MODELLING WILDEBEEST DISTRIBUTION IN SERENGETI NATIONAL PARK, TANZANIA: AN APPLICATION OF GIS AND SPACE-BORNE IMAGERY

By
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Modelling Wildebeest Distribution in Serengeti National Park, Tanzania: An application of GIS and Space-borne Imagery

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Disclaimer

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Dedication

This thesis is dedicated to my late parents and my late lovely sister Ashura who laid my academic foundation. May the Almighty God rest them in peace!

Abstract

Animal presence in a given time at a particular location is determined by multiple biotic and abiotic factors. In view of this, the study applied GIS and remote sensing techniques and statistical tools to analyze the effect of multiple environmental factors and single out the most important factors explaining wildebeest density in Serengeti Plains, Tanzania. Five species-environment hypotheses related to vegetation structure, rainfall, rivers (water availability), roads and elevation together with wildebeest density data were analyzed using simple and multiple regression. Positive relationship was detected for elevation and distance from the roads, while other factors were negatively related to wildebeest density. Based on coefficient of determination (r^2), individually, higher variations were accounted by elevation (30%), vegetation structure (12%), and distance from rivers (8.3%), rainfall (6.4%) and distance from roads (2%). However, on the final model elevation turned out as the most important factor influencing density and spatial distribution of wildebeest by explaining a total variation of 35.5%. Future researches are proposed to repeat the present study with census data from different years and to include other factors such as vegetation greenness, soil types, and effect of fire, temperature, predation and other human induced disturbances which were beyond the scope of the present study. Findings of the present study are expected to contribute information to the existing species-environment knowledge and to facilitate management and conservation of wildebeest in Serengeti ecosystem.

Keywords: *Wildebeest, environmental factors, spatial distribution, Serengeti Plains, GIS, Remote sensing.*

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List of abbreviations

APS	Aerial Point Sampling
ANOVA	Analysis of Variance
CIMU	Conservation Information and Monitoring Unit
ETM +	Enhanced Thematic Mapper Plus
FZS	Frankfurt Zoological Society
GIS	Geographical Information System
GPS	Geographical Positioning System
RS	Remote Sensing
SNP	Serengeti National Park
TAWIRI	Tanzania Wildlife Research Institute
UTM	Universal Transverse Mercator
WGS	Word Geodetic System

1. Introduction

1.1. Background

Common wildebeest (*Connochaetes taurinus*) are medium to large sized social antelopes belonging in the order: Perisodactyla (odd-toed ungulates), and tribe; Alcelaphini (Estes, 1992). Wildebeest colour range from dark brown to black with an erect mane and a long straight tail. Both male and female wildebeest bear horns and males are large bodied than females (Estes, 1992; Kingdon, 1997). Wildebeest body mass is between 200-250 kilograms and the life span is about 20 years (Estes, 1992). They live in social groups and herds are made up of females accompanied with males and young (Estes, 1992). Group size varies from few individuals to thousands, and their home range is usually determined by availability of water, mineral nutrients and grasses (Inglis, 1976; Haltenorth and Diller, 1996; Wilmshurst *et al.*, 1999). Their major predators include lion, hyena, leopard, cheetah and wild dogs (Haltenorth and Diller, 1996).

Wildebeest are commonly found in southern, central, and eastern Africa savannas especially in Tanzania, Kenya, Mozambique, Botswana, Malawi, Angola, Zimbabwe, South Africa and Zambia (Estes, 1992; Haltenorth and Diller, 1996). Wildebeest habitat consist mainly of short and medium grassland, and sometimes are found in shrublands and acacia woodlands (Estes, 1992; Haltenorth and Diller, 1996).

Wildebeest are selective grazers, exclusively feeding on short grasses (Owaga, 1975; Murray, 1993). Wildebeest play an important ecological role in shaping the ecosystem by keeping the grass short through grazing and trampling and create an ideal grazing mosaic for small/other grazers after the vegetation opened by large species such as buffaloes and zebra (Owaga, 1975). According to Maddock (1979), it implies that wildebeest are dependant on large species in the grazing succession which later favours small grazers. This grazing pattern stimulates vegetation growth and can alter the distribution of soil nutrients and vegetation in the ecosystem through foraging and nutrient cycling (Augustine and Mcnaughton, 1998; 2006).

In Serengeti National Park, wildebeest are in two distinguished groups. These are resident and migratory wildebeest. Migratory wildebeest occupy the grassland plains in the southern part in the wet season and move to the western and northern parts of the park as dry period advances (Mduma *et al.*, 1999; Thirgood *et al.*, 2004). The resident wildebeest normally reside in the western part of the park throughout a year (Inglis, 1976). In August the migratory herd moves across the Tanzania border to Kenya side (Masai-Mara), where they spend few months before they start moving back to Serengeti Plains in November/early December (Inglis, 1976).

1.2. Spatial distribution of wild herbivores

Spatial and temporal distribution of wildlife species is influenced by many factors, both biotic and abiotic (Bailey *et al.,* 1996; Bailey and Provenza, 2008). Biotic factors include vegetation greenness and grass nutritional values (Verlinden and Masogo, 1997; Mutanga *et al.,* 2004; Anderson *et al.,* 2007; Mueller *et al.,* 2007). Biotic factors (e.g. vegetation) plays an important role in maintaining animals population (Mduma *et al.,* 1999). Abiotic factors such as rainfall and distribution of water points (Gereta and Wolanski, 1998; Ogutu *et al.,* 2008), soil mineral nutrients and texture, temperature and topography all plays a role in determining spatial distribution of wild animals over time (Leyequien *et al.,* 2007). Human-related factors such as land use changes (Serneels and Lambin, 2001), poaching and hunting (Manyenye, 2008), temporal reduction in food availability due to fire incidences are also well known in influencing the spatial distribution of wild animals (Verlinden *et al.,* 1998).

1.3. Wildebeest-environment interaction

Wildebeest like other herbivores are influenced by environmental factors. They depend on resources such as vegetation (Owaga, 1975) and water availability. Water is required for its daily metabolic activities, such as forage digestibility (Murray, 1993). The role of water cannot be ignored in species survival, and previous work in Botswana estimated water requirements for wildebeest to be 10 litres per day (Taylor, 1968 cited in Williamson *et al.,* 1988). There are many source of water availability. For example, surface water run-off due to rainfall can contribute to water availability in rivers and temporary water points. Availability of water can stimulate vegetation growth on which animals depend on (Seagle and Mcnaughton, 1992). Water availability (rainfall, rivers or surface water) have been reported to influence wildebeest density (Williamson *et al.,* 1988; Kgathi and Kalikawe, 1993) and other water dependant herbivores.

Elevation is also an important biogeographical factor and can influence wild herbivores distribution (Bailey *et al.,* 1996; Metzger *et al.,* 2007; Bailey and Provenza, 2008). Elevation can influence animal distribution in different ways (direct or indirect), for example, in Kenya (Ngene 2008, in press), it has been reported to influence elephants distribution by acting as a proxy in shaping vegetation structure.

The influence of human-induced disturbances such land cover change (Serneels and Lambin, 2001), roads and fire has been reported to influence wildebeest and other herbivores distribution. For example, in western Serengeti fire has been reported to affect animal distribution through sward structure, i.e. the burnt areas stimulate resprouting of fresh grasses which can be attractive to animals (Hassan *et al.,* 2007). The effect of roads and dust from traffic vehicles has been also reported to decrease grazing along roadsides (Ndibalema *et al.,* 2008).

Other factors such as soil types and soil mineral contents have been reported to influence distribution of wild herbivores. For example, according to McNaughton (1990) grasslands of Serengeti Plains have higher amount of soil minerals required by wildebeest. Minerals e.g. calcium has been reported to play essential role to female wildebeest especially during lactation and early pregnancies (Kreulen, 1975). Soil types have been related to nutrient levels in vegetation, as well as foraging behaviour of wildebeest as pointed by Ben-Shahar and Coe (1992) who reported the role of soil mineral nutrients on vegetation which in turn influence herbivore distribution.

Understanding species distribution and environmental interaction in conservation ecology is important (Altrichter and Boaglio, 2004) for several reasons. For example, it can provide information such as where species are found (Newton-Cross *et al.,* 2007), help in monitoring species abundance at a specific location over time (De Leeuw *et al.,* 2002). Such knowledge can contribute significantly to understand processes such as species population decline resulting from animal-environment interaction (Newton-Cross *et al.,* 2007).

1.4. Geographical Information System and Remote Sensing in spatial modelling

The potential of (GIS) and remotely-sensed (RS) data in natural resources monitoring and mapping as a source of input data for environmental modelling has gained popularity in recent years (Guisan and Zimmermann, 2000; Melesse *et al.,* 2007). Cardillo et al. (1999) pointed out usefulness and cost-effectiveness of using remote sensing and GIS data in conservation research compared to ground based approaches. Remote sensing data can address these needs by identifying and detailing the biophysical characteristics of species habitats and predicting species distribution and spatial variability in species richness at local and global scale (Kerr and Ostrovsky, 2003). The role of GIS and RS techniques in species-environment has proven successful in several parts of the world. For example, Braunisch et al. (2008) modelled species niche distribution using a GIS approach. Debeljak et al. (2001) used GIS and RS in modelling potential distribution habitats for red deer (Cervus elaphus L.) in South-central Slovenia. Herkt (2007) also modelled potential distribution areas for Erhad's Wall Lizards (Podarus erhardii) in Crete.

1.5. Problem statement and justification

Literature review suggests that animal densities, spatial distribution and their movements are influenced by several biotic and abiotic factors (Wilmshurst *et al.,* 1999; Lehmkuhl *et al.,* 2001). However, to my understanding, until now there is no comprehensive study related wildebeest density and/or distribution with multiple environmental factors to assess which one explain better the density and spatial distribution of wildebeest in the Serengeti National Park. Previous studies within the park and the ecosystem at large have only related wildebeest or other herbivores densities, distribution and/or movement with only few environmental factors, either one or two. For example, food resource (Mduma *et al.,* 1999; Wilmshurst *et al.,* 1999; Musiega and Kazadi, 2004), topography and climate (Metzger *et al.,* 2007), soil mineral nutrients (Inglis, 1976; Mcnaughton and Banyikwa, 1995), distribution of permanent and seasonal water (Gereta and Wolanski 1998), human-induced disturbances such as fire incidences (Hassan, 2007), land use changes (Homewood *et al.,* 2001; Serneels and Lambin, 2001) and the influence of man made infrastructure such as roads (Ndibalema *et al.,* 2008).

Given the fact that animal presence at a certain location in a given time is a function of several biotic and abiotic factors, there is need for a comprehensive study to understand how multiple environmental factors can influence wildebeest density and distribution. Identification of key factors, relationship and mechanisms is important for ecologists, researchers and conservation managers. For example, they can use the knowledge to predict the effects of these factors on species density and distribution when environmental factors alter in a given time or season. Lack of such understanding can hamper conservation efforts and lead to species decline and/or altering the ecosystem which support species survival.

The study applied GIS and remote sensing techniques and statistical tools to analyze the effect of multiple environmental factors (vegetation structure, rainfall, water availability, roads and elevation) on wildebeest. The findings are expected to contribute information to the existing species knowledge and facilitate management and conservation of wildebeest in Serengeti ecosystem.

1.5.1. Conceptual diagram

Figure 1-1 summarizes the possible factors which can influence density and spatial distribution of wildebeest in Serengeti Plains and the Serengeti ecosystem at large. These environmental factors were deduced from literature reviews (see 1.2 and 1.3). Solid box refers to state. The dotted box indicates the system boundary (factors considered in the present study looked), while the solid and dotted arrows indicate direct and indirect relationship respectively.

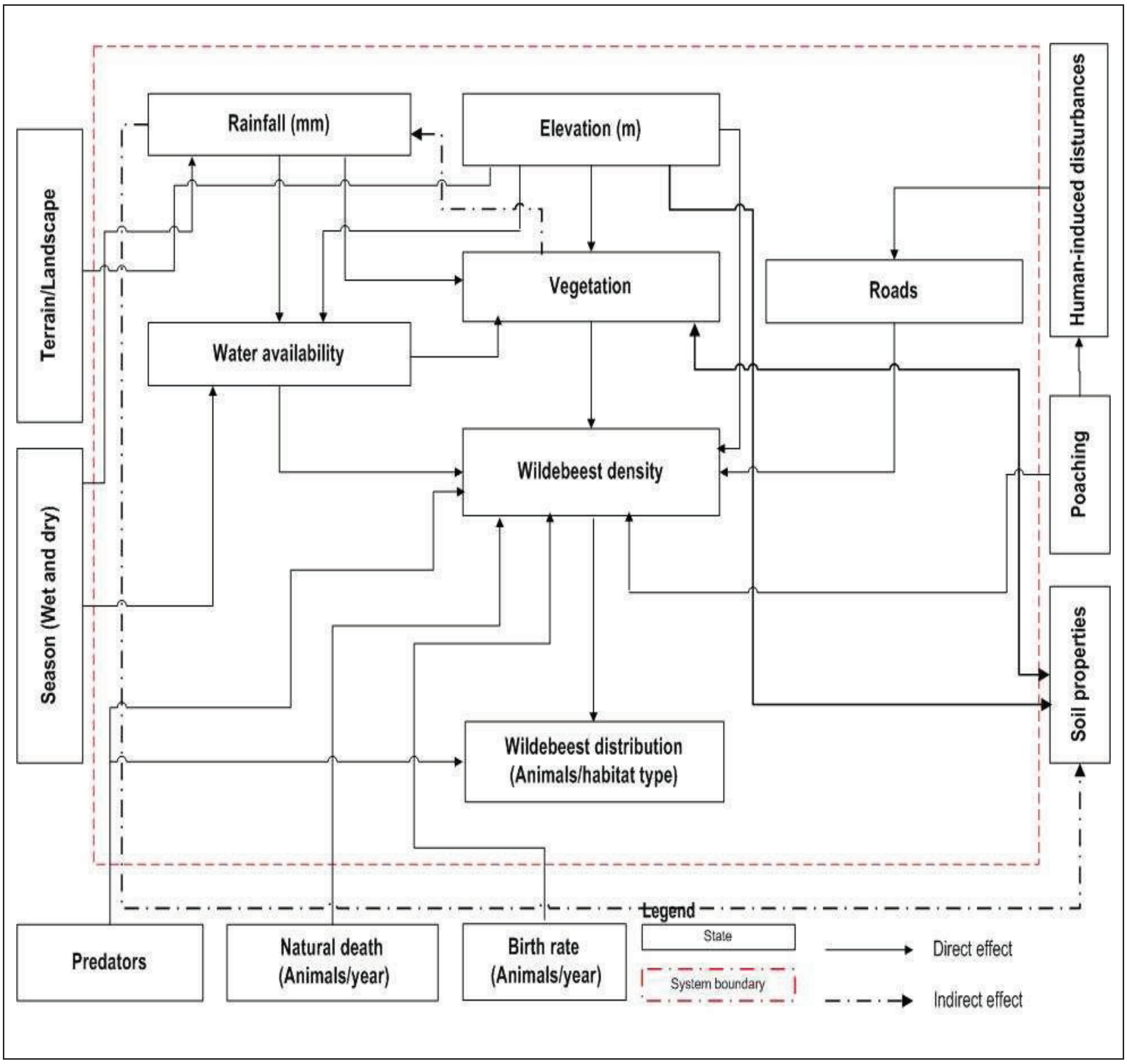

Figure 1-1: Conceptual diagram of wildebeest-environmental interaction

1.6. Study objectives

1.6.1. Main objective

The main objective of this study is to assess environmental factors and their influence on wildebeest density and to develop a spatial predictive model for Serengeti Plains.

1.6.2. Specific objectives

Specifically, the study aims to -

1. Assess the relationship between environmental factors and wildebeest density
2. Assess which environmental factors most influencing wildebeest density
3. Predict suitable areas for wildebeest in the Serengeti Plains

1.7. Research questions and hypotheses

1.7.1. Research questions

The study aims to answer the following research questions:-

Objective 1: Assess the relationship between environmental factors and wildebeest density

Questions:

1. Does different vegetation structure influence wildebeest density?
2. Does rainfall influence wildebeest density?
3. Does distance from rivers influence wildebeest density?
4. Does distance from roads influence wildebeest density?
5. Does differences in elevation influence wildebeest density?

Objective 2: Assess which environmental factors most influence wildebeest density
Question 6: Which environmental factors best explain wildebeest density in the study area?

Objective 3: Predict suitable areas for wildebeest distribution
Question 7: Which are potential suitable areas for wildebeest distribution in the study area?

1.7.2. Research hypotheses

1-Ho: Wildebeest shows no preference on vegetation structure ($\beta = 0$)
1-Ha: Wildebeest prefers short grass over other vegetation structure ($\beta \neq 0$)

2-Ho: Rainfall has a negative effect on wildebeest density ($\beta = 0$)
2-Ha: Rainfall has a positive effect on wildebeest density ($\beta \neq 0$)

3-Ho: Distance from rivers has no effect on wildebeest density ($\beta = 0$)
3-Ha: Distance from rivers has a positive effect on wildebeest density ($\beta \neq 0$)

4-Ho: Distance from roads has no effect on wildebeest distribution ($\beta = 0$)
4-Ha: Distance from roads has a positive effect on wildebeest density ($\beta \neq 0$)

5-Ho: Elevation has a negative effect on wildebeest density ($\beta = 0$)
5-Ha: Elevation has a positive effect on wildebeest density ($\beta \neq 0$)

6-Ho: None of the environmental factors has an effect on wildebeest density ($\beta = 0$)
6-Ha: At least one of the environmental factors has an effect wildebeest density ($\beta \neq 0$)

7-Ho: Not the entire study area can be predicted suitable based on significant environmental factors
7-Ha: Certain area can be predicted suitable for wildebeest based on potential environmental factors

2. Study area description

2.1. Geographical location

Serengeti National Park (2^0 to 3^0 45'S, and 33^0 45' to $35^0$15' E) covers about 14760 km^2. The study was carried out in the southern part of the park (The Serengeti Plains), which covers approximately 6500 km^2 and is dominated by treeless grasslands (Kreulen, 1975; Inglis, 1976). The park is surrounded by six protected areas, namely; Masai-Mara Reserve (North: In Kenya, not shown in the present map), Loliondo Game Controlled Area and Ngorongoro Conservation Area (South-east), Maswa Game Reserve (South-west). Grumeti Game Reserve and Ikorongo Game Reserve (North-west). The map of study area is shown in figure 2-1.

2.1.1. Choice and justification of the study area

Wildebeest census data in this study were collected in the Serengeti Plains. Normally aerial census for wildebeest in the Serengeti and surrounding protected areas is done in the wet season. The Serengeti Plains are remarkably productive (quality forage and enough temporary water points) during the wet season and preferred by wildebeest compared to other parts of the Serengeti ecosystem (Mcnaughton, 1990; Sinclair *et al.,* 2008). However, during the dry season the area is not preferred by wildebeest due to lack of water and desiccated vegetation (Olff and Hopcraft, 2008). The Serengeti Plains are feeding grounds to wildebeest whereby their mass calving, early lactation and late pregnancies coincide with the wet season (Kreulen, 1975). According to McNaughton (1990) the grass of plains have higher amount of calcium, phosphorus, sodium and nitrogen during the wet season. Availability of these minerals in grasses during the wet season is important to wildebeest. For example, calcium and phosphate plays an important role in bone formation and helps female wildebeest to produce sufficient milk for their young (Kreulen, 1975).

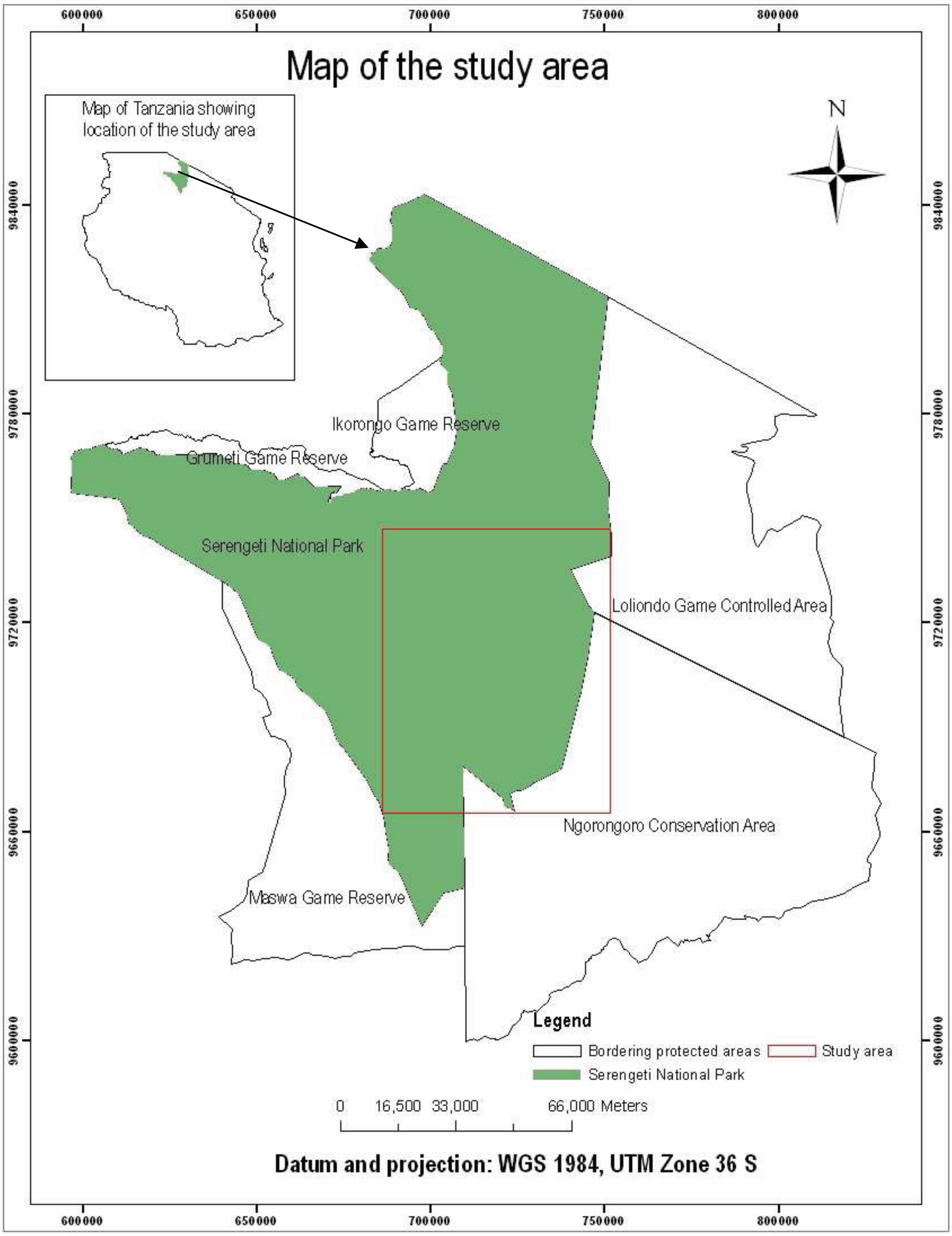

Figure 2-1: Map of the study area

2.1.2. Climate and vegetation

Serengeti National Park experiences a mean annual average temperature of 220C (150C – 300C), with an increasing annual rainfall gradient, from south-east (500 mm) where the plains are to the north-west (1100 mm). Rainfall falls in two periods, between December and May (wet season) and June to November (dry season). The vegetation consist predominantly of grasslands in the south-east (Plains), and woodlands, shrublands and savannas in the western and northern parts of the park (Mduma *et al.,* 1999). The plains are dominated by Digitaria microbrephra, Sporobolus ioclades and Cynodon dactylon, which form open grasslands (Kreulen, 1975; Sinclair *et al.,* 2008, Pg 7-46).

2.1.3. Soil

There is variation in soil properties within the park, the plains soils are alkaline in nature with abundant organic matter (Sinclair *et al.,* 2008, Pg 112) which make the soil more neutral and ideal for vegetation growth. The plain soil is rich in different minerals such as calcium, magnesium and sodium minerals which provide essential nutrients needed by plants (Mcnaughton, 1990). The soil of Serengeti National Park is described in detail by Jager (1982).

2.1.4. Flora and fauna

Serengeti National Park is well known for its flora and fauna, mainly characterized by wildebeest as the dominant migratory species (Mduma *et al.,* 1999). Recent reports shows a total of 58 herbivore species within the park (Sinclair *et al.,* 2008, Pg 497-506). To mention a few, include wildebeest, zebras, buffaloes, topi, lion, elephants, impala, eland, grant gazelle, waterbuck, warthog and other small mammals.

2.1.5. Human population, socio-economic and land use

Increase in human population alters any ecosystem. In Tanzania protected areas, activities such as agriculture are prohibited except for Ngorongoro Conservation Area (NCA). NCA is a multiple use area, where agriculture is permitted in a controlled manner to Masai people living in the area. In the greater Serengeti, activities such as farming are practised in areas with high rainfall, mainly outside the park.

3. Material and Methods

3.1. Methods

In order to establish relationship between environmental factors and wildebeest density, various approaches were used. The summary of the procedures used since the initial phase to research completion is shown in the methods flow chart (figure 3-1).

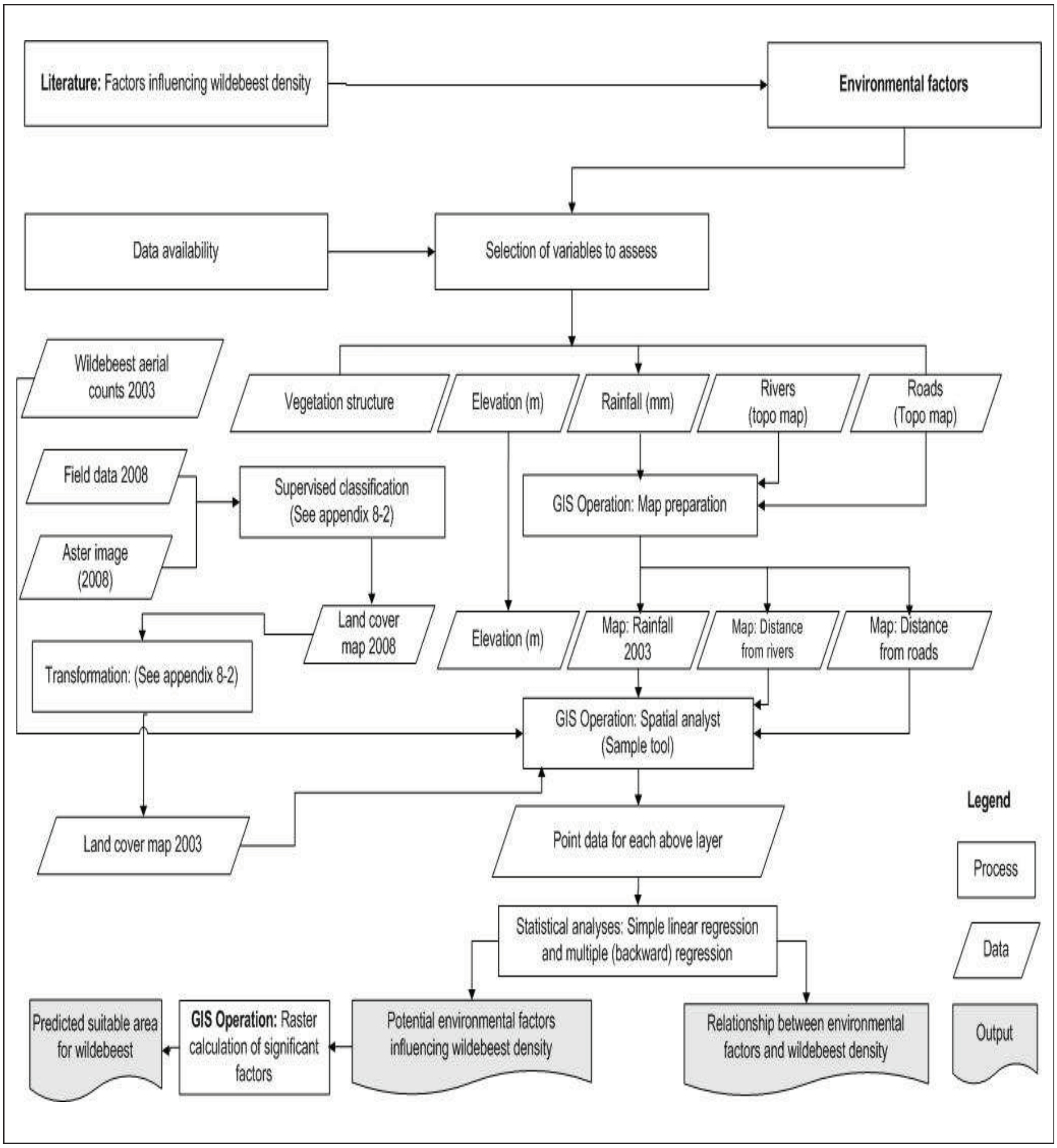

Figure 3-1: Methods flow chart

3.2. Material

3.2.1. Environmental data

Based on wildebeest-environment relationship (Section 1.2 and 1.3) and data availability, five factors were considered at the study scale. These factors are vegetation structure, rainfall, distance from the rivers, distance from the roads and elevation. Data used in the present study is shown in table 3-1.

Table 3-1: List of data used and sources

Category	Variable	Data source
Topography	Elevation (m)	SRTM (DEM)
Vegetation	Grass cover and height (%, cm)	Field data, 2008
	Shrubs cover and height (%, cm)	Field data, 2008
	Woodlands cover and height (%, cm)	Field data, 2008
	Shrubs cover and height (%, cm)	Field data, 2008
Climate	Wet season rainfall (mm) data (2003)	Serengeti Ecological Monitoring Program
Human-related	Distances from roads (km)	Serengeti Ecological Monitoring Program
Water points	Distances from rivers (km)	Serengeti Ecological Monitoring Program
Images	Landsat ETM+ 2003 and Aster 2008	ITC Remote sensing Laboratory
Animal data	Wildebeest aerial census data	CIMU/Frankfurt Zoological Society

3.2.2. Vegetation structure sampling

Vegetation data for land cover mapping were collected using representative sampling technique. Representative sampling was used because: (i) It is efficient can be done with less time and limted budget (ii) it improves accuracy of estimation in sampling area, and (iii) reduce sampling error as described by Clarke *et al.* (1986, 60-76 pp) and Thompson (2002). The method was used to sample 306 points (plot size of 5 x 5 meters for grasslands and 10 x 10 meters for mixed vegetation) throughout the study area. Six strata were developed based on a combination of image characteristics, vegetation types and existing roads within the study area. A Global Positioning System (GPS) was used to record the coordinates of sample points. Distribution of sample points is shown in appendix 8-1(a).

At each sampling point, the following data were collected: (i) Trees and shrubs cover and height (trees refers to all woody plants higher than one meter and shrub cover all woody plants less than a meter), (ii) Grass cover and height (short and long) and (iii) Bare ground/unvegetated areas (soil, leaf litter and rock). Ground cover percentage for woodlands, shrubs and grass were visually assessed. Height estimation were visual assessed for woodlands and/or shrubs (relative to own body height), while for grass measurement a disc pasture with a ruler was used.

3.2.3. Animal census data

Wildebeest aerial census of 2003 was used as dependent variable. The data were obtained from the Centre for Information and Conservation Unit (Under Tanzania Wildlife Research Institute). The data were collected following Aerial Point Sampling (APS) as described by Campbell and Borner (1995). Transect were flewn (Using a fixed wing Cessna aircraft) at an elevation of 1000 ft in east-west direction at a spacing of 2.5 km between transects.

Photographs were taken in each sub-unit (20 seconds flying time) except where animals were not seen. The length of transects are adjusted to accommodate all animals within transects. A Global Positioning System (GPS) was used for navigation and recording locations. Population size estimates were calculated in 2.5 km^2 grids.

3.3. Data processing

3.3.1. Animal census data

Wildebeest density was calculated in 2.5 km^2 grid cells by summing up counts in each sub unit (area covered by 20 seconds flying time). Animal location was assigned at the middle (Centroid location) of the grid cell (See appendix 8-x). This resolution was used to extract environmental data from raster layers (3.3.2 to 3.3.6). However, for land cover mapping (vegetation structure), animal population size was assigned at the centre of the area covered by sub units. This is because, the animal may be located at long grass but when using the centroid of 2.5 km^2 grid cells animals might be assigned in a different vegetation structure.

3.3.2. Land cover mapping

Before image classification field data (grassland samples) were categorized into two groups based on height. These groups were (i) short grass (1-15 cm) and (ii) long grass (more than 15 cm). The criteria for categorizing the height was based on amount of dead biomass (Long grass had higher amount of dead biomass compared to short grass, see appendix 8-1 c). Height categorization was based on visual assessment of field photos and comparing with field data as well as field experience in the study area. This categorization was also due to the fact that there is no existing document indicating which height range belongs to either of the two classes; existing documents categorize species height based on species characters.

Using a training set, a supervised classification of Aster (Advanced Spaceborne Thermal Emission and Reflection Radiometer) image of January 8, 2008 using Maximum Likelihood Classification (MLC) was done. MLC has a high classification power and provides good results because it takes into account the shape, size and orientation of a cluster in feature space (Hansen *et al.*, 1996). Prior to classification, geometric corrections were done in ERDAS 9.2 and georeferenced to Universal Transverse Mecartor (UTM), Word Geodetic System (WGS 1984, Zone 36 S). Accuracy assessment was performed using the validation set to validate the classified map land cover map.

The classified map was not covering the entire study area. In order to accommodate the aerial census data which were not covered in Aster 2008 image, a Landsat Enhanced Thematic Mapper Plus (ETM+) image of 2003 was used. Landsat ETM+ was used for the following reasons (i) was the only free cloud available image, and (ii) was covering the entire study area. Supervised classification needs training data, since the field data were collected in 2008, the validated land cover map of 2008 (see figure 4-1 and table 4-2) was used as a training set to classify Landsat ETM+ image of 2003. Procedures (flow chart) for classification of Aster and Landsat ETM+ images are shown in appendix 8-2.

3.3.3. Rainfall data

Monthly average (wet season, i.e. November-May) rainfall point data (in Microsoft excel format) from 27 active rainfall stations in the study area were imported and processed in ArcGIS 9.3 (Esri, 2006) and interpolated into a continuous map using a Kriging. Kriging interpolation technique assumes the distance and variations between known data points when estimating values in unknown areas. The method is good in unbiased estimation of interpolated parameter (Kassim and Kottegoda, 1991). The sample function in ArcGIS 9.3 was used to extract the rainfall values from the interpolated rainfall map (see appendix 8-4, output cell size 2500 m) using census point data as an input file. The point data were then exported in Microsoft excel for statistical analyses.

3.3.4. Distance from rivers

Distance map (Euclidean distance) was prepared using rivers (seasonal and permanent rivers) and wildebeest census as input data. The resulting map (see appendix 8-5, output cell size 2500 m) was used to extract distance corresponding to the centroid location in the 2.5 km^2 grid using sample function in ArcGIS 9.3 in ArcGIS 9.3. The point data were then exported in Microsoft excel for statistical analyses.

3.3.5. Distance from roads

Roads distances map (Euclidean distance map see appendix 8-6) was prepared using roads shapefile. To match census data resolution, the output cell size was set to 2500 m. Then distances from roads to animals were calculated using sample function in ArcGIS 9.3. Road distances map was an input raster and wildebeest point data were the input feature. The resulting data were exported to Microsoft excel for further statistically analyses.

3.3.6. Elevation

Digital Elevation Model (DEM) was derived from the Shuttle Radar Topography Mission **(**SRTM**)**. SRTM has the spatial resolution of 90 m. The sample option (ArcGIS 9.3) was used to extract the elevation values from the DEM using wildebeest point data as an input feature. The extracted values were then used for statistical analysis.

3.4. Data analysis

3.4.1. Relationship between species and environmental factors

Simple regression was used in assessing the relationship between wildebeest (dependent) and environmental factors (dependent). Simple regression is a good method in analyzing relationship two variables (Moore *et al.*, 2008). Environmental factors were analyzed separately using simple linear regression to establish the relationship with wildebeest density. Since the land cover (vegetation structure) was categorical data, it has to be analyzed in two ways before used. First, Analysis of Variance (ANOVA) was performed to tests the mean differences of density between different vegetation structures. The method was considered useful as it has an advantage of reducing the probability of type I error (false rejection of the null hypothesis) in statistical analyses (Moore *et al.*, 2008). Secondly, the vegetation structure was coded into dummy variables before used in multiple regression model. Dummy variables have been reported useful in regression analysis as it allow to use a single regression equation to represent multiple groups (Garavaglia and Sharma, 1998). Then correlated each other to assess the relationships and find out which variables were highly correlated (Table 4-9). All statistical analyses in the present study were carried out using the SPSS software package for window, version 16.0.

3.4.2. Selection of potential factors

Multiple regression (backward) analysis was performed to find out which variables were most explaining the distribution. The method is commonly used in ecological modelling to predict the value of one dependent variable from a set of independent variables. The equation takes the form of $Y = b_o + b_1x_1 + b_2x_2 + b_3x_3 \ldots\ldots\ldots\ldots b_nx_n$

Whereby:

Y = dependent variable

b_n is the slope for n_{th} independent variable

b is the constant or intercept

x_n is the n_{th} independent variable

Backward multiple regression starts by incorporating all variables in the model and on the process it removes variables which are least significant (Field, 2005). The process was repeated until all least significant variables were removed (Table 4-10).

3.4.3. Predicted suitability map

The significant variables retained in the model (see 3.3.2) were used to test the null hypothesis and generate the predicted habitat suitability map/preferred areas for wildebeest distribution. The following equation was used to generate the predicted map

$$Y = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$

Whereby:

b_o is the constant = - 329.951

b_1 = Elevation intercept = 0.42 x_1 = Elevation raster map

b_3 = Land cover map intercept = - 0.35 x_3 = Land cover map

b_4 = Rivers map intercept = - 0.17 x_4 = Rivers distance map

4. Results

4.1. Analysis of environmental factors related to wildebeest density

4.1.1. Land cover mapping

Before the influence of vegetation types in relation to wildebeest density could be investigated, there was a need to have a land cover map. Land cover was considered as an important factor before hand because it can determine and influence presence and spatial distribution of animals.

4.1.1.1. Classified land cover map 2003 (Aster image of January 8, 2008)

Five vegetation structures were mapped using Aster image of January 8, 2008. These were dense and open woodlands, shrublands and short and long grasslands. Other land cover types such as water and bare areas were also mapped (See figure 4-1 and table 4-1).

Most of the area was classified as grasslands (52% as long grass and 29% as short), while other vegetation and land cover types covered 19 % (table 4-1).

Table 4-1: Area covered by different land cover types (Aster land cover map, January 8, 2008)

Class Name	**Coverage (ha)**	**Percentage (%)**	**Description**
Closed woodlands	12425	7.64	Dominant species: Mixed acacia woodlands
Open woodlands	6203	3.82	Dominant species: *Commiphora spp* mixed acacias
Shrublands	10045	6.18	Dominant species: *Croton spp*
Long grass	84112	51.74	Dominant species:*Cynodon dactylon, Panicum spp, Penisetum mezianum, Themeda triandra*
Short grass	47072	28.96	Dominant species: *Sprobolus spp, Digitaria scalarum, Digitaria macrobrephra*
Water	38	0.02	Areas dominated by water bodies
Bare areas	2656	1.63	Un-vegetated area
Total	**162551**	**100**	

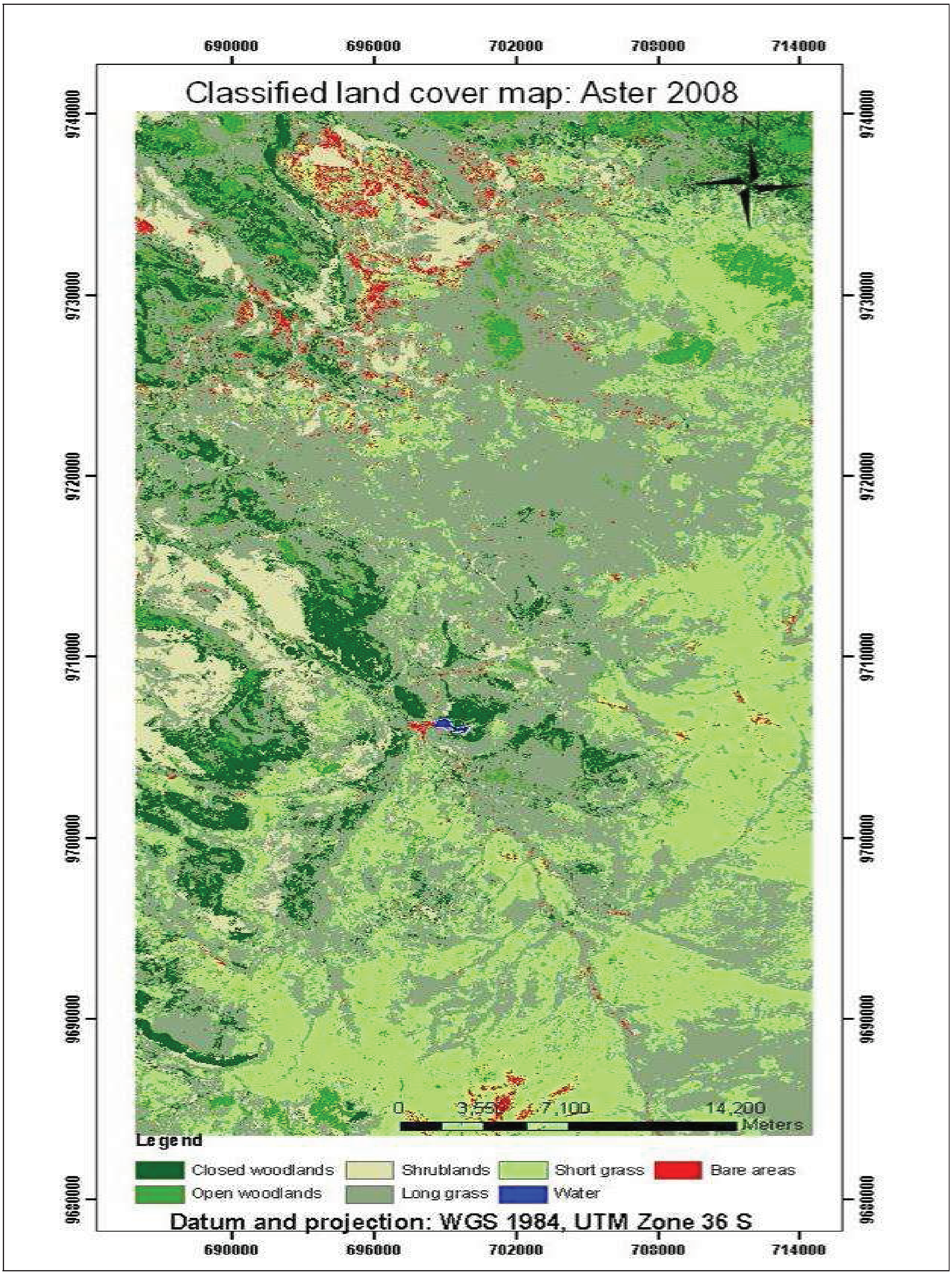

Figure 4-1: Classified land cover map (Aster image, January 8, 2008)

4.1.1.2. Accuracy assessment

The accuracy of the mapped land cover is shown in table 4-2. An overall accuracy of 75.24% was obtained from the Aster image of January 8, 2008. The overall Kappa statistic was 0.64 (Table 8-2c). The error matrix is annexed in 8-2c.

Table 4-2: Accuracy assessment for the classified Aster land cover map of 2008

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy (%)	Users Accuracy (%)
Closed woodlands	6	9	6	100.00	66.67
Open woodlands	9	5	4	44.44	80.00
Shrublands	5	6	3	60.00	50.00
Long grass	39	50	36	92.31	72.00
Short grass	40	31	27	67.50	87.10
Water	0	0	0	---	---
Bare areas	6	4	3	50.00	75.00
Totals	105	105	79		
Overall Classification Accuracy		**75.24%**			

4.1.1.3. Classified land cover map 2003 (Landsat ETM+ image, February 6, 2003)

The classified land cover map of January 2008 was used as a training set (see details on section 3.2.1.1 and appendix 8-2) to classify the Landsat ETM+ image of February 6, 2003 which covered the entire study area. Seventy six percent (76%) of the area was classified as grasslands and other land cover types covered 24%. The area covered by different land cover types is shown in table 4-3 and the classified land cover map is shown in figure 4-2.

Table 4-3: Area covered by different land cover types (Landsat ETM+, February 6, 2003)

Class Name	Coverage (ha)	Percentage (%)
Closed woodlands	8075	1.51
Open woodlands	15255	2.85
Shrublands	93557	17.49
Long grass	201221	37.62
Short grass	206369	38.58
Water	347	0.06
Bare areas	10035	1.88
Total	**534859**	**100**

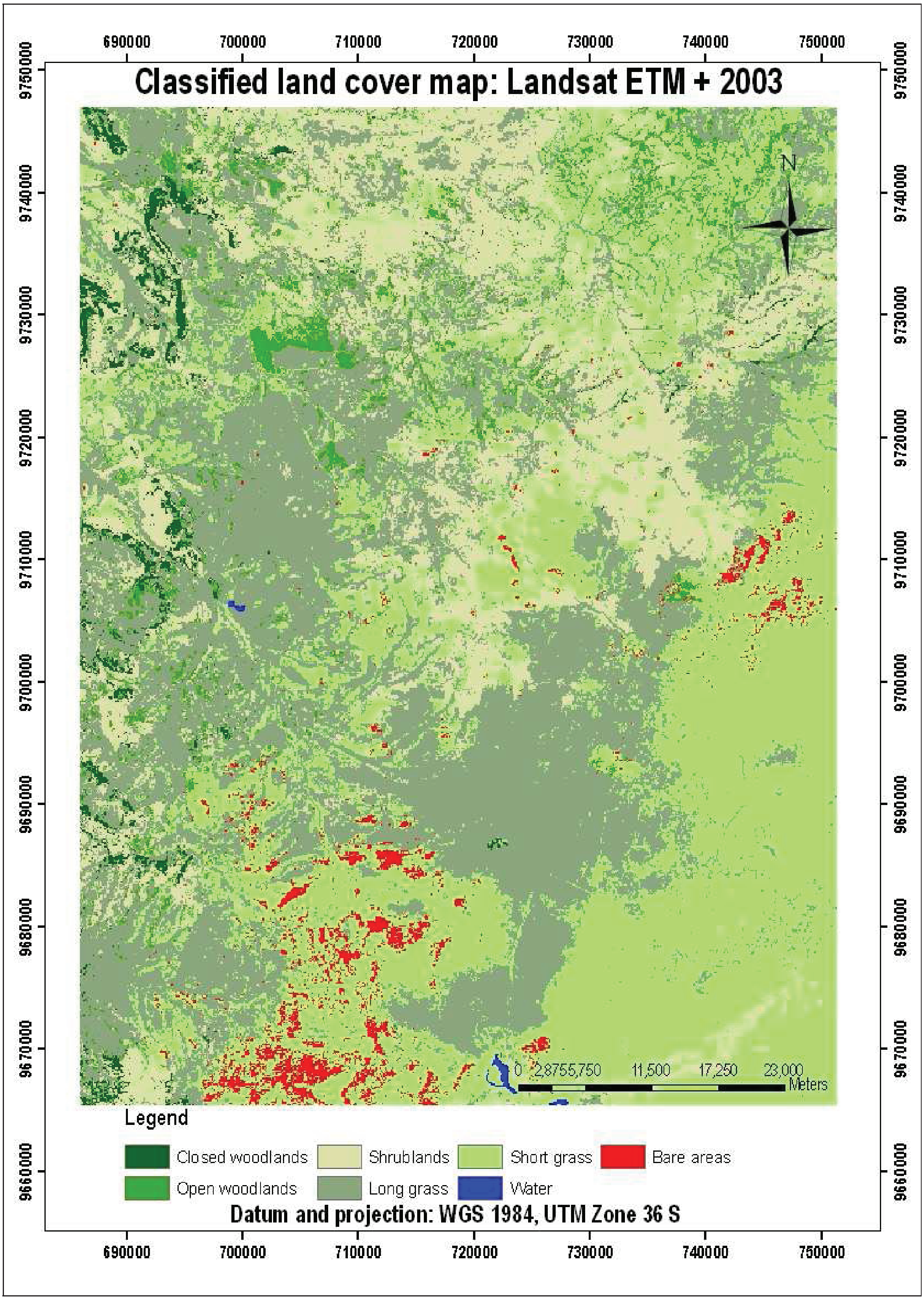

Figure 4-2: Classified land cover map (Landsat ETM+ image, February 6, 2003)

4.2. Wildebeest density in relation to vegetation structure

Linear regression was performed to assess the influence of vegetation structure on wildebeest density. Results revealed a highly significant (Multiple regression, $r^2 = 0.124$, df=2, P=0.002) between density and vegetation structure (shrublands, long grass and short grass). Regression determination indicates that vegetation structure explains 12.4% of the total variation on density. The high significant value gives evidence to reject the null hypothesis (β=0), and opt for the alternative hypothesis. Regression results are shown in table 4-4.

Table 4-4: Regression coefficient between wildebeest density and vegetation structure

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	81.75	13.20		6.19	0.00
	Shrublands	2.42	17.04	0.02	0.14	0.89
	Long grass	-35.43	13.90	-0.59	-2.55	0.01
	Short grass	-32.06	13.57	-0.57	-2.36	0.02

a. Dependent Variable: Density

Descriptive analysis shows that ninety one percent (91%) of total counts was observed in grasslands (short grass 61% and long grass 30% compared to shrublands (Figure. 4-3).

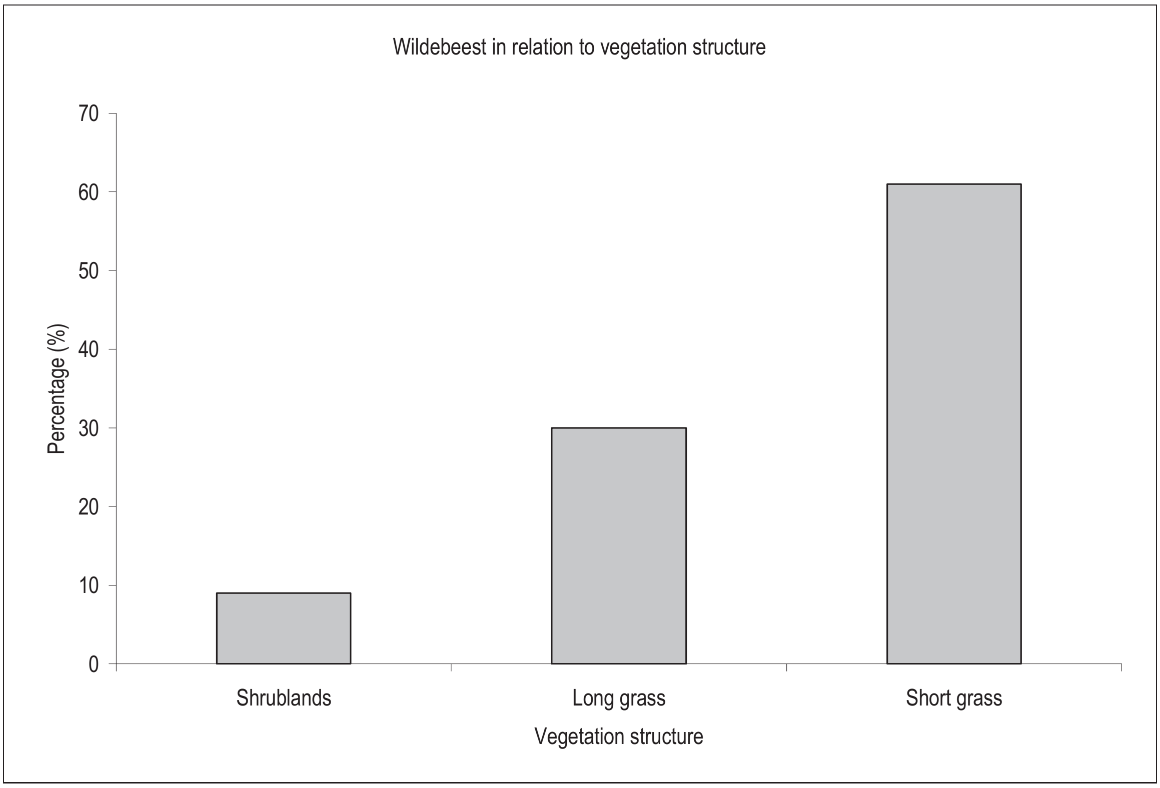

Figure 4-3: Wildebeest density in relation to vegetation structure

4.3. Wildebeest density in relation to rainfall

Simple linear regression analysis between wildebeest density and rainfall revealed a significant relationship (Linear regression, $r^2 = 0.064$, df=118, P = 0.005). The coefficient of estimate (β = -0.027) indicates negative relationship between wildebeest density and rainfall and it accounts only 6.4% of the total variation on density. The significant results obtained provide evidence to reject the null hypothesis (β=0), and opt for the alternative hypothesis ($\beta \neq 0$). Regression results are shown in table 4-5.

Table 4-5: Regression coefficient between wildebeest density and rainfall

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	71.443	7.465		9.57	0.000
	Rainfall (mm)	-0.027	0.009	-0.254	-2.839	0.005

a. Dependent Variable: Density

4.4. Wildebeest density in relation to distance from rivers

Relationship between wildebeest density and distance from rivers was analyzed. Simple linear regression results revealed a significant relationship (Linear regression, $r^2 = 0.083$, df=118, P=0.01). The coefficient of estimate between the variables (β = - 6.584) indicates a negative relationship between the two variables. The explanatory variable (Distance from rivers) accounts 8.3% of the total variation on density. This provided evidence to reject the null hypothesis (β=0), and favour the alternative hypothesis ($\beta \neq 0$). Regression results are shown in table 4-6.

Table 4-6: Regression coefficient between wildebeest density and distance from rivers

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	62.115	4.084		15.209	0.000
	Rivers (km)	-6.584	2.019	-0.289	-3.261	0.001

a. Dependent Variable: Density

Furthermore, descriptive analysis results shows that fifty two percent (52%) of the mean density was observed within 2 km from rivers and the rest were observed more than 2 km from rivers (figure 4-4).

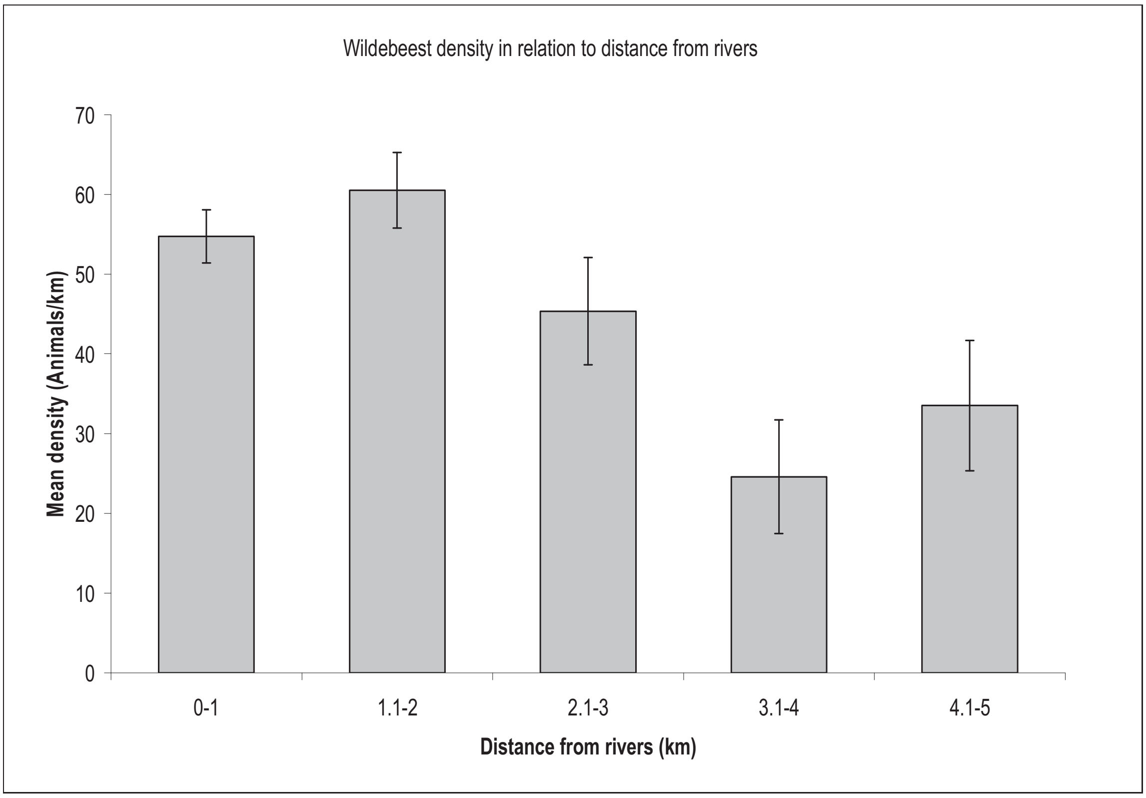

Figure 4-4: Wildebeest density in relation to distance from rivers

4.5. Wildebeest density in relation to distance from roads

Simple linear regression revealed a non-significant relationship (Linear regression, $r^2 = 0.023$, df=118, P = 0.103). The regression coefficient ($\beta = 1.786$) shows positive relationship between distance from roads to animals. The coefficients of determination shows that distance from roads only explain 2.3% of the total variations. Regression results are shown in table 4-7.

The non-significant results fail to reject the null hypothesis (β=0). High mean wildebeest density (64%) was found 4 km and above away from roads (Figure 4-5).

Table 4-7: Regression coefficient between wildebeest density and distance from roads

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	45.857	4.235		10.827	0.000
	Rivers (km)	1.786	1.087	.150	1.643	0.103

a. Dependent Variable: Density

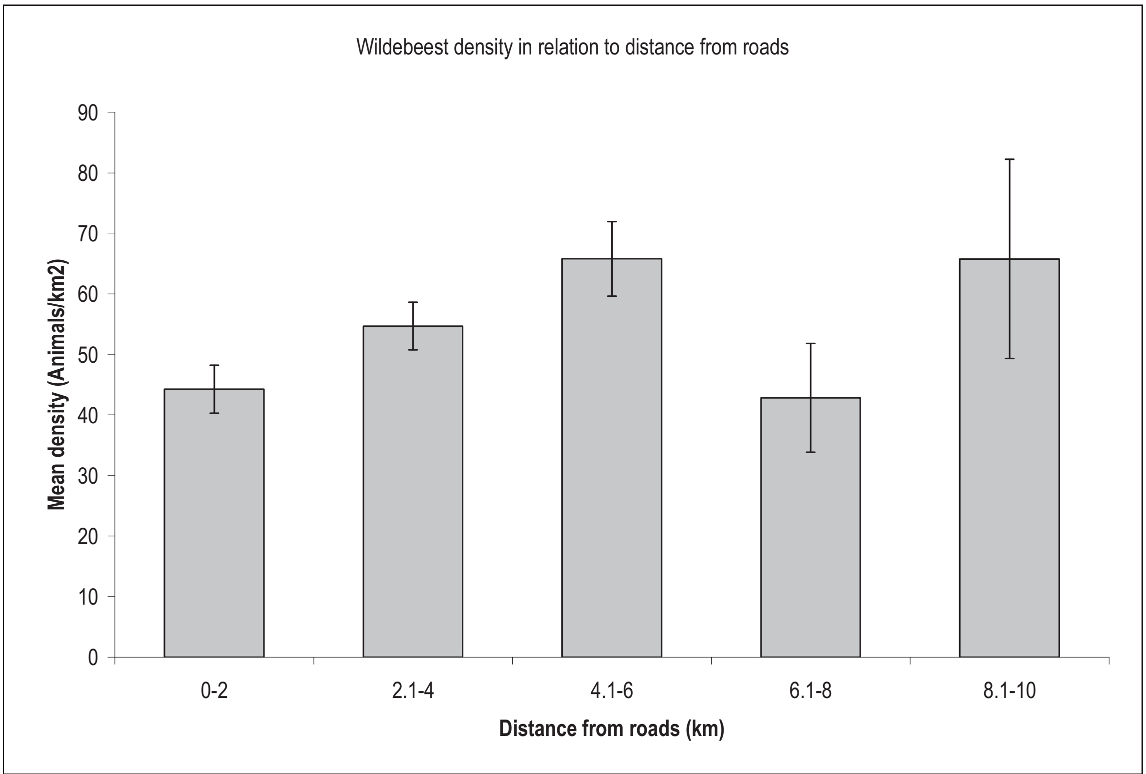

Figure 4-5: Wildebeest density in relation to distance from roads

4.6. Wildebeest density in relation to elevation

The relationship between wildebeest density and elevation was analyzed using simple linear regression. Regression results revealed elevation is highly significant (Linear regression, $r^2 = 0.305$, df=118, $P < 0.01$). The regression coefficient ($\beta = 0.309$) indicates positive relationship between positive relationship between the density and elevation. The coefficient of regression reveals that elevation explained 30.5% of the total variation. The significant results obtained provides evidence to reject the null hypothesis (β=0) and favour the alternative hypothesis ($\beta \neq 0$). Regression results are shown in table 4-8.

Table 4-8: Regression coefficient between wildebeest density and elevation

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-476.608	73.666		-6.470	0.000
	Rivers (km)	0.309	.043	.553	7.171	0.000

a. Dependent Variable: Density

Descriptive statistics revealed that 25% of wildebeest was observed between 1600 and 1680 (m.a.s.l) and 75% of the mean density was recorded between 1781 and 1800 (m.a.s.l).

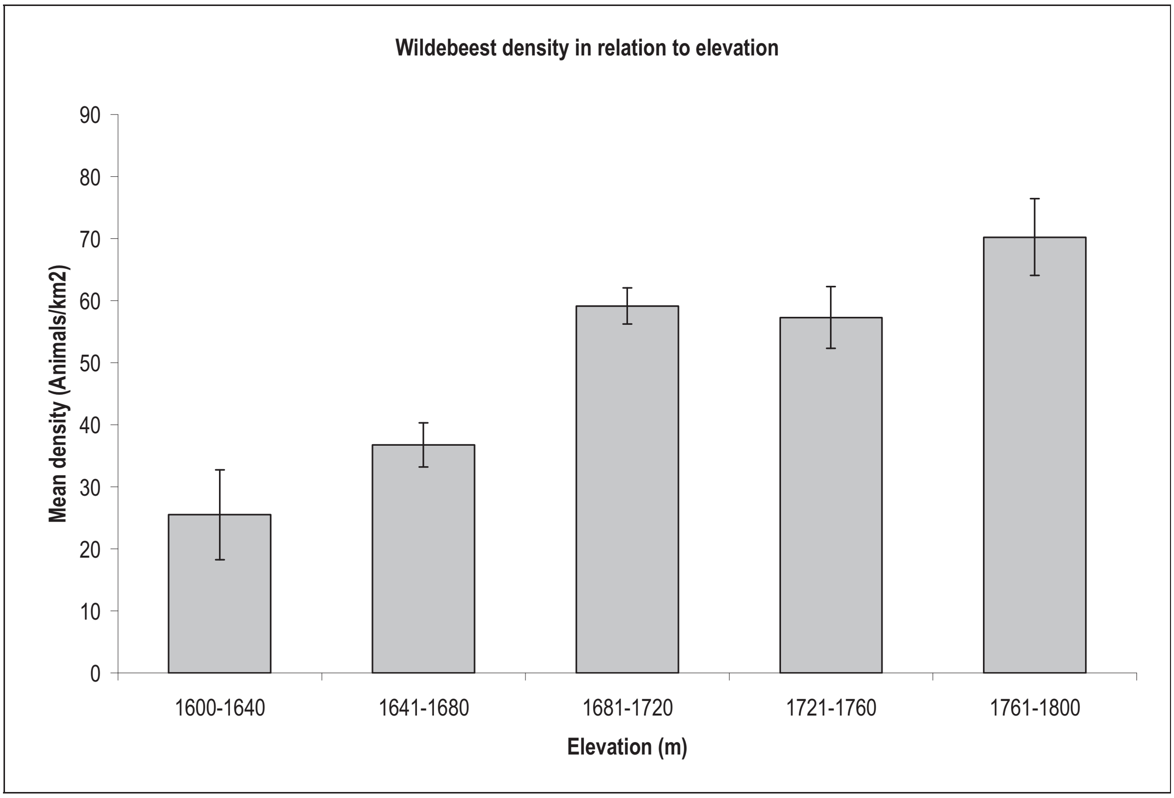

Figure 4-6: Wildebeest density in relation to elevation

4.7. Analysis of potential factors influencing wildebeest density

4.7.1. Screening potential environmental variables for regression model

Before screening potential factors, correlation matrix has to be performed to assess how environmental predictors are related each other (table 4-9). Backward multiple regression (section 3.3.2) was then performed to single out factors (used in the present study) influencing wildebeest density Five environmental factors were entered into the model, after the process four factors (land cover, rainfall, distance to rivers and distance to roads), were non significant, therefore were removed from the model. The final model which included grasslands, distance from rivers and elevation only (Multiple regression, r^2 = 0.355, df=118, P = 0.000). This provided evidence to reject the null hypothesis (β=0). Results of the backward multiple regression is summarized in table 4-10. The retained predictor (Elevation) explained a proportional variance of 35.5% (See the model summary in table 4-11)

Table 4-9: Correlations matrix between variables

		Density	Shrublands	Long grass	Short grass	Rainfall (mm)	Rivers (km)	Roads (km)
Density	Pearson Correlation	1.000						
	Sig. (2-tailed)							
Shrublands	Pearson Correlation	0.273	1.000					
	Sig. (2-tailed)	0.003						
Long grass	Pearson Correlation	-0.126	-0.156	1.000				
	Sig. (2-tailed)	0.176	0.091					
Short grass	Pearson Correlation	-0.079	-0.284	-0.831	1.000			
	Sig. (2-tailed)	0.395	0.002	0.000				
Rainfall (mm)	Pearson Correlation	-0.254	-0.035	0.117	-0.008	1.000		
	Sig. (2-tailed)	0.005	0.703	0.206	0.929			
Rivers (km)	Pearson Correlation	-0.289	0.107	0.027	-0.096	0.053	1.000	
	Sig. (2-tailed)	0.001	0.248	0.773	0.302	0.567		
Roads (km)	Pearson Correlation	0.150	-0.018	-0.073	0.063	-0.244	-0.392	1.000
	Sig. (2-tailed)	0.103	0.847	0.433	0.498	0.008	0.000	
Elevation (m)	Pearson Correlation	0.553	0.325	-0.079	-0.155	-0.258	-0.351	0.412
	Sig. (2-tailed)	0.000	0.000	0.396	0.095	0.005	0.000	0.000

Table 4-10: Summary of backward multiple regression model

Model	**Predictors**	**Unstandardized Coefficients**	**Std. Error**	**Standardized Coefficients Beta**	**t**	**Sig.**
1	(Constant)	-329.4	98.7		-3.3	0.00
	Shrublands	3.8	14.9	0.0	0.3	0.80
	Long grass	-17.1	12.7	-0.3	-1.3	0.18
	Short grass	-14.3	12.5	-0.3	-1.1	0.25
	Rainfall (mm)	0.0	0.0	-0.1	-1.6	0.11
	Rivers (km)	-4.7	2.0	-0.2	-2.4	0.02
	Roads (km)	-1.7	1.1	-0.1	-1.6	0.12
	Elevation (m)	0.2	0.1	0.4	4.5	0.00
2	(Constant)	-329.3	98.3		-3.4	0.00
	Long grass	-19.3	9.1	-0.3	-2.1	0.04
	Short grass	-16.5	8.8	-0.3	-1.9	0.06
	Rainfall (mm)	0.0	0.0	-0.1	-1.6	0.11
	Rivers (km)	-4.7	2.0	-0.2	-2.4	0.02
	Roads (km)	-1.7	1.1	-0.1	-1.6	0.12
	Elevation (m)	0.2	0.1	0.4	4.5	0.00
3	(Constant)	-293.2	96.2		-3.0	0.00
	Long grass	-20.7	9.1	-0.3	-2.3	0.02
	Short grass	-18.3	8.8	-0.3	-2.1	0.04

	Rainfall (mm)	0.0	0.0	-0.1	-1.3	0.19
	Rivers (km)	-3.9	1.9	-0.2	-2.0	0.05
	Elevation (m)	0.2	0.1	0.4	4.2	0.00
4	(Constant)	-324.0	93.6		-3.5	0.00
	Long grass	-21.9	9.1	-0.4	-2.4	0.02
	Short grass	-19.0	8.8	-0.3	-2.2	0.03
	Rivers (km)	-3.9	1.9	-0.2	-2.0	0.05
	Elevation (m)	0.2	0.1	0.4	4.5	0.00

a. Dependent Variable: Density

Table 4-11: Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.61466651	0.377814921	0.338221325	22.65461445
2	0.61436681	0.377446573	0.343795036	22.55901053
3	0.60284986	0.363427955	0.335009561	22.70952195
4	0.59473311	0.353707471	0.330829859	22.78077886

a. Predictors: (Constant), Elevation (m), Long grass, Rainfall (mm), Rivers (km), Shrublands, Roads (km), Short grass

b. Predictors: (Constant), Elevation (m), Long grass, Rainfall (mm), Rivers (km), Roads (km), Short grass

c. Predictors: (Constant), Elevation (m), Long grass, Rainfall (mm), Rivers (km), Short grass

d. Predictors: (Constant), Elevation (m), Long grass, Rivers (km), Short grass

4.7.2. Predicted suitable areas for wildebeest distribution

Preferred areas for wildebeest distribution were to be predicted based on multiple regression coefficients (see table 4-6) retained in section 4.7.1. Due to time limitation, the habitat map was not developed.

5. Discusion

5.1. Analysis of environmental factors influencing wildebeest density

5.1.1. Wildebeest density in relation to vegetation structure

Regression analysis revealed that wildebeest density is associated with vegetation structure. ANOVA test confirmed grasslands being different from other vegetation structure/land cover types. Figure 4-3 shows about 91% of wildebeest were recorded in grasslands (short and long grass). Significant relationship between wildebeest density and grassland types (short and long) obtained in the present study agree with previous studies which reported high preference of wildebeest in short grass. These results can be linked to several reasons, for example, short grasses have been reported to provide high quality and quantity nutritive forage (Olff and Hopcraft, 2008), and are palatable at early growing stage (Kreulen, 1975; Musiega and Kazadi, 2004). Furthermore, at its early growing stage short grass are non-lignin, this character favour animal digestibility and probably make them a preferred forage over long grass or other types of vegetation structure (Kreulen, 1975). Preference of wildebeest in short grass is also linked to their high calcium demand especially for female wildebeest during mass calving and early pregnancies (Kreulen, 1975).

Availability of important mineral nutrients required for vegetation growth (e.g. Sodium) probably makes the short grasses a preferred environment for wildebeest (Mcnaughton, 1990). Short grasslands have also been reported to serve as refuge environment from predators (Sinclair, 1979). Due to openness, it is easy for wildebeest and other grazing herbivores on the short grass to spot a predator from a distant. These factors, might have contributed to high wildebeest presence.

Other studies in elsewhere have related wildebeest preference on short grass. For example, Voeten and Prins (1999), reported a high wildebeest presence in short grass in Tarangire National Park.

5.1.2. Wildebeest density in relation to rainfall

Negative association between wildebeest density and rainfall was detected in study findings. This implies that at the spatial scale investigated, lower rainfall is associated with higher wildebeest density. Low rainfall could be associated with the geographical location of the Serengeti Plains, which is situated along a low rainfall gradient compared to other parts of the park (e.g. northern part) which receives high rainfall. The low rainfall is caused by Ngorongoro crater and Meru-Kilimanjaro mountains rain shadow which block the moisture from the Indian ocean (Sinclair *et al.*, 2008).

Most parts of the Serengeti Plains do not have black cotton soil (*Mbuga*), therefore there is a little possibility for muddy areas compared to other parts of the park where rich black cotton soil (which causes muddy) is common. This conforms to wildebeest behavioural avoidance of muddy and sticky soil areas as reported by Pennycuick (1975), and Talbot and Talbot (1963), and agrees with Ottichilo *et al.*, (2001) findings at a small scale in Loita Plains. These findings are contrary to the common expectation and well known hypotheses of rainfall-vegetation-animal interaction, i.e. the areas with high rainfall amount are expected to have high amount of biomass, which in turn attract grazing herbivores (Owen-Smith, 2004; Norman Owen-Smith, 2005; Ogutu *et al.*, 2008).

Present findings are also contrary to Ottichilo *et al.*, (2001) who found a strong positive relationship (at large scale) between wildebeest density and rainfall in the Mara ecosystem. Ottichilo *et al.*, (2001) related wildebeest decline due to shortage of rainfall, which is a determinant of biomass production as reported by Phillipson (Phillipson, 1975 cited in Ottichilo *et al.*, 2001) and McNaughton (1985).

Maddock (1979) and Thirgood *et. al* (2004), have also related the influence of rainfall on animal distribution. These two authors reported that rainfall might influence vegetation productivity and surface water. The effect of rainfall on biomass production can further affect wild herbivore density and distribution (Ottichilo *et al.*, 2001; Ogutu *et al.*, 2008). Thus, at the spatial scale investigated, suggestion is made that rainfall is not strongly associated with wildebeest density, though at large scale it has reported as a driving factor for herbivores distribution in Serengeti ecosystem (Sinclair *et al.*, 2007).

5.1.3. Wildebeest density in relation to distance from rivers

Wildebeest density is negatively associated with distance from rivers. This suggests that closer to rivers and other water points there is a high probability of higher wildebeest density compared to areas away from rivers. This is possibly due to water dependence nature of wildebeest, therefore they require daily water intake to meet their metabolic activities (Inglis, 1976; Estes, 1992; Kgathi and Kalikawe, 1993). Shortage of water availability to water-dependent animals may lead to declined density (Dunham et al., 2004).

At spatial scale the present study focused, 52% of wildebeest were recorded within 2 km from rivers. This distance is supported by Smit (2007) who found higher density of water-dependent animals in Kruger National park were associated with permanent and seasonal water sources within 4 km from water sources. Furthermore, Kgathi and Kalikawe (1993) reported that wildebeest in Sub-Saharan Africa can walk between a distance of 10 km to in search for water. Williamson et al (1988) also reported that wildebeest can walk up to 60 km in search of water and forage and the density near water points is higher compared to areas away from water sources. High density of water dependent animals closer to different water sources has also been reported in Kenya by Sitters (2008).

Based on present results and literature suggestions, it can be inferred that, water availability can largely influence abundance and spatial distribution of wild wildebeest and other water dependent animals like buffalo and waterbuck.

5.1.4. Wildebeest density in relation to distance from roads

Wildebeest density was found to be positively associated with distance from roads. This association was statistically non-significant. However, based on descriptive results (See figure 4-5), as the distance from roads increased wildebeest density was increasing. The possible cause for this increase might be due to the fact that animals tend to avoid areas near to roads, thus, the shorter the distance to the roads, there is a high probability of animals to confront roads associated disturbances and threats such as traffic dust, road kills and noise from moving vehicles.

5.1.5. Wildebeest density in relation to elevation

Significant positive relationship was detected between wildebeest density and elevation. This implies, at higher elevation wildebeest density is expected to increase compared to areas with low elevation within the plains. No literature suggesting the effect of elevation exist in Serengeti, therefore the observed high wildebeest presence and a highly significant ($P<0.001$) relationship between elevation and wildebeest density is assumed to be related to the fact that elevation might have a direct effect on climate (e.g. rainfall and temperature) and vegetation. The assumed effect of elevation on climate is supported by highly significant ($P=0.005$, $r= - 0. 258$) negative association between rainfall and elevation found in the present study (see table 4-9). From this relationship, it implies that at higher elevation there is less rainfall. This holds true for Serengeti Plains which are situated in a relatively higher elevation compared to other parts of the park. Evidence exist in Serengeti (Thirgood *et al.,* 2004) and elsewhere (Marshal *et al.,* 2005) that rainfall acts as an important factor that determine vegetation growth and availability of forage biomass. Lower rainfall per year received in the plains has been discussed in previous (section 5.2).

Literature suggests that differences in elevation can affect temperature and rainfall (Gillis *et al.,* 2005; Körner, 2007). For example, temperature and rainfall change with elevation, thus change in either can affect soil microbial activities which alter soil characteristics and availability of soil nutrients. Combination of these factors can determine availability of forage which in turn can influence species abundance and spatial distribution. Furthermore, evidence exist that climate influence vegetation growth and composition (Skarpe, 1996). The effect of elevation on shaping vegetation structure and its relationship with density has also been reported in Kenya (Ngene, 2008 in press), and in Guinea (Schlossman, 2006).

5.2. Analysis of potential factors influencing wildebeest density

Generally, in any ecosystem, there are multiple factors and processes that can act separately or in combination with others to exert their influence. The present study assessed the relationship between five environmental factors and wildebeest density. Separately, three of these variables had a negative and two had a positive influence on wildebeest. Combination of these environmental variables in determining which ones are the most influencing wildebeest density and spatial distribution revealed that short and long grass, distance from rivers and elevation were the main factors explaining wildebeest density and spatial distribution. Among the five variables in regression model, only elevation contributed significantly to the final model. Generally, within the study area elevation range from 1300 to 2000 m.a.s.l (see appendix 8-8), it is possible for this altitude range to have impact on animal abundance. Elevation on its own explained 30% of the total variation in the final model. This can be attributed to have an indirect effect on spatial distribution of wildebeest through influencing climate. Elevation has been reported as an important ecological and biophysical factor elsewhere, however, in Serengeti ecosystem this factor is probably ignored and remains undocumented. To re-confirms its influence, elevation can be further investigated with a broader set of other predictors (not addressed in this study) in combination with cumulative wildebeest density (wet and dry season) in future studies to assess how these factors can influence density and spatial distribution of wildebeest. Understanding factors which explain wildebeest distribution should be a key for conservation managers as wildebeest plays an important role in maintaining the ecosystem.

5.3. Summary of study findings

In determining the most important factors, multiple regression revealed grasslands (short and long), distance from rivers and elevation turned out as factors explaining wildebeest density and spatial distribution. This does not necessarily mean that factors excluded in the final model are not important or have negligible effect on abundance and spatial distribution of wildebeest. Based on these findings, it is apparent that consideration of other factors in the model such as vegetation greenness, soil types, and effect of fire, temperature, predation and other human induced disturbances which were beyond the scope of the present study could have explained better abundance and spatial distribution of wildebeest significant factors explained 35.5% of total variation. Therefore, it would be worth to repeat this work over several years (using data of different years) to find out if elevation real is a main contributor in variation of wildebeest presence in the study area or it is a matter of coincidence.

5.4. Data quality and study limitation

The initial dataset planned for this study was sufficiently large enough for modelling purposes, but due to unavailability of satellite images matching with census data it was not possible to use entire dataset (wildebeest census data for 1998, 1999, 2000, 2003 and 2006), therefore opted for 2003 census data. Furthermore, present study does not assume to have included all factors that could have better explained wildebeest-environmental interaction. Lastly, it should be understood that the study findings are only valid under the same condition in the study area.

6. Conclusion

6.1. Specific conclusion

The present study aimed at assessing relationship between environmental factors and wildebeest abundance and distribution at a local scale within the Serengeti National Park. To achieve study objectives, statistics together with GIS and remote sensing techniques were used. Study findings have demonstrated that these tools can provide information on important factors influencing animal abundance and distribution. Following study results and discussion, the following conclusions (based on hypotheses) are presented.

Hypothesis 1: Wildebeest shows no preference on vegetation types (density in short grass = other vegetation). The null hypothesis was rejected. Wildebeest shows preference either on short grass or long grass vegetation types. High percentage of density was observed in short grassland compared to other vegetation structure.

Hypothesis 2: Rainfall has a negative effect on wildebeest density (β=0)

There is a significant negative relationship between wildebeest density and rainfall. Therefore, the null hypothesis on the influence of rainfall on density was rejected. Rainfall seems to have a negative effect on wildebeest density; at the spatial and temporal scale investigated it implies that high wildebeest densities in Serengeti plains are expected in areas with low rainfall.

Hypothesis 3: Distance from rivers has no effect on wildebeest density ($\beta = 0$)

There is a significant negative relationship between wildebeest density and distance from rivers; therefore the null hypothesis was rejected. This implies that closer to rivers higher wildebeest densities are expected. This is observation is possible because wildebeest are water-dependent animals, therefore are expected closer to water points.

Hypothesis 4: Distance from roads has no effect on wildebeest distribution ($\beta = 0$)
There is a non-significant positive relationship between wildebeest density and distance from roads, therefore failed to reject the null hypothesis.

Hypothesis 5: Elevation has a negative effect on wildebeest density ($\beta = 0$)

There is a significant positive relationship between wildebeest density and elevation. Therefore the null hypothesis was rejected. This implies that at the particular local scale investigated, higher wildebeest densities are related with altitude. This is possible because at high altitude few water points exist and the possibility for surface run off water is reduced. This observation conforms to wildebeest tendency of avoiding wetter areas.

Hypothesis 6: None of the environmental factors has an effect on wildebeest density (β = 0)
Backward multiple regression model provided evidence to reject the null hypothesis and conclude that among the five predictors used at least one factor is explaining better wildebeest density. Out of the five factors used in the model, grasslands (short and long), distance from rivers and elevation turned out as factors explaining wildebeest density.

Hypothesis 7: Wildebeest are randomly distributed within the study area
This hypothesis was not archieved

6.2. General conclusion

As previously mentioned, the purpose of the present study was to establish the relationship based on knowledge between species and the environment. Study findings have revealed existence of relationship between these factors and wildebeest density. In simple linear regression analysis, four out of five factors were significant related to wildebeest density. However, a combination of all environmental factors in multiple (backward) regression long grass, short grass, distance from rivers and elevation remained in the final.

It should be understood that animal presence in a given area at a given time is a function of multiple factors, therefore acknowledgment is made that not all important factors influencing wildebeest density and distribution were considered in the present study. However, the present study can contribute to bridge a gap and add a body of knowledge related to wildebeest and the environment and can be a good step for future research to confirm or refute present findings.

6.3. Recommendation

The following recommendations are put forward for conservation managers and researchers:-

- The present work should be repeated for other years to establish whether elevation contributes significantly to wildebeest distribution or it is a coincidence. In case the repeated study yields the same results, then elevation can be considered as an important biophysical factor influencing wildebeest distribution and possibly other related herbivores (e.g. zebra).

- Future work on species-environment relationship should include other environmental factors such as vegetation greenness, soil types, and effect of fire, temperature, predation, competition and other human induced disturbances which were beyond the scope of the present study.

- GIS and remote sensing techniques have proven successful in mapping and monitoring wildlife as mentioned in chapter one, but the role of these techniques in Serengeti National Park is not emphasized. Only very few studies exist which explored potentiality of these techniques. Therefore it is proposed to explore the potential of these techniques in conservation and management of wildlife species.

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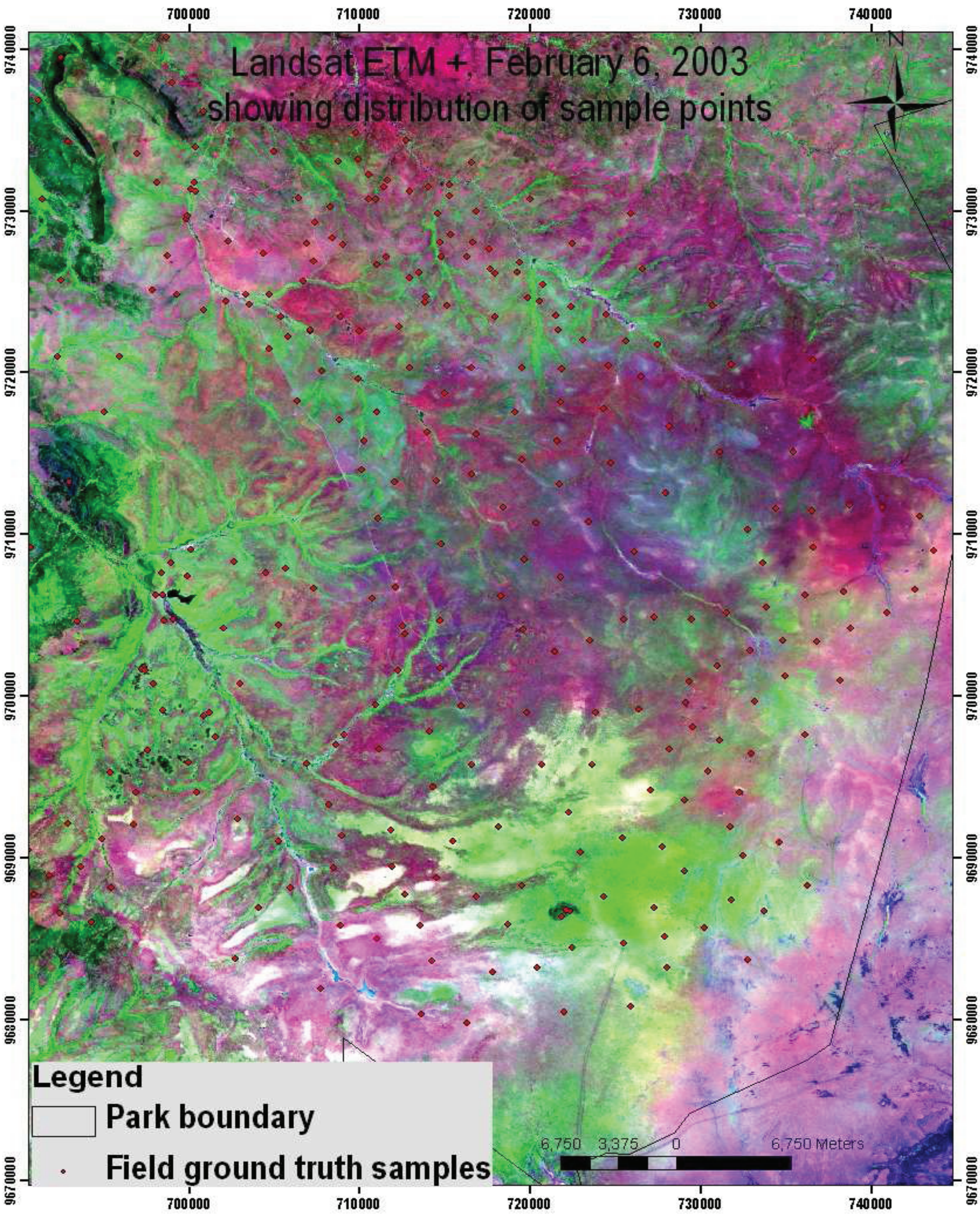
8. Appendices

Appendix 8-1 (a): Map showing distribution of field sample points



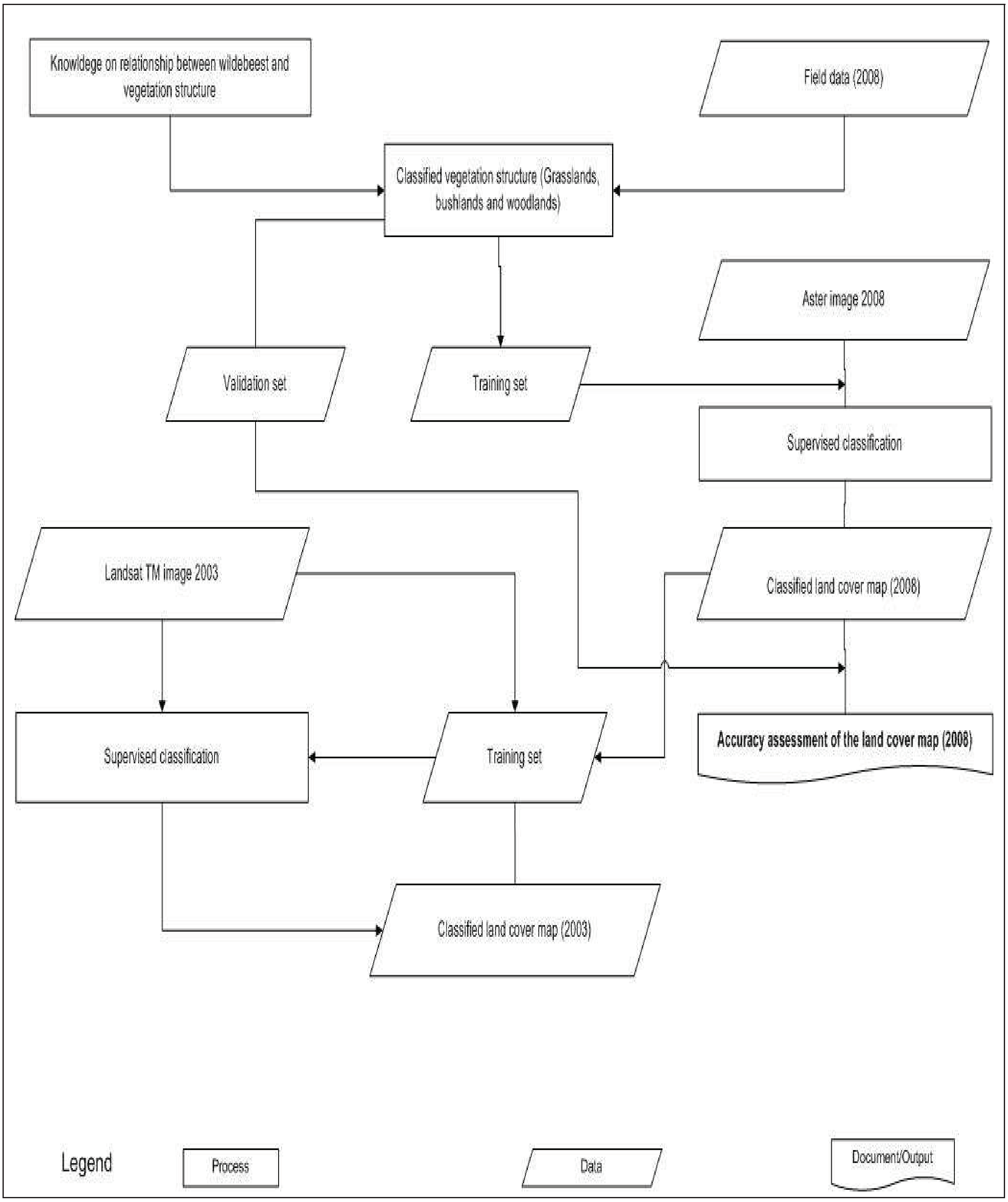
Appendix 8-1 (b): Vegetation sampling data form

Serengeti Plains (Southern of Serengeti National Park)				Sample No:
Date:		GPS reading	X	Observer name:
Photo no:			Y	
Layer / Strata	Height (m)	% Cover	Dominant species	% cover
Woodlands layer				
Shrub layer				
Grasslands layer				
Bare soil				
Total % cover in each layer				
Plot size:		5 x 5 meters	10 x 10 meters	
Other observations:				

Appendix 8-1 (c): Grassland categorization (Based on height and amount of dead biomass)

	
Photo -1: Long grass	Photo -2: Long grass
	
Photo -3: Short grass	Photo-4: Short grass

Appendix 8-2: Classification flow chart for Aster 2008 and Landsat ETM + 2003 images



Appendix 8-2: (a): ERROR MATRIX REFERENCE DATA

Classified Data	Dense woodlands	Open woodlands	Shrublands	Long grass	Short grass	Water	Bare areas
Dense woodlands	0	0	0	0	0	0	0
Open woodlands	6	2	1	0	0	0	0
Shrublands	0	4	1	0	0	0	0
Long grass	0	3	3	36	13	0	1
Short grass	0	0	0	2	27	0	2
Water	0	0	0	0	0	0	0
Bare areas	0	0	0	1	0	0	3
Column Total	6	9	5	39	40	0	6

Appendix 8-2: (b): KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.6446

Conditional Kappa for each Category

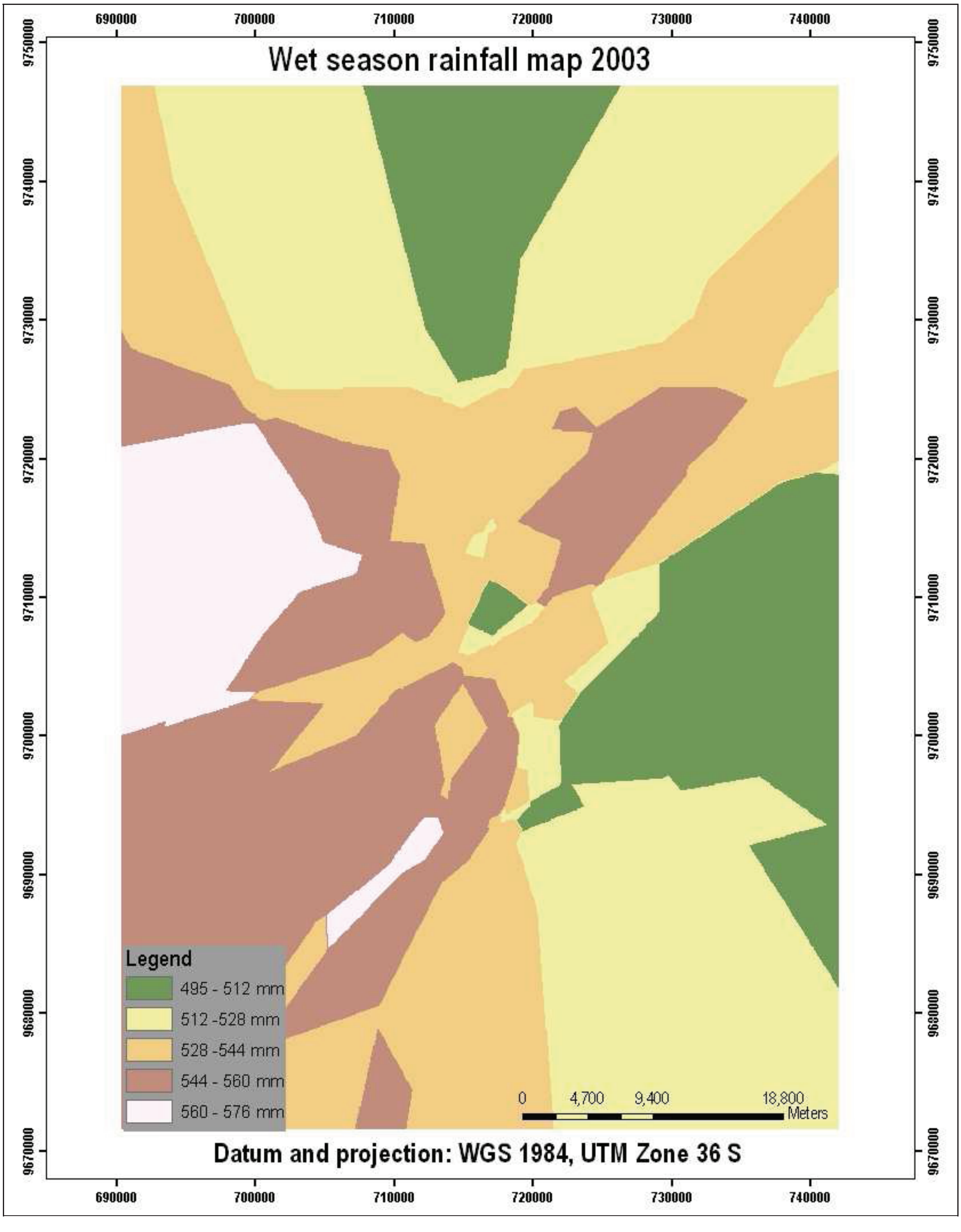
Class Name	Kappa
Dense woodlands	0.6465
Open woodlands	0.7813
Shrublands	0.475
Long grass	0.5545
Short grass	0.7916
Water	0
Bare areas	0.7348

Appendix 8-3: Distance from rivers and roads (Ascending order)

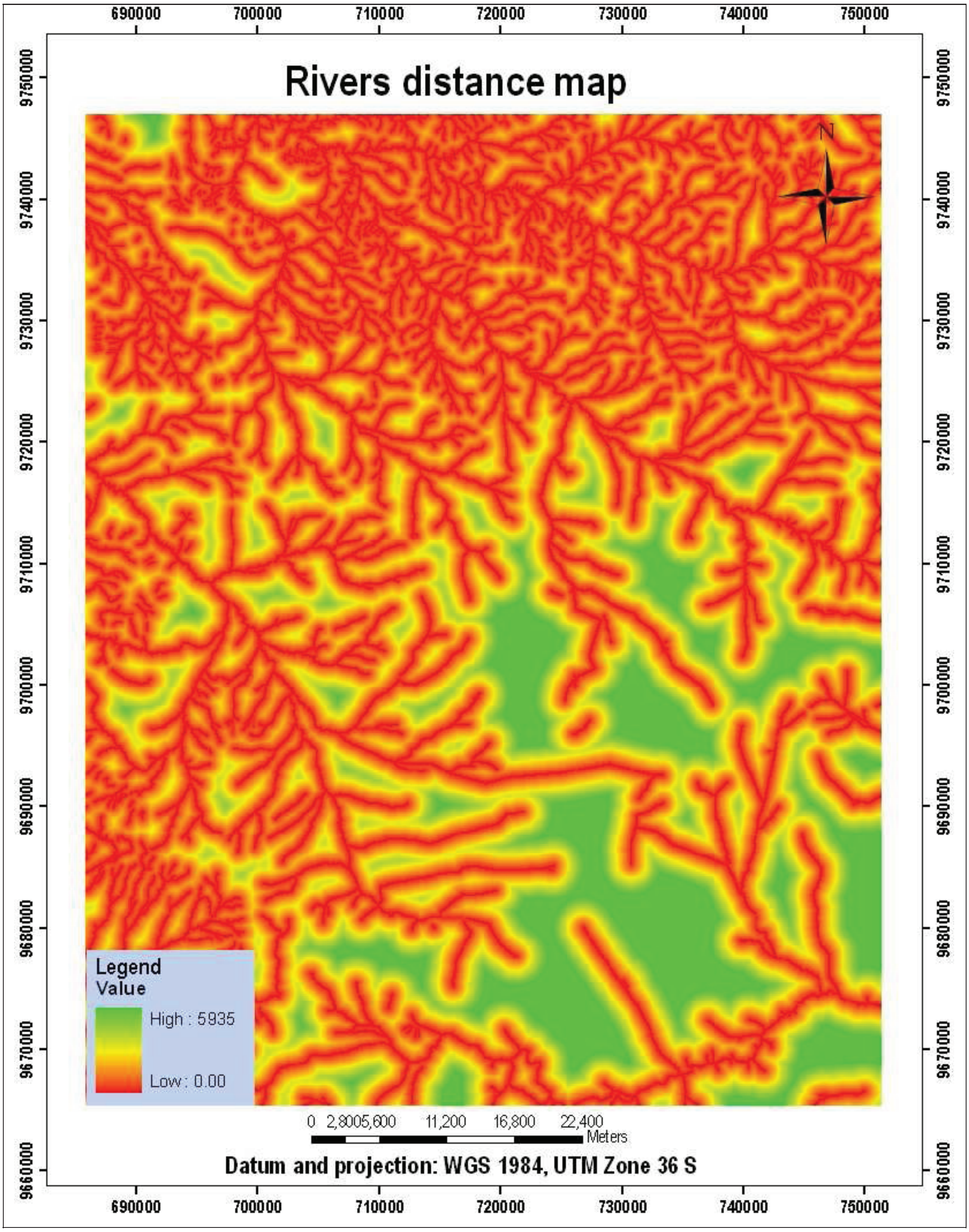
No	Rivers (km)	No	Rivers (km)	No	Roads (km)	No	Roads (km)
1	0.06	61	1.43	1	0.1	61	2.8
2	0.07	62	1.44	2	0.1	62	2.9
3	0.10	63	1.46	3	0.1	63	2.9
4	0.12	64	1.51	4	0.2	64	2.9
5	0.13	65	1.51	5	0.2	65	3.1
6	0.17	66	1.55	6	0.3	66	3.1
7	0.19	67	1.56	7	0.3	67	3.1
8	0.21	68	1.56	8	0.3	68	3.1
9	0.28	69	1.56	9	0.4	69	3.2
10	0.31	70	1.57	10	0.5	70	3.2
11	0.33	71	1.60	11	0.5	71	3.2
12	0.33	72	1.61	12	0.5	72	3.2
13	0.34	73	1.62	13	0.5	73	3.3
14	0.37	74	1.68	14	0.6	74	3.3
15	0.38	75	1.73	15	0.6	75	3.3
16	0.40	76	1.76	16	0.7	76	3.4
17	0.44	77	1.80	17	0.7	77	3.4
18	0.44	78	1.92	18	0.7	78	3.4
19	0.44	79	1.94	19	0.7	79	3.7
20	0.45	80	1.96	20	0.8	80	3.8
21	0.46	81	2.02	21	0.8	81	3.9
22	0.52	82	2.03	22	0.8	82	4.0
23	0.53	83	2.04	23	0.8	83	4.0
24	0.53	84	2.06	24	0.9	84	4.0
25	0.55	85	2.08	25	0.9	85	4.2
26	0.56	86	2.08	26	0.9	86	4.2
27	0.64	87	2.11	27	1.1	87	4.3
28	0.66	88	2.15	28	1.1	88	4.5
29	0.67	89	2.26	29	1.1	89	4.7
30	0.69	90	2.32	30	1.2	90	4.7
31	0.69	91	2.32	31	1.3	91	4.8
32	0.70	92	2.41	32	1.3	92	5.1
33	0.72	93	2.41	33	1.3	93	5.1
34	0.72	94	2.41	34	1.4	94	5.3
35	0.73	95	2.51	35	1.4	95	5.4
36	0.74	96	2.59	36	1.5	96	5.5
37	0.74	97	2.65	37	1.6	97	5.5
38	0.78	98	2.66	38	1.6	98	5.5
39	0.82	99	2.67	39	1.6	99	5.7
40	0.83	100	2.68	40	1.6	100	5.7
41	0.86	101	2.70	41	1.7	101	5.8
42	0.87	102	2.85	42	1.7	102	6.0

43	0.90	103	2.94	43	1.7	103	6.0
44	0.91	104	2.96	44	1.7	104	6.0
45	0.96	105	3.07	45	1.8	105	6.4
46	0.98	106	3.21	46	1.9	106	6.4
47	0.99	107	3.39	47	1.9	107	6.6
48	0.99	108	3.53	48	2.0	108	6.7
49	1.01	109	3.80	49	2.0	109	6.9
50	1.07	110	3.87	50	2.0	110	6.9
51	1.07	111	3.98	51	2.2	111	7.2
52	1.15	112	4.03	52	2.2	112	7.3
53	1.16	113	4.21	53	2.2	113	7.5
54	1.19	114	4.22	54	2.5	114	7.8
55	1.26	115	4.56	55	2.5	115	7.8
56	1.27	116	4.79	56	2.5	116	8.4
57	1.33	117	4.80	57	2.5	117	8.6
58	1.35	118	4.86	58	2.5	118	9.0
59	1.40	119	4.87	59	2.6	119	9.3
60	1.41		1.41	60	2.8		

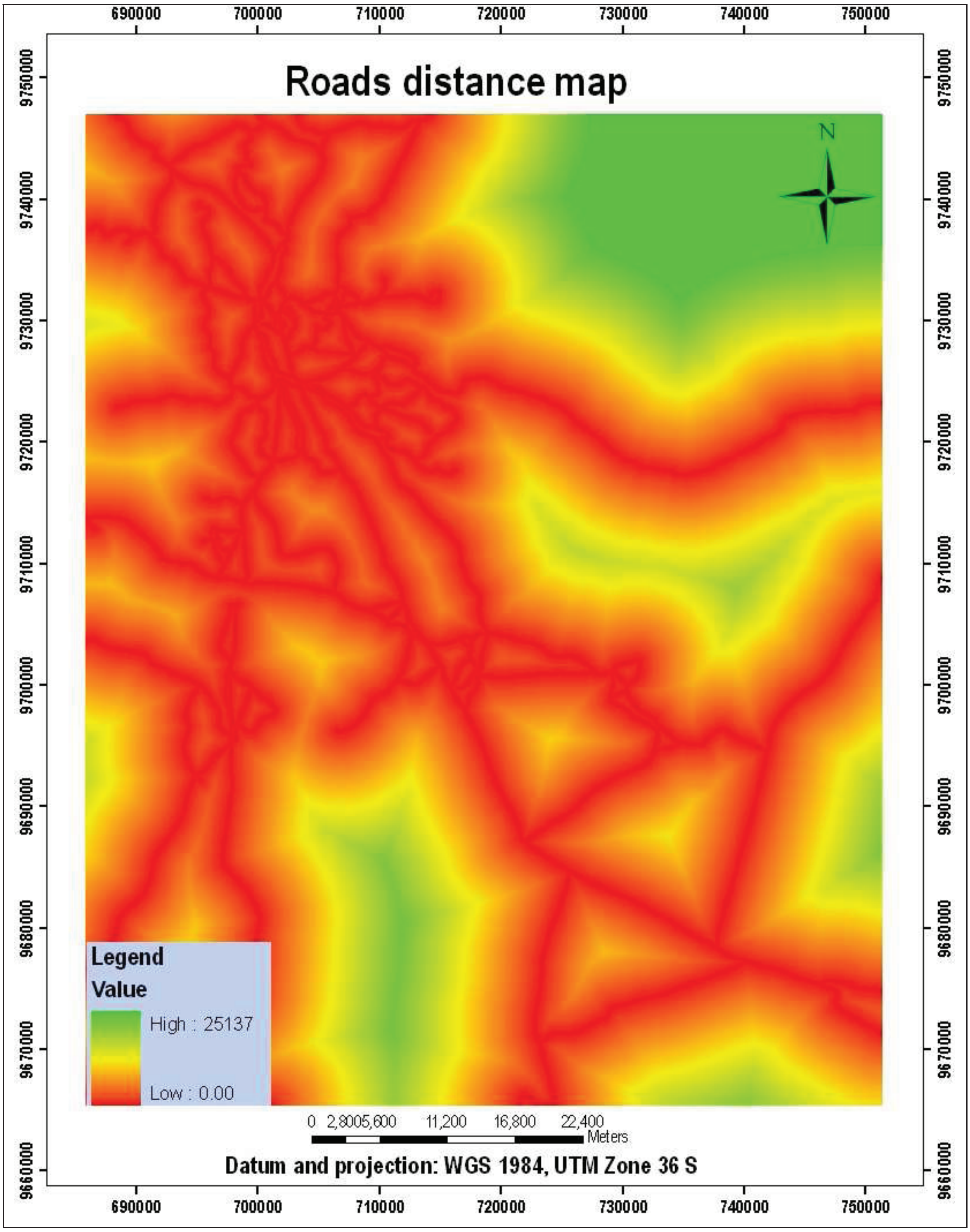
Appendix 8-4: Rainfall map of wet season of 2003



Appendix 8-5: Rivers distance map



Appendix 8-6: Roads distance map



Appendix 8-7: Elevation raster map