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An attempt to investigate the impact of 1994 Tutsi Genocide in Rwanda on Landscape using Remote Sensing and GIS analysis

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ABSTRACT

The 1994 Tutsi Genocide in Rwanda affected the society, as well as its surrounding environment. This study presents an attempt to investigate the impact of 1994 Tutsi genocide in Rwanda on landscape using remote sensing and GIS analysis. It looked at the evidence of change to the landscape based on NDVI change as a sign of vegetation change. To explain the reason behind the noticed change, rainfall variations, refugees and population number, GDP and agricultural production were used as parameters. Rainfall was representing other facts not related to Genocide while the rest of parameters were assessed as a result of Genocide. By the combination of Satellite images data from Landstat TM and ETM+, and socio-economic and environmental analysis based on deductive approach, it was found that Remote Sensing can be integrated to conflict study, were it helped the reconstruction of the landscape vegetation based on NDVI which decreased during the genocide period, from 0.54 in 1987 to 0.52 in 1995, and increased after the genocide up to 0.54 in 2003. The main reason of the decrease of NDVI in 1995 is the rise of refugees number within the region of study which hosted over 1,000,000 refugees that were fleeing the genocide toward the neighbouring country of DRC.

Keywords: Landsat TM and ETM+, NDVI, Agricultural Production and GDP, Refugees, Rainfall.

CONTENTS

ABSTRACT ..... **i**

FIGURES ..... **v**

TABLES ..... **vi**

ABBREVIATION ..... **vii**

INTRODUCTION **1**

Background 1

Thesis statement 2

Objectives 2

Research questions 2

Hypothesis 2

Scope of the study 2

Limitation of research 3

Implications of research 3

Study area 4

LITERATURE REVIEW **6**

Remote sensing 6

Electromagnetic spectrum 6

Spectral reflectance of the surface 7

Landscape and vegetation indices (NDVI) 8

Landscape change and digital change detection methods 10

Landsat 11

Genocide 12

Remote sensing and the study of war and conflict 13

MATERIAL AND METHODS **15**

Data acquisition ... 15
Geometric and radiometric correction ... 17
Data normalization ... 19
Change detection and NDVI temporal image differencing ... 19
Integrating socio-spatial analysis to the landscape change ... 20
Rainfall ... 21
Population ... 21
Agricultural production ... 21
GIS software (ArcMap and Idrisi) ... 21
IMAGE PROCESSING RESULTS ... 23
NDVI ... 23
Change detection, change no change threshold ... 23
NDVI differenced image result ... 26
Rainfall ... 27
Population ... 28
Agricultural production ... 29
RESULT AND DISCUSSION ... 32
NDVI and rainfall ... 32
NDVI and agricultural production ... 33
NDVI and population ... 34
Source of errors ... 35
CONCLUSIONS AND RECOMMENDATIONS ... 36
Key findings ... 36
Future development ... 36
ACKNOWLEDGEMENT ... 38

BIBLIOGRAPHY **39**

APPENDIX A **43**

APPENDIX B **44**

APPENDIX C **46**

APPENDIX D **47**

APPENDIX E **50**

APPENDIX F **51**

FIGURES

Figure 1: Map of Rwanda representing the region of study *4*
Figure 2: Spectral reflectance curve for vegetation, soil and water *8*
Figure 3: Flow chart diagram *16*
Figure 4: NDIV of 1987, 1995 and 2003 .... *23*
Figure 5: Histogram of NDVI differenced image of 1987 and 1995 .... *24*
Figure 6: Histogram of NDVI differenced image of 1987 and 2003 .... *24*
Figure 7: Histogram of NDVI differenced image of 1995 and 2003 .... *25*
Figure 8: Differenced NDVI of 1987, 1995 and 2003. .... *26*
Figure 9: Rainfall of 1987, 1995 and 2003 .... *27*
Figure 10: Population of Rwanda from 1934 to 1997 .... *28*
Figure 11: Total population of Rwanda and the number of refugees from 1986 to 2004 .... *28*
Figure 12: Agriculture and livestock *29*
Figure 13: Population working in agricultural sector and its contribution to GDP *30*
Figure 14: Rwandan GDP growth rate from 1967 to 1996 .... *31*
Figure 15: GDP growth for the study periods *31*
Figure 16: NDVI and rainfall fluctuation *32*
Figure 17: NDVI 87, 95, 03 versus agriculture and livestock *33*
Figure 18: NDVI 87, 95, 03 versus population and refugees *34*

TABLES

Table 1: Land use of Cyangugu *5*

Table 2: Important wavelength in Remote Sensing *7*

Table 3: Common VI and their characteristics.. *9*

Table 4: Landsat ETM+ spectral bands *12*

Table 5: Landsat TM spectral bands *12*

Table 6: The satellite images *15*

Table 7: Used measures to compute at-satellite reflectance for Landsat ETM+2003 .... *18*

Table 8: Used measures to compute at-satellite reflectance for Landsat TM5, 1987 and 1995). *19*

Table 9: Used months for rainfall.. *21*

Table 10: NDVI difference between 1987, 1995 and 2003 .... *25*

Table 11: Average rainfall for 1987, 1995 and 2003 .... *27*

Table 12: NDVI mean values, rainfall, population, refugees, GDP, crop and livestock mean values *32*

ABBREVIATION

DN: Digital Number

ETM: Enhanced Thematic Mapper

ETM+: Enhanced Thematic Mapper Plus

GDP: Gross Domestic Product

GIS: Geographical Information System

MINAGRI: Ministry of Agricultural of Rwanda

NATO: North Atlantic Treaty Organization

NDVI: Normalized Difference Vegetation Index

NIR: Near Infrared

RDC: Republique Democratique du Congo

RNIS: Rwanda National Institute of Statistics

RPF: Rwanda Patriotic Front

IR: Infra-red

SSD: Solar System Dynamics

TM: Thematic Mapper

USGS: United States Geological Survey

VI: Vegetation Index

WB: World Bank

INTRODUCTION

Background

The 1994 Tutsi Genocide killed over 1,000,000 Tutsi and moderate Hutu (De La Pradelle, 2005). This made a big impact on Rwandan society and shaped the image of present Rwanda. Many studies were conducted to explain what happened and how a society can derive into the extreme horror. Not so many studies have focused on environmental changes due to warfare.

The Tutsi Genocide in Rwanda occurred during a period of twelve weeks, from the 6th April to the 4th July 1994. The most intensive period was from April 10th to May 30th. The majority of victims were Tutsi, but also tens of thousands of Hutu opposed to the genocidal government numbered among the victims (Schimmer, 2010).

Like everywhere else in Rwanda, the killings affected Cyangugu Prefecture (figure1, section1.2.7). During the genocide period, a refugee camp was established in Nyarushishi hills located in Cyangugu Prefecture (Currently in the Western Region, district of Rusizi), regrouping escaped Tutsi from the surrounding region (De Saint-Exupéry, 2004). It was under the protection of French soldiers within the boundaries of what was called "Zone Humanitaire Sure" under "Operation Turquoise". More than that, thousands of peoples were escaping the war between RPF and genocide government troops as the region was under French control (De Saint-Exupéry, 2004). This situation had a great impact on both the landscape and the land use because of the mass displacement resulting from the situation, which makes it a relevant site to study the impact of 1994 Tutsi Genocide in Rwanda on landscape vegetation, as the region was one of the most affected by the killings and human displacement during that period.

Remote sensing is increasingly used in past, present and post conflict studies and monitoring. It was effectively used to track the genocide in Darfur by looking at population displacement (Schimmer, 2008). As past conflict, remote sensing was used to study the environmental impact of genocide in Guatemala (Schimmer, 2006). Even though it has been effectively used, mainly by Yale University scholars in the study of genocide, it still need to be more widely applied to cover conflicts around the world.

The use of remote sensing data can help in the study of conflicts and its impact on society (Per, et al., 2003). It can help to assess the impact of war or conflict on environment. Mainly used for military purpose for long time, the non-military use of satellite data came to public attention during the 1991 Gulf war in Iraq and Kuwait due to the increased interest in the war's environmental consequences (Witmer & John, 2009).

Since then, remote sensing has been used in many different conflict studies, such as urban infrastructural and housing impacts of NATO bombings of Yugoslav cities during the Kosovo war (Witmer & O'Loughlin, 2009) or indication of Genocide in the Bisesero Hills, Rwanda 1994 (Schimmer, 2006) amongst others.

In many aspects of everyday life, such as science, government, and business, remote sensing has become an essential tool (Lillesand, et al, 2004). It can be applied in conflict studies as well as other social related issues. Moreover, the integration of remote sensing in the study of conflict can enhance the interpretation by giving additional measures and information such as time series-data and illustration of the landscape of the conflict period that would otherwise be hard to get.

Thesis statement

Objectives

The primary goal of the research was to investigate the impact of 1994 Tutsi Genocide in Rwanda on landscape vegetation with focus on NDVI as a tool to assess vegetation change in Cyangugu prefecture, currently within the western part of Rwanda.

The combination of remote sensing based data and GIS was used to find evidence of change to the landscape vegetation.

NDVI was used as indicator of increase, decrease or consistence of the vegetation vigour.

To assess the reason behind the vegetation change, correlation between temporal and spatial landscape change and genocidal related events were established by analysing:

- rainfall variations;
- population facts;
- agricultural production.

Research questions

To achieve the cited objectives, the following questions were answered:

- Could remote sensing data indicate changes in vegetation that could be associated to land use changes due to the 1994 genocide
- If so, could natural variations in climate have caused these changes

Hypothesis

By the use of remote sensing images, it is possible to investigate landscape change caused by 1994 Tutsi genocide through identification of vegetation change based on NDVI with the combination of socio-economic and environmental analysis.

Scope of the study

The study intend to look at the environmental change as a consequence of 1994 Tutsi genocide based on landscape change both in time and space. This was done by the use of remote sensing and GIS analysis over the district of Rusizi, located in the western part of Rwanda. By the time of the facts, the region of Rusizi was within Cyangugu Prefecture and it sheltered a refugee camp at Nyarushishi hills. In time, the study analysed remote sensing scenes for a period of 8 years before the genocide (1987), right after the genocide (1995) and 8 years after the genocide (2003). The change analysis was based on vegetation change, with NDVI as indicator for the mentioned period. To explain the reason behind the change, socio-economical and environmental analyses were performed by looking at rainfall variations, population facts and agricultural production.

Limitation of research

The main problem with the research was to get free satellites images, with good quality covering the period of genocide; and representing rainfall period as well; from April to July for years before, during and after the genocide. Most of the images were too cloudy to be treated. Nevertheless, the month of January proved to be the one with fewer clouds for the study period of 1987, 1995 and 2003. But, the year of 1987 and 2003 still had clouds which were removed. The removal of clouds affected the quality of results.

Another problem is that the month of January represents a short dry season, right after the short rainy season from mid-September to mid-December.

The used social-economical and environmental data was affected by limited means and time. For that reason, it was not possible to find population data of the region; instead, the total population of Rwanda as whole as well as agricultural production were used. It is good to mention that due to the size of the country, which is small, and the similarity in culture and behaviour, the population trend and agricultural practices are almost the same for all the country with minor changes. Though limited, it gives a general picture of how the things are.

The integration of remote sensing and social science based study, especially, war and conflict that still surprisingly limited and is not widespread.

Implications of research

The research project is interesting in the sense that it applies remote sensing in the study of past conflict. It is a useful tool because it makes it possible to have evidence, hence acting as a tangible proof of what happened that otherwise will be hard to get.

Specifically, the genocide impact on environment was analysed by coupling socio-economical and environmental data analysis, to get the cost of war and instability caused by human on nature. This can be a reminder for current and future generation of what happened to help prevent it. Last but not least, it is a humble contribution to the emerging field of remote sensing application in the conflict studies.

Study area

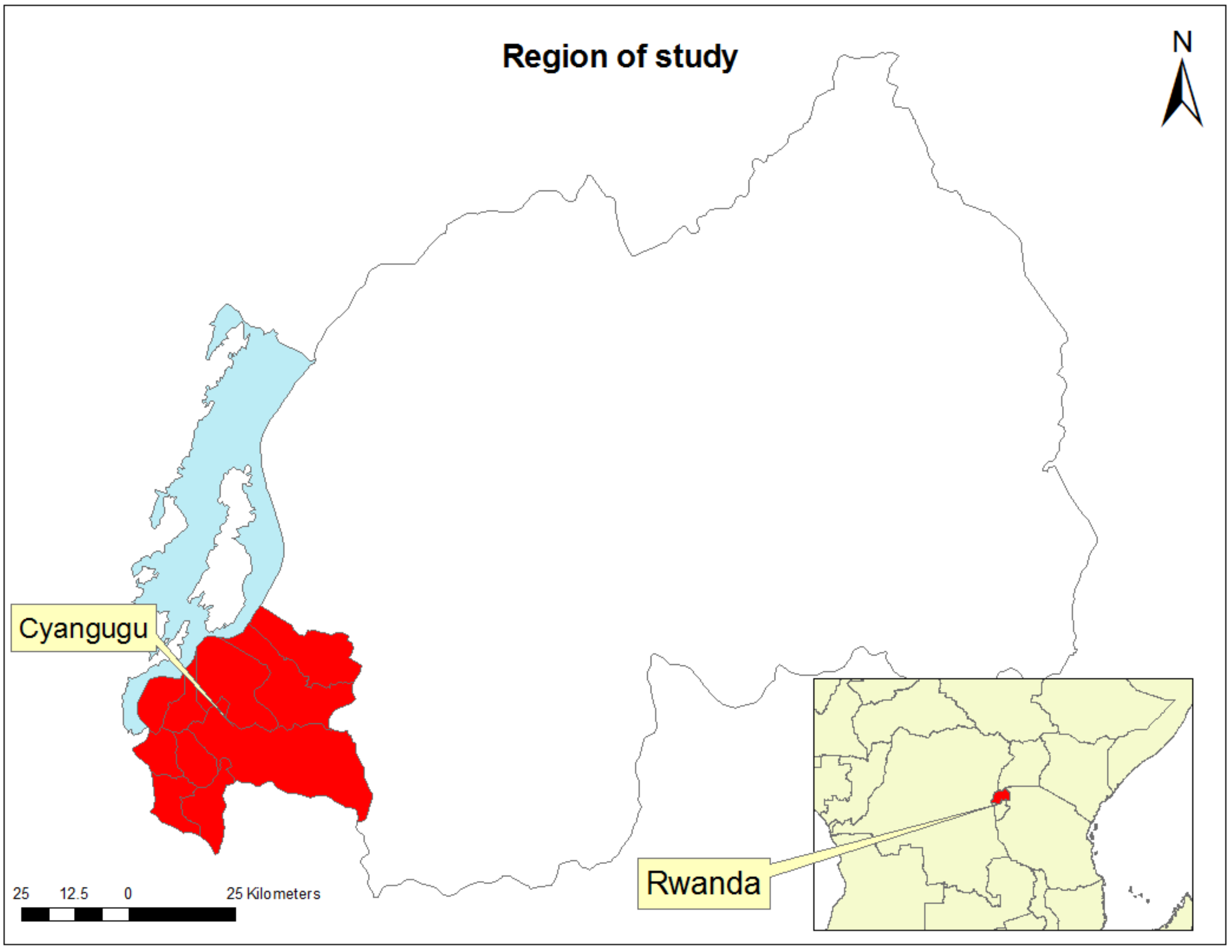

Figure 1: Map of Rwanda representing the region of study (Generated from Rwanda National Institute of Statistics data)

The study area is located in Rwanda, the province of Cyangugu, currently located in the region of West Rwanda, district of Rusizi. It shares border with the city of Bukavu, Congo in West, the province of Cibitoke, Burundi in South, the province of Kibuye, in North, the province of Gikongoro, now composed by the districts of Nyaruguru and Nyamagabe in East. It is composed by 18 sectors, 94 cellules, 594 villages and 68,790 household with area of 718.9 km^2 and a high population density of 390 people per square kilometer (Rusizi District, 2010).

The district of Rusizi is characterised by moderate tropical climate. The average temperatures vary between 20^0C and 30^0C. The annual average rainfall is about 1,450mm. 90% of the district population is engaged in agricultural activities.

By 1994, there were over 800,000 herds of cattle and 2.7 million small stocks. The tragic events of 1994 decimated livestock by 80% and the small stock by 90% (Minagri, 2010).

Like everywhere else in Rwanda, the region of Rusizi experiences a short rainy season from mid-September to mid-December and a long rainy season from February to May. The short dry season runs from mid-December to January, and the long dry season from June to mid-September. (Minagri, 2004)

The district of Rusizi is dominated by three topographical features, the big plain of Bugarama, a chain of plateau and Congo-Nile crest. The district soils are Impala basalt, permeable and rich in iron (Minagri, 2010).

The vegetation is dominated by Savana shrubs, miscellaneous thorny plants and ferns in the west part. In the eastern part, it is dominated by Nyungwe natural forest which is home to various animal species like monkeys, baboons, nanny goats, jackals, reptiles, various species of birds and insects (Rutagarama & Martin, 2006).

The main cultivated crops are banana, beans, cereals, root crops, industrial crops (tea and coffee), vegetables and fruits.

Table 1: Land use of Cyangugu (Minagri, 2004)

Land use	% area occupation
Cultivable area	59.12
Non-cultivable and housing	2.30
Fallow and pasture	8.43
Woodland	6.03
Forest and water	24.12
Total	100

The area was chosen because of its location at the border of DRC (Zaire during the events), as well as the fact that it was within a protected area under French control as part of rescue and humanitarian mission. The genocidal government were fleeing the country with population as human shield because they were defeated and followed by RPF troops (De La Pradelle, 2005). It is interesting in the sense that, the number of local population were affected by the killings and decreasing like everywhere else in the country, but at the same time, after the establishment of the protected area by French, the number of population increased a lot as it hosted people coming from other regions that were fleeing the war to the neighbouring country.

LITERATURE REVIEW

Remote sensing

Remote sensing can be defined as the science and art of obtaining information about an object, area, or phenomenon through analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand, et al., 2008).

The use of remote sensing has the potential for contributing to studies for land cover and change detection by making globally comprehensive evaluations of many environmental and human actions possible (Campbell, 2007). It makes it possible to generate a large amount of data at different spatial, spectral and temporal resolution by the use of appropriate combination of bands to bring out geographical and manmade features (Satellite Imaging Corporation, 2010).

By the use of various sensors, data can be remotely collected and may be analyzed (Campbell, 2007). The study used electromagnetic energy sensors operated from space borne platforms to assist inventorying, mapping, and monitoring earth resources. These sensors acquire data on the way various earth surface features emit and reflect electromagnetic energy, and these data are analyzed to provide information about the resources under investigation (Lillesand, et al., 2008).

Electromagnetic spectrum

The electromagnetic spectrum of an object is the characteristic of distribution of electromagnetic radiation emitted or absorbed by the particular object.

Objects with the temperature above the absolute zero emit electromagnetic radiation. Some objects reflect radiation that has been emitted by other objects. It is possible to develop knowledge about objects behaviour and characters of features such as vegetation, structures, soils, etc., by recording emitted and reflected radiation.

In remote sensing, electromagnetic waves are categorised based on their wavelength location within the electromagnetic spectrum. Visible light is the most familiar form of electromagnetic radiation.

Below is the table of the most important wavelength regions, among which visible range and NIR were used for this study.

Table 2: Important wavelength in Remote Sensing (Swain & Davis, 1978)

Spectral region	Wavelength
Visible (VIS)	0.38 – 0.72 µm
Near infrared (NIR)	0.72 – 1.30 µm
Middle infrared (MIR)	1.30 – 3.00 µm
Far infrared	7.00 – 15.00 µm

Spectral reflectance of the surface

When electromagnetic energy strikes any given feature on the Earth surface, three types of interaction are possible: reflection, absorption and/or transmission (Charles & Jacob, 2006). The reflected component is important for remote sensing purposes because this sort of radiation can be measured by the sensor system (Congalton, 2010). The reflected energy is equivalent to the incident radiation on a given feature minus the energy absorbed and/or transmitted by that feature. The reflection of a certain surface depends on different factors. The most important ones include (Cronquist & Elg, 2000):

- Nature of the material
- Physical condition (*e.g.* wet – dry, healthy – stressed)
- Surface roughness of the object
- Exposure to the sun and solar elevation angle
- Spectral features (color tone) of the object
- Viewing angle (sensor)

The amount of reflected energy varies not only with different materials but also with the same materials in having different conditions (Congalton, 2010). Furthermore, as far as a single feature type is concerned, its reflection varies at different wavelengths (Congalton, 2010). As a consequence, each surface material has its characteristic reflection over a range of wavelengths, which corresponds to the so-called spectral signatures or profiles (Figure 2) (Cronquist & Elg, 2000)

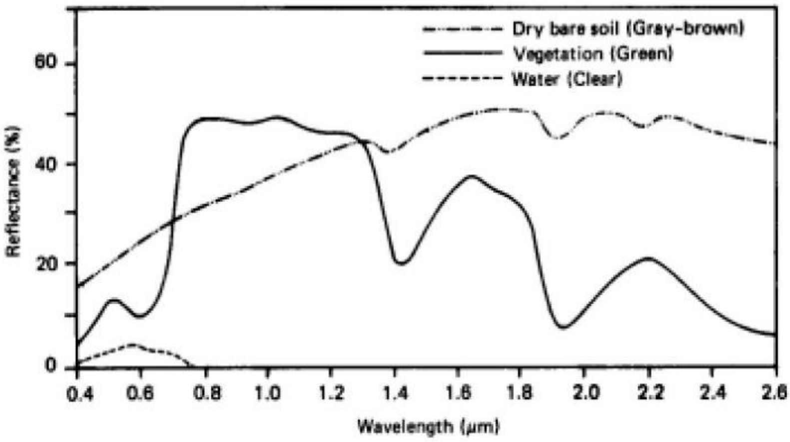

Figure 2: Spectral reflectance curve for vegetation, soil and water **(**Lillesand and Kieffer, 1994)

The spectral characteristics of a feature may be altered according to seasonal variations or geographic locations (Mutanga, J, & L, 2009). Regarding the temporal effects, the same land cover type in a dry season may look very different during a rainy season. The spatial effects are also important because some features show different spectral characteristics at different geographic locations, which vary in terms of soil types, climate, or cultivation practices (Cronquist & Elg, 2000).

Landscape and vegetation indices (NDVI)

One of the approaches to estimate biophysical vegetation properties is the use of VIs. They are among the oldest tools in remote sensing studies. Most of VIs ratio the reflection of the light in red and NIR sections of the spectrum to separate the landscape into water, soil, and vegetation (Glenn, et al, 2008)

Numerous studies have shown that satellite derived VIs are optical estimates of canopy greenness, a composite property of leaf chlorophyll content, leaf area, canopy cover and structure (Glenn, et al, 2008). They can be calculated by ratioing, differencing, ratioing differences and sums and by forming linear combinations of spectral band data (Ray & Alfred, 1991). The calculation can be done from sensor voltage outputs, radiance values, reflectance values and digital numbers (Ray & Alfred, 1991).

In general, there are two classes of VIs: ratios and linear combinations. Ratio VI is the simple ratio of any two spectral bands, or the ratio of sums, differences or products of any number of bands. Linear combinations are orthogonal sets of *n* linear equation calculated using data from *n* spectral bands (Ray & Alfred, 1991).

Table 3: Common VI and their characteristics (For details, Ray, D.J. and Alfredo R.H., 1991 or Glenn E. et Al., 2008)

VI	Name	Class	Formula
RVI	Ratio Vegetation Index	Ratios	$\frac{NIR}{Red}$
NDVI	Normalized Difference Vegetation Index	Ratios	$\frac{NIR - Red}{NIR + Red}$
EVI	Enhanced Vegetation Index	Ratios	$\frac{2.5 \times (NIR - Red)}{(1 + NIR + (6 \times Red - 7.5)}$
LCV	Linear Vegetation Index	Linear	$\sum_{i=1}^{n} aixi$
SAVI	Soil Adjusted Vegetation Index	Both	$\frac{NIR - Red}{NIR + Red + L}(1 + L)$

The most used VI is the NDVI. It is based on the near-infrared and red spectral bands, and have been shown to be well correlated with crop biomass accumulation, leaf chlorophyll levels, leaf area index values, and the photosynthetically active radiation absorbed by a crop canopy (Lillesand, et al., 2004).

Moreover, NDVI compensate for changing illumination conditions, surface slope, aspect, and other extraneous factors. Clouds, snow, and bright non-vegetated surfaces have NDVI values of less than zero (Lillesand, et al, 2004).

Hence, NDVI is an index that provides a standardized method of comparing vegetation greenness between satellites images. The NDVI range is from -1 to +1.

NDVI is a standard remote sensing application for detecting temporal change in land cover, especially vegetation. It is related to vegetation because healthy vegetation is absorbed in the 500-700 nm red (figure 2) visible range of the electromagnetic spectrum and reflects very well in the 700-1300 nm NIR range of spectrum (Congalton, 2010).

Since NDVI is sensitive to variations in precipitation during vegetation growth cycle (Lunetta & Elvidge, 1999), it should have been better to focus on period from April to July, with particular attention for April and May as they are part of the long rainy season in Rwanda. Due to the image availability and quality and as applied by Schimmer R. (2006); by choosing months that are not within the peak of rainfall season and choosing months within short dry season, but with better image quality; the study focussed on the month of January as it proved to be the one with the best image quality that can cover the study period.

Landscape change and digital change detection methods

Spectral change detection techniques rely on the principle that land cover changes result in persistent changes in the spectral signature of the affected land surface (Munyati, 2000). The areas of spectral change are highlighted by the transformation of two original images to a new single band or multi band image (Lunetta & Elvidge, 1999).

For change detection to be effective, the use of multitemporal data sets is required to discriminate areas of land cover change between dates of imaging (Jensen, 2004). Ideally, change detection procedures should involve data acquired by the same sensor and be recorded using the same spatial resolution, viewing geometry, spectral bands, radiometric resolution, and time of the day (Lillesand, et al, 2004). Accurate spatial registration of the various dates of imagery is also a requirement for effective change detection.

The reliability of the change detection process may also be strongly influenced by various environmental factors that might change between the image dates In addition to atmospheric effects, such factors as lake levels, tidal stage, wind, or soil moisture condition might also be important. Influences as different planting dates and season to season changes in plant phenology must be considered (Jensen, 2004).

Discriminating changes between 2 dates of imaging can be done by employing post-classification comparison (Munyati, 2000). In this approach, two dates of imagery are independently classified and registered. Then algorithm can be employed to determine those pixels with a change in classification between dates. In addition, statistics and change maps can be compiled to express the specific nature of the changes between the dates of imagery (Lillesand, et al, 2004). The accuracy of such procedures depends on the accuracy of each of the independent classifications used in the analysis. The errors present in each of the initial classifications are compounded in the change detection process (Lillesand, et al, 2004).

Another approach using the spectral pattern recognition is the classification of multitemporal data sets (Stafanov, et al, 2001). In this method, a single classification is performed on a combined data set for the two dates of interest. Land cover classes are then categorized in the combined image based on supervised or unsupervised classification (Stafanov, et al, 2001). The success of such efforts depends upon the extent to which change classes are significantly different spectrally from no change classes (Lillesand, et al, 2008).

Temporal image differencing is another common approach to change detection (Manavalan, et al, 1995). In the image differencing procedure, digital numbers from one date are simply subtracted from those of the other (Hayer & Sader, 2001). The difference in areas of change will be very small (approaching zero), and areas of change will manifest larger negative or positive values. If 8-bit images are used, the possible range of values for the difference image is -255 to +255 (Hall & Hay, 2003).

When using temporal image differencing, the analyst must find a meaningful "change-no-change threshold" (Hayer & Sader, 2001). This can be done by compiling a histogram for the differenced image data and noting that the change areas will reside within the tails of the distribution (Lillesand, et al, 2004).

Instead of using raw digital numbers to prepare temporal difference or ratio images, it is often desirable to correct for illumination and atmospheric effects and to transform the image data into physically meaningful quantities such as radiances or reflectance (Manavalan, et al 1995). Also, the images may be prepared using spatial filtering or transformations such as principal components or vegetation components. Likewise, linear regression procedures may be used to compare the two dates of imagery (Lillesand, et al, 2004).

The last change method, temporal image differencing is the one that will be the main focus for this study. It was chosen for its accuracy, simplicity in computation, and ease in interpretation. The combination of image differencing and NDVI as change detection method is quite simple to understand and can reduce uncertainty. As reported by Lyon et al. (1998), NDVI was among seven vegetation indices used to detect land cover change in Chiapias, Mexico study site, the least affected by topographic factors and was the only index that shows histograms with normal distributions.

Therefore, it can be easy to detect change in canopy or vegetation biomass by analyzing NDVI values from separates dates, using NDVI image differencing as this method is simply the subtraction of the pixel digital values of an image recorded at one date from the corresponding pixel values of the second date. Then, the histogram of the resulting image depicts a range of pixel values from negative to positive numbers, where those clustered around zero represent no change and those within the tails of distribution represent reflectance changes from one image date to the next. (Hayer & Sader, 2001)

Landsat

Landsat has been launched for the first time in 1972 as Landsat 1 MSS. Since then, different version were lunched till 1999 with Landsat 7 ETM+ (Williams, S, & T, 2006). MSS spatial resolution is 80 m with 4 bands, while more advanced TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper Plus) range from 15-120 m resolution with 8 bands. Curently, Landsat is malfunctioning (Williams, S, & T, 2006).

For the current study, Landsat TM and ETM+ were used. Below are TM and ETM+ spectral bands:

Table 4: Landsat ETM+ spectral bands (Williams, S, & T, 2006)

Band	Wavelength µm	Nominal spectral location
Panchromatic	0.520 – 0.900	Black and white imagery
1	0.450 – 0.515	Blue
2	0.52 5– 0.605	Green
3	0.630 – 0.690	Red
4	0.775 – 0.900	Near IR
5	1.550 – 1.750	Mid IR
6	10.40 – 12.50	Thermal IR
7	2.090 – 2.350	Mid IR

Table 5: Landsat TM spectral bands (Williams, S, & T, 2006)

Band	Wavelength µm	Nominal spectral location
1	0.45 – 0.52	Blue
2	0.52 – 0.60	Green
3	0.63 – 0.69	Red
4	0.76 – 0.90	Near IR
5	1.55 – 1.75	Mid IR
6	10.4 – 12.5	Thermal IR
7	2.08 – 2.35	Mid IR

Genocide

The word genocide is derived from the combination of the Greek word *geno*-(race or tribe) and the Latin word *–cine* (killing). (United States Holocaust Memorial Museum, 2010)

According to the article 2 of the Human Right convention of 1948, the word genocide refers to any of the following acts committed with intent to destroy, in whole or in part, a national, ethnical, racial or religious group, as such:

- Killing members of the groups
- Causing serious bodily or mental harm to the members of the group;

- Deliberately inflicting on the group conditions of life calculated to bring about its physical destruction in whole or in part;
- Imposing measures intended to prevent birth within the group;
- Forcibly transferring children of the group to another group

In the Rwandan case, the above acts have been committed in 1994 against Tutsi ethnic group. Started long ago, the International commission of investigation on human Rights violation in Rwanda from 1990 to 1993 reported that massacre of Bahima in 1990, Bagogwe in 1991 and Tutsi in 1992 were acts of genocide. The situation culminated in 1994 when more than 800,000 people were killed in less than 3 month. The Tutsi genocide was then recognised by the UN (United States Holocaust Memorial Museum, 2010).

Remote sensing and the study of war and conflict

Academic study on war and conflict that examines remote sensing data is still limited (Witmer & O'Loughlin, 2009). Remote sensing has played an important role in the military field since 1960, it was used in providing information concerning enemy missiles, troop deployments, and military positioning (Corson & Palka, 2004).

The use of satellite data came to public attention during the 1991 Gulf war in Iraq and Kuwait due to the increased interest in the war's environmental consequences (Witmer & O'Loughlin, 2009). Interest to other conflicts has focused on vegetation changes caused by military actions. The use of herbicides by the United States during the Vietnam war reduced the total mangrove area by one third in South Vietnam (Witmer & O'Loughlin, 2009).

Remote sensing has played also an important role in monitoring nuclear weapons testing based on Landsat data to decide whether nuclear test are imminent using different criteria such as: roads construction, tunnels and land disturbances, as well as change in the earth surface structure due to detonation (Hall, 2010).

Using remote sensing, it was possible to track the genocide in Darfur, where the findings showed an increasing return of natural vegetation which was not a result of increased rainfall but of the abrupt change in land use directly related to the systematic violence committed by Sudanese government and militia forces against people of Darfur. As an agricultural based society, the noticed vegetation rebound resulted from the loss of livestock and the inability to farm, caused by human displacement and the destruction of subsistence resources from 2003 to 2007 (Schimmer R., 2008).

The above examples showed that remote sensing can be used effectively in the study of social sciences in general, as well as war and conflict in particular. As proved by Liverman, et al. (1998), there can be two way interaction between remote sensing and social sciences, where remote sensing can help social science in:

- Measuring the context of social phenomena;

- Measuring social phenomena and their effects;
- Providing additional measures for social sciences;
- Providing time-series data on socially relevant phenomena

The other way around, social sciences can help remote sensing in:

- Validation and interpretation of remote observation;
- Data confidentiality and public use;

The interaction of remote sensing and social sciences can finally improve understanding of human-environment interaction (Liverman, et al., 1998).

MATERIAL AND METHODS

Data acquisition

The satellite images from Landsat TM and ETM+ sensor (table 6)were acquired freely from the USGS, U.S Geological Survey interface. The USGS undertake scientific research, monitoring, remote sensing, synthesis, and forecasting to address the effect of climate and land use change on the Nations resources.

Table 6: The satellite images

Satellite images	Acquisition date	WRS path	WRS row	Coordinate System and projection
Landsat TM	1987-01-27	173	62	UTM-35 WGS84
Landsat TM	1995-01-17	173	62	UTM-35 WGS84
Landsat ETM+	2003-01-31	173	62	UTM-35 WGS84

For all the scenes used, there were no sensor anomalies and the quality of the entire bands scenes was excellent (9 which is the highest).

NDVI were analysed based on satellite imagery:

- spectral data resolution,
- spatial data resolution and
- temporal data resolution.

The figure 3 below is the satellite imagery data analysis approach and processing flow diagram as well as socio-economic and rainfall analysis flow diagram.

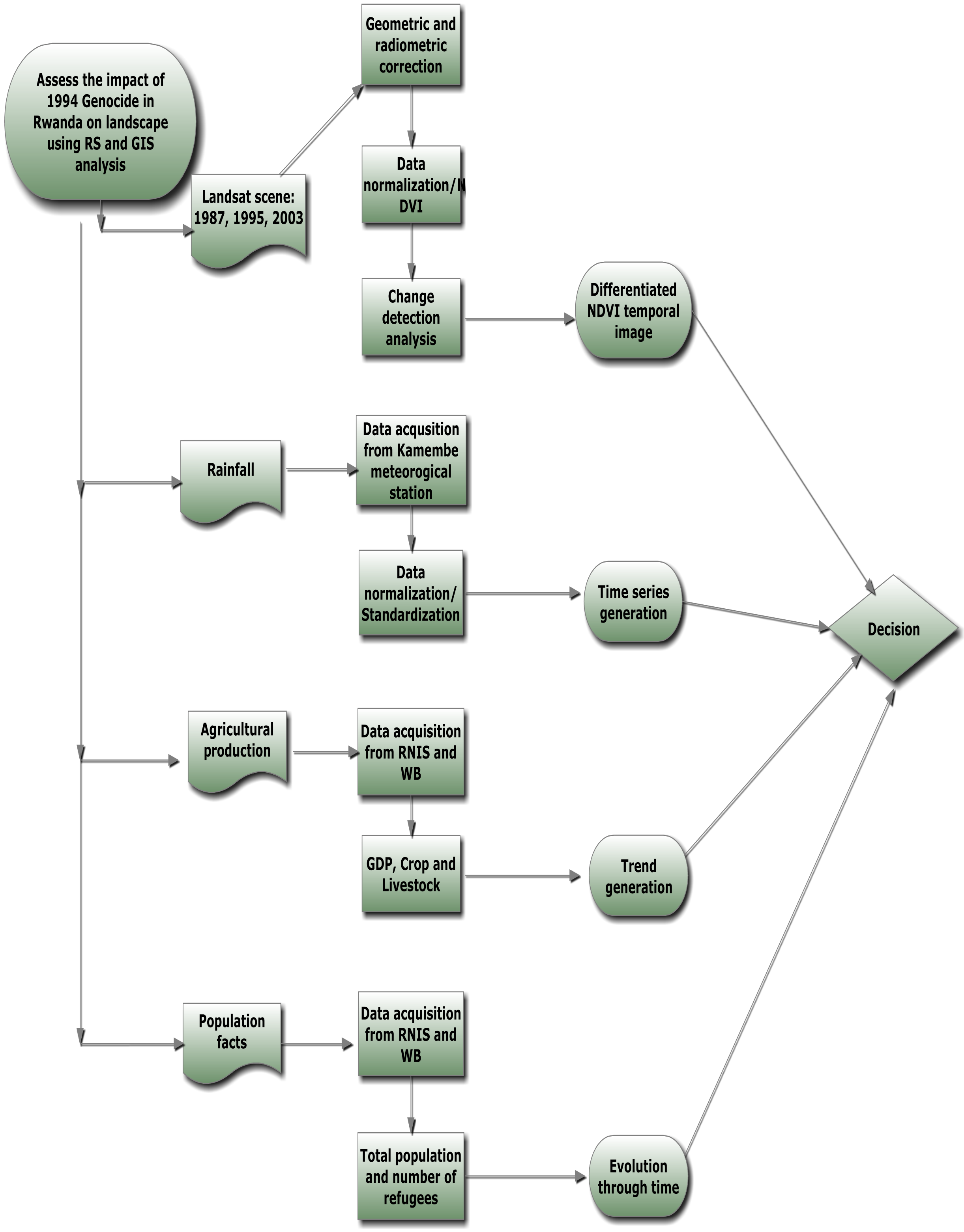

Figure 3: Flow chart diagram

Geometric and radiometric correction

All the images were acquired already geometrically and radiometrically calibrated from the ground stations. But for the purpose of the research, image restoration (registration) was performed to reduce distortion. As the table 5 shows, the main problem with the used image for this study is that the date and time of the day of acquisition are not the same; moreover, two images have the same sensor (TM) while the other is different (ETM+). The acquired images were given the same reference parameters and pixel resolution.

To register the images, the following steps are used (Zitová & Flusser, 2003):

- Feature detection, where distinctive objects are detected from the sensed image, together with the reference image and used as control point.
- Feature matching, where correspondence between feature detected in the sensed image and those detected in the reference image are established;
- Transform model estimation, to estimate the accuracy of the used control points, to assess if they really match;
- Then, band 3 and 4 are resampled and transformed. This is done by performing an affine transformation for the geometric restoration.

Since images were already registered, the only task performed was extracting the region of study and defining the same reference parameters and pixel resolution.

A full radiometric correction was done, mainly because of the chosen change detection method for the study, the temporal image differencing approach (see section 2.2.5). For the result to be meaningful, it is desirable to correct for illumination and atmospheric effects and transform the image data into quantities such as radiances or reflectance.

Since illumination and atmospheric effects were already corrected from the ground station, only spectral radiances and reflectance were computed.

For this study, conversion from absolutely calibrated DN to spectral radiance was accomplished and at satellite reflectance computed to get spectral signature that is as close as possible to the original ground ones.

First spectral radiance was computed for image scene band 3 and 4 for the different study period, 1987, 1995 and 2003. It was accomplished through the following equation (Glenn, et al, 2008)

$$\mathrm{Li} = \mathrm{Lmin} + \left(\frac{\mathrm{Lmax} - \mathrm{Lmin}}{\mathrm{DN\ max}}\right) \times \mathrm{DN}$$

Where

Li = Spectral radiance (mW/cm2 sr µm) (i=band)

Lmin = Minimum spectral radiance (mW/cm2 sr µm)

Lmax = Maximum spectral radiance (mW/cm2 sr µm)

DN = Absolute calibrated digital numbers on CCT

DNmax = Maximum digital numbers

Lmin and Lmax were taken from metadata of the images.

From there, at satellite reflectance was computed through the following equation:

$$pp\lambda = \frac{(P \times Li \times d^2)}{(Esun \times \cos(\theta))}$$

Where

ppλ = Unitless effective at-satellite reflectance

Li = Spectral radiance (mW/cm2 sr µm) from equation 1

d = Earth-sun distance in astronomical units

Esun = Mean solar exoatmospheric spectral irradiance in mW/cm2 sr µm

Θ = Solar zenith angle → ($\frac{pi}{2}$) - (sun elevation angle in radians which was delivered with image metadata)

Below are the tables where Esun was derived from:

Table 7: Used measures to compute at-satellite reflectance for Landsat ETM+2003 (derived from image metadata and Gyanesh, et al, 2009)

Band	Band width	Lmin	Lmax	ESUN	d	Θ
3	0.631-0.692	-5.0	152.9	1533	1.792	0.628
4	0.772-0.898	-5.1	241.1	1039	1.792	0.628

Table 8: Used measures to compute at-satellite reflectance for Landsat TM5, 1987 and 1995 (derived from image metadata and (Gyanesh, et al, 2009).

Band	**Band width**	**Lmin**	**Lmax**	**ESUN**	**d**	**Θ**
3	0.626-0.693	-1.17	264	1536	0.746(1995)	0.773(1995)
					1.560(1987	0.742(1987)
4	0.776-0904	-1.51	221	1031	0.746(1995)	0.773(1987)
					1.560(1987)	0.742(1995)

Earth sun distance in astronomical units was generated from SSD interface. (NASA, 2010). It is a web based interface to JPL's Horizons system which can be used to generate ephemerides for solar-system bodies.

JPL's Horizons system provide access to key solar system data and flexible production of highly accurate ephemerides for solar system objects (NASA, 2010). Ephemerides are tables of values that gives the positions of astronomical objects in the sky at a given time. Within those table, Earth sun distance in astronomical units can be found under the subtitle delta in the results table.

Data normalization

In this section a multi-image manipulation was performed through the vegetation component to get the vegetation indices NDVI which helped for change detection analysis.

The computation was based on Red and NIR (Near Infrared) bands, respectively band 3 and band 4, as explained in the table 3.

Change detection and NDVI temporal image differencing

For the purpose of analysis and the results to be meaningful, the original NDVI values were reclassified into 5 classes using standard deviation. From the results, the normal range with value between -1 to 1, were given new values range from 1 to 5 where 1 represents areas with the lowest NDVI and 5 areas with the highest NDVI. It was done for data treatment in Arcmap after exporting NDVI results from Idrisi to Arcmap.

The reclassification was performed as the exported image in Arcmap needed to be interpolated to reduce clouds, and to do so, the image was converted from raster to polygon, where clouds were removed as most of them were located into class 2 and 3. So, those classes were removed to only remain with class 1 (representing the water), 4 and 5 (representing high NDVI). The resulting polygon was converted to point, and then the Krigging interpolation was performed to fill the generated gap and the missing values (appendix E for accuracy assessment). Finally, the resulting NDVI images were reclassified based on 1987 values, to compare the evolution throughout the time. The performed interpolation brought uncertainty as it affected the quality of the results.

From there, temporal image differencing approach was used. Generated NDVI values of the three different periods, 1987, 1995 and 2003 were utilized by subtracting values from one date from those of the other.

A meaningful change-no-change threshold trend (see section 2.2.5) used comes from generated histogram based on standard deviation. Area that resides within the tails of the distribution represents the region of change while areas close to the mean are region of no change.

The degree of skewness was considered to know if the vegetation increased or decreased by falling at the negative side of the tails of distribution, between -2 and -1 for the negative skewness or 1 and 2 for the positive skewness.

For the region of change, the resulted negative values meant that the vegetation decreased for that period and when the values were positive it meant that the vegetation increased.

Integrating socio-spatial analysis to the landscape change

This part intends to integrate socio-economic and environmental analysis to noticed landscape change. Socio-economic and environmental analysis was performed based on deductive approach (Steinberg & Steinberg, 2006). The main objective of this approach is to show the current state of the things, to explore data and to explain why things are the way they are. With this type of research, the researcher begins by reviewing the literature, generating a conceptual framework, developing a hypothesis, and then testing the hypothesis by gathering data (Steinberg & Steinberg, 2006).

For this specific research, it was done through the analysis of rainfall, population facts and agricultural production.

The Rwandan traditional way of life is mainly based on agricultural activities. Based on Schimmer, R. (2010) findings and the ground reality of Rusizi population, the following assumption has been made:

- Change in natural vegetation is based on fluctuation in rainfall as well as land use.
- Mainly, the land in Rusizi is used for farming and livestock grazing.
- Farming and livestock grazing reduce NDVI vegetation vigour, regardless water availability.
- Reduction in farming and livestock grazing will stimulate a rebound in natural vegetation vigour.

The human displacement and the rate of killings will have an impact on agricultural production and livestock, which in turn will affect the land cover.

Rainfall

Rainfall time series were generated using excel spreadsheet from the data acquired at Kamembe airport meteorological station which is the main city of the region of study (Rusizi-Cyangugu). The details can be found in appendice B. It is important to mention that rainfall data of 1994, 1995 and 1996 were missing. This is due to the fact that the station was not in function during that time because of the damage resulted from the 1994 war. To get 1995 rainfall, data for 2 years before and 2 years later, 1993 and 1997 were averaged.

For the results to be meaningful, 3 month before the study period of January for each year of concern were considered. That period include the short rainy season, from October to mid December and the short dry season from mid-December to January (Minagri, 2004). Therefore, the months of October, November, December of the previous year and January of the year of study were considered. Below is the table 9, showing the used months:

Table 9: Used months for rainfall

Study period	**Previous year**	**Year of study**
1987	October, November, December of 1986	January 1987
1995	Average October November, December, 1993 and 1997	January 1994 and 1998
2003	October, November, December of 2002	January 2003

Population

Population data were acquired through the National Institute of Statistics of Rwanda and World Bank. Graphs and time series were generated with excel spreadsheets. The generated results were coupled by previous study result performed by the ministry of agriculture of Rwanda and animal resources.

The analysis was based on increase and decrease of the number of the total population and the total number of refugees as well.

Agricultural production

To assess agricultural production, GDP growth rate, crop, and livestock production were taken into account. The used data were acquired through the National Institute of Statistics of Rwanda and World Bank. The indices used for crop, and livestock are the ones used by the World Bank to calculate the trend relative to the base period of 1999-2001 production which equals to 100.

GIS software (ArcMap and Idrisi)

IDRISI package was used to extract, treat and analyse satellite scenes as well as NDVI data. For analysis and socio-spatial data, Arcmap was used to generate map illustrating different scenarios explaining the reason behind noticed land cover change and Excel was used to create graphs and time series of socio-economic and environmental data.

IMAGE PROCESSING RESULTS

NDVI

The values of NDVI vary from 1 to 5, 4 and 5 representing regions with high NDVI. The regions with less value are represented in red. It represents water and clouds. The regions with high vegetation vigour are represented in dark green.

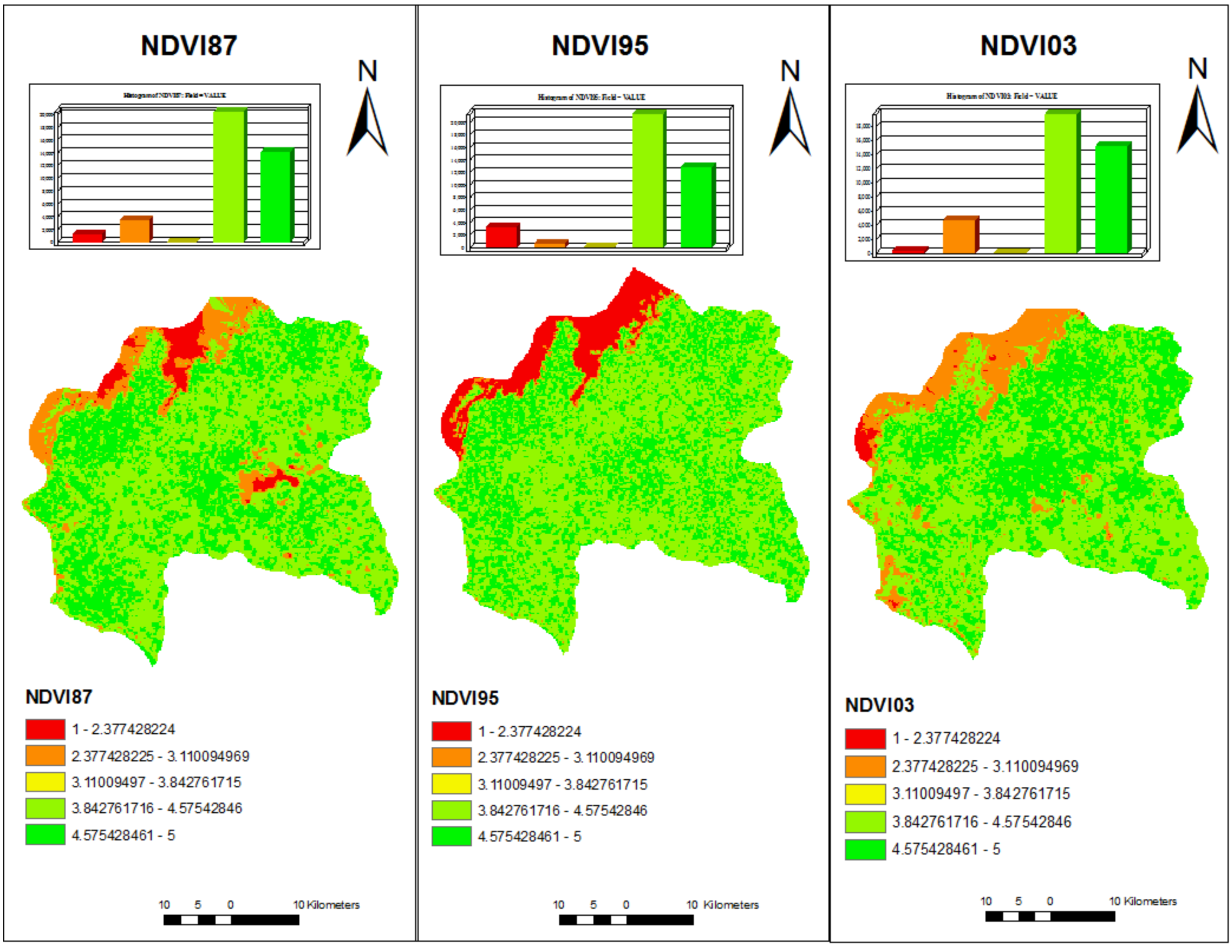

Figure 4: NDIV of 1987, 1995 and 2003

The areas represented in dark green by figure 4 occupy a bigger part for the year of 1987 and 2003 compare to 1995. Therefore, the two years have higher NDVI, meaning that the vegetation decreased from 1987 to 1995 and increased in 2003. But for 1987 and 2003, it is hard to get the difference.

Change detection, change no change threshold

The histogram of NDVI differenced image was obtained by subtracting NDVI 1987, and 1995 based on their corresponding standard deviation shows that the regions close to the mean are the regions of no change while the regions of change deviate from the mean, either negatively or positively. When it is positive, the years of subtraction have more vegetation over the same area and the same way has less vegetation when it is negative from the mean.

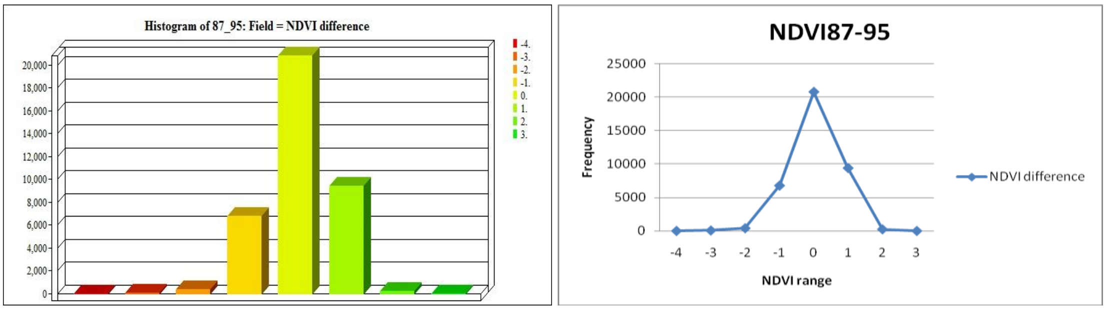

Figure 5: Histogram of NDVI differenced image of 1987 and 1995. Skewness = 1.741

Apart from the yellow bar in the middle representing values of no change (figure 5), the year of 1987 have higher NDVI as more values are represented by the second bar on the right in green and it is evident from the figure 5 that NDVI of 1995 is less or decreased with more values on the left of the yellow band. That is the reason why the distribution on the right figure is highly skewed on the left and most of the distribution is at the right tail of the distribution

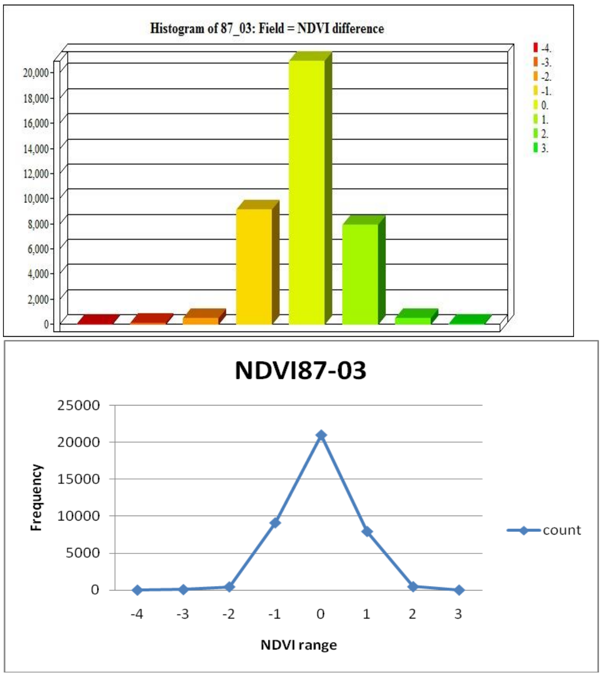

Figure 6: Histogram of NDVI differenced image of 1987 and 2003. Skewness = 1.170

The year of 1987 and 2003 (figure 6) seems to be normally distributed and it is hard to get the difference. Nevertheless, 2003 have a bit higher NDVI than 1987. As the figure 6 on right show, the distribution is highly skewed on the right, which means that most of the data are distributed on the left tail. It shows that the vegetation increased from 1987 to 2003.

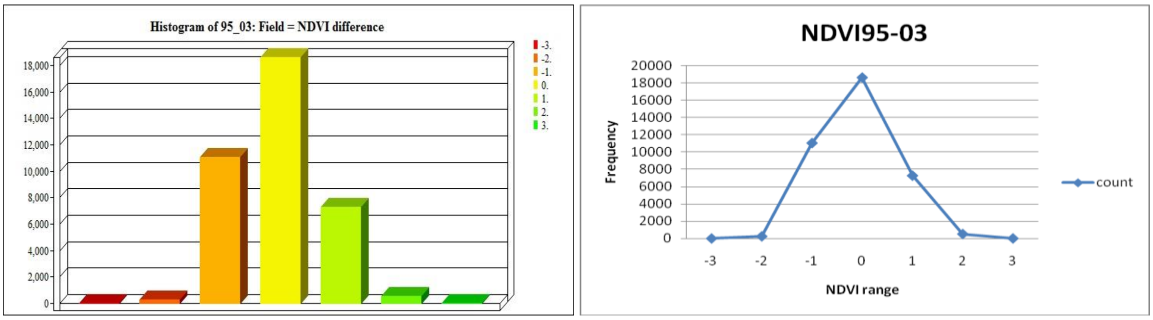

Figure 7: Histogram of NDVI differenced image of 1995 and 2003. Skewness = 1.684

The above figure 7 shows that the NDVI of 1995 is lower than the one of 2003 as many values are represented on the first left bar, the same way, the distribution is highly skewed on the right, meaning that more data are on the left side of the tail of distribution, therefore the population decreased from 1995 to 2003.

To summarise, 1995 NDVI is lower than 1987 and 2003 as proved by the mean values presented in the table 10, generated from original NDVI values (for details, appendix d).

Table 10: NDVI difference between 1987, 1995 and 2003

Years	Mean	Std	N
1987	0. 537	0.244	3639564
1995	0. 519	0. 256	3639564
2003	0.539	0.265	3639564

To assess if the results are statistically significant, two sample t-test was performed and the results presented in the table 11 below:

Table 11: t-test

Years	Hypothesis	Rejection criteria	t- statistic	Decision
1987-1995	Ho: x87 = x95	df: 7279126	97.09	t > α
	Ha: x87 ≠ x95	α: 0.05→1.960		Ho rejected
1995-2003	Ho: x95 = x03	df: 7279126	-103.55	t < α
	Ha: x95 ≠ x03	α: 0.05→1.960		Ho rejected
1987-2003	Ho: x87 = x03	df: 7279126	-10.59	t > α
	Ha: x87 ≠ x03	α: 0.05→1.960		Ho rejected

To conclude, the above results rejected the null hypothesis, there is statistically significant difference between the means of 1987, 1995 and 2003 NDVIs. It can be confirmed with

95% degree of confidence that the noticed difference is not a result of chance (For details, refer to the appendix F).

NDVI differenced image result

The following figure 8 represents NDVI differenced images, where area range is from -4 to 3. Region that are close to 0, which is the mean represents area of no change, while region that extend from zero positively represents area with more vegetation and those extend from zero negatively area with less vegetation.

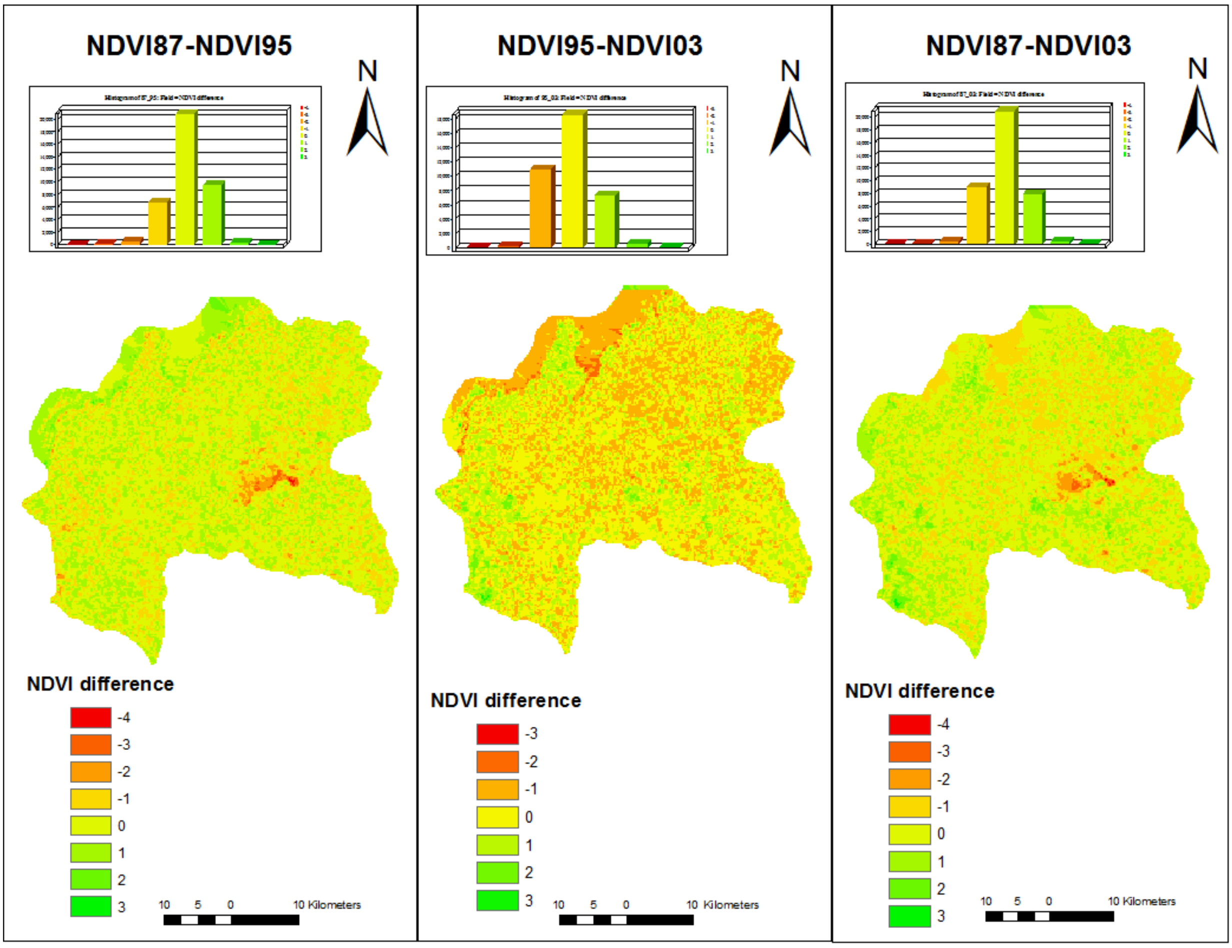

Figure 8: Differenced NDVI of 1987, 1995 and 2003.

The areas in yellow (figure 8) are areas of no change, red represents lost of vegetation and green more vegetation.

Many parts are in green for NDVI differenced image of 1987-1995. This is an indication that 1987 was greener than 1995, therefore, the vegetation was intense in 1987 and it decreased in 1995.

From 1995 to 2003, most of the areas are represented in red, meaning that 1995 lost vegetation over those areas in red. It indicates that 1995 had less vegetation than 2003.

But if we look at the difference between 1987 and 2003, the region is characterised by mixed colours between red and green, red being a bit more pronounced.

Rainfall

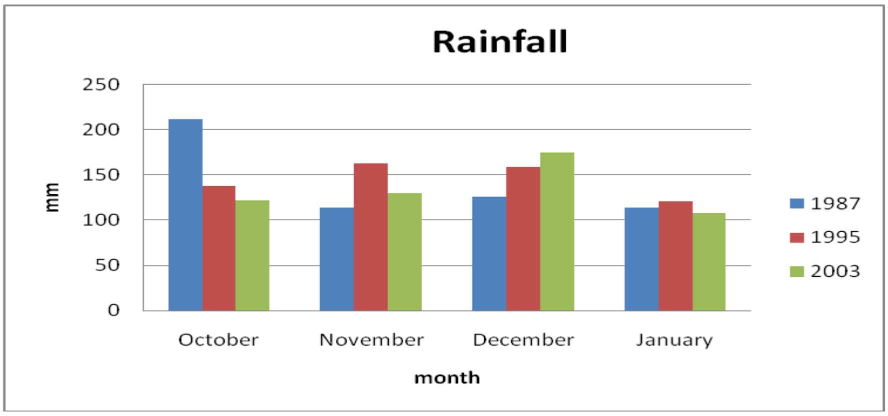

Figure 9: Rainfall of 1987, 1995 and 2003

As the figure 9 shows, the rainfall of 1987, 1995 and 2003 did not change much. It was characterised by fluctuations, where in one month the rainfall was higher in one year, to be the lowest in the other. If we look at October, the rainfall was higher in 1987, while it was lower in November.

Table 11: Average rainfall for 1987, 1995 and 2003

Rainfall	1986/1987	1994/1995	2002/2003
October	211.6	137.9	122.3
November	114	163.25	129.9
December	125.6	158.7	175.3
January	113.9	120.75	107.6
Average	141.275	145.15	133.775

The table 11 shows that the average rainfall didn't change much; nevertheless, 1995 was slightly wetter than 1987 and 2003.

Population

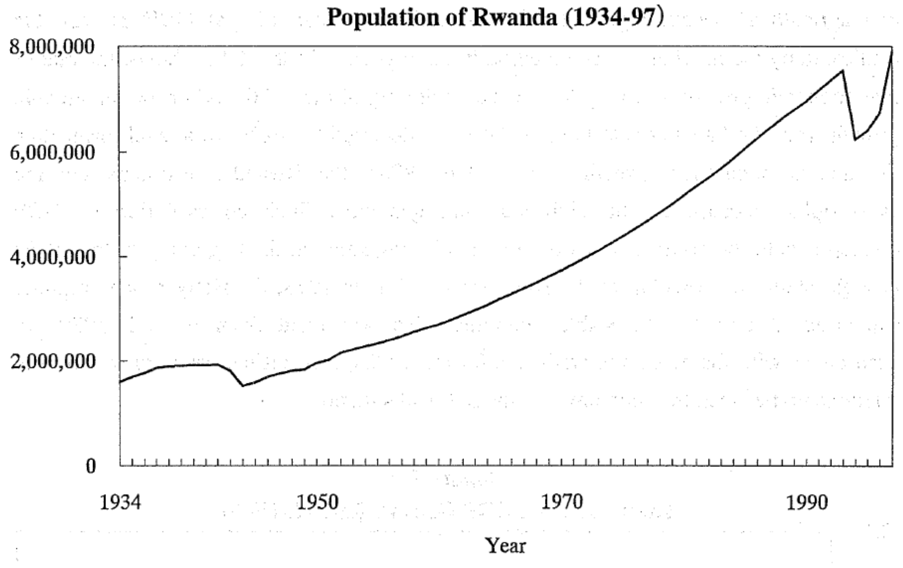

Figure 10: Population of Rwanda from 1934 to 1997 (Office National de la Population, 1997)

The figure 10 illustrates the evolution of the population of Rwanda since 1934 to 1997. It has increased throughout the whole period except for the period from 1940 to 1945 and from 1990 to 1995. Those periods of decrease represent the Second World War and the war between RPF and the Rwandan government respectively.

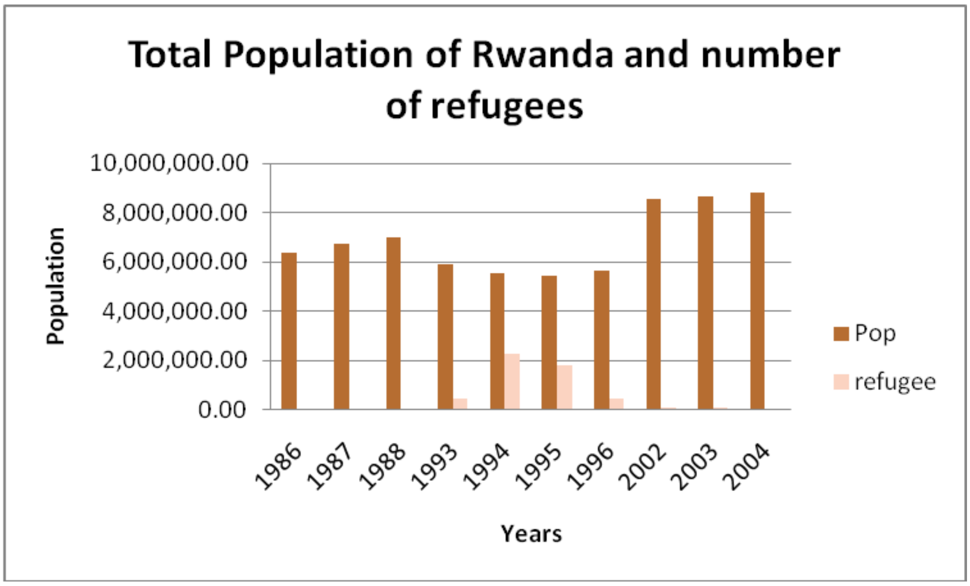

Figure 11: Total population of Rwanda and the number of refugees from 1986 to 2004

The figure 11 represents years covering the period of study, starting from one year before 1987 and one year after 2003. It was divided into three periods:

- Period of peace from 1986 to 1988;
- Period of war and genocide from 1993 to 1996; and

- Period of recovery and stability from 2002 to 2004.

For all those periods, the figure includes the number of total population and the number of refugees. The population increased from 1986 to 1988 and there were no refugees during that period of peace.

From 1993 to 1996, the population number decreased, but a small increase is noticed in 1996. The number of refugees follows the opposite trend, where it increased in 1993 to reach the top in 1994 and decreased in 1995 and 1996.

The last period from 2002 to 2004, the population increased.

Agricultural production

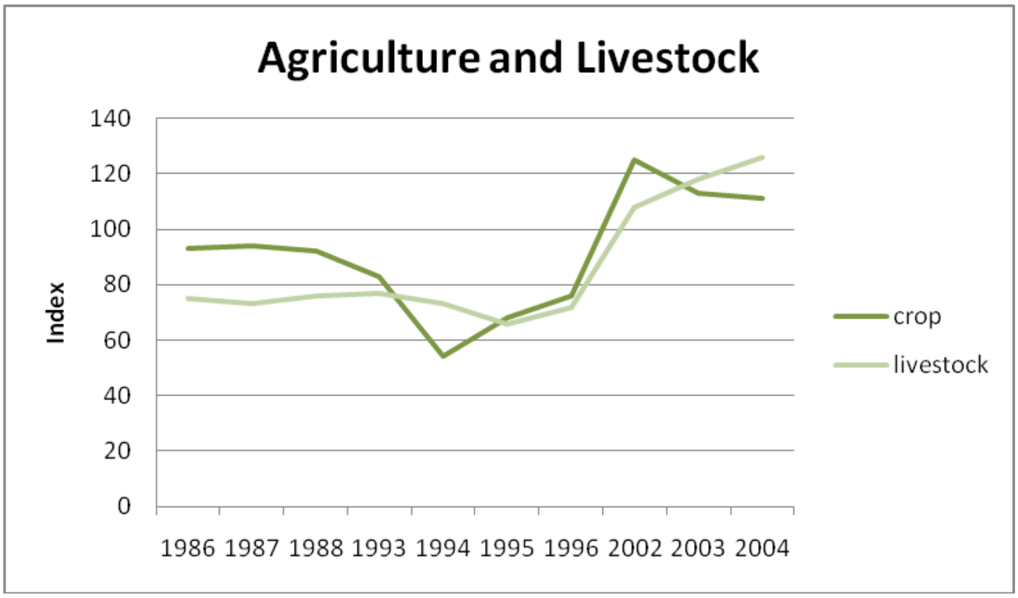

Figure 12: Agriculture and livestock

The figure 12 shows the evolution of agricultural production and livestock. It is divided into the three periods, used in section 4.5. Crop, and livestock were analysed to illustrate the evolution.

For the period of peace from 1987 to 1988, the trend was the same, the production didn't increase or decrease much for both.

From 1993, both decreased to reach to bottom in 1994, where crops decreased the most. In 1995, crop increased, but livestock decreased.

During the period of stability, all the items increased, and the same way, the change from 2002 was not high. It decreased slighlty from 2002 to 2003 and from 2003 to 2004 it stabilise, but the increase in livestock was continuous since 1996 up to 2004.

To summarize the above and give a general picture of the socio-economic situation, GDP growth rate was analysed.

The GDP growth rate situation illustrates quite well the agriculture situation of Rwanda as agricultural production constitutes the main contributor (figure 13). It has also an advantage of giving a general picture of the political situation of the country in question as it take into consideration other facts such as population, generated production of all the sectors of economy such as service, industry and mining (Office National de la Population, 1997) (Minagri, 2010).

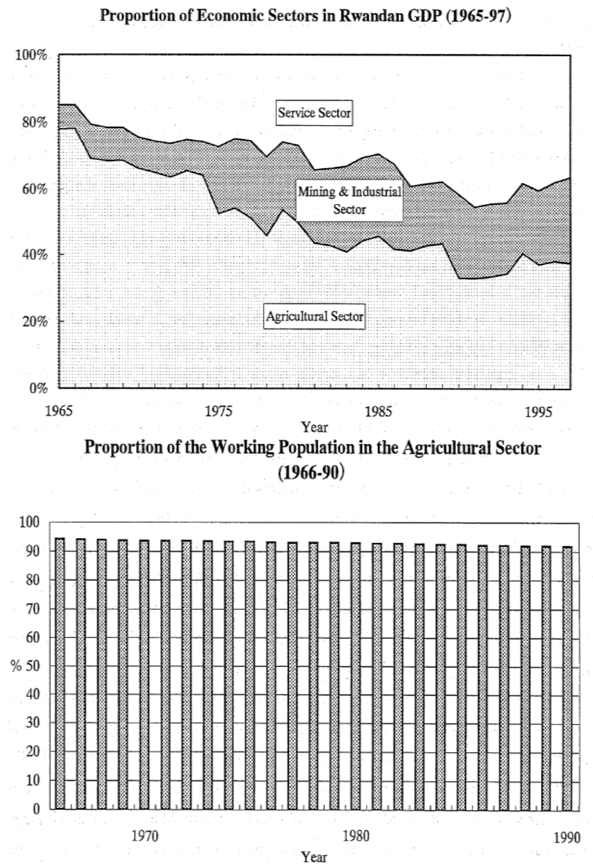

Figure 13: Population working in agricultural sector and its contribution to GDP (Minagri, 2004)

As proven by the figure 14 below, the GDP growth rate has fluctuated continuously from 1967 to 1996, where it was higher for periods before 1970 and between 1975 and 1983. Regardless any situation, it had never gone down below zero, except for the period from 1989 to 1995, where it reached the bottom in 1993 and 1994.

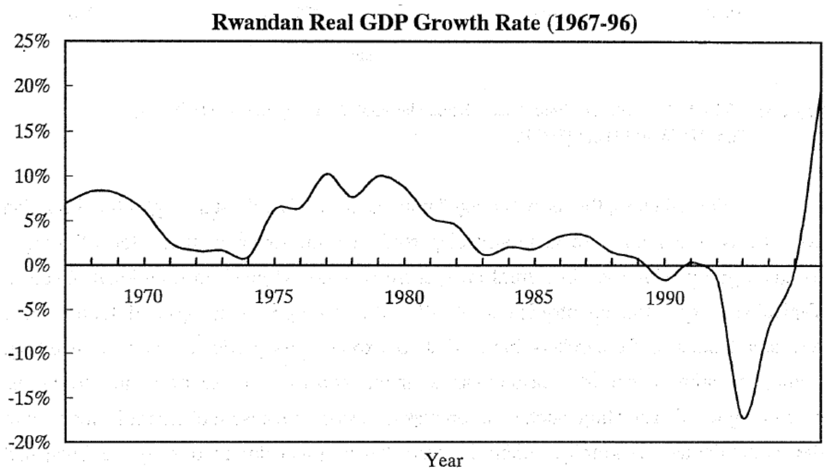

Figure 14: Rwandan GDP growth rate from 1967 to 1996 (Minagri, 2004)

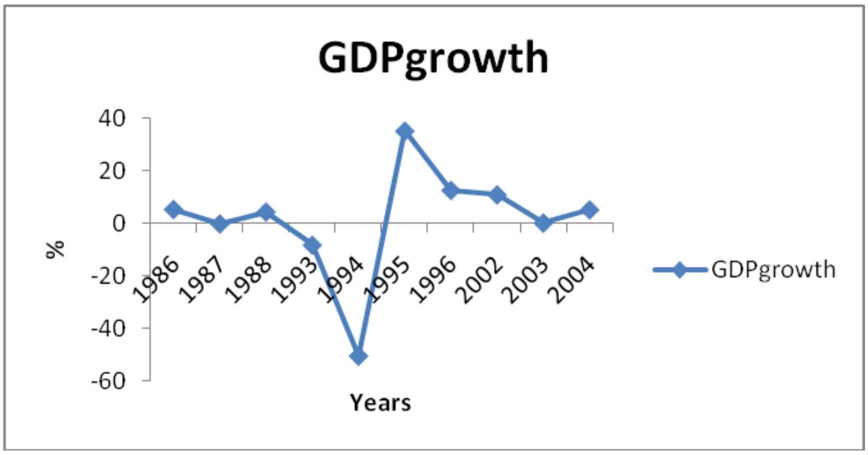

Figure 15: GDP growth for the study periods

During the period of peace, figure 15, the GDP was almost the same for 1986 and 1988, while it was lower in 1987, around zero. It decreased during the period of war and genocide in 1993 and 1994, where it was at the bottom. In 1995, it increased dramatically, to go down in 1996. During the period of stability it was at the level of 1996 in 2002, decreased in 2003, to recover in 2004.

RESULT AND DISCUSSION

To assess the reason behind the noticed NDVI vegetation change as showed in table 12, rainfall was analysed as natural cause indicator, population and refugee’s number, agricultural production and GDP as 1994 genocide related events indicator.

Table 12: NDVI mean values, rainfall, population, refugees, GDP, crop and livestock mean values

Years	NDVI	Rainfall	Population	Refugees	GDP	Crop	Livestock
1987	0.537	113.9	6,709,010	0	3.31	93	74.66
1995	0.519	120.75	5,641,466	1,249,134	-2.59	70.25	72
2003	0.539	107.6	8,681,280	71,274	5.53	116.33	117.33

NDVI and rainfall

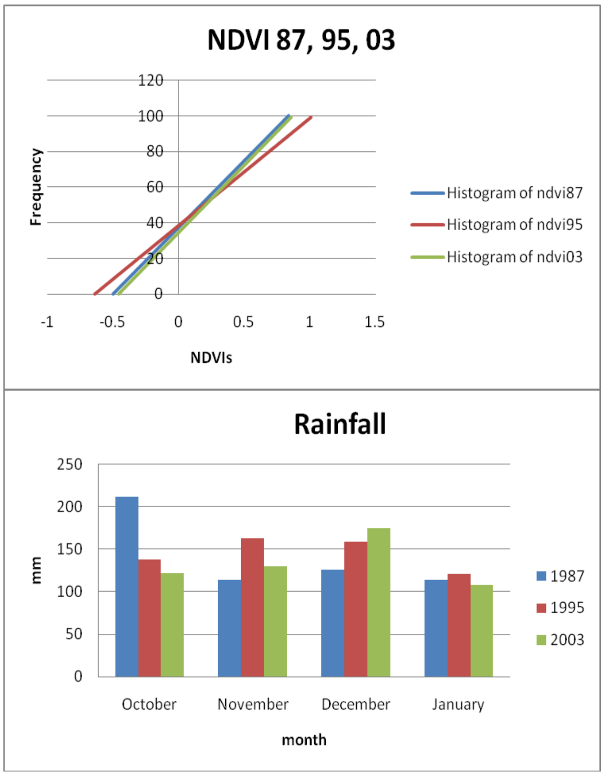

Figure 16: NDVI and rainfall fluctuation

The figure 16 shows a decrease in NDVI from 1987 to 1995, and an increase from 1995 to 2003. By comparing to the rainfall trend, the pattern is different. The year of 1987 has higher rainfall for the month of October, to be the lowest from December to January. While the rainfall trend of 1995 is on avarage between 1987 and 2003, except for

November. The same situation is valid for 2003 where it is the lowest in October to top for the month of December.

It is good to mention that those months represent the short rain season (National agricultural policy, 2004), except the last half of December and the month of January which constitute the short dry season.

From the above, it is obvious that the rainfall is not directly related to the change in NDVI as it fluctuates for the period in question. In case, the NDVI was only driven by rainfall, it will not have the noticed pattern; instead it should have been more or less the same. Based on this, the natural cause did not influence NDVI change.

NDVI and agricultural production

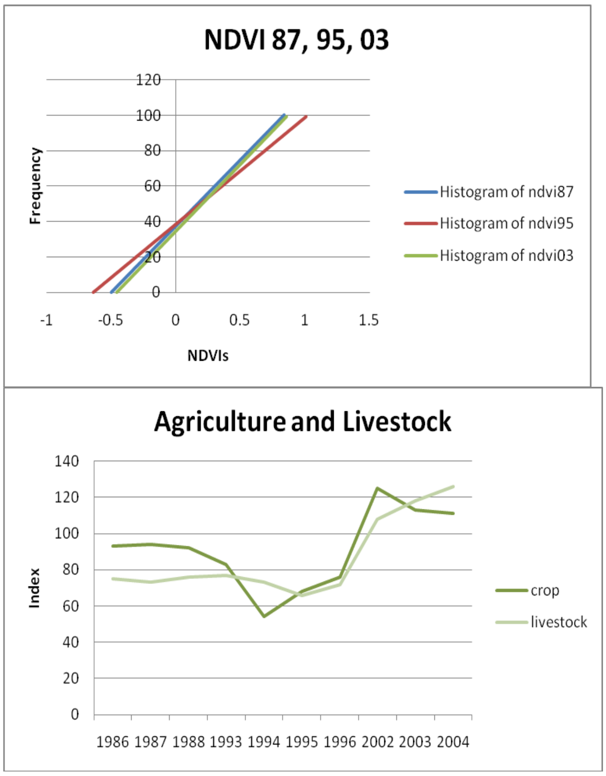

Figure 17: NDVI 87, 95, 03 versus agriculture and livestock

For the period of peace, from 1986 to 1988 (figure 17), crop production and livestock were constant, around 80 and 100 respectively. It drop from 1993 to 1994 and increased in 1995 and 1996, but still lower than the production of the period of peace. During the period of recovery and stabilasation, crop and livestock increased even more to reach and surpass the level of 1987.

This should have a positive impact on NDVI since we know that agriculture and livestock reduces the vegetation (Section 3.6, based on Schimmer, R. 2010). Meaning that during the period of war, between 1993 and 1996, the NDVI should have been higher, and lower during the peace period from 1986 to 1988, to be the lowest for the recovery period from 2002 to 2004.

Therefore, the reason of NDVI change for the mentioned periods is not the agriculture production nor livestock.

NDVI and population

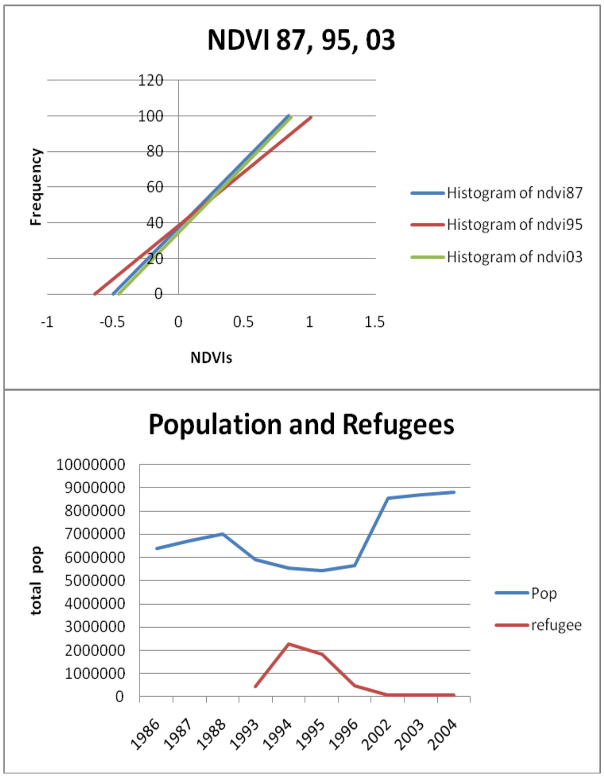

Figure 18: NDVI 87, 95, 03 versus population and refugees

As the above figure 18 shows, the number of population decreased during the war period, 1993 to 1996. The period before and after the war the number of population was higher, where it was at the top from 2002 to 2004.

Compared to NDVI, both periods, before and after the 1994 genocide, the NDVI was higher than 1995. Based on the fact that when the number of population is big, the landscape exploitation is more intense, then the NDVI should have been lower in 1987 and 2003, and higher for 1995, where the population number was lower. Therefore the total number of population did not affect the change in NDVI.

If, we go deeper in the details of population, by looking at the number of refugees, it comes up that there were no refugees before 1993 and the number increased dramatically, to reach the top in 1994 with more than 2 million refugees (De La Pradelle, 2005). It decreases, up to 0 from 2002 to 2004.

It is interesting to mention that Cyangugu (Currently Rusizi) is located at the border of RDC, and was under French control during humanitarian and military operation called 'Operation Turquoise' (De La Pradelle, 2005). Millions of people were hosted in Cyangugu, as they were under the influence of the genocidal government which took them as human shield (Taylor, 1999).

This should be the reason of the change in NDVI as it follows the same trend. Based on the huge number of population hosted by the region, more than one million, it changed a lot of things, and land use is among them.

Even if the total number of population dropped during that time, the number of population increased in Cyangugu, due to two different facts, the location of Cyangugu at the border of RDC and the situation created by the genocide events, which made it one of the place within the protected zone by French soldiers under Operation Turquoise.

Source of errors

In summary, the results give a general picture of what happened, and how remote sensing can be applied in the study of conflict. However, it has to be acknowledged that some of the parameters used are subject to uncertainty. The removal of clouds by interpolation affected the results, as well as the lack of sufficient data over the region of study. It concerns the GDP, population number and agricultural production which are mainly those of the entire country, but during the time of the facts, the situation was similar in general, the number of population decreased and all the production system was not functioning for all the period of genocide. Therefore, there is a certain confidence that the presented results give a good picture of the situation over the study area, though limited.

It is in that sense that this study can serve as basis for further advanced studies, such as comparing the region of study with another region which didn't host refugees, the impact on different type of vegetation, and many more.

CONCLUSIONS AND RECOMMENDATIONS

The study investigated the impact of 1994 Tutsi Genocide in Rwanda on environment with focus on NDVI as a tool to assess vegetation change in Cyangugu prefecture. Using remote sensing and GIS analysis, the study assessed evidence of the change in vegetation before, during and after 1994 and the reason behind the change, either a result of natural phenomenon or 1994 Genocide events based on rainfall, population and agriculture.

Key findings

From Landsat TM and ETM+ imagery data, the NDVI change has been noticed over the study period:

- NDVI decreased from 1987 to 1995, and increased from 1995 to 2003. In 2003, the NDVI was the highest, followed by 1987, and 1995 NDVI was the lowest.

- The rainfall fluctuation proved to be different with the NDVI trend.

- Agricultural production and livestock showed that 1995 production was the lowest and 2003 the highest.

- The total number of Rwandan population was higher in 2003 and lower in 1995. Therefore, NDVI was not influenced by the total number if we look Rwanda as a whole.

- The number of refugees increased a lot in 1995; it was more than one million in Cyangugu, the region of study. It hosted that huge number, making it an exception in Rwanda, where, instead of having a decrease in population number, it witnessed an incredible increase, which resulted in an extensive use of land, and vegetation as well. This situation impacted the landscape, and is the main reason of the noticed change in NDVI, which was at its lowest in 1995.

Future development

The use Remote Sensing proved that it is possible to assess the impact of war or a conflict. Though the study picked out the vegetation by the use of NDVI, it only gives a general picture of what happened and how was the situation. With more means and enough time, it should give even much more interesting facts by looking at different types of vegetation.

Such way, the analysis will be object oriented by discriminating different types of vegetation such as forest, urban area, fields and looking at the vegetation change within those different classes. This will make it possible to be more objective and to link it with the genocidal events, as each land use type is related to the interaction of its population and the nature.

To conclude, this study showed that remote sensing and vegetation indices could be used as an indicator of changes in vegetation related to human activities such as the 1994 Tutsi Genocide in Rwanda.

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APPENDIX A

Landsat TM, ETM+ metadata

ACQUISITION_DATE	1/27/1987	1/17/1995	1/31/2003
WRS_PATH	173	173	173
STARTING_ROW	62	62	62
ENDING_ROW	62	62	62
BAND_COMBINATION	1234567	1234567	123456678
GROUP	MIN_MAX_RADIANCE	MIN_MAX_RADIANCE	MIN_MAX_RADIANCE
LMAX_BAND3	264	264	152.9
LMIN_BAND3	-1.17	-1.17	-5
LMAX_BAND4	221	221	241.1
LMIN_BAND4	-1.51	-1.51	-5.1
GROUP	MIN_MAX_PIXEL_VALUE	MIN_MAX_PIXEL_VALUE	MIN_MAX_PIXEL_VALUE
QCALMAX_BAND3	255	255	255
QCALMIN_BAND3	1	1	1
QCALMAX_BAND4	255	255	255
QCALMIN_BAND4	1	1	1
CLOUD COVER	20	0	14.75
SUN_AZIMUTH	114.5870482	117.1980038	116.1880488
SUN_ELEVATION	47.4235905	45.6509876	53.9770681
REFERENCE_DATUM	WGS84	WGS84	WGS84
REFERENCE_ELLIPSOID	WGS84	WGS84	WGS84
GRID_CELL_SIZE_THM	30	30	30
GRID_CELL_SIZE_REF	30	30	30
MAP_PROJECTION	UTM	UTM	UTM
ZONE_NUMBER	35	35	35

APPENDIX B

Rainfall data

ANNEE	JAN.	FEV.	MARS	AVRIL	MAI	JUIN	JUIL.	AOUT	SEPT.	OCT.	NOV.	DEC.
1958	55.9	117.1	204.4	135.8	131.3	20.1	1.7	116.8	86	113	185.7	139.8
1959	192	111.8	153.7	215.6	83.8	6.1	2.3	43.9	133.5	180.2	202.8	155.3
1960	108.8	206.6	263.6	167.6	105.9	4.5	0	28.1	87	198.9	170.9	87.9
1961	97.5	262.3	145.5	268.3	51.3	5.1	5.8	0.8	179.5	192.4	169.7	152.6
1962	80.6	112.8	179.2	226.4	170.5	56.2	3.6	55	120.3	206.2	148.1	181.8
1963	278.9	128.5	157.8	255.4	189.3	10.8	2.6	7.5	120.3	91.3	178.4	236.1
1964	141.4	158.6	102.5	177.8	110.9	19.4	1.6	54.3	33.9	170.4	195.1	104.4
1965	28	155	229	199.3	59.1	34.3	0.4	8.2	134.7	161.5	186	134.7
1966	170	200.4	169.1	184.4	83.6	12.6	0	51.6	116.1	152.5	96.1	160
1967	176.9	110.5	191.4	140.1	196.7	45.1	1.6	0.9	191.6	166.6	234.7	120
1968	115	151.2	157.4	110.3	88.8	40.9	2.3	0	82.2	237.7	219.2	167.2
1969	260.2	122.9	180.3	106.8	115.2	1.9	7.9	7.9	85.5	174.7	132	126.5
1970	139.8	172.7	200.3	190.8	82.3	12	50.8	74.6	54	82.1	179.8	126.2
1971	192	102.6	126.6	172.5	122.2	0.4	22.1	65.5	101.6	150.1	219.3	166.4
1972	103.3	145	165	93.6	105.1	79.5	0.2	43.6	183.1	197.4	189.7	210.4
1973	193.7	119.6	91.1	176.4	112.7	23.6	0.1	0.8	250.1	109.6	148.4	109.1
1974	98.4	81.9	140.2	114.7	112.7	52.1	55.7	6.5	73.6	134.6	239	84.6
1975	199.6	211.8	113.2	264.2	75	31.3	30.8	11.3	133.1	204.9	178.2	144.9
1976	81.7	125.8	147.6	292.5	79.1	40.6	0.3	79.2	145.6	148.8	142.6	162.8
1977	173.8	157.3	123.8	170.8	89.7	33.2	14.6	110.2	93.3	120	238.5	80.5
1978	91.3	97.3	253.4	124.2	87	44.9	1.2	113	117.2	175.6	238.5	167.3
1979	73.5	109.5	164	137.9	144.6	44.3	14.4	14.8	120.1	130.5	167.3	144.9
1980	129.5	75.2	165	110.3	177.5	40.1	3.7	2.4	133.2	171.9	204.8	175.8
1981	195.6	204.5	168.1	97.3	105.7	48	2.3	0	0	105.4	138.3	132.6
1982	179	101.6	108.1	159.9	86.1	44.1	0	34.9	148	236	224.2	113.2
1983	67.1	140.7	296.7	245.1	81.5	24.2	2.6	120.1	69.6	190.9	182.3	186.6
1984	139.3	159.5	179.3	189.7	19.6	0.4	33.1	52.9	62	112.3	254.9	127.8
1985	106	136.5	221.1	252.5	48.1	60.2	1.8	3.5	115.5	159.3	165.3	152.8
1986	121.1	129.5	215.6	232.8	63.3	20.3	0.2	0.8	94.1	211.6	114	125.6
1987	113.9	184.1	213.8	142.9	179	47.5	0.2	29.4	128.3	143.6	202	49.6
1988	124.3	215	218.1	177.9	91.4	23.3	15.7	121	149.4	162.7	168.2	94
1989	313.7	169.8	303.9	87.5	89.7	9.8	14.5	57.3	136.7	262.3	191.4	140.8
1990	150	221.7	208.1	137.4	81.8	8.5	0	41.4	159.6	148	155.1	105.8
1991	198.1	166.2	228.9	161.7	117.5	33.4	14.5	2	77.7	237	187.5	110.5
1991	198.1	166.2	228.9	161.7	117.5	33.4	14.5	2	77.7	237	187.5	110.5
1992	92.8	138.9	174.4	124.7	66.8	33.3	0	0	55.5	234	167.9	106.2
1993	173	123.6	108	196.3	176.7	20.8	0	38	108.2	92	132.7	180.3
1994	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1995	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9

1996	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1997	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	0.7	9	5.9	183.8	193.8	137.1
1998	68.5	99.6	192.9	151.8	68	42	-99.9	-99.9	176.7	102.6	113.3	-99.9
1999	107.7	64.3	191	126.4	36.2	2.7	0.3	-99.9	-99.9	-99.9	-99.9	-99.9
2000			206.4	151.8	35							
2002		122.1	110	176.5	77.4	3		4.4	69.4	122.3	129.9	175.3
2003	107.6	100.8	98.3	117	166.5	18.1	3.7	57.9	93.1	97	187.7	107.8

APPENDIX C

Population and agricultural facts

Year	Pop	GDPgrowth	crop	food	livestock	refugee
1986	6394139	5.472137487	93	90	75	
1987	6719259	-0.02403611	94	90	73	
1988	7013632	4.498824996	92	88	76	
1993	5919662	-8.108691867	83	81	77	450462
1994	5545631	-50.24806711	54	57	73	2257573
1995	5440441	35.22407831	68	68	66	1819366
1996	5660132	12.74569576	76	76	72	469136
2002	8538697	11	125	124	108	75251
2003	8685457	0.3	113	114	118	75263
2004	8819688	5.3	111	113	126	63308

APPENDIX D

Histogram of NDVI values generated from Idrisi

Class	Mean Upper/Lower limit 1987	Mean Upper/Lower limit 1995	Mean Upper/Lower limit 2003
1	-0.6305	-0.4955	-0.4545
2	-0.614	-0.482	-0.4415
3	-0.597	-0.4685	-0.4285
4	-0.5805	-0.4555	-0.415
5	-0.564	-0.442	-0.4015
6	-0.5475	-0.4285	-0.3885
7	-0.5305	-0.415	-0.3755
8	-0.514	-0.4015	-0.3615
9	-0.4975	-0.3885	-0.3485
10	-0.481	-0.375	-0.3355
11	-0.4645	-0.3615	-0.322
12	-0.4475	-0.3485	-0.3085
13	-0.431	-0.3345	-0.2955
14	-0.4145	-0.3215	-0.2825
15	-0.398	-0.308	-0.269
16	-0.3815	-0.2945	-0.2555
17	-0.3645	-0.2815	-0.2425
18	-0.348	-0.2675	-0.2295
19	-0.3315	-0.2545	-0.2155
20	-0.315	-0.241	-0.2025
21	-0.2985	-0.2275	-0.1895
22	-0.2815	-0.2145	-0.176
23	-0.265	-0.2005	-0.1625
24	-0.2485	-0.1875	-0.1495
25	-0.232	-0.174	-0.1365
26	-0.215	-0.1605	-0.123
27	-0.1985	-0.1475	-0.1095
28	-0.182	-0.134	-0.0965
29	-0.1655	-0.1205	-0.0835
30	-0.149	-0.107	-0.0695
31	-0.132	-0.0935	-0.0565
32	-0.1155	-0.0805	-0.0435
33	-0.099	-0.067	-0.03
34	-0.0825	-0.0535	-0.0165
35	-0.066	-0.04	-0.0035
36	-0.049	-0.0265	0.0095
37	-0.0325	-0.0135	0.023
38	-0.016	0	0.0365
39	0.0005	0.0135	0.0495

40	0.017	0.0265	0.0625
41	0.034	0.0405	0.0765
42	0.0505	0.0535	0.0895
43	0.067	0.067	0.1025
44	0.0835	0.0805	0.116
45	0.1	0.0935	0.1295
46	0.117	0.1075	0.1425
47	0.1335	0.1205	0.1555
48	0.15	0.134	0.169
49	0.1665	0.1475	0.1825
50	0.1835	0.1605	0.1955
51	0.2	0.1745	0.2085
52	0.2165	0.1875	0.2225
53	0.233	0.201	0.2355
54	0.2495	0.2145	0.2485
55	0.2665	0.2275	0.262
56	0.283	0.241	0.2755
57	0.2995	0.2545	0.2885
58	0.316	0.268	0.3015
59	0.3325	0.2815	0.315
60	0.3495	0.2945	0.3285
61	0.366	0.308	0.3415
62	0.3825	0.3215	0.3545
63	0.399	0.335	0.3685
64	0.4155	0.3485	0.3815
65	0.4325	0.3615	0.3945
66	0.449	0.375	0.408
67	0.4655	0.3885	0.4215
68	0.482	0.4015	0.4345
69	0.4985	0.4155	0.4475
70	0.5155	0.4285	0.461
71	0.532	0.442	0.4745
72	0.5485	0.4555	0.4875
73	0.565	0.4685	0.5005
74	0.582	0.4825	0.5145
75	0.5985	0.4955	0.5275
76	0.615	0.509	0.5405
77	0.6315	0.5225	0.554
78	0.648	0.5355	0.5675
79	0.665	0.549	0.5805
80	0.6815	0.5625	0.5935
81	0.698	0.576	0.607
82	0.7145	0.5895	0.6205
83	0.731	0.6025	0.6335
84	0.748	0.616	0.6465

85	0.7645	0.6295	0.6605
86	0.781	0.643	0.6735
87	0.7975	0.6565	0.6865
88	0.814	0.6695	0.7
89	0.831	0.683	0.7135
90	0.8475	0.6965	0.7265
91	0.864	0.7095	0.7395
92	0.8805	0.7235	0.753
93	0.8975	0.7365	0.7665
94	0.914	0.75	0.7795
95	0.9305	0.7635	0.7925
96	0.947	0.7765	0.8065
97	0.9635	0.7905	0.8195
98	0.9805	0.8035	0.8325
99	0.997	0.817	0.8455
100	1.0135	0.8305	0.8595
101		0.8435	
Mean	0.537	0.519	0.539
Stand	0.256	0.244	0.265
N	3639564	3639564	3639564

APPENDIX E

Krigging error prediction	**1987**	**1995**	**2003**
Mean	-0.000006155	-0.000008293	0.00008123
RMS	0.1067	0.183	0.1745
Average standard error	0.2448	0.3547	0.3514
Mean standardised	-0.00002283	-0.00002349	0.0002265
RMS standardised	-0.00002283	0.5159	0.4966

APPENDIX F

Years	**t-test**	$t_{0.025,7279126}$	**Conclusion**
1987-1995	97.09	1.960	Ho rejected
1995-2003	-103.55	1.960	Ho rejected
1987-2003	-10.59	1.960	Ho rejected

The hypothesis for NDVI mean of 1987 and 1995 is:

Ho: there is no statistically significant difference between the 1987 and 1995 NDVI means

→ x87 = x95

Ha: there is a statistically difference between 1987 and 1995 NDVI means

→ x87 > x95

The degree of freedom is 7279126 and the critical value is 0.05

The standard error was computed through the following:

$$S_{\overline{x}_1-\overline{x}_2} = \sqrt{\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{n_1+n_2-2}}\sqrt{\frac{n_1+n_2}{n_1 n_2}}$$

Where Sx_1-x_2 stands for standard error

n: total population number

S: Standard deviation

x_1-x_2: Means of either 1987, 1995 or 2003.

The t-test was computed as:

$$t = \frac{\overline{X_1} - \overline{X_2}}{S_{\overline{x}_1-\overline{x}_2}}$$

The results show that the t-test statistic 97.09 exceed the critical value of 1.960, therefore Ho is rejected. It means that there is statistically significant difference between the mean of 1987 and 1995 NDVIs.

For NDVI mean of 1995 and 2003, the following hypothesis was used:

Ho: there is no statistically significant difference between the 1995 and 2003 NDVI means

→ x95 = x03

Ha: there is a statistically difference between 1987 and 1995 NDVI means

→ x95 < x03

The results proved that the test statistic -103.55 is not equal and less than the critical value of 1.960; therefore, the null hypothesis (Ho) is rejected. So, there is no statistically significant difference between 1995 and 2003.

The NDVI mean of 1999

Years	**Hypothesis**	**Rejection criteria**	**t- statistic**	**Decision**
1987-1995	Ho: x87 = x95	df: 7279126	97.09	t > α
	Ha: x87 > x95	α: 0.05		Ho rejected
1995-2003	Ho: x95 = x03	df: 7279126	-103.55	t < α
	Ha: x95 < x03	α: 0.05		Ho rejected
1987-2003	Ho: x87 = x03	df: 7279126	-10.59	t > α
	Ha: x87 > x03	α: 0.05		Ho rejected

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