Methods

In order to derive precise information about LULC and its change in the years 2001-2013, three consecutive methods were applied in this study. *First*, pre-processed MODIS imagery was enhanced and a time-series as well as seasonal parameters (SP) were calculated and stacked (section 9.5.1). *Secondly*, we constructed endmembers of LULC classes based on Landsat data which we classified with support vector machines (SVM) and upscaled to MODIS resolution (9.5.3). Finally, the endmember dataset was used to

run a random forest classification (RF) on the MODIS data stacks (9.5.4), the yearly results were reclassified to binary yearly datasets (rainfed/non-rainfed).
To assess the regional applicability of these methods, we required the need of an agro-ecological stratification (9.5.2), as well as an improvement of class separability (9.5.3). Furthermore, the final binary results were extracted to former freehold tenure as the region of interest (9.5.5). This workflow is visualized in Figure 9.4.

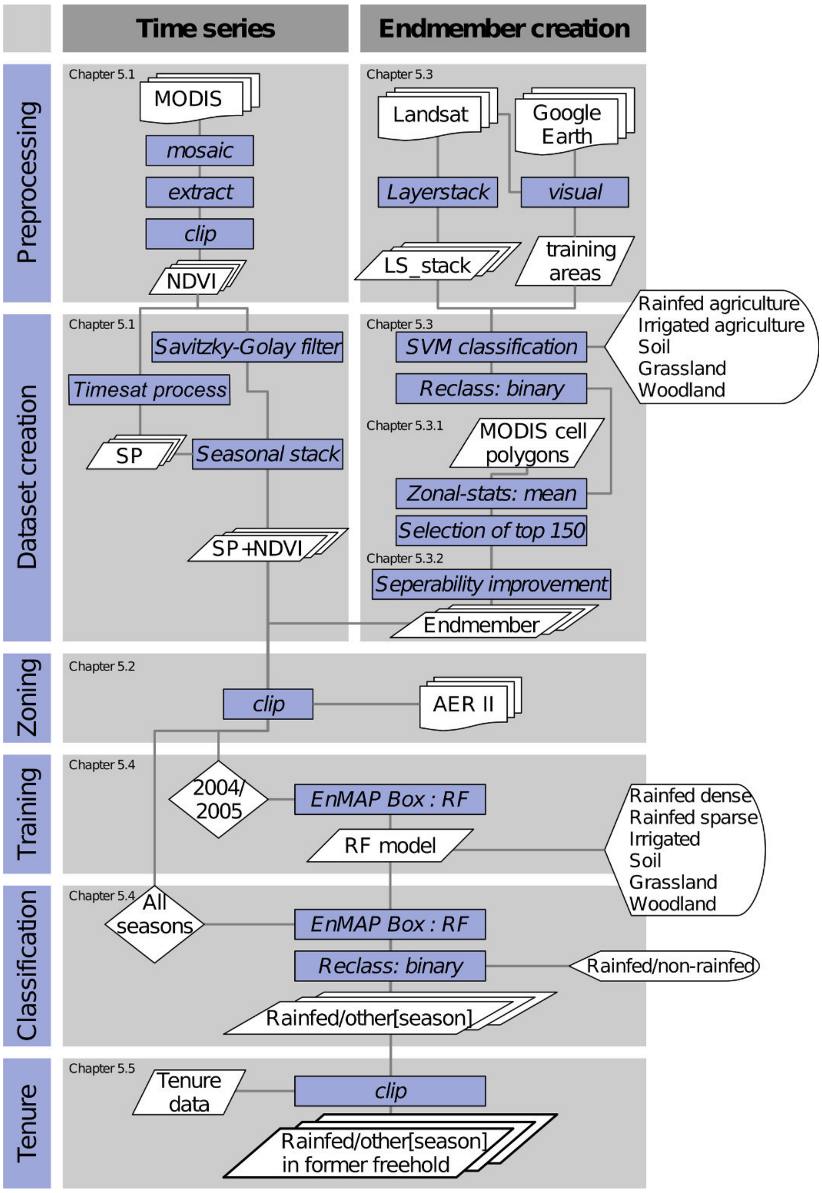

Figure 9.4: Flowchart of the processing chain for LULC classification.

9.5.1 Time-series analysis

Applying the software TIMESAT on the average phenological year, parameters for the smoothing algorithm were tested and used for further analysis. A phenological year is

characterized by seasonal plant activities and does not have to relate to the calendar year. TIMESAT provides different methods to reduce noise and to smooth the temporal curve as well as the option to derive SP (Jönsson & Eklundh 2004).
A Savitzky-Golay filtering was chosen to smooth the NDVI curve of the time-series. This method ensures a high locality by using a moving window which replaces values by new smoothed values, derived from neighbouring values (Chen et al. 2004). Testing showed best results for a spike-method with value 2 to calculate 11 seasonal parameters:

1. *Start of Season* (**SOS**), which we defined as the increase of NDVI of the fitted function to 0.2 above the minimum. It is located on the left side of the yearly maximum.
2. *End of Season* (**EOS**), which we defined as the decrease to 0.2 above the minimum following the peak of the function.
3. *Length of Season* (**LOS**), the time between the SOS and EOS.
4. *Base Level* (**BAL**) is the average of the minimum values left and right of the season.
5. *Mid of Season* (**MOS**) is computed as the mean of times where 80% values occur left and right of the absolute maximum of the NDVI function.
6. *Largest Data Value* (**LDV**), the absolute highest single value in the whole season.
7. *Seasonal Amplitude* (**SEA**), which is the difference between the LDV and the BAL.
8. *Increase at Beginning of Season* (**IBS**), the calculated ratio between the first 20% and 80% value (left) of the fitted function (in Figure 9.5 between SOS and IBS).
9. *Decrease at End of Season* (**DES**), the absolute between the second 80% and 20% value (right) of the fitted function (in Figure 9.5 between EOS and DES).
10. *Large Seasonal Integral* (**LSI**), the area under the NDVI curve between SOS and EOS.
11. *Small Seasonal Integral* (**SSI**), the area of the difference between LSI and BAL between SOS and EOS (Eklundh & Jönsson 2012).

We then created two types of composites (C_1 and C_2) for each phenological year (PY_i). C_1 with a specific amount of layers consisting of NDVI composites (MVC) and seasonal Parameters (SP), C_2 with (RED) and (NIR) added. Classifications were run on both composite types, and accuracies were compared to evaluate whether the addition of reflectances improves classification results.

Because the phenological year does not match the calendar year on the southern hemisphere, we created composites according to SOS and EOS of the calculated mean year.

$$C_1PY_i = (MVC_{(i-1)}13\text{-}23\tilde{}MVC_{(i)}1\text{-}12) + SP_i[SOS_i,EOS_i,\ldots,LSI_i,SSI_i]$$

$$C_2PY_i = (MVC_{(i-1)}13\text{-}23\tilde{}MVC_{(i)}1\text{-}12) + (RED_{(i-1)}13\text{-}23\tilde{}RED_{(i)}1\text{-}12) + (NIR_{(i-1)}13\text{-}23\tilde{}NIR_{(i)}1\text{-}12) + SP_i\,[SOS_i\,,EOS_i\,,\ldots,LSI_i\,,SSI_i\,]$$

For each C_i, a random forest (RF) classification was carried out, based on a classifier trained and verified in the reference season (2004/2005). We demonstrated the need of climatic stratification and stratified this national time-series data set according to Zimbabwe's agro-ecological zones.

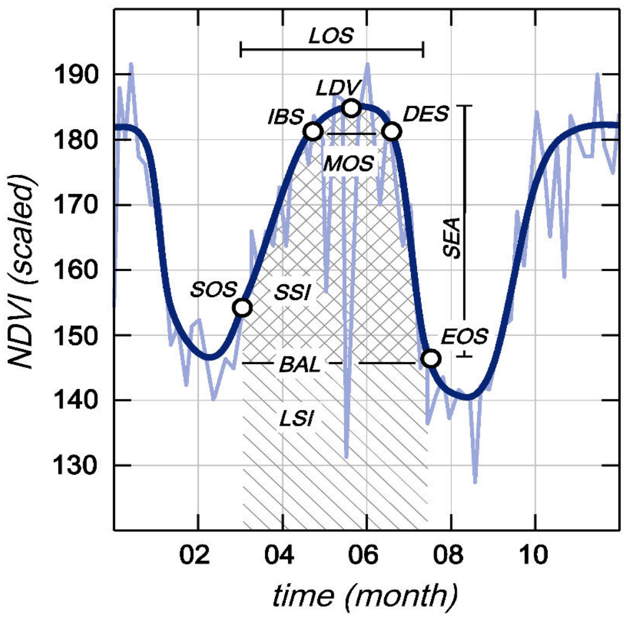

Figure 9.5: Exemplary visualization of an original and a filtered NDVI-curve, as well as 11 Seasonal Parameters. Adapted from (EKLUNDH & JÖNSSON 2012).

9.5.2 Agro-ecological stratification

Regional climatic conditions and resulting heterogeneous phenological characteristics form a major limitation for the creation of universal large-area LULC datasets. As discussed above, one restriction of global and continental classifications is the class-definition over different agro-ecological regions which differ in temperature, rainfall, soil type and altitude. Adapted from landscape ecology, where complexity is reduced by breaking areas into patches of similarity (FORMAN 1995, SAURA 2004), climatic stratification in other studies has shown to be able to improve multi-temporal classification results (Vintrou et al. 2012). To proof the necessity of a agro-ecological stratification, we constructed 750 endmembers per LULC class following a North-South gradient through Zimbabwe. The endmember construction is described in section 9.5.3. It became apparent, that similar classes have different seasonal NDVI profiles in different parts of the country, hence preliminary countrywide classifications did not deliver satisfactory results. Figure 9.6 exemplifies 750 profiles of pure 'grassland' pixels and relates them by color to the North-South gradient. As a consequence of this heterogeneity, we stratified the datasets according to Zimbabwe's agro-ecological zones, restricted the time-series analysis to region AER II and therefore used the endmembers created from Landsat tile 170/72 only. Figure 9.3 shows the Landsat tiles used for the initial creation of all endmembers for different agro-ecological zones and highlights the tile which was used as input for the final classifications restricted to AER II.

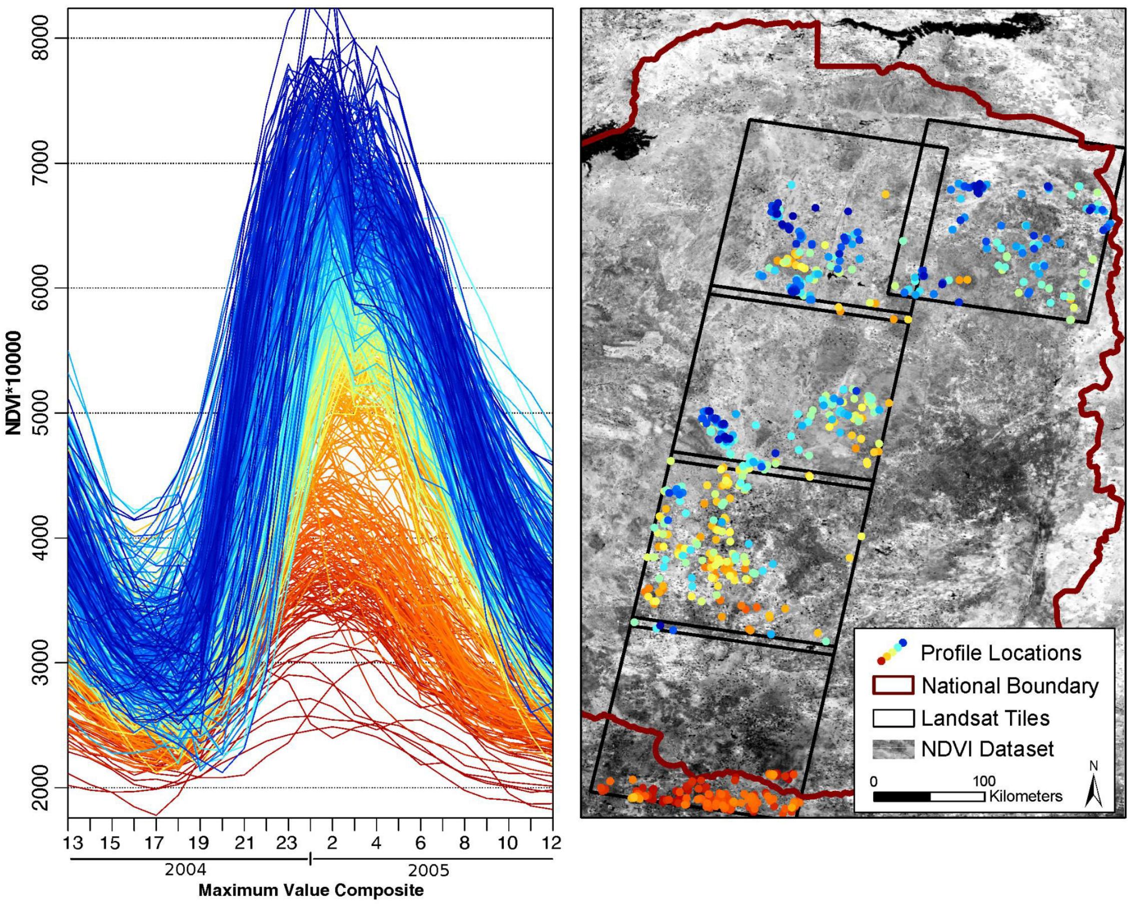

Figure 9.6: Temporal profiles and spatial location of 750 pure grassland MODIS pixels for phenological season 2004/2005. Color codes represent the maximum value of the NDVI profile. Maximum values follow a South-North increment, related to agro-ecological conditions.

9.5.3 Endmember construction

To build a training data set of endmembers, a comprehensive classification of Landsat data for season 2004/2005 was carried out. Endmembers are defined as pure MODIS pixels in the training seasons which show a distinctive seasonal curve, representing one LULC class ('rainfed agriculture', 'irrigated agriculture', 'soil', 'grassland', 'woodland'). From the national data set, five Landsat Scenes (170/72-170/75, 169/72; compare Figure 9.3) were chosen due to their low cloud cover and North-South extent, representing five of six agro-ecological zones across the country. These five scenes were individually processed. To further improve the input dataset for classification, endmembers were stratified according to agro-ecological conditions, as Figure 9.6 exemplifies its necessity, and their curve separability was improved. Finally, only endmembers of one scene (170/72) were used since we proved that a climatic stratification was necessary and limited the classification to AER II. For this endmember set, an additional LULC class ('sparse rainfed') was introduced after the temporal stratification.

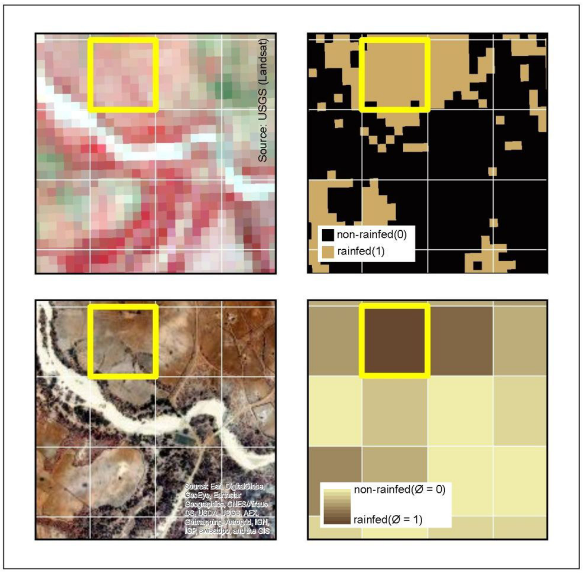

Figure 9.7: Spatial visualization of endmember construction. Comparison of a pure 'rainfed' endmember (yellow) in Landsat false color image (a), binary classification result for rainfed/other (b), ESRI-basemap (c) and purity grid on MODIS resolution (d).

Upscaling of Landsat classification

Without historical on-site knowledge, LULC classes were assigned by interpretation of remote sensing data and the external SADC LULC classification data set. Criteria for

training areas were: 1) visual differentiation by shape, greenness and location possible using Landsat imagery, 2) training area within the same class in LULC data set of SADC, 3) shape and location identified in recent high resolution imagery (Bing Maps, Google Earth). If all criteria were met, the feature was considered as a “training area” for the SVM classification. SVM has shown to be able to deliver high accuracies in LULC classifications based on Landsat data and can be used with small training datasets (Pal 2005). For the five classified Landsat scenes, overall accuracies ranged between 75% and 85% with high class separability. From these LULC classifications, binary images were produced, which represented one respective class versus all other classes. The inaccuracies of classification were a result of the low separability of grassland, shrubland, and rainfed agriculture which was to be addressed by the multi-temporal analysis. Furthermore, scattered single pixels of different classes occurred throughout the overall solid classifications. To account for the inseparability of classes and scattered pixels, we chose a sampling design which produced pure MODIS pixels with highest accuracy as endmembers. The binary images were resampled to a grid with MODIS resolution of 250 by 250 meters, leading to a purity index for each MODIS pixel. From the polygons with highest purity values, 150 pixels per class were selected for each Landsat tile after they could be manually verified again with the three criteria used for the creation of training data. Figure 9.7 contrasts the different datasets involved in the selection of pure MODIS training pixels (example visualized in yellow) as endmembers for time-series based classifications.
The upper left part shows an RGB composite of NIR, RED and GREEN bands, where rainfed agriculture is identifiable by its light red color; the MODIS resolution (250x250m) is overlayed as a white grid in all subsets. The upper right detail depicts the same area as the reclassified SVM result. The lower left part shows an ESRI-basemap layer to allow the comparison with data of higher resolution. Finally, the MODIS purity grid is visualized in the lower right part of the figure. To account for difficulties of variable waterbodies, 150 clean pixels were selected manually from an unsupervised classification of NDVI (2004/2005).

Improvement of class separability

After the selection and verification of 150 pure pixels per class for each of the five Landsat tiles, all 750 temporal NDVI profiles of every LULC were plotted. Figure 9.8 visualizes NDVI profiles for 750 pixels of each LULC class (water 150) which have been defined as pure pixels according to the endmember construction elaborated previously. From these plots, it becomes evident that the MODIS dataset shows huge variability of temporal NDVI profiles within LULC classes considered as homogeneous according to different datasets which were used to create pure pixels. To create distinct LULC endmembers, temporal profiles were cleaned after the agro-ecological stratification, to generate unique classes with improved separability (Figure 9.9). To account for differences in the class 'rainfed agriculture', the class was stratified again in 'dense rainfed' and 'sparse rainfed' agriculture. This was done with references from high resolution imagery and unsupervised classification which helped to differentiate the two density types of rainfed agriculture.

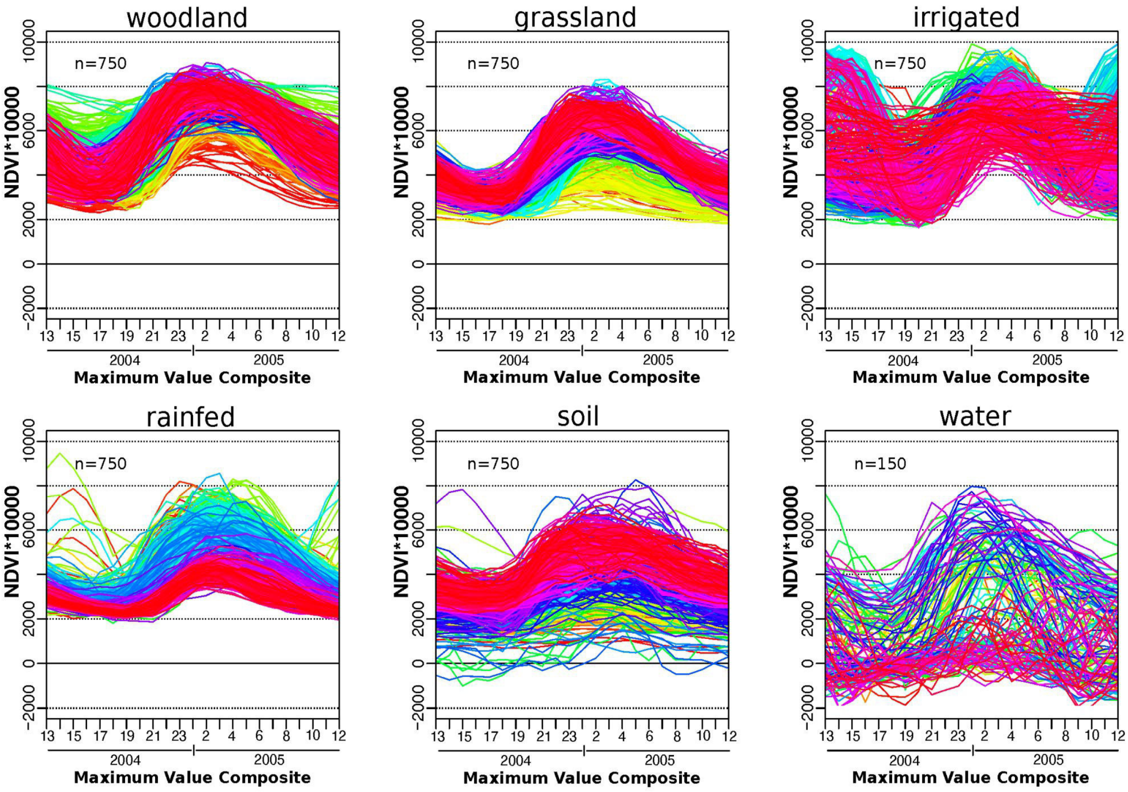

Figure 9.8: Visualization of heterogeneity of land use classes. Profiles are colored according to longitude. For the selection and verification process of endmember pixels, we made use of two external datasets.

9.5.4 Supervised Random Forest classifications of time-series-data

A classfile was created from endmembers of the seven classes which were created based on Landsat tile 170/72, and formed the basis for subsequent supervised classifications. We made use of imageRF, the random forest (RF) classification implemented in the EnMap-Box. The number of trees was limited to 100, reported as sufficient in other studies and tested in exploratory classifications (Senf, Hostert & van der Linden 2012). The IDL based EnMap-Box provides a convenient environment for supervised classifications such as RF or SVM and was successfully applied in different contexts with similar research designs (van der Linden et al. 2015). Figure 9.9 correlates mean NDVI as well as standard deviation and a visual pixel example from ESRI-basemap data for each LULC class.

The classes soil (Figure 9.9a) and water bodies (Figure 9.9b) show a high variability of NDVI functions although training points were reduced to the most significant. We assume that sparse vegetation for soil and aquatic plants, and siltation for water bodies contribute to the seasonal profile, together with an overall predominant seasonal signal, a side effect of preprocessing in advance of the MOD13Q1 creation. Although this exemplifies difficulties of indifferent reflectance values, it is considered as negligible because differences to the agricultural classes of interest are significant. Studies have proven that RF classification is a suitable method for LULC classification and are capable to separate indifferent classes (Pal 2005, Rodriguez-Galiano et al. 2012).

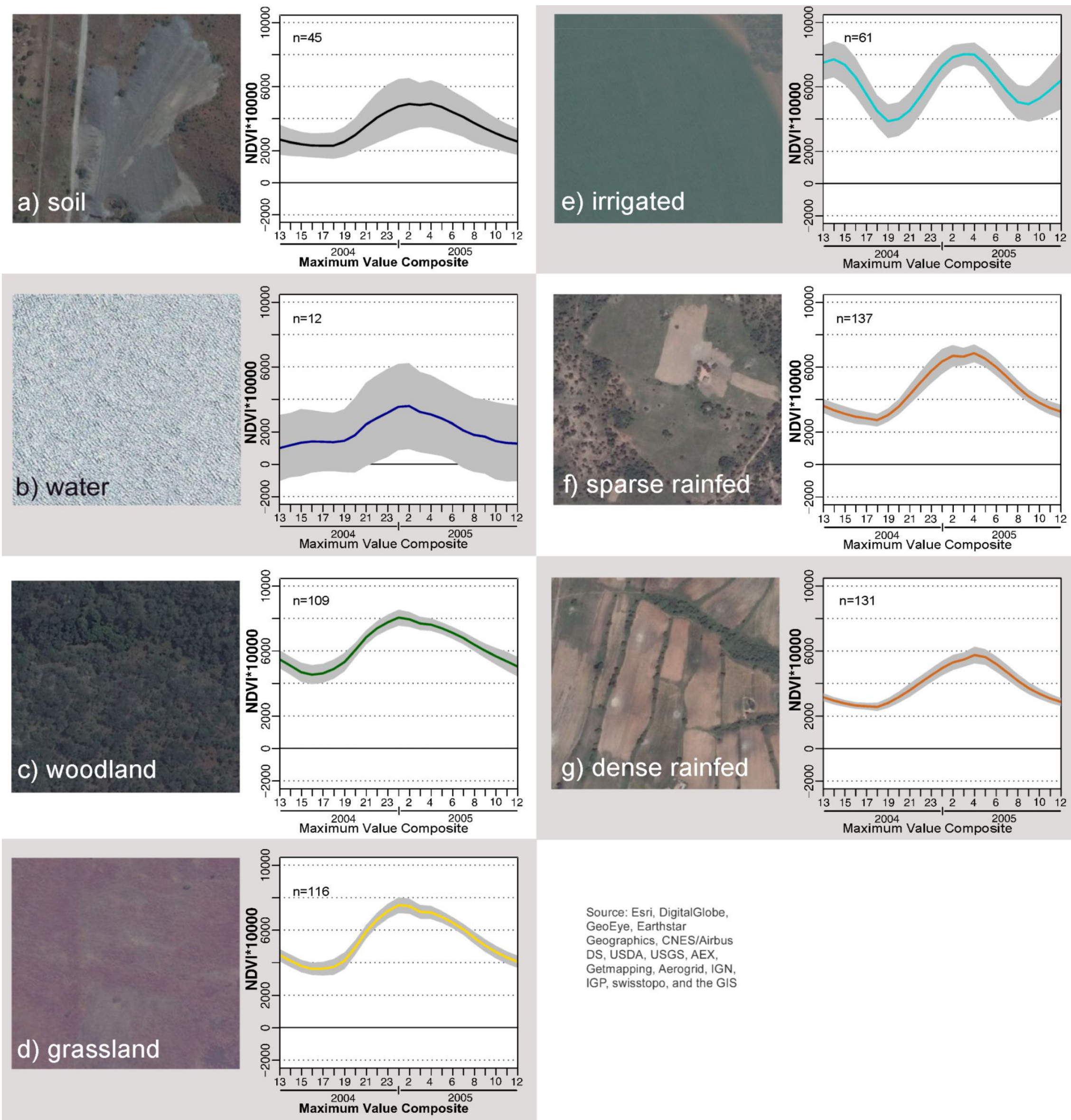

Figure 9.9: Examples of pure pixels (250x250m) and mean NDVI profiles (2004/2005) including standard deviations for each LULC class.

9.5.5 Extraction to freehold tenure

The results of the RF classification of climatically stratified time-series were reclassified to binary datasets for each agricultural season to produce datasets of rainfed/non-rainfed area. Because the aim of the research was to test whether MODIS time-series data was able to depict changes in an area of former freehold tenure, we clipped the yearly binary rainfed/non-rainfed datasets to former commercial farms where information on current land tenure was available through the FAS tenure dataset. For this climatically, temporally, and tenure-based stratified classification result, we conducted an accuracy assessment and were therefore able to put focus explicitly on the research question.

9.6 Results and Discussion

The goal of this study was to accurately map the annual extent of rainfed agricultural area between 2001 and 2013 in former commercial farmlands in one specific agro-ecological region in Zimbabwe using MODIS time-series. Our results show spatio-temporal improvements compared to existing regional LULC datasets which, in most cases, are out of date. The additional spectral information (NIR, RED) did not improve RF classification results, as reported by other authors (Alcantara et al. 2012). In order to evaluate the suitability of RF classifications to map rainfed agriculture, reclassified results (rainfed/non-rainfed) were assessed in an error matrix (Tables 9.2 and 9.3).

Table 9.2: Accuracy report for NDVI+SP, 2004/2005

	rainfed	other	#pixels	UA
rainfed	**95**	55	150	**63,33%**
other	3	**147**	150	**98,00%**
#pixels	98	202	300	
PA	**96,94%**	**72,77%**		**OA = 80,67%**

PA = Producer Accuracy, UA = User Accuracy, OA = Overall Accuracy

Table 9.3: Accuracy report for NDVI+SP,+NIR+RED, 2004/2005

	rainfed	other	#pixels	UA
rainfed	**92**	58	150	**61,33%**
other	14	**136**	150	**90,67%**
#pixels	106	194	300	
PA	**86,79%**	**70,10%**		**OA = 76,00%**

PA = Producer Accuracy, UA = User Accuracy, OA = Overall Accuracy

Through stratified sampling, 150 pixels for each of the two classes (rainfed/non-rainfed) were selected and compared to historical Google Earth data for the seasons (2004/2005) and (2007/2008) respectively. If more than approximately 75% of the pixel area correlated to the classification result, the pixel was considered as accurate. Google

Earth has been used as a verification in other accuracy assessments and provides a convenient method to overcome data unavailability, especially for remote areas on the African continent (Fritz et al. 2011). Furthermore, it serves as the crucial information independent to the training data. García-Mora et al. emphasize this necessity together with the importance of systematic accuracy assessment with clear protocol. In their review of MODIS based classifications, they conclude that this is often not carried out properly or optimistically biased (García-Mora, Mas & Hinkley 2012). Through the selection of the verification dataset, the conservative pixel value of 75% and the grouped report for two classes, we avoid such an optimistic bias. Overall accuracies (OA) for the mapping of rainfed agriculture based on MODIS time-series in the season 2004/2005 ranged from 76% to 80%. Producer accuracies (PA) were high but user accuracies (UA) for 'rainfed' were limited to below 65%. Accuracies for other seasons were within this range. Figure 9.10a) and Figure 9.10b) contrast the classification result based on NDVI data for season 2004/2005 with recent ESRI-basemap imagery (Figure 9.10b).

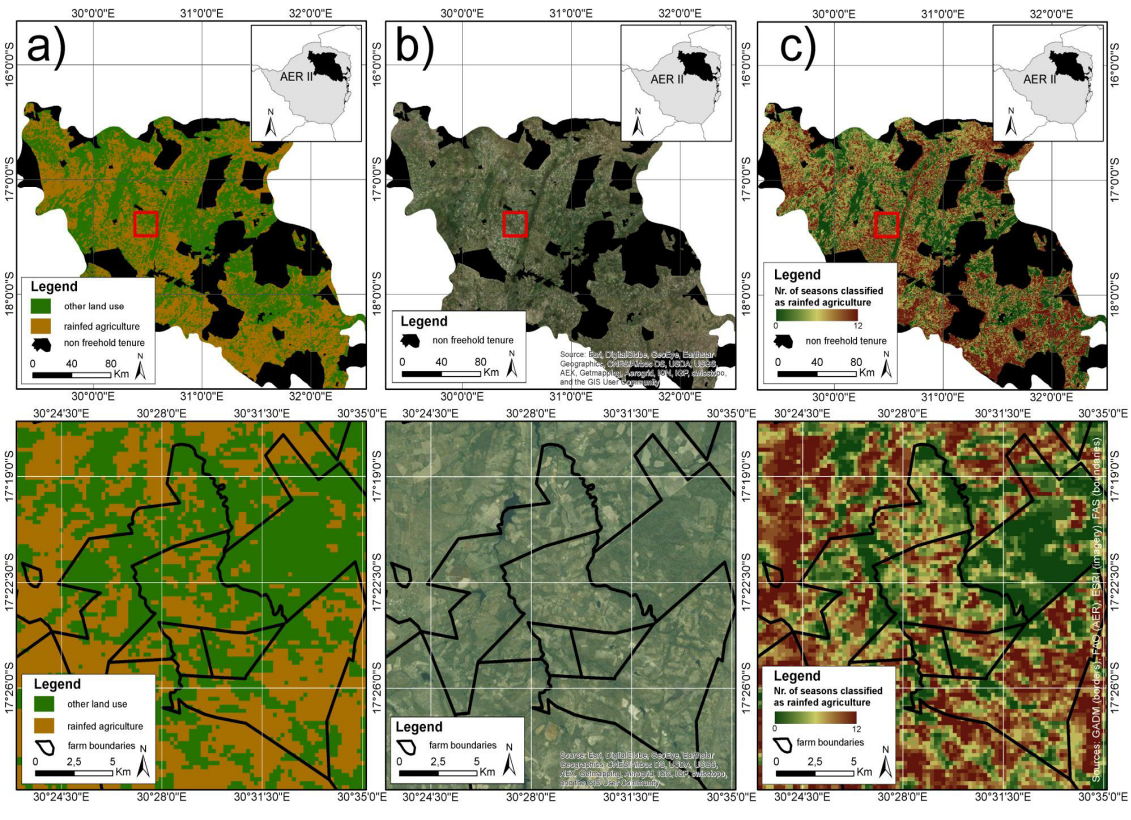

Figure 9.10: Spatial results of Random Forest classification.(a) classification result (2004/2005) for former freehold tenure area in AERII, (b) recent ESRI-basemap data for comparison, (c) numbers of seasons classified as rainfed or other land use. Details are overlayed with farm boundaries.

The upper row of maps show AER II clipped to former freehold tenure, the lower row of maps depicts a detail overlayed with commercial farm boundaries. Here, we observe the underestimation of agricultural fields which links to the low user accuracies of the class rainfed agriculture. This is a critical error because it limits the spatially-explicit assessment of land reform effects. Changes in cropping patterns are likely to not be recognized by the classification approach, especially because they appear at the edges of LULC patches. This is demonstrated in Figure 9.10c) which summarizes classification results of all twelve consecutive seasons from 2001-2013 and therefore identifies areas which are continuously classified as 'rainfed agriculture' and areas which are considered as 'other' throughout. In-between these stable land use patches, areas were not continuously classified as one land use type. This might either be related to a sensitive classifier, or a systematic error resulting from low separability of sparse rainfed agriculture. But with class accuracies below 65%, the volatility cannot be considered to be a consequence of changes in land ownership in former freehold tenure area. Inconsistent land use classification occurs only at the edges of stable areas and does not depict agricultural patches. This temporal stack might be used to improve general land use classifications, but it does not allow a linkage of cropping pattern and land tenure.

Although time-series as a method has proven to be able to depict general LULC patterns over time, and change models as well as trajectories have been applied successfully in the region (PETIT, SCUDDER & LAMBIN 2001), our evaluation demonstrates the limitations of the method. The difficulties of correctly mapping rainfed area, are related to shortcomings which have been formulated by other authors (HEROLD ET AL. 2008, LOBELL & ASNER 2004, PETIT ET AL. 2001, K. . WESSELS ET AL. 2004). Spatially-accurate crop mapping remains a bottleneck in multi-temporal analysis, although we have produced higher accuracies than studies in different contexts (VINTROU ET AL. 2012).

We identified two major limitations of multi-temporal analysis of MODIS NDVI data to map commercial farmland structures in Zimbabwe: *1) Spatial resolution* of imagery and *2) heterogeneity* of spatiotemporal profiles. Alongside successful studies, which also have characterized Zimbabwean smallholder farming structures of sizes below MODIS resolution (SIBANDA & MURWIRA 2012), authors report high inaccuracies for detection of smaller LULC patches such as heterogeneous, sparse cropland in other study areas (LOBELL & ASNER 2004, VINTROU ET AL. 2012). Low user accuracies, combined with high producer accuracies such as in this analysis, can be sufficient for general LULC classifications with several classes. For the spatial explicit mapping of one specific land-use class and its spatial correlation with land tenure, they are not adequate. Our accuracy assessment was designed to test the ability of regional time-series analysis to map crop area in former freehold tenure, because its sparse and heterogeneous patterns differ from rainfed agriculture in communal areas. The communal form of land use is characterized by dense fields with distinct reflectance values and is therefore clearly recognized in classifications and has received attention in other studies (Prince et al. 2009, K. . Wessels et al. 2004). With the difficulties to map sparse commercial farm structures, we conclude that coarse-scale spatio-temporal analysis is not suitable to generate well-founded knowledge of change patterns for cultivated areas as a consequence of tenure change. Also regional assessments of spatio-temporal land reform effects should therefore be carried out on smaller scale with high resolution imagery, which was applied somewhat successfully (Matsa & Muringaniza 2011, Melisa M. Matavire 2015). Current approaches in Zimbabwe which aim to map the abandonment of dams as part of an intact irrigation system are another possible solution.

Overall, we experienced shortcomings of regional assessment based MODIS data which we identified for global land-cover mapping earlier. Our plots of NDVI functions of training pixels, on a country-wide basis (Figure 9.8), as well as the stratified sample within the AERII (Figure 9.9), demonstrate the difficulties to assign classes with distinct and homogeneous temporal profiles. Even after agro-ecological and temporal stratification, which limited training pixels to a small and very distinct number, the plotted standard deviations demonstrate that unique classes cannot be defined based on temporal profiles. This has also been formulated for large scale, global and continental classifications (Lhermitte et al. 2011, Lotsch et al. 2003, K. J. Wessels et al. 2004).

Because MODIS multi-temporal data is not able to accurately classify sparse former commercial farmland on a spatial resolution which allows a correlation with land tenure data, we propose a different approach: Vegetation productivity and trend analysis. Both can be determined based on NDVI time-series and are methods which determine relative parameters instead of a hard classification into different LULC classes. They therefore avoid inseparability of classes and sub-pixel heterogeneity which we identified as the major limitations of medium-resolution, high temporal imagery. Productivity and trend analysis have been used extensively in the context of agricultural mapping, also in Zimbabwe (Dubovyk et al. 2013, Kuri et al. 2014, Prince et al. 2009). In South Africa, these methods have also been applied to assess the effect of unequal land tenure and population density (K. . Wessels et al. 2004). A synergistic research design of a productivity trend analysis and our agro-ecological and tenure-based stratification would allow to assess the condition of redistributed commercial farmland in Zimbabwe.

9.7 Conclusion

Spatial datasets on agricultural land are crucial in order to understand the intensively debated process of the FTLRP of Zimbabwe as well as its consequences. The overall research question of this methodological assessment was whether multi-temporal LULC classification is able to produce spatially accurate maps of rainfed cropping area to determine changes in agricultural production as a consequence of redistribution of farmland in Zimbabwe. To answer this question, MODIS NDVI and spectral data was smoothed with a Savitzky-Golay filtering approach, temporally and climatically stratified and limited to former freehold tenure. Endmembers were created by an upscaling approach of Landsat classification. Random forest classifications of time-series based on the stratified endmembers showed higher accuracies than existing global and regional LULC products and similar studies. General distribution of LULC classes were depicted using the RF classifier. However, the classification results cannot be used in the context of an assessment of land reform in Zimbabwe. Because commercial farms form fragmented agricultural landscapes, they cannot be accurately depicted by MODIS time-series and are often underestimated and confused with grassland.

Our research with a focus on coupling of land tenure and land use has revealed major shortcomings of regional classification approaches and MODIS MOD13Q1 NDVI data. 1) regional classifications stretch over climatic gradients which leads to large differences in the phenological cycle of one land-cover class making the creation of homogeneous classes impossible. Even within similar agro-ecological conditions, a high variability of temporal NDVI profiles persists within classes. 2) spatial heterogeneity, combined with the resolution of MODIS and class inseparability, leads to inter-annual inaccuracies of time-series based land-cover classification decisions. Classification results aggregated over several seasons show a high variability at land-use patches highlighting the likeliness of wrong allocation. 3) These shortcomings weaken mapping of land-cover change based on multi-temporal classifications, and highlight the necessity of detailed information on the ground. Given the fact that land-use, especially changes of cropping patterns, are frequent products of immediate socio-economic decisions, the volatile multitemporal products do not allow to draw conclusions whether and when a change of land use has occurred over the course of several years. As a consequence, the information of moderate-resolution is not able to be linked to possible socio-economic drivers of land-cover change such as ownership or management change due to a land reform program. However, long sequences of several continuous classifications could provide useful input to land use classification by providing information of probability and confidence.

As time-series analysis as a valuable and approved method has difficulties to detect LULC types and change in an area of interest for a FTLRP assessment, we propose to use this methodology for a vegetation trend and productivity analysis among different land tenure types. It should be tested whether MODIS data is capable to differentiate productivity trends in redistributed farmland and therefore be able to allow a comparative assessment of the impact of farmland redistribution and the role of land tenure.

V. Trends and breaks: mapping spatial effects after the FTLRP

10 About the strength of multi-method approaches and the problem of correlating spatial data to land reform

After the IV. Main Section of this thesis has demonstrated that shortcomings of geospatial methods exist, despite a general suitability for land reform assessments conceptualized in section one, attention is now put on the selection of sensors and methods. A key finding of chapter 9 is that land reform assessments suffer from the resolution dilemma of remote sensing just as any other research area (Lam & Quattrochi 1992). The need for high temporal resolution data for continuous mapping of land cover to understand the direction of change vectors requires the use of low spatial resolution which does not allow accurate land cover mapping in the region. The limits of LULC classification based on time-series have been highlighted by many authors, while at the same time, others have labelled the method as suitable to differentiate crop types, or to map abandoned agriculture (Alcantara et al. 2012, Herold et al. 2008, Maguranyanga et al. 2014, Sibanda & Murwira 2012). To a step further, trend analysis was carried out to assess the capacity of MODIS data to map vegetation trends in the context of land reform.

But although strong negative vegetation trends were detected in agricultural areas of Zimbabwe, the low significance of these trends underlined again the importance of selection of method and sensor. The advantage of the following study was its multi-method approach, as seasonal trend analysis alone did not generate powerful results with information on land reform events. Therefore, this part of the thesis joins a fraction of classification studies which put effort on the combination of existing methods to enhance capacity and applicability of remote sensing tools and geomatics (Mather & Tso 2016). As data availability may form a key limitation of spatial analysis, and methods might not be able to address relevant research questions directly, new combinations have to be developed in order to maximize the impact of research with currently available means (Dong et al. 2009). Also in regional studies on LULCC in Zimbabwe, hybrid methods have been used to improved results (Kamusoko & Aniya 2009). Two general concepts of enhancement can be distinguished: a combination of methods, and a combination of datasets. While fusion of data from different sensors often addresses the resolution trade-off and requires a number of new techniques, a combination of methods is a more straightforward approach to retrieve additional information already inherent in the dataset (Jianya et al. 2008, Zhang 2010). In change detection, the latter is commonly achieved by either using two different methods to focus on two change characteristics (procedure-based hybrid analysis), or by comprehensively analysing the results of different methods (result-based hybrid analysis) as Sui et al. elaborate in their overview of multitemporal change detection methods (Sui et al. 2008). For the study of FTLRP-induced agricultural change, it was the fusion of two established time-series analysis methods which explained strong negative trends of production and revealed the power of combined methodological approaches.

Although multi-method approaches successfully tap the hidden potential of remote sensing, they do not overcome two major challenges of LULCC mapping, which also have been a constant limiting factor in this analysis on tenure change induced agricultural production patterns. The problem of validation of results and the check-up of hypothesis are core issues of applied remote sensing (Nightingale et al. 2013). Obtaining verification data is especially complex in the context of the FTLRP, as land reform is an emotional and an explosive political issue. Hence, tenure datasets cannot be verified against others, information on farm evictions is not available and stops of irrigation schemes have never been assessed on a regional scale. While this underlines the necessity of efforts made in this thesis, it also epitomizes the problem of the 'remoteness' in remote sensing which leads to a disconnection from the studied subject. Although sound spatial data on irrigation stop could be mapped, it was not possible to correlate them to farm eviction as this data does not exist publicly.

As research on land reform and governmental issues, especially in terms of data collection, is everything but easy in Zimbabwe (Mandiyanike 2009), the idea of a participatory land reform assessment was put into practice for this PhD project. An online Public Participatory Geographic Information System (PPGIS) was developed, where expropriated farmers could enter information about eviction processes (Hentze n.d.). The aim of this effort was to bridge the gap between the social and the physical, to enhance knowledge about land reform, and to provide an innovative approach to verify land use change. But as farmers moved away from Zimbabwe, are widespread over the globe and reluctant to provide information, this approach was not successful (Fisher 2010). Yet, the 'Valuation Consortium', a Zimbabwean organization which represents commercial farmers in negotiations with the government about compensation, struggles to complete its own internal database which is unfortunately not open for public and science ("The Valuation Consortium" n.d.). The reluctance of individuals to cooperate in surveys or participatory approaches is a major challenge for PPGIS, formulated by many others (Fan & Yan 2010). Apart from the general unwillingness to participate, PPGIS is often perceived as a "wild card" with "little control over the outcome" and were the "the process can be 'gamed'" (Brown 2012). In Southern Africa, complexity due to the racial dimension of the land reform, the

economic effects on states and individuals, and the personal tragedies make white farmers unwilling to participate and share information on redistribution; a challenge other researchers faced in the region as well (Harris & Weiner 2002).
Without this direct link to farm evictions, it is not possible to tell whether irrigation stopped due to land tenure change, or due to other difficulties, such as power cuts which also lead to a stop of irrigation schemes (Merrey et al. 2008, ReliefWeb 2012). Nonetheless does the procedure-based hybrid analysis provide a dataset which generates information for both, the remote sensing community, and the land reform researchers in the region, especially because of the ready-to-use character of the method.

11 Beyond trend analysis: how a modified breakpoint analysis enhances knowledge of agricultural production after Zimbabwe's fast track land reform.

11.1 Introduction

Land use and land cover (LULC) change analysis is about the understanding of the impact and magnitude human activities have on the earth's surface, mainly vegetation. As almost 50% of the planets terrestrial surface can be considered as transformed by human impact (Vintrou et al. 2012), there is a global interest among land use scientists to link effects of human decision and action to changing patterns of land cover (Geoghegan et al. 1998, Lambin et al. 2001). This study presents a regional case study of LULC change analysis in Zimbabwe with an explicit effort to map spatial consequences of changing national politics, land use policy, land ownership, and land tenure. With a two method approach, we assessed to what extent remote sensing based time-series can give insights to human induced LULC changes, and whether these methods provide results which can be used within the land reform discourse.
With its “Fast Track Land Reform Programme” (FTLRP), the nation of Zimbabwe has experienced a major political and socio-economic transition which lead to a rapid and thorough shift of land use patterns throughout the country (Scoones et al. 2010). From 2000 onwards, large scale farming enterprises were occupied, redistributed and subdivided, resulting in changes of cropping and productivity (Matondi 2012). A number of studies on the successfulness of this program has been published since then, but a lack of spatial and objective data has been formulated within the discourse on the evaluation of this sequence of Zimbabwe’s land reform (Cliffe et al. 2011, Scoones 2014b). Despite the recognizable interest to understand what has happened where after the FTLRP, only few remote sensing studies with a respective focus exist (Hentze & Menz 2015). We argue that satellite-based monitoring of crop area allows spatio-

temporal correlations of long term and abrupt land use change and land tenure in Zimbabwe. Furthermore, it is capable to separate climate and human induced changes which both have been identified as central drivers of changes of vegetation patterns (OMUTO ET AL. 2010).

Polar orbiting sensors with high temporal resolution provide continuous data sets of consistent quality and map vegetation cover at all stages of its phenological cycle (LLOYD 1990). Through temporal analysis of this data, remote sensing is able to make use of the specific relationship between land cover characteristics and plant reflectances over the course of a phenological year. Important measures to differentiate and characterize plant cover are: green-up onset, peak of greeness, start of senescence or length of the vegetative season (ZHANG ET AL. 2003). By making use of these parameters, the analysis of satellite imagery time-series offers an effective and objective methodological framework to investigate long term trends or abrupt changes of natural and agricultural vegetation cover. In Southern Africa, time-series has contributed meaningful to the research on land systems by assessing impacts of changing land cover, land use management and climatic conditions (MAMBO & ARCHER 2007, PRINCE ET AL. 2009, WESSELS ET AL. 2007).

But although time-series analysis has been carried out successfully in various local contexts, a research focus on productivity and land tenure linked to Zimbabwe's land reform is still to be applied. To proof the suitability of remote sensing datasets, and to achieve this link, Normalized Difference Vegetation Index (NDVI) data of the Moderate Resolution Imaging Spectroradiometer (MODIS) is used for a time-series based trend and breakpoint analysis. MODIS is characterized by a higher spatial resolution compared to previously used sensors and has served as a source for numerous LULC classifications, as it has been explicitly designed for these applications (FRIEDL ET AL. 2002). However, it often fails to recognize the complex vegetation mosaic of Southern Africa with its micro-site variations of soil, altitude, temperature and rainfall (DUBOVYK ET AL. 2015). We have shown in a previous study, that time-series analysis is not capable to classify land use types in Zimbabwe with satisfying accuracy (HENTZE, THONFELD & MENZ 2016). A trend analysis of NDVI values however, overcomes limitations of hard classifications, as it focuses on the relative measure of productivity where spatial resolution is of lesser importance.

Using the FTLRP of Zimbabwe as a case study, this article links changes in land tenure as a result of policy, individual decision and group dynamics, with change of vegetation in cropped area, rainfed and irrigated. To achieve this link, we use two methods: 'Seasonal Trend Analysis' (STA), to characterize land use efficiency by productivity trends, and 'Breaks For Additive Season and Trend' (BFAST) to localize and assess land use changes, characterized by abrupt changes of seasonal signal (EASTMAN ET AL.

2009, Verbesselt, Hyndman, Zeileis, et al. 2010a). We assume that irrigated fields show bimodal NDVI curves displaying two cropping seasons per year, whereas non-irrigated land use is characterized by unimodal NDVI patterns, linked to rainfall events. As irrigation was an important method of commercial farmers to ensure high yields of staple and export crops before the FTLRP, a dataset on fallow irrigation relates to land reform, national economy, and food security. Our hypotheses for this two method approach are:

1. MODIS NDVI data is suitable to estimate overall trend and abrupt changes in land use
2. Time-series based STA is able to accurately map long term trends of agricultural productivity in different tenure regimes
3. BFAST can be used to detect abrupt changes of irrigated land use in Zimbabwe

After an introduction to the FTLRP (section 11.2), we give an overview of the study area and applied methods (section 11.3). Subsequently, we critically discuss our results (section 11.4) before we finally reflect on the hypotheses and draw a conclusion on the suitability of time-series based analysis as an additional tool for land reform assessments (section 11.5).

11.2 Subject of study: Zimbabwe's 1Fast Track Land Reform Programme2

Land has always been a contentious issue in the region of Southern Africa: The majority of farmland in the three settler colonies Namibia (German Southwest Africa), South Africa and Zimbabwe (Rhodesia) was distributed and managed by white minorities, while black majorities were concentrated on the remaining, often less arable land (with a general exception in Namibia, where fertile soils have always been under communal tenure) (Potts 2012). Although absolute figures are hard to get, it is believed that around 6000 white commercial land owners owned almost half of Zimbabwe's arable land (Deininger et al. 2004). Through legislation like the “Group Area Act” in South Africa, or the “Land Apportionment Act” in Rhodesia (both 1930), the land question was intensively racialized in the region (Moyo 2004). Tenure of and access to land formed a central part within the liberation struggles and obliged governments of these countries to redress inequities of ownership. Following independence of the nation of Zimbabwe in 1980, the land redistribution program was on the forefront of internal politics (Shava 2010). Redistribution, restitution and tenure reforms are tasks of great importance to the Zimbabwean society as Southern Africa is one of the world's regions with the highest percentage of rural population, dependent on local agricultural production (Livingston, Schonberger & Delaney 2011).

Generally, three phases of the Zimbabwean redistributive land reform program can be distinguished: First, 1980 until 1990, land reform proceeded relatively swiftly and successfully. Backed by finances from the British Government, white commercial farms where bought on the market with a pre-emption right by the state. Then, 1990 until 2000, the redistribution of farmland slowed down significantly, contrasted by increasing official numbers of land to be redistributed which could not be met by governmental institutions (PALMER 1990).

As a partial result of this perception of a failed land reform, a third phase of redistribution began. A complex set of political strategies to maintain power, of individual interests and of a society which sought reparation, secure tenure and equity, lead to an intensified, indifferent process of land reform (CHAUMBA ET AL. 2003): The hunger for equal distribution of agricultural land culminated in farm evictions which started in 2000 and lasted for about four years (PILOSSOF 2012). With following attempts to formalize these redistributions, two different farming models were introduced on former commercial farms: "A1", a type of smallholder farms and "A2", indigenized intermediate sized commercial farms. As a general immediate result, national agricultural production - especially of cash crops, but also grains - declined and lead together with a beginning recession, inflation, political instability and violence to a meltdown of economy and nationwide food shortages (RAFTOPOULOS & PHIMISTER 2004). As a consequence of the different land reform phases, a conglomerate of farming types exists in today's Zimbabwe which is explained in Table 11.1.

Table 11.1: Tenure type in farming areas in 2011, according to (MATONDI 2012)

Farming Sector	Area (ha)	Number of plots/beneficiaries
A1[1]	5,759,154	145,775
A2[2]	2,978,334	16,386
Communal areas[3]	16,000,000	1,200,000
Old Resettlement Areas (Phase 1 and 2)[4]	3,667,708	75,569
Large-scale commercial farms (unacquired)[5]	648,041	1,154
Small-scale commercial farms[6]	1,400,000	8,000
Conservancies[7]	792,009	-
Institutional farms[8]	145,693	113
Unsettled gazetted land[9]	757,558	517
Total	32,148,517	1,447,523

[1]small scale farming for decongestion in AERIIa, ca. 15 ha; [2]commercial farms to empower indigenous farming, >50 ha; [3]state land with tenure regulated by customary law; [4]plots < 50 ha, from resettlement between 1980 and 1997; [5]land which was not gazetted and remains with old title deeds holder; [6]former Native

Purchase Areas, freehold titles <50ha for well-situated Africans; [7]Areas of different tenure regimes with registered conservation status; [8]Parastatal-, Church-, School-, College-, and mining land; [9]land gazetted, but not used for resettlement.

There is an ongoing debate about to what extent the collapse of agriculture has contributed to the economic depression and food insecurity in Zimbabwe and to what extent droughts played a role (Richardson 2007a). Another debate focuses on the question, whether the FTLRP can be seen as successful or not with regard to the partial recovery of agricultural production and the more equitable access and ownership of farmland (Scoones 2014b). Within these scientific discourses, a lack of reliable spatial data can be identified (Hentze & Menz 2015). It has often been stated that ideology is driving conclusion and judgments of Zimbabwe's land reform (Elich n.d.) as well as the reception of media. Spatio-temporal data which supports nuanced answers to questions of regional disparity and temporal changes, especially in terms of agricultural area and productivity, is rare.

The lack of consistent, long term datasets of any kind complicate assessments further (Zikhali 2008) and some authors conclude that it is too early to judge the process of land reform (Southall 2011). Because methods of geography are prone to answer questions of land reforms, mainly due to the spatial character of the subject (Fraser 2008), our aim is to contribute spatio-temporal data towards a better understanding of the intensively debated consequences of the Zimbabwe's FTLRP.

11.3 Data and Methods

11.3.1 Study area

Zimbabwe, with a size of 390.757 km² and a population of about 13 million people ("The World Factbook, Zimbabwe" n.d.), is characterized by a distinct topography, a climatic north-south gradient and heterogeneous soil types which all together lead to diverse plant growth conditions. This heterogeneity is best expressed by the six agro-ecological regions Zimbabwe is commonly subdivided into Figure 11.1 (Vincent et al. 1960). Agriculture - with an established export-oriented and specialized production - formed a major contribution to national economy, as over 60 percent of Zimbabweans were employed in the agricultural sector before the FTLRP (Tekere, Hurungo & Rusare 2003). Because the suitability for plant growth and crop production varies greatly throughout the country, proven by large differences in seasonal phenological cycles (Hentze et al. 2016), we restricted our analysis to agro-ecological region IIa (AERIIa). With an annual precipitation of over 750 mm, it is perceived as the most suitable area for rainfed cropping systems and is situated on high altitudes close to Harare. The proximity of farms to the capital lead to distinct beneficiaries of land reform, patterns of redistribution and land use decisions (Marongwe 2011). To focus on productivity of redistributed agricultural area, we applied a crop mask and used only areas where data on tenure after the FTLRP was available. Due to the research focus on resettlement, we excluded communal tenure as well as conservation areas in our stratified trend analysis and examined six categories of tenure: “A1”, “A2”, “Small-scale commercial”, “Large-scale commercial”, “Old resettlement” and “State” (see table 11.1). in Figure 11.1 black areas represent the cropped area of these tenure regimes within AERIIa which was used as a study area for the trend analysis. For the mapping of breakpoints, we did not apply the crop mask to account for emerging agricultural land.

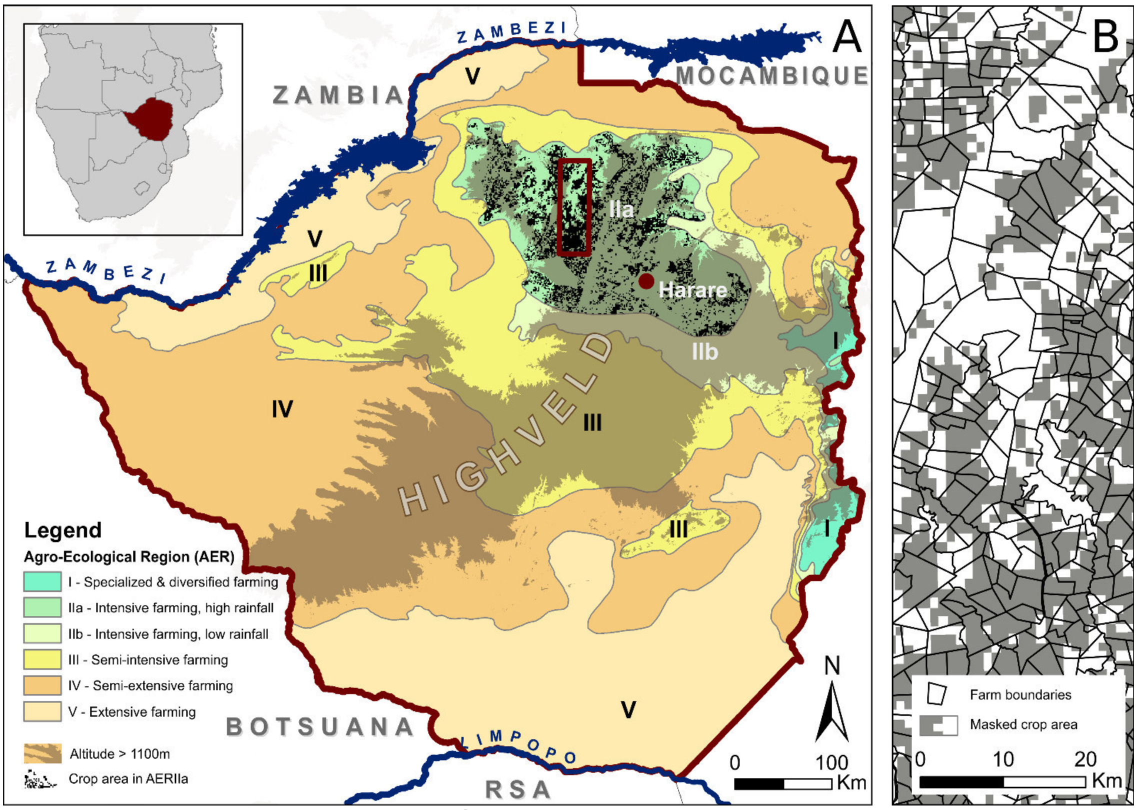

Figure 11.1: Study area: Cropped area of A1, A2, small scale, large scale, old resettlement and state land within AERIIa (A), the enlarged area relates the crop mask to historic boundaries of commercial farms (B).

11.3.2 Data

Remote sensing data

For the temporal analysis of crop production in the study area, we preprocessed and stratified a MODIS NDVI dataset for 16 years (2000-2015), as the sensor has been used extensively for similar research designs and regional applications (Dubovyk et al. 2015, Maguranyanga et al. 2014, Prince et al. 2009, Vintrou et al. 2012). MOD13Q1 NDVI data from the Terra platform is highly suitable for land use analysis and has a spatial resolution of 250 m and a temporal resolution of 16 days (USGS n.d.). Because MODIS was not fully operative beginning 2000, we replaced the three first time-steps with mean values of the corresponding sequence.

Agro-Ecological Zone for stratification

To account for Zimbabwe's heterogeneous climatic conditions, a dataset of agro-ecological regions (Vincent et al. 1960) was acquired to mask out NDVI data of similar plant growth conditions.

Agricultural area for crop mask

As we aimed to restrict the analysis of productivity to agricultural area, we used the respective class of a Southern African Development Community (SADC) land-cover classification from 1997 (CSIR 2016). It can be considered as one of the most accurate and extensive countrywide land-cover mapping approaches for Zimbabwe which has been proven suitable by other remote sensing studies (Kuri et al. 2014). By using a dataset which was produced before the FTLRP, we make sure to avoid aspects of redistribution and to use an area which was under agricultural use before farm evictions took place.

Tenure dataset on property rights after the FTLRP

A core feature of our analysis was to provide information on changes in land-cover and productivity across different tenure regimes. Therefore, a tenure dataset was obtained from the Foreign Agricultural Service (FAS) of the United States Department of Agriculture (USDA). It has been used for similar analysis and stratifies areas in tenure after the FTLRP, of which we extracted the six classes A1, A2, Small-scale, Large-scale, Old Resettlement and State (USDA n.d.).

11.3.3 Methods

After preprocessing the time-series of sixteen years (2000-2015), we first applied STA to map developments of vegetation productivity in Zimbabwe. We used the resulting mean NDVI and investigated its trend in crop area of different tenure regimes. Furthermore, we applied BFAST to provide additional information on areas of significant trend. Figure 11.2 shows the workflow of this study and exemplifies how products of STA served as the basis for a tenure based analysis, and how they were applied to BFAST results in order to map changes of irrigation patterns. To focus on changes of irrigation only, we made use of the magnitude of all sixteen times of peak calculated with STA.

The direction of mean trend indicates whether irrigation has stopped, or if new irrigation schemes have been set up.

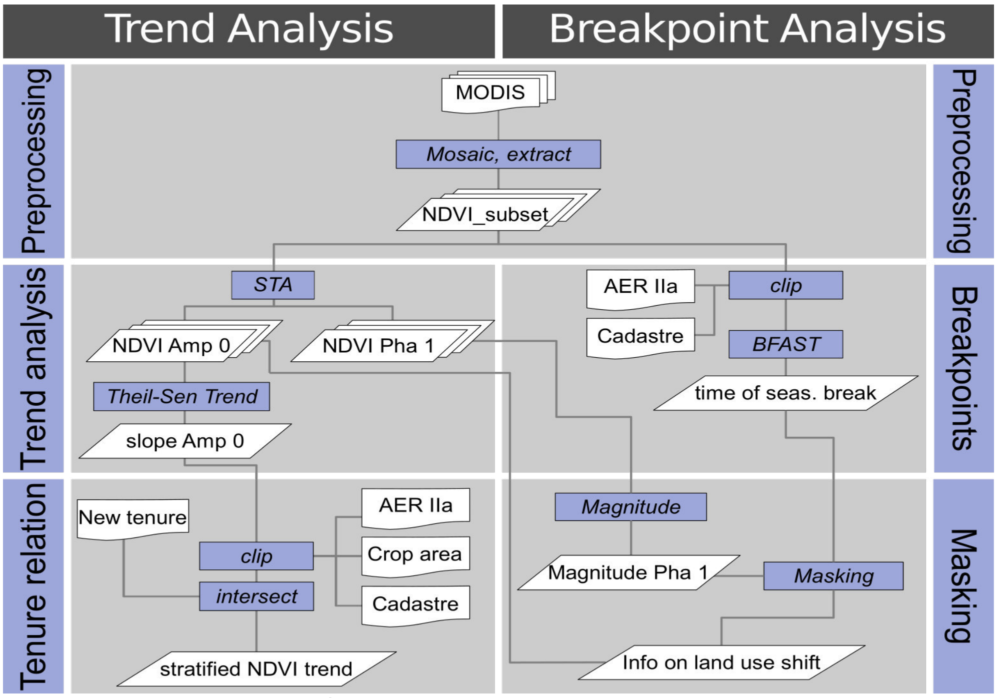

Figure 11.2: Flow diagram of Seasonal trend and breakpoint analysis.

Seasonal Trend Analysis

Methods to transform NDVI values to seasonal curves can be distinguished into three different conceptional groups: harmonic analysis, slope extraction and function-based filtering (Pan et al. 2015). With the STA, we chose a harmonic regression, similar to the Windowed Fourier Analysis (Torrence & Compo 1998). STA is a robust pixel based method and derives harmonic parameters from a yearly rearrangement of terms (Eastman et al. 2009). First, the seasonal curve is expressed as:

$$y=\alpha_0\sum_{n=1}^{n=2}\{a_n\sin(\frac{2\pi nt}{T})+b_n\cos(\frac{2\pi nt}{T})\}+e$$

Where t is a time value, T the overall length of the series, n is an integer multiplier which serves as a harmonic value, e is an error term and α_n the overall mean value. Ignoring the error value and rearrangement of parameters leads to a curve which

$$y=\alpha_0+\sum_{n=1}^{n=2}\alpha_0\sin(\frac{2\pi nt}{T}+\varphi_n)$$

expresses seasonal parameters through amplitudes (α_n) and phase angles (φ_n):
The output of a STA are transformations of reflectances and temporal values which are produced as continuous raster datasets. We made use of $\boldsymbol{\alpha_0}$, the annual mean NDVI as

Amplitude0, and φ_1, the timing of the NDVI peak as *Phase1.* Both area visualized for an ideal NDVI curve in Figure 11.3 together with α_1 , the peak of NDVI as *Amplitude1*.
In a second stage, the trend of Amplitude0 was calculated using the Theil-Sen approach which provides a robust measurement compared to other trend calculations such as the overall linear trend, as it is applicable to heteroscedastic data and calculates a median trend line through all pairwise calculated trend lines (Sen 1968, Theil 1950). The Theil-Sen trend is especially suitable for short time-series as it is robust against outliers up to a derivation of 0.29 of the whole time-series (Hoaglin, Mosteller & Tukey 1983), it has therefore been applied successfully on MODIS time-series, also in the region of Southern Africa (Dubovyk et al. 2015).

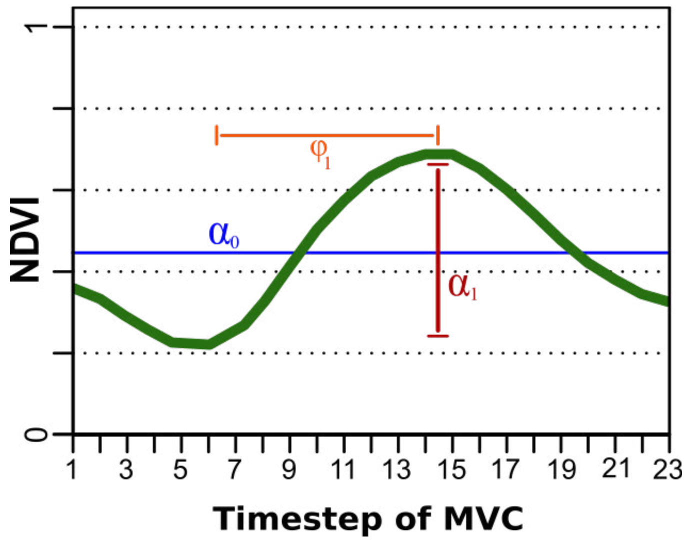

Figure 11.3: Visualization of STA Parameters for an ideal NDVI curve: Phase1 (time of peak, orange), Amplitude0 (overall mean NDVI, blue) and Amplitude1 (Magnitude of peak, red) for an ideal NDVI curve (green).

Breakpoint Analysis for Additive Season and Trend

Three types of changes in time series can be detected and characterized: 1.) Seasonal or phenological change, 2.) Abrupt change, and 3.) Gradual or long term trend which we determined with STA (Verbesselt, Hyndman, Newnham, et al. 2010). In comparison to long term trend mapping, the detection of abrupt changes adds possibilities to account for distinct causes of changes in plant cover. Breaks For Additive Season and Trend (BFAST), is a method which decomposes a temporal signal based on linear analysis into a seasonal curve, an overall trend and remainder components (Verbesselt, Zeileis & Herold 2012). Figure 11.4 provides an overview of the decomposition function components and their products, based on Clevelands LOcally wEighted regreSsion Smoother (LOESS) approach (Cleveland et al. 1990). Where *Y* is the data observed at time *t*. *S* the seasonal signal, *T* the trend and *e* remainder signals, all observed at time t. The seasonal signal is the function of period of seasonality s and seasonal variable d_t.

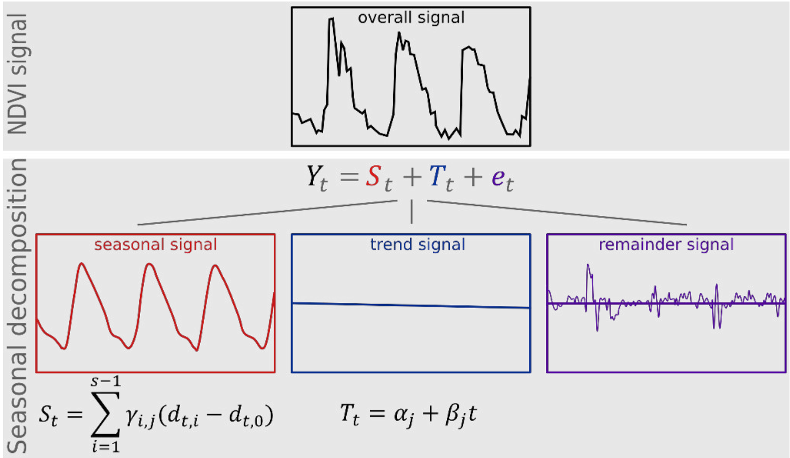

Figure 11.4: Overview of the BFAST decomposition function and functions for Seasonal component and Trend component.

Through an iterative analysis, BFAST detects breakpoints of the decomposed signal as abrupt changes of the linear trend if existent, or of the seasonal signal, which do not have to coincide. For the breakpoint test, the ordinary least square residual based method MOving SUM (MOSUM) is applied (ZEILEIS 2005). The iterative process works as follows: first, the series is tested on breakpoints in the trend component, quantity and location are determined; in a second step, the coefficients of the functions between, before and after the breakpoints are computed for the trend component. After this, both steps are applied on the seasonal component of the signal (VERBESSELT, HYNDMAN, ZEILEIS, ET AL. 2010b).

Changes in seasonal component result from changing agro-ecological conditions, changes in long term linear trend occur as a consequence of abrupt manipulation of vegetation cover. The method of breakpoint detection has effectively been applied in different research contexts to map abrupt changes, such as forest disturbance in Ethiopia (DEVRIES ET AL. 2013), or burned area mapping in the Mediterranean ecosystem (KATAGIS ET AL. 2014). We have used the method to explicitly map breakpoints of the seasonal component. As BFAST focuses on the magnitude of the seasonal change, rather than the timing of peak (VERBESSELT, HYNDMAN, ZEILEIS, ET AL. 2010b), we enhanced the result with the time of peak (Phase1) calculated with the STA. Using the magnitude of Phase1, we were able to mask out pixels which changed from a double peak season to a single peak season and vice versa. This allowed us to map changes from irrigated agricultural to non-irrigated agricultural land, because irrigation allows two growth cycles in subtropical Zimbabwe. This modification also meets suggestions which state that sensor or platform caused influences and discontinuities have effects on BFAST (JONG ET AL. 2012).Figure 11.5 demonstrates the relation of peaks per season and Phase1 for both directions of change.

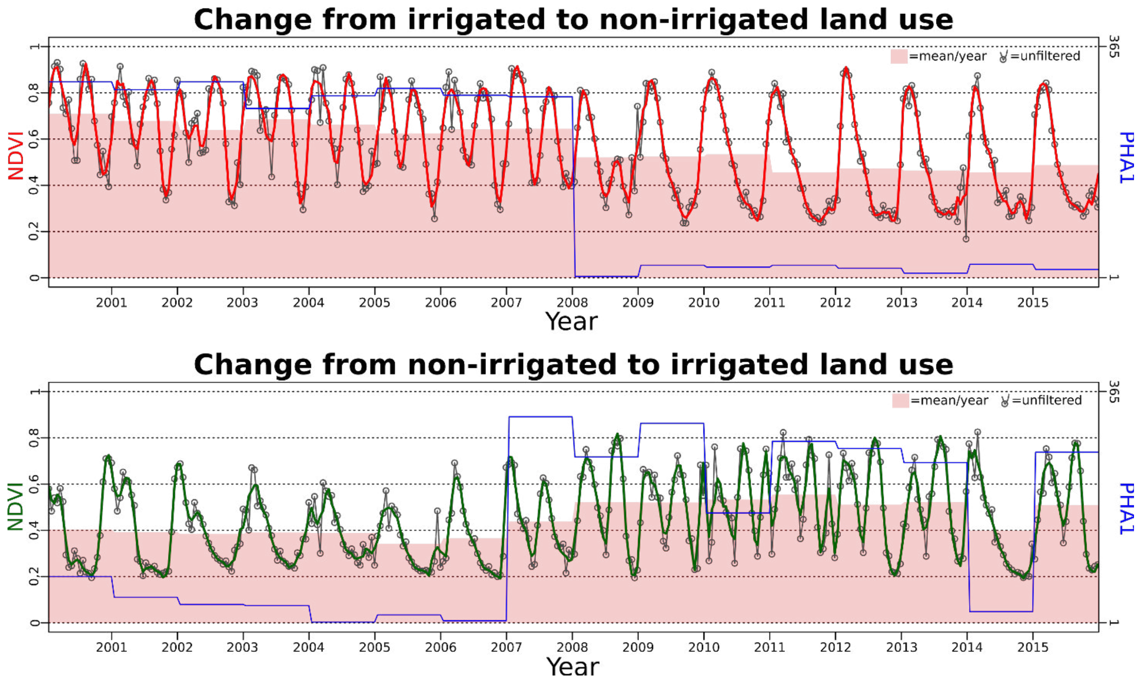

Figure 11.5: Full temporal NDVI profiles for conversion of cropping patterns with respective phase from Seasonal Trend Analysis. Single peak years show low Pha1 values, double peak years high values.

Tenure based spatial Analysis

To link the agricultural productivity to current land tenure in Zimbabwe, we related the mean NDVI trend to classes of the dataset acquired from FAS. Furthermore, we identified farms where irrigation systems have stopped operating or where cropping systems have been turned to less productive ones.

11.4 Results and discussion

We have generated two datasets containing information on recent developments of agricultural production in Zimbabwe: a linear trend of crop production depicted in Figure 11.6 (in a later step stratified according to tenure, compare Figure 11.7), and changes in cropping patterns from irrigated farming to other land use and vice versa (Figure 11.8). Both show patterns which can be correlated to land use structures of higher resolution and therefore confirm the sensitivity of MODIS to local vegetation structure. This proofs the first hypothesis, which stated that MODIS NDVI data is capable to recognize long term and abrupt changes in agricultural area in Zimbabwe. Furthermore, the datasets contain information on change in land management, as the P-values of the vegetation trend show that negative trends in crop area of Zimbabwe correlate with extremely low levels of significance. This relationship indicates that nonlinear factors are dominant reasons for the decrease in biomass and demonstrate the need of a nonlinear decomposition approach. Also, the apparent heterogeneity of trend values within one agro-ecological zone of homogeneous plant growth conditions demonstrate the human-induced impacts these areas have been exposed to. These findings are in line with results of other studies, which see land tenure and management as dominant drivers of local heterogeneous degradation in the region (K. . Wessels et al. 2004). Time-series of precipitation and GDP suggest a strong disconnection between rainfall and agricultural production after the FTLRP (Richardson 2007b).

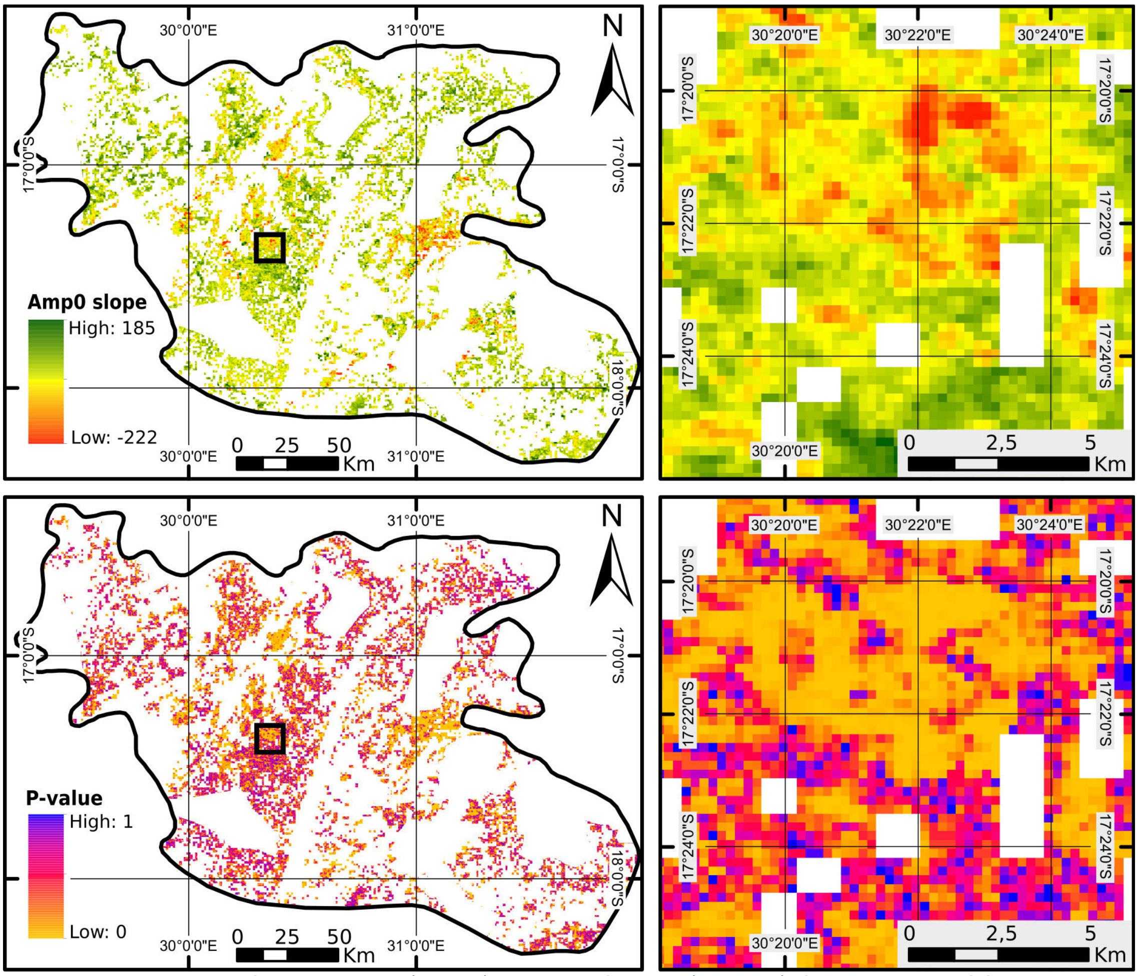

Figure 11.6: Trend of mean NDVI (Amp0) and significance (P-value) for crop area of former commercial farm land in AERIIa and detail.

11.4.1 Tenure based trend Analysis

We were able to map trends of agricultural production within different land regimes. However, the tenure based stratification, where data was analysed according to six different tenure classes following the FTLRP, did not show significant differences among land tenure regimes. A general decline of agricultural productivity is observable and can be linked to reports of a collapsing commercial farming sector and economy in

Zimbabwe (Robertson 2011). Figure 11.7 shows the mean trend of farms covered with more than 20% crop area, grouped according to the land tenure they fall into (compare table 11.1). The boxplot diagram demonstrates the overall negative trend in all land tenure regimes of former commercial area with no significant differences. Exploratory comparisons revealed contrasts between communal areas and former commercial land: Communal areas experience a more spatially homogeneous and stable trend of mean NDVI which relates to the history of land use and planning, compared to the former commercial areas where recent, heterogeneous changes are dominant as p-values also indicate. However, these areas have been juxtaposed in several other studies and therefore have been excluded from this research (Mberego, Sanga-Ngoie & Kobayashi 2013, Prince et al. 2009, K. . Wessels et al. 2004). We finally have to conclude that a remote sensing based judgement on the performance of a specific tenure system following the redistribution of commercial land is impossible (Hypothesis 2). But although significant differences between types of tenure cannot be recognized, regions or clusters of negative trend can be mapped; they mainly correlate with former areas of intensive farming and irrigation structures.

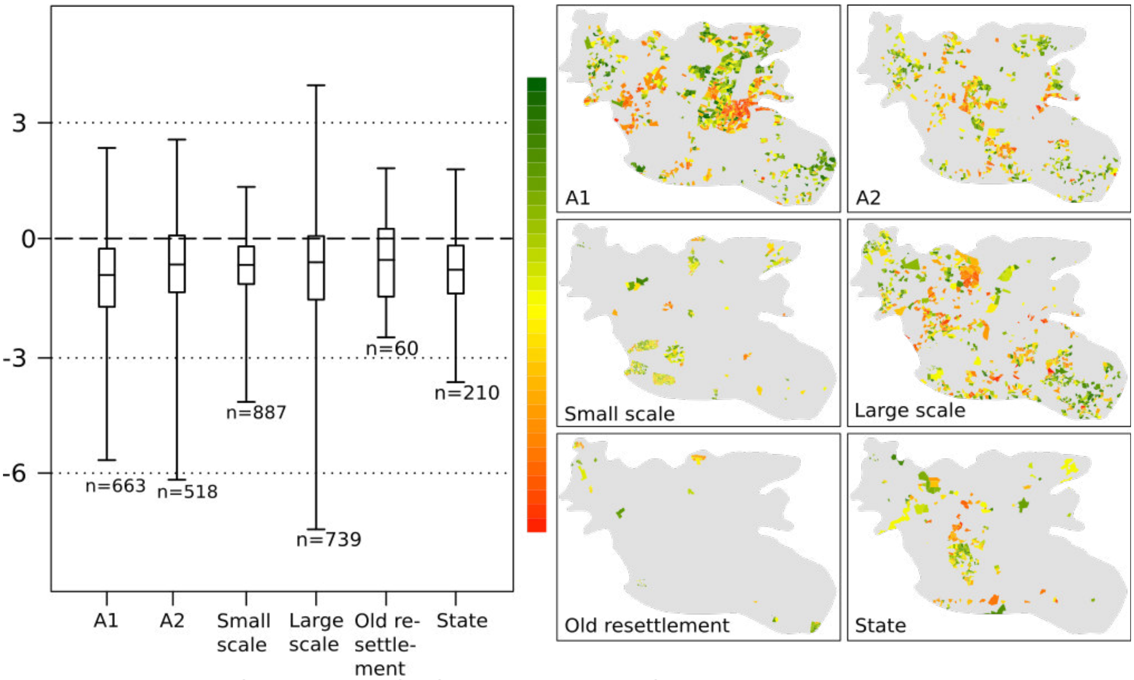

Figure 11.7: Slope of NDVI trend for former commercial farms in Zimbabwe, as boxplot diagram and spatially visualized. No tenure relation can be observed, but clusters of negative trend regardless of tenure.

11.4.2 Breakpoint Analysis

To explain the spatially clustered vegetation trends in the research area, we applied BFAST as a method of breakpoint analysis. Investigation of temporal profiles has shown that a large proportion of pixels with strong decrease in overall production experiences abrupt changes in their NDVI curve, as shown in Figure 11.5. The time-series of these two pixels from 2000 to 2015 exemplify the change from irrigation pattern with two vegetation peaks per year (one in the rainy season, one from irrigation in the dry season) to a curve with a single maximum during rainy season, and vice versa. This patterns correlate with the fact that large areas in Zimbabwe were irrigated to allow two crop cycles per year and to be independent from the rainy season in summer. More than 80% of all irrigated area was found in former commercial production schemes (Scoones 2013). During the FTLRP, a large proportion of these structures was destroyed or left abandoned (Frayne et al. 2012). As BFAST is sensitive to the magnitude of the seasonal curve, rather than the temporal characteristics, we sucessfully modified the BFAST result by incorporating Pha1 values calculated with STA. Figure 11.8 demonstrates a subset of our breakpoint mapping result, overlayed with digitized field structures visible in datasets of higher resolution and multiple acquisition dates.

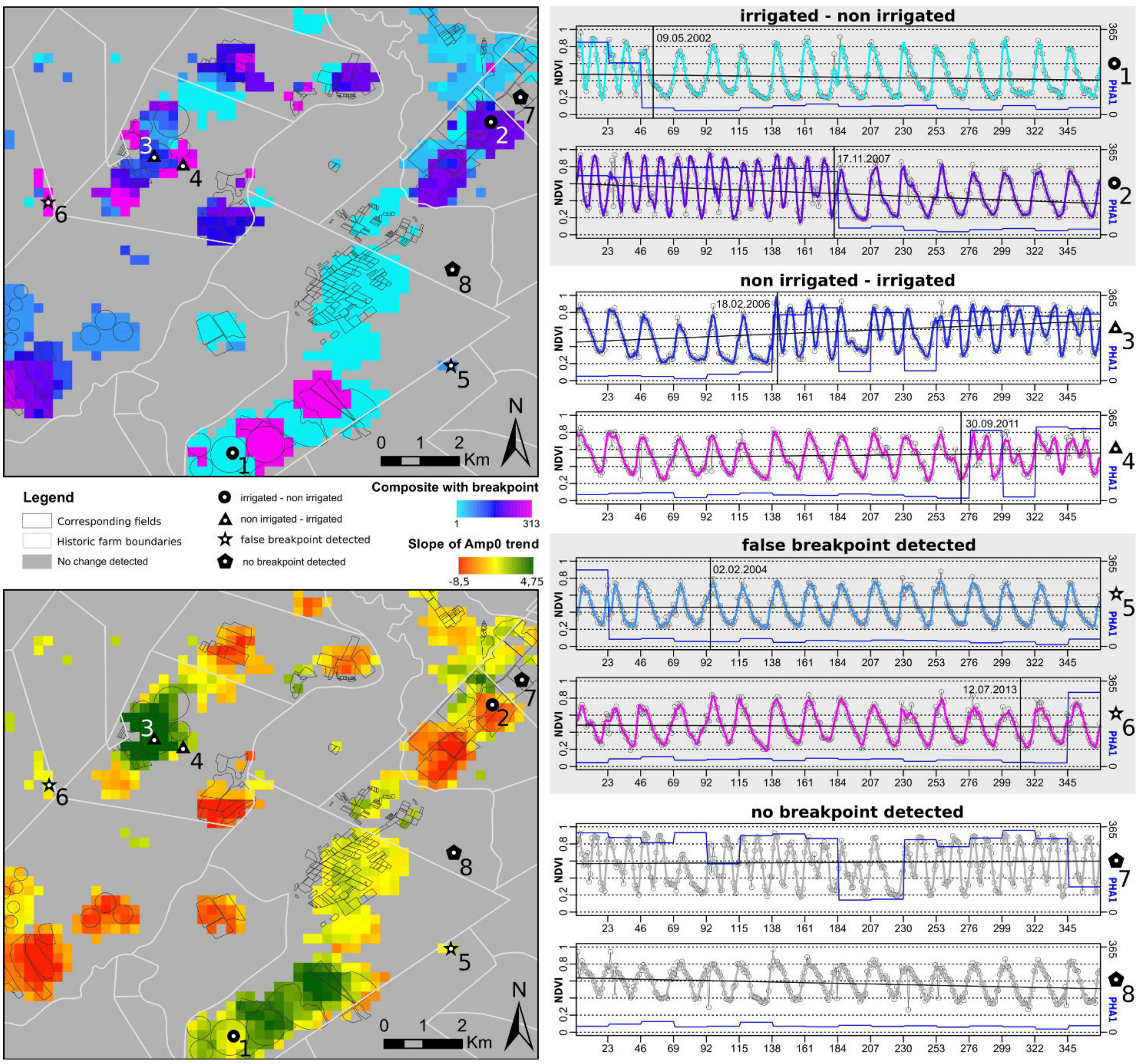

Figure 11.8: Subset of results of BFAST and STA analysis with exemplary NDVI profiles for different change trajectories. Time of abrupt change and Theil-Sen slope allow a detailed description of agricultural decision making.

Three different groups of NDVI profiles were identified and masked correctly: abrupt change from irrigated to non-irrigated (profile 1&2), from non-irrigated to irrigated (profile 4&4) and no change (permanent irrigated, profile 7; permanent non-irrigated, profile 8). The direction of change is expressed by the Amp0 trend, also plotted in Figure 11.8. Errors occur, where the breakpoint dataset is not masked correctly (profile 5&6). This happens when gaps in the time-series lead to double peaks in one year, affecting the Pha1 magnitude calculated to mask out pixels which did not experience a change from double peak to single peak or vice versa.

As the modified breakpoint analysis provides exact information about location and time of change, it provides valuable information to understand the countrywide consequences of the FTLRP. The overall dominant negative trajectory of irrigation, opposed to less emerging agriculture has also been mapped by others which used exploratory conventional change analysis (2001-2008) based on one Landsat scene (GMES-GMOSAIC 2011). Although the results of our modified breakpoint analysis show high correspondence to field structure and production trends, we were not able to correlate our dataset with take-overs of farms which occurred during and after the FTLRP, to produce a regional dataset of irrigation stops in AERIIa. This is due to the fact, that the only public available information on redistribution are gazettes and listings from the Zimbabwean government, which did not result in an immediate stop of operation, and do not coincide with farm seizures as commercial farmers often continued with their operation until the later takeover (Zamchiya 2011).

11.5 Conclusion

By using a MODIS time-series to map changes of agricultural production within sixteen years after the first farm take overs, we have met the persistent demand for spatial data on land reform consequences. As detailed knowledge on recent development of agricultural area is key for a critical but objective discussion on Zimbabwe's FTLRP, this article contributes to the scientific debate by assessing capabilities of two methods to map agricultural change patterns. We showed with STA that the abandonment of high productive farming schemes is a more dominant factor for trend than the current tenure, agricultural areas fall into. At the same time, we demonstrated the limited explanatory power of linear trend analysis for the investigation of redistribution patterns. Lacking the recognition of sudden changes in land management or plant cover, the commonly used conventional trend analysis does not answer the often posed question of "what has happened where" during and after the FTLRP of Zimbabwe sufficiently. To overcome restrictions of linear trends, we provide a ready to use solution based on BFAST and STA, which generates information on thorough structural events such as the nationwide expropriation of commercial irrigation schemes. This result, together with the direction of overall trend, provides spatio-temporal information on farm trajectories in Zimbabwe. The unconventional and unique application of BFAST to map changes of seasonal signal provides convincing results using MODIS-NDVI data, which is itself limited in terms of spatial resolution and applicability for trend analysis. However, our exploratory data on stop of irrigation schemes cannot be verified because information on the abandonment of farms is not existent to the public which underlines the importance of this study. As we were not able to access meaningful validation data, we emphasize the necessity of correlation with other data, as stop of irrigation might not be directly linked to farm evictions as part of the FTLRP. Still, abandoned irrigation schemes mapped with our proposed method can serve government officials to identify areas in need of extension or regrowth initiatives, and scholars to enhance their findings or to decide on research designs. We conclude that the careful selection and combination of methods in remote sensing and time-series analysis can provide input to the land reform debate, bridge the gap between social and environmental sciences, and enhance the explanatory power of data.

VI. Drawing conclusions

12 Summary and conclusion

From “settler-colonial accumulation by dispossession” (Moyo & Nyoni 2013) to dispersal by 'Jamabanja', Zimbabwe has gone through a broad range of land tenure changes which all had unquestionable impact on Zimbabwe's economy, politics, society, food security and land use (Kamusoko & Aniya 2009, Richardson 2007a, Zikhali 2008). The direction and magnitude of these changes however, as well as the criteria to assess and evaluate them, provide ample food for impassionate debate. Within this debate, a lack of quantitative and spatial data is evident, hindering conclusion and sound decisions.

The overall aim of the thesis “Suitability Analysis of Satellite Remote Sensing Methods to Map Agricultural Land Use Change after Zimbabwe's 'Fast Track Land Reform'” was to address this lack of data and to provide solutions which enhance spatial knowledge of the Zimbabwean land redistribution processes from 2000 onwards. Therefore, it presents a methodological framework for geospatial analysis of the FTLRP (Main Section III), evaluates the suitability of remote sensing methods for particular research questions (Main Section IV), and develops a solution for applied remote sensing of agricultural production trends in Zimbabwe (Main Section V).

The reasons for passion in the discourse on land reform lie in the importance of land in the region of Southern Africa which is elaborated on in the contextual background provided by chapter 4. A more general factor is the manifoldness of assessment criteria, which leads to different and sometimes opposed conclusions about the FTLRP process. To address *conseptional research question C1 “How can land reforms be evaluated?”,* a structured overview of multidimensional land reform assessment criteria is presented in chapter 7. It explains that the FTLRP can be evaluated with criteria of seven broad success aspects which can be applied at four different time-steps of the process. These are aspects of legality, efficiency, effectiveness, equity, economic viability, as well as governmental and environmental aspects. All can be applied to the situation before the FTLRP, to the expropriation process, to the redistribution process and to the situation after the FTLRP. A number of assessment criteria are of spatial character and can be addressed with GIS and remote sensing. For this thesis, the two most intensively discussed spatial criteria have been selected as thematic research questions: one criterion of effectiveness after FTLRP (overall crop area in redistributed area), and one criterion of efficiency after FTLRP (crop production of different tenure regimes).

As consecutive chapters delve into the research framework and critically evaluate the suitability of proposed remote sensing methods to answer these two questions, they also give practical feedback to *research question C2 “What contributions can spatial methods* *make to land reform assessments".* Main Section III provides the theoretical answers to this question, as conceptual chapter 6 emphasizes the potential of integrated analysis drawing from research methods of Human and Ecological science, a core strength of Geography. It elaborates the later demonstrated power of innovative geospatial methods to bridge exaggerated divisions of 'quantitative' and 'qualitative', of 'dynamic' and 'static', and of 'scientific' and 'unscientific' data and methods. This power is mostly rooted in the fact that geospatial research assigns spatio-temporal characteristics to objects and therefore provides connecting factors for integration. Furthermore, the chapter accentuates the interdisciplinary character of land reform and its effects and therefore stresses the applicability of geospatial analysis.

After this promising potential of geomatics has been pointed on, chapter 7 examines to what extent GIS and remote sensing have been used within the research on land reform in Zimbabwe. The results of a quantitative, structured literature survey of major scientific databases give a sobering answer to *research question C3 "Has this potential been tapped on?"* Figures proof that there is an engaged community researching on land reform in Zimbabwe, but also, that it regrettably does not tap the full potential of spatial analysis. The survey found that only 3.2% of publications which mentioned the land reform in Zimbabwe also contained the words "remote sensing". At the time the study was carried out, no title of articles included "land reform", "Zimbabwe" and "remote sensing". It was concluded that capabilities of geospatial-methodological potential have been neglected, but that at the same time, Geography has not addressed the spatial dimension of the FTLRP adequately.

After producing these results, and after the call for a re-focus on spatiality within the discourse on Zimbabwe's FTLRP, as well as for a re-engagement of spatial sciences, this PhD project has stepped up to the plate. Moving away from conceptional aspects, it was tested in Main section IV whether the multi-temporal method of NDVI time-series based land use classification can answer *thematic research question T1 "How did total crop area develop after the FTLRP?"* In chapter 9, focus was put on the method's applicability to map the trajectory of commercial farms in the agricultural heartland of Zimbabwe and therefore to reveal information on land reform effects. A link to the FTLRP however, could not be established because the approach of NDVI time-series analysis does not provide acceptable results as accuracies of land cover classes are below thresholds of plausibility. Even after climatic stratification to account for heterogeneous growth conditions, rainfed agricultural land in the Highveld of Zimbabwe was mapped with an accuracy of below 65%. Therefore, chapter 9 dismisses both, *research question T1* and *methodological research question M1 "Are MODIS datasets suited to classify land cover after Zimbabwe's FTLRP?"* by stating that MODIS-NDVI data is unsuitable for hard classification approaches in the semi-arid region. This statement is of significance for the scientific community, as it does not only challenge time-series as an assessment tool for the FTLRP, but also temporal LULC classifications based on MODIS-NDVI and phenological parameters. With temporal land use classification still being an often "unquestioningly" applied method, and accuracy matrices being neglected or underutilized (FOODY 2002), the decision was made to publish an elaboration of shortcomings of time-series based LULCC mapping. The conceptualizing chapter 8 critically reflects on reasons why methods of automated spatial analysis are reproduced, and how quality and applicability are adversely affected.

That analysis of MODIS-NDVI data can generate promising results was demonstrated in MAIN SECTION V. To overcome the mixed pixel problem and the limitations due to low resolution of MODIS products leading to indifferent reflectance profiles, a relative approach to map vegetation change was chosen in chapter 11. The selected method STA is able to provide meaningful trends of mean annual vegetative biomass in agricultural areas of Zimbabwe's Highveld. And although time series which investigate land use after the FTLRP have to be short, as first farm evictions took place in 2000, can the spatially aggregated clusters of trends be linked to field structures in imagery of higher resolution. It is therefore concluded that this part of the thesis addresses the *research question M2 "Can trend analysis generate information on agricultural production in Zimbabwe?"* successfully. Beyond the answer to this research question however, shortcomings of NDVI based trend mapping are apparent. They demonstrate that solely used linear trend based methods are not sufficient as land reform assessment tools. Because despite being able to differentiate positive and negative trend within agricultural area, the explanatory power of the STA results is limited. P values were calculated which show that negative trends are characterized by low significance and are therefore not a result of continuous degradation or underutilisation. It was suggested that they are rather an outcome of abrupt change which does make trend analysis an unsuitable method to explain the reason for the strong negative trends.

As STA delivered sound trend results, an answer was given to the *thematic research question T2 "Are there different developments in different land tenure schemes?"* The Theil-Sen trend of STA products was related to new land tenure after FTLRP. With slight negative trends in all categories of ownership, no significant relationship can be determined between agricultural trend and land tenure. A key finding of this thesis was that strong negative trends in Zimbabwe's agricultural area are spatially clustered and a result of operation stop of irrigation schemes. As biomass values plunged in these areas, they predominate the spatial pattern of trend over other production factors linked to land tenure such knowledge, market access, or investment capacity.

As more than 80 percent of irrigated cropland was found on commercial farms before the FTLRP, mapping the abandonment of irrigation schemes provides great opportunity for remote sensing to generate data on land reform effects. Therefore, a fusion of methods was developed to increase the information retrieved from MODIS-

NDVI data. Breakpoint analysis was used together with results from the STA to map location and time of change from irrigated to non-irrigated land use and vice versa. This did not only answer the *research question M3 "Is breakpoint analysis an adequate method to locate the changes of Zimbabwean irrigation schemes in space and time?"*, but also emphasizes the power of multi-method approaches as data is often too dense to be hauled with a single method only. While chapter 10 provides conceptional background and emphasizes the importance of multi-method analysis in the field of remote sensing, chapter 11 demonstrates its applicability in the context of applied land reform research. Therefore, MAIN SECTION V shows that the procedure-based hybrid analysis which combined BFAST and STA is well suited to determine location and date of irrigated field abandonment in years subsequent to Zimbabwe's FTLRP. Breakpoint detection adds value to seasonal trend analysis which assumes a linear trend pattern although in reality, causes might be of abrupt character. On the other hand, breakpoint analysis by its own is not applicable to map change of irrigation, as the breakpoint of seasonal signal does not always relate to a change from double to single peak and vice versa. A combination of both temporal analysis methods made it possible to use MODIS-NDVI data for a specific research question and in a distinct regional context.

Finally, the *research question T3 remains: "Are significant changes of production patterns linked to the FTLRP?"* Despite the powerful results presented in chapter 11, thorough approaches of linking fallow irrigation schemes with farm evictions still have to be applied. While there is no correlation between tenure and productivity trend apparent, fallow irrigation is a very visible outcome of the FTLRP and bears great potential to link objective, remote sensing based results to land reform events. However, it cannot yet be stated whether the identified stop of irrigation is in fact a direct outcome of land reform or a result from other factors. Currently, there is no accessible dataset on farm evictions, which again underlines the importance of this study. A major challenge for correlations and accuracy assessments is the historic nature of the FTLRP, which makes secondary data the only possibility to retrieve information. But with the tense political situation in Zimbabwe and with authorities and organizations being reluctant to share data, no information could be acquired to contrast the mapped stop of irrigation schemes with farm takeovers.

13 Impact and outlook

Overall, the thesis has faced considerable challenges, but has also given a number of successful answers to conceptual, methodological and thematic research questions. Its aim was to contribute to and to challenge both, land tenure science and the remote sensing community.

The latter is hopefully stimulated by a publication which challenges one of its core approaches of LULC and LULCC mapping. Although the limitations of hard classifications based on NDVI and phenology are known, and alternatives have been published (MUCHONEY & STRAHLER 2002), there are numerous temporal LULC classifications with user accuracies well below the 65% presented in chapter 9. Other studies which use the very same method of time-series based phenological analysis to research similar questions of agricultural change present challenging user accuracies below 50% (ALCANTARA ET AL. 2013). Or they conclude that abandoned agriculture can be mapped with acurracies of 65% (ALCANTARA ET AL. 2012), after comparing these results with those of other studies. Even if the limitations of Kappa and error matrices are accounted for, and the possibility of high spatial agreements is considered (FOODY 2002, PONTIUS & MILLONES 2011), such levels of accuracies from reproduced methodology have to be seriously challenged.

This thesis emphasizes that questions have to be raised and seeks to stimulate a debate about whether results with such accuracy levels generate sound knowledge and whether they are applicable. Furthermore, it reminds the remote sensing community that its products can have tremendous impact. The political sensitive research climate around land redistribution efforts in Southern Africa, together with the need for reliable spatial data to make sound judgements demonstrate why accuracy does matter. It is hoped that case studies presented in this work stimulate an already successful remote sensing community to provide even more useful data which can be utilized by other disciplines.

Woodcocks answer to the question "Is it possible to map agricultural lands using remote sensing?" puts it all in a nutshell: "Of course, it is *possible* to make a map of agricultural lands using remote sensing. However that is not really what is being asked. What is being asked is whether or not remote sensing can be used to provide someone with the information about agricultural lands they desire with suitable precision and at a level of accuracy which makes the map useful for their purposes." (WOODCOCK 2002)

One way forward has been presented in this thesis: with limited available imagery and ground data, a combination of remote sensing methods enhanced the information needed to map the past. With an exponential growth of various datasets, of open source solutions and of computation power, the capability of hybrid approaches knows no limit. The remote sensing community should use this potential but remember that the method shall suit the recipient and not the recipient the method.

Land tenure scientists and practitioners from the region as recipients of remote sensing data can directly profit from this project. To ensure this benefit, focus was put on ready-to-use solutions, published mainly in open source journals. Working on a case study in a region where researchers fail to "acquaint themselves with the current state-of-the-art within a particular scientific field" due to lack of resources and information (MUTULA 2005), it is believed that this work will close the digital divide, which has been identified in remote sensing as well (Fuchs & Horak 2008, Heumann 2011).

Generated results which highlight the lack of correlation between new land tenure and negative trend of production might help to calm the heated debate about the success of land tenure types and appease opposed fractions arguing about the adequateness of farm sizes, both are ideological discourses in the region. It can also stimulate to put focus on measures to increase future production and to overcome the limitations all tenure systems currently experience.

The here presented unique approach to map fallow irrigation countrywide on an automated basis, is an important contribution towards the achievement of an improved agricultural production. The result of the hybrid-method generates knowledge of area, location and length of fallow period of irrigation schemes which once formed a cornerstone of an agriculture which made Zimbabwe the 'breadbasket of Africa'. This result should not be used to mourn and to praise the past, but to identify the unused potential of agricultural production, where structures maybe still existent, where extension could make impact, or where new concepts of production have to be developed.

It is widely accepted, that outcomes of the FTLRP will not be redressed. Expropriated farmers mostly plead for compensation of investments, not for return of their land, and new farmers start to establish profitable, market connected businesses. With the FTLRP, Zimbabwe has undergone thorough changes, for better or for worse. But during all struggles the country experienced, there have always been people who moved forward with vision, pragmatism and solutions. White farmers leasing land back from their new owners, cooperatives, joint production and outgrower schemes are some examples which have helped the agricultural sector to slightly recover and raise hope for a productive, and yet multiracial agrarian sector. What is needed in the light of current developments in Southern Africa, are people who join hands and strive together for progress. Let's develop solutions they need.

VII. Supplementary material

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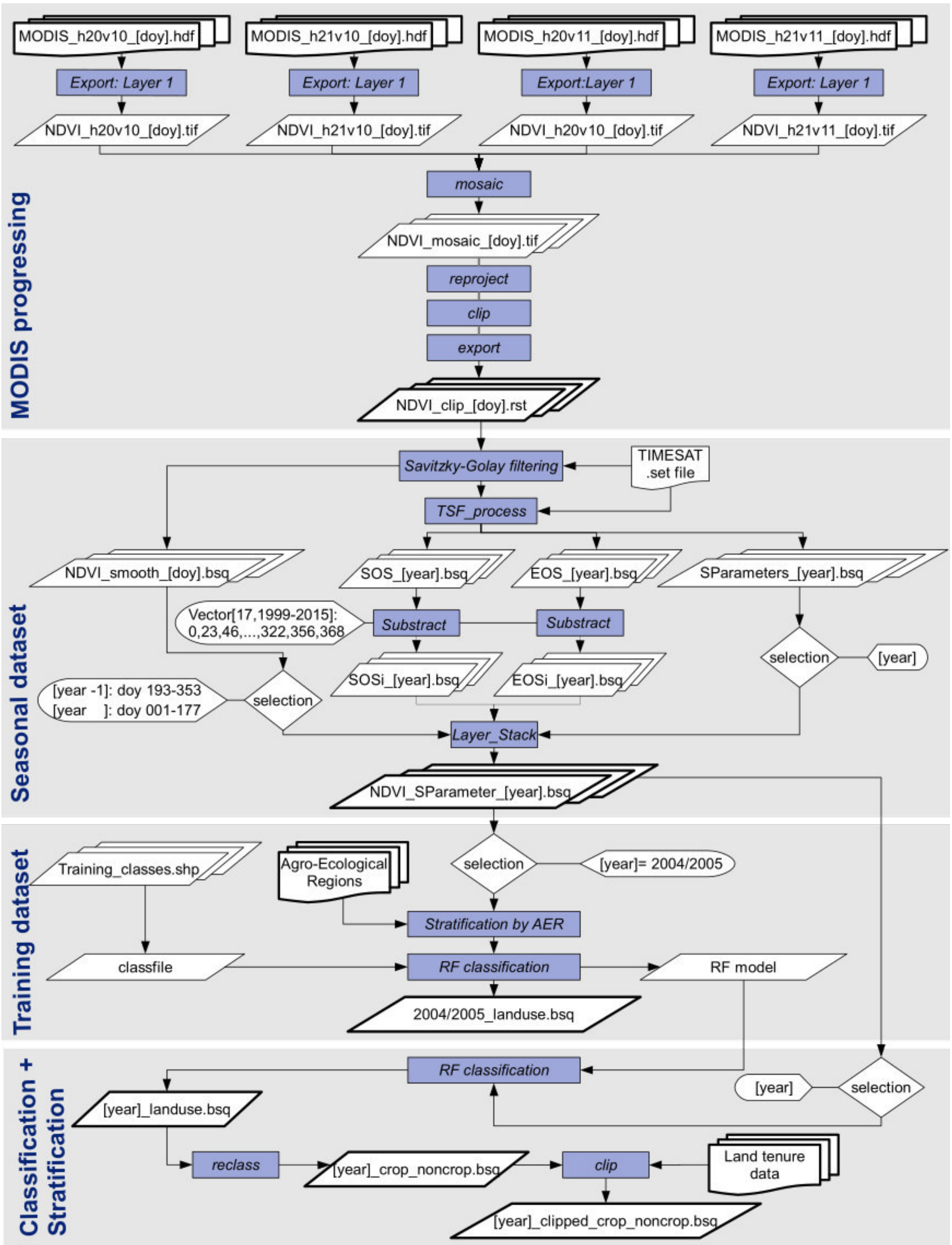
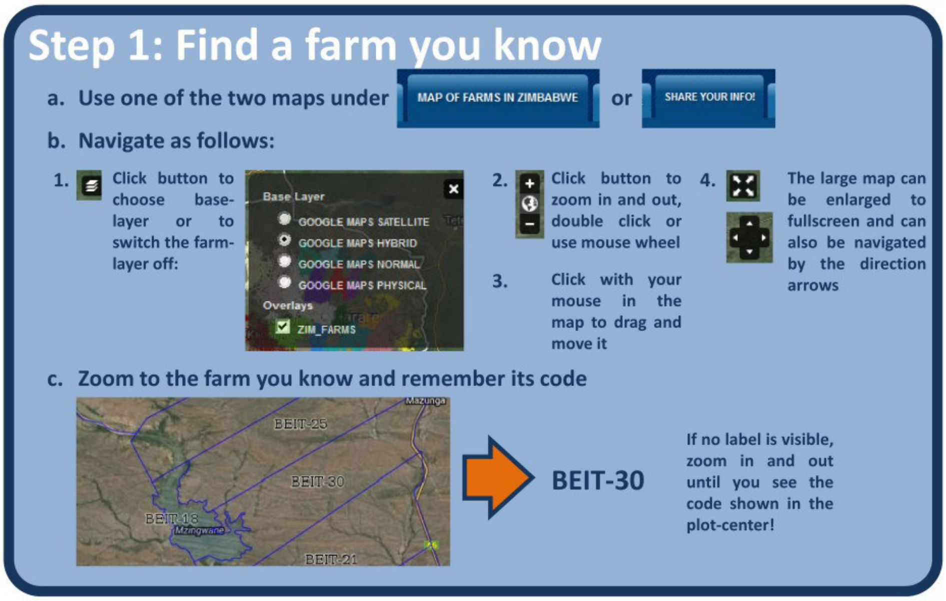
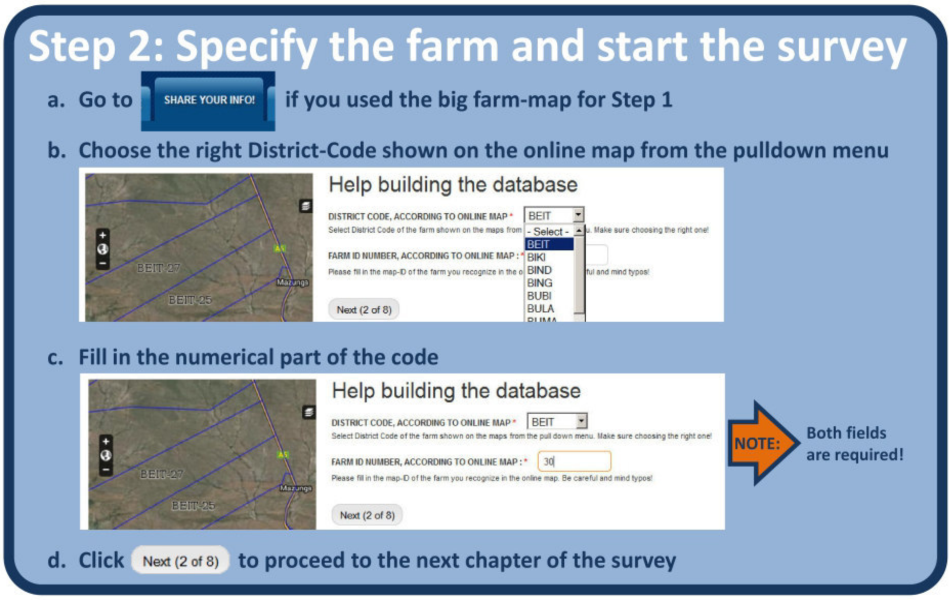
Appendix

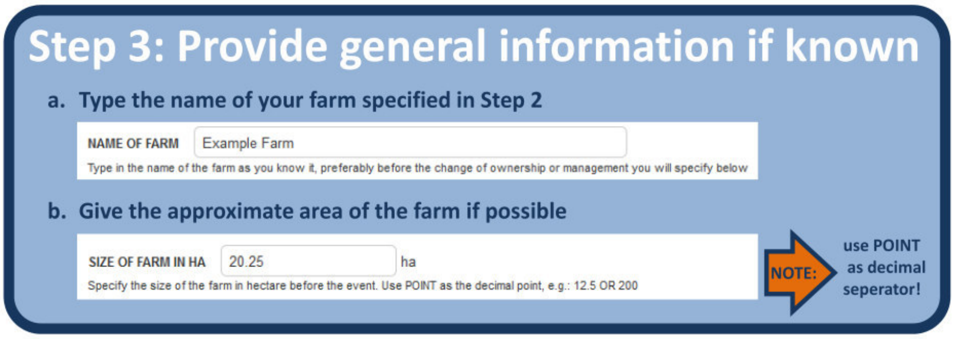
1. Detailed Version of Figure Figure 9.4, page 76



2. **Instruction for PPGIS survey designed to acquire information on evictions (compare Figure 7.2, page 59)**







Step 4: Give information on the change event

a. Specify the event of change

REASON OF CHANGE
- ○ MANAGEMENT
- ○ INHERITED
- ○ BOUGHT BY PRIVATE PERSON
- ○ BOUGHT BY STATE
- ◉ EVICTED

Put...

MANAGEMENT: If ownership has not changed, but the decision maker
INHERITED: If landuse/crops have changed due to generation change
BOUGHT BY PRIVATE PERSON: If cropping change followed vending
BOUGHT BY STATE: If cropping change followed acquisition by state
EVICTED: If changes occured without legal status: fast track land reform

If NOTHING happened and the farm is still owned by the same person, skip this section and the following sections related to AFTER the event!

b. Enter the date of the event mentioned above

DATE OF CHANGE EVENT | Mar | 1 | 2000

If you don't know the exact day, just put 1. !

c. State whether the farm was subdivided

SUBDIVIDED?
- ◉ YES
- ○ NO

Choose yes, if farm is owned or managed by more people than before the event: If occupants got a share, if the state distributed the bought farm among beneficiaries etc.

Step 5: Specify landuse BEFORE the event

a. Tick the crops which have been grown on the farm before it was sold, evicted etc.

MANAGEMENT BEFORE CHANGE
- ☑ GRAZING (CATTLE, GOATS, SHEEP, ETC.)
- ☐ CONSERVATION/GAME
- ☑ MAIZE
- ☐ WHEAT
- ☑ TABACCO
- ☐ COFFEE
- ☐ GROUNDNUTS
- ☐ COTTON
- ☐ SUGAR CANE
- ☐ SORGHUM/PEARL MILLET
- ☐ OTHER

NOTE: It is possible to tick as many choices as desired

b. Click Next (5 of 8)

c. Estimate the area covered by the crops mentioned before

PERCENTAGE AREA OF GRAZING AREA OF TOTAL FARM AREA BEFORE EVENT
60 % Grazing

PERCENTAGE OF MAIZE AREA OF TOTAL FARM AREA BEFORE EVENT
30 % Maize

PERCENTAGE OF TABACCO AREA OF TOTAL FARM AREA BEFORE EVENT
- None - % Tabacco

- None -
0
10
20

Next (6 of 8)

Make sure the sum adds to 100%, but leave fields blank if you don't know. This is a rough estimate to get an idea of the landcover fraction. Put ZERO if the area is really really small and likely to be below 0.

Step 6: Specify landuse AFTER the event

a. Tick the crops which have been grown on the farm after it was sold, evicted etc.

MANAGEMENT AFTER CHANGE
- [x] GRAZING (CATTLE, GOATS, SHEEP, ETC.)
- [ ] CONSERVATION/GAME
- [x] MAIZE
- [ ] WHEAT
- [ ] TABACCO
- [ ] COFFEE
- [ ] GROUNDNUTS
- [x] COTTON
- [ ] SUGAR CANE
- [x] SORGHUM/PEARL MILLET
- [ ] OTHER

NOTE: It is possible to tick as many choices as desired

b. Click Next (7 of 8)

c. Estimate the area covered by the crops mentioned before

PERCENTAGE AREA OF GRAZING AREA OF TOTAL FARM AREA AFTER EVENT
30 % Grazing

PERCENTAGE AREA OF MAIZE AREA OF TOTAL FARM AREA AFTER EVENT
10 % Maize

PERCENTAGE AREA OF COTTON AREA OF TOTAL FARM AREA AFTER EVENT
0 % Cotton

PERCENTAGE AREA OF SORGHUM AREA OF TOTAL FARM AREA AFTER EVENT
60 % Sorghum

Make sure the sum adds to 100%, but leave fields blank if you don't know. This is a rough estimate to get an idea of the landcover fraction. Put ZERO if the area is really really small and likely to be below 0.

Step 7: Share information on ownership

a. Chose the type of ownership BEFORE the change occured

OWNERSHIP BEFORE CHANGE
- ◯ WHITE INDIVIDUAL
- ◯ BLACK INDIVIDUAL
- ◯ WHITE MULTIPLE
- ◯ BLACK MULTIPLE
- ◯ COMPANY
- ◯ STATE
- ◯ OTHER

Please state if the farm was owned by a group or individual. The skin color is related to the agenda of the land reform.

If the farm was owned by a large company, also foreign, or by the state, tick the appropriate.

b. Estimate the area covered by the crops mentioned before

OWNERSHIP AFTER CHANGE
- ◯ WHITE INDIVIDUAL
- ◯ BLACK INDIVIDUAL
- ◯ WHITE MULTIPLE
- ◯ BLACK MULTIPLE
- ◯ COMPANY
- ◯ STATE
- ◯ OTHER

Please state if the farm is owned by a group or individual. The skin color is related to the agenda of the land reform.

If the farm was owned by a large company, also foreign, or by the state, tick the appropriate.

If the farm was subdivided after the change, choose multiple.

c. Click Submit

DONE! You are welcome to continue for as many farms as you know!

Versicherung an Eides statt

Hiermit erkläre ich, dass ich die vorliegende Dissertationsschrift mit dem Titel „Suitability Analysis of Remote Sensing Methods to Map Agricultural Land Use Change after Zimbabwe's "Fast Track Land Reform Programme"" selbstständig verfasst habe und keine anderen Quellen und Hilfsmittel als die angegebenen benutzt habe. Stellen in Text, Abbildungen und Tabellen, die anderen Werken den Worten oder Sinn nach entnommen wurden, sind jedem Falle als Entlehnung kenntlich gemacht. Die Arbeit wurde nur in diesem und keinem anderen Promotionsverfahren eingereicht und an keiner anderen Stelle veröffentlicht, mit Ausnahme der folgenden Aufsätze:

Hentze, K., and G. Menz; 2015. **"Bring Back the Land"—A Call to Refocus on the Spatial Dimension of Zimbabwe's Land Reform.** Land 4(2), 355-377.

Hentze, K., Thonfeld, F., G. Menz; 2016. **Evaluating crop area mapping from MODIS time-series as an assessment tool for Zimbabwe's "Fast Track Land Reform Programme".** PLoSONE 11(6), e0156630.

Eine Veröffentlichung des folgenden Aufsatzes ist geplant:

Hentze, K., Thonfeld, F., G. Menz; 2016. **Beyond trend analysis: how a modified breakpoint analysis enhances knowledge of agricultural production after Zimbabwe's fast track land reform.** Journal of Applied Earth Observation and Geoinformation.

Bonn, den 15.07.2016

Konrad Hentze