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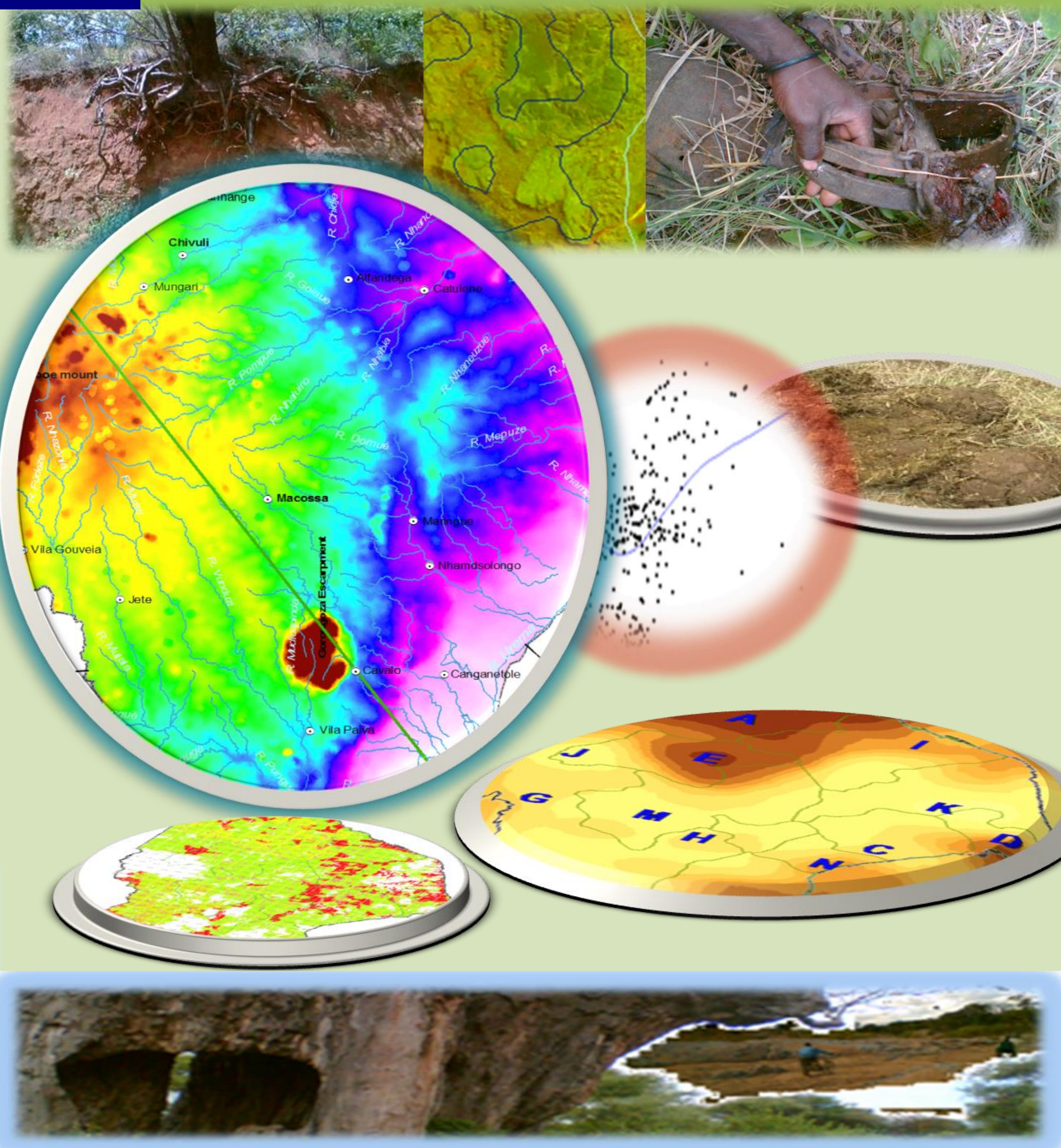

Elephant Conservation Planning and Monitoring in the Mozambique Central Ecosystem Using Geographic Information System and Remote Sensing

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Elephant Conservation Planning and Monitoring in the Mozambique Central Ecosystem Using GIS and Remote Sensing

Abstract

Kernel spatial movement analysis was used to access elephant distribution. Elephant core home range was primarily (48.54%) found in community land comparatively to hunting blocks (35.00%) and national parks (16.45%). The analysis of habitat distribution diversity and availability by means of Landsat ETM+ NDVI imageries, Shannon Winner Index and General Linear Model-GLM long-established that NDVI performance differed significantly ($p = 0.000$) between the habitats, expressing the larger effect size variability between them (Partial Eta= 0.952; $p=0.000$). Further, NDVI increases with altitude (r=0.945, $p= 0.001$) and decreases with plant richness (r= -0.416; $p= 0.727$). This had implications to elephant habitat use. Spatial correlation between elephant distribution and habitat types denoted that Elephant foremost (53.54%) utilized the semi-arid plateau of *combretum spp* and *Colophospermum mopane*; reasonably (34.92%) used the degraded lowlands of Urema and Zambezi floodplains and relatively avoided (11.54%) the moist evergreen afro-montane of *Brachystegia spiciformis*. Repeated ANOVA has shown that elephant habitat use differed significantly ($p = 0.003$) between habitats. Semi-arid plateau was 118.51 times more utilized than the moist evergreen afro-montane. Spatial Model for Landscape Elephant Conservation-SMLEC identified that habitat use by elephant was detrimental to water availability (40.2%; $p=0.000$), human activities (36.80%; $p=0.000$) and vegetation diversity (35.00%; $p=0.000$). Aridity index mostly (8.3%; $p=0.000$) determined the factors influencing elephant habitat use at different landscape units, confirming the hypothesis that elephant survivor at the ecosystem was any strategy of adaptation to the impacts of climate variability.

Elephant Habitat Prediction Model-EHPM based on kriging analysis of ranking scores of elephant critical factors and NDVI, prioritized elephant conservation sites, which were almost found outside protected areas with more prominence in Chivuli (22.23%), Nhamassonge (17.66%), Nhacafula (5.19%) and Chiramba (3.46%) communities. Unfortunately, the habitats are water limited during 8 months. Thus, kriging and NDVI geostatistics induced to the prioritization of future elephant conservation habitats. Kriging was mostly applicable to macro scale prediction while NDVI denoted smaller site details. However it's highly recommended the use of geostatistics for elephant conservation priority setting particularly in developing countries where the rate of habit loss is more likely hasty than preservation strategies.

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List of abreviations and acronyms

%	Percentage
$\overline{X}$	Mean
∑	Sum
<	Less than
=	Equal
>	More than
±	Approximately
≈	Approximately
≥	More or equal to
3D	Three Dimension
Adjusted R square	Standardized R square based on the sample size and degrees of freedom
AI	Aridity index
ANOVA	Analysis of Variance
Arc tool box	a component of ArcGIS containing tools for data analysis
ArcCatalog	a component of ArcGIS for database management
ArcGIS	ESRI Geographic Information System

ArcMap	a component of ArcGIS used for viewing maps
ArcView 3.2	ESRI Geographic Information System
AWF	African Wildlife Foundation
C.V	Coefficient of Variability
D	Simpson index of dominance
DINAT	National Directorate of Land
DTM	Digital Terrain Model
e.g.	Example
EAs	Enumeration Areas
ESRI	Environmental Systems Research Institute
et. al.	and others
FAO	United Nations Organization for Food and Agriculture
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System
GLM	General Linear Model
GNP	Gorongoza National Park
GPS	Global Positioning System
H'	Shannon Winner Index
H_0	Null hypothesis
Ha	Hectare
I-J	Mean Difference
INAM	National Institute of Meteorology
INE	National Institute of Statistics
INIA	National Institute of Agricultural Research
IUCN	International Union for Conservation of Nature
J	Species Evenness
Kg	Kilogram
Km	Kilometre
Km^2	Square Kilometre
LANDSAT ETM^+	Landsat Enhanced Thematic Mapper
LANDSAT MSS	Landsat Multispectral Scanner Subsystem
LANDSAT TM	Landsat Thematic Mapper

LANDSAT	American Satellite for Natural Resources Mapping
Max	Maximal
MICOA	Ministry of for Coordination of Environmental Affairs
Min	Minimal
MITUR	Ministry of Tourism
N	Total number of individuals in each plot
NCA	Ngorongoro Conservation Authority
NDVI	Normalized Difference Vegetation Index
ni	number of individuals of each specie
NIR	Near Infrared Spectral Band
NNE	North to North East
NP	National Park
nr.	number
NRMMP	Natural Resources Management and Monitoring Plans
NSME	National Strategy for the Management of Elephant
p:	Probability
Pas	Protected Areas
PET	Potential Evapotranspiration
Pi	Proportion of total sample
R square	Coefficient of Multiple Determination
R	Rainfall
R	Red spectral band
r	Coefficient of correlation
RENAMO	Resistência Nacional de Moçambique
RS	Remote Sensing
S	Total number of species in each plot
S^2	Variance
SCP	Systematic Conservation Planning
Sdev	Standard deviation
sig.	Significance
SMLEC	Spatial Model for Landscape Elephant Conservation
SPOT	French Satellite

Spp	Species
SPSS	Statistical Package for Social Science
sq km	Square Kilometre
SSE	South to South East
SWRA	Sengwa Wildlife Research Area
T	Temperature
TAWIRE	Tanzania Wildlife Research Institute
TIN	Triangular Irregular Network
UNEP	United Nations for Environmental Protection
UTM	Universal Transversal Mercator
WGS 84	World Geographic System of 84

Chapter 1

Introduction to Biodiversity Conservation, Geographic Information System and Remote Sensing

1.1. General outline

Protected areas in developing countries are faced with a number of management challenges and this has led to a loss of habitat, the largest threat facing wildlife in Africa in particular for large mammals. The reduction of large habitats to smaller and isolated remnants affects their abundance and cut-off migration corridors. As a result when wild fauna move beyond their sanctuaries in search of food they inevitably run into trouble, often from farmers trying to protect their crops. To secure habitats and their wild animals there is a need to understand where the animals are, what they are doing and how do they do. This goes hand-to-hand on monitoring the gaps in the ecosystems which are not conserved (Margules and Pressey, 2000; Margules *et al.*, 2002; Smith, 2006). To monitor the gaps needs a complete consideration of biodiversity measures that go beyond abundance (species richness, diversity within and between species) to the consideration of species distribution and variation over time and scale. One of the greatest difficulties has been the lack of reliable and comprehensive method for surveying, recording, storing and analysing spatial data on ecosystem (Spllerberg, 1991; Margules *et al.*, 2002). Recent trends in Geographic Information Systems (GIS) and Remote Sensing (RS) technologies have undoubtedly enhanced the problem of natural resources management (Yhodeg and Lweno, 2003). GIS integrate all of the natural and human variables operating at a variety of spatial and temporal scales (Wang, 2006). It allows all data to be displayed at once-facilitating comparisons between feature classes (Palminteri *et al.*, 1999; Core, 2006). Thus, GIS facilitate analysis; integrate multiple data types for decision making; depict areas of human-wildlife interactions; denotes landscape utilization by wildlife; store data in geodatabase; determine priority sites for future wildlife conservation (Griffiths-Norton, 1978; Miller, 1996; Palminteri *et al.*, 1999; African Wildlife Foundation *et al.*, 2002; Yhodeg and Lweno, 2003; Hien, 2005; Da Silva 2005; Da Silva and Kaswamila, 2007).

GIS tools work hand to hand with remote sensing data. Remote sensing aims to acquire at long-distance, land surface imageries using sensors (Anderson, 1982; Rudorff, 2000).

These imageries can denote animal numbers and distribution in their environment; evaluate and monitor natural resources overtime; provide data for mapping and characterizing species habitats; assist stratified random sampling strategies for field inventories; facilitate gap analysis assessing the distribution of suitable habitat and protected areas networks in order to determine the degree to which high biodiversity areas are protected; provide data for landscape fragmentation metrics such as patch size, edge length, connectivity; provide data for leaf area and normalized difference vegetation indices as measures of biological productivity; monitor deforestation trends and the spread of invasive species (Griffiths-Norton, 1978; Miller, 1996; Palminteri *et al.*, 1999; Yhodeg and Lweno, 2003; Pacheco, 2004; Ribeiro, 2004; Hien, 2005; De Sherbinin, 2005; Da Silva 2005; Da Silva and Kaswamila, 2007).

This report focuses on Elephant conservation planning and monitoring in Mozambique central ecosystem, particularly in the Gorongoza-Macossa-Guro corridor and uses a GIS technique to analyse the relationship between elephant and their habitats in order to wisely decide which sites can be of prior to Elephant conservation in the country.

This chapter concentrates on the review of different techniques used to map the relationship between Elephant and their habitats.

1.2. **Sampling and patterns of species distribution**

Sampling is the analysis of a group by determining the characteristics of a significant percentage of its members chosen at random (Nie *et al*., 1989; Furlanello *et al*., 2003; Pallant, 2005; USGS, 2007). The concept of a sample can be generalized to the case of multiple measurements on the same locality (Burrough and McDonnell, 1996).

Patterns, the spatial arrangement, texture and orientation of resources, refers to the shape and configuration (arrangement), size and spacing (texture) and direction (orientation) of resources (Anderson, 1982; Anselin, 1992; Robinson *et al*., 1995; ICRUM; 2006) and indicate location, spatial interactions, spatial structures and spatial processes at work, which order ecological communities (Wiens, 1989; Allen and Starr, 1982; Noss 1990; Anselin, 1992).

The critical and often difficult task, of finding species distributions and assemblages is identifying the spatial scale at which those patterns occur (Sandler *at al.*, 1998), since they are many and vary accordingly to our capacities of detection (Spellerberg, 1991; Wiens, 1989).

Patterns of species distribution can be identified using sampling and this relies on sampling method and sample size (Duzgun and Usul, 2007). Spatial configuration of the sampling design influences results and subsequent management systems (Sandler *at al.*, 1998; Mao *et al*., 2000).

The sampling methods are basically divided into two categories such as, probability and non-probability sampling (Freiden *et al*., 1997; Furlanello *et al*., 2003; Duzgun and Usul, 2007). The non-probability sampling is based on subjective judgement, while the probability sampling uses random chance to select observation to be involved in the sample (Walford, 1995).

Random sampling is mostly applied particularly for situations where the population size is known (Duzgun and Usul, 2007). However, this method can not select the sample points accurately as it is not based on the error distribution (Mao *et al*., 2000). This needs a consideration of spatial heterogeneity and spatial dependence (Anselin, 1992).

The spatial heterogeneity pertains to habitats differentiation, which follows from the intrinsic uniqueness of each location. The specification of each area is determined by taking samples and calculating the mean ($\overline{X}$) and variance (S^2); if $S^2 = 0$ the population is dispersed uniformly, $\overline{X} = S^2$ the population is randomly distributed and then if $S^2 > \overline{X}$ aggregation occurs (Spellerberg, 1991).Thus, to draw conclusions from the study of a sample, it is necessary that it represents some equilibrium (Olsen *et al*., 2005). For example, when sampling different habitats in Tanzania Conservation Lands Trust it was found that there was a variation of vegetation density; some habitats stated greater spatial density of vegetation than other habitats, which led to suggest that a balanced sample would reflect these variations in spatial density pattern (Da Silva and Kaswamila, 2007).

The second spatial effect is spatial dependence that is related to spatial autocorrelation, where everything is related to everything else, but near things are more related than distant things (Anselin, 1992). The spatial dependency is present in every direction and gets weaker the more the dispersion (Camara *et al.,* 2003).As a consequence, similar values for a variable will tend to occur in nearby locations, leading to spatial clusters (G'omez-Rubio *et al*., 2003). This spatial clustering implies that many samples of geographical data will no longer satisfy statistical assumption of independence of observations (Mao *et al*., 2000; Jenness, 2006).

The dependence in single judge-based sampling scheme may result in points located in easy-going place while the points located in difficult to reach areas will be neglected and misestimated, and this can not reflect the true appearance and accuracy of the map.

These issues may be remedied by designing a sampling scheme that spaces observations such that their interaction is negligible. Indeed, a sampling method that incorporates sampling in two or more dimensions is called spatial sampling (Anselin, 1992; Burrough and McDonnell, 1996; Majure *et al.*, 2004).

1.2.1. **Spatial sampling and optimum sample size**

Spatial sampling considers the population to be represented and the models within the population to be sampled. In this respect, because samples are done spatially, they are located evenly over the area (Burrough and McDonnell, 1996).

This sampling is not merely regular, stratified, cluster, random; it should be a flexible technique where individual points are located at random within stratums and regularly laid out blocks (*quadtree*) (Burrough and McDonnell, 1996; Shriner and Simons, 2005; Duzgun and Usul, 2007).

In spatial sampling the population is divided into segments, the segments are assigned weights or proportions mathematically, and then the segments are spatial sampled randomly (Freiden *et al.*, 1997; Todorovic *at al.,* 1998).

For sampling and determination of optimum sample size in GIS, available digital contour line data was converted into set of points with attributes of elevation (Mao *et al*., 2000; Duzgun and Usul, 2007). First, a Triangular Irregular Network (TIN) layer from the contours was created. Then the raster TIN layer was transformed into a vector layer of points. Later the TIN vector layer was associated with the elevation attributes by using the spatial join operation in ArcGIS. In joining the elevation attributes to the points, each point is given a mean elevation value from the contour lines (ESRI, 2000). Using this method Duzgun and Usul (2007) obtained a layer composed of 89728 points of elevation values. The Elevation points (89728) were classified into four stratums based on there values. Depending on total number of points in each stratum the size of population for sampling was randomly selected.

In order to determine optimum sample size, several numbers of samples were drawn and it was found that when the sample size increases, the length of internal confidence and the standard error decrease (Duzgun and Usul, 2007). A sample size of 5% (4486) of total population (89728) can be considered as optimum sample size, since the curves start levelling out at this sample size. However, based on the length of confidence interval and standard error of the mean it was possible to design optimum sample size for topographic data.

A study on vegetation of Simanjiro plain-Tanzania has shown, from a specie number curve and for quadrats of 1 m x 1 m, that approximately 50 quadrats would be required to make a representative sample of most, if not all, of the grass species present. A comparison of sampled size against sampled area will help to determine the appropriate combination for a vegetation unit of interest (Kahurananga, 1974). Area is important in determining the shape of the extinction curve. High specie richness is present in large areas and not in those containing few species, simply because there will be more rare species present (Wiens, 1989). Thus positive correlation between species numbers and extension must exist and might be explained by different theories.

Island Biogeography theory states that the probability of extinction of any single species, however, is expected to increase as area decreases, as population sizes should be smaller and therefore more sensitive to chance catastrophes (*ibid*).

Challenging Biogeography theory, the habitat diversity theory considers that a positive correlation derives from the fact that large areas contain more types of habitat, and so consequently more species (Connor and McCoy, 1979).

Therefore to determine precisely the reality of each theory it is more difficult when there are more factors that can determine the specie-area relationship (Wiens, 1989; Tilman and Pacala, 1993), such as successional stage of the community, unplanned human activities, neighbour effect, characteristics of the species, dispersal distance.

For instance, large body mammals are associated to larger home range. This led to suggest that longer dispersal distance is significantly dependent on the degree of heterogeneity of the surrounding habitats (Da Silva, 2007b). Thus, where water and food are abundant and disturbance is minimal, it can be expected that home ranges will be smaller; consequently smaller area will contain higher species diversity (Kernick, 1980; Barnes, 1996).

Sample area shape is also of concern. Data on vegetation is mostly sampled using point centered quadrats, transects and quadrats (Kernick, 1980). Quadrats are of rectangular, circular and square shape. The shape of sampling unit influences spatial configuration of the sampled area and consequently the sampling error.

Using quadrats of different shape but similar area, different species density values were obtained due to the perimeter-area ratios of both square and circular plots (Waddington, 1994). The specie-area relationship shown that standard deviation was very much lower for square plots than the circular, suggesting a higher degree of consistency and thus predictability through that data set. The square quadrat is spatially related to point spatial model.

One of critical issue in point model is the fact that it does not offer complete cover of the area (Burrough and McDonnell, 1996). Furthermore, full field inventories of the vast tracts of land that have not yet been surveyed would be cost prohibitive basing on that model (De Sherbinin, 2005).This situation added to the fact that sampling can not achieve the same levels of data confidence and accuracy as 100% checking (Freiden *et al*., 1997), take us to conclude that field observations must be combined with satellite imageries and aerial photos for predictive mapping of species richness (Burrough and McDonnell, 1996; Pittman *et al*., 2005; Shriner and Simons, 2005; De Sherbinin, 2002 & 2005).

1.3. **Satellite imageries-aerial photos and habitats patterns**

Many data sets in African countries are outdated due to lack of a regular data collection as a resulted by poor economic and financial status.

In fact detailed land cover types conducted in broad-scale studies is cost full but a combination of low cost satellite imagery and available elevation data and relevant species distribution data, can provide a valuable basis for any planning exercise (Somasiri and Herath, 1996; Wiens and Moss, 2005; Smith *et al*, 2006).

Landsat satellite imagery has been widely used for vegetation mapping (Tucker, 1979 and 1981; Rimsten, 1994; Junior, 1998; Miller, 1996; Beilfuss *et. al.*, 2001; Moreira, 2001; Da Silva 2005 and 2007; Da Silva and Kaswamila, 2007). A map of vegetation types and/or environmental classes provides spatial consistency across wide areas (Margules and Pressey, 2000).Thus, a quality vegetation map is provided by a combination of spatial sampling and vegetation classes obtained by multi-spectral satellite imagery, digital or visual interpretated.

Using digital interpretation of LANDSAT TM imagery it was shown not only vegetation location, distribution and extent but also its vulnerability (density), using Normalized Difference Vegetation Index (NDVI) (Tucker, 1979 and 1981; Rimsten, 1994; Junior, 1998; Moreira, 2001; Da Silva, 2005 and 2007a).

The NDVI is based on subtraction of digital values intensity present in near infrared and red bands, pixel by pixel, and a result is obtained by dividing the addition of near-infrared and red bands, the value of the difference between the two spectral bands. The resulted pixel value varies between 0.1 and 1 for vegetation, in LANDSAT TM (Tucker, 1979; Tucker, 1981 and Moreira, 2001). Higher values of NDVI denote dense vegetation, decreasing with reduction of digital values (ESRI, 1998).

For example, when analysing the relationship between biodiversity and environmental indicators in Tanzania Conservation Lands Trust using LANDSAT ETM$^+$ it was found that plant species diversity differed from different spatial patterns of distribution of NDVI. The higher (0.2101) NDVI values were associated to Acacia woodland habitat dominated by *Acacia drepanolobium* (38.18%) gradually decreasing (0.1103) for Bushland habitat dominated by *Dichrostachys cinerea* (55.86%), lower (0.0499) for Grassland habitat dominated by *Sporabus iocladus* (51.47%) and very lower (-0.0440) for bare soil and water points of any plant species governing the area (Da Silva 2007a; Da Silva and Kaswamila, 2007). Thus, there is a relationship between habitat categorizations based on NDVI patterns and plant species distributions. Moreover, this has led to suggest that bare soil and water bodies can result in digital values that reach zero or even negative, respectively (ESRI, 1998; Da Silva 2007a).

A study on evaluation of mangrove vegetation dynamics in Zambezi Delta River-Mozambique using LANDSAT TM of two dates has shown that NDVI of bare soil reaches zero, although difficult in mapping these areas due to the presence of small spatial fragmentations resulted by another land use/cover practices (Da Silva, 2005).

When comparing spectral reflectance differences in areas of bare soil that had cattle grazing with protected areas of dense vegetation cover, Otterman (1981) has noted occurrence of higher spectral reflectance in two thirds of unprotected bare soils compared to Protected Areas (Rimsten, 1994).

Combining SPOT panchromatic band (high spatial resolution) with the infra-red bands of TM, using the stereoscopic view of the SPOT imagery, lithologic discriminations were mapped and it was noted that altitudinal differences (e.g. slope percentage) result in higher erosion vulnerability of steeper slopes (Paradela *et al*., 1990).

Using hydrologic network to evaluate the risk of erosion it was noted that areas of higher level of erosion are associated to dendritic and parallel patterns due to higher inclination and these areas are of low vegetation density (Anderson, 1982).

LANDSAT MSS (Multispectral Scanner Subsystem) imagery was used for soil erosion risk identification basing on correlation of ravine’s frequency (extracted from aerial photography) and vegetation density (extracted from satellite imagery). A scale of erosion risk was composed, having concluded that MSS imagery is a potential data for erosion risk areas survey through NDVI variation. Thus, areas of higher erosion risk are correlated to low NDVI values of low vegetation cover (Pinto, 1996; ESRI, 1998).

Therefore, threats in the field of remote sensing systems use are noticed. When correlating wavelength and capacity of detention and visualization of the components it was suggested that the shorter the wave length, the smaller size objects detect but the easier abortion by the atmosphere while the longer wavelength although easier across the atmosphere, is related to the aggregation of objects due to low spatial resolution (De Sherbinin, 2002).

In Malawi, forest inventory using LANDSATTM imagery had its limitations due to the availability of the imagery only in the dry season where the deciduous vegetation (e.g. *Impatiens flanaganiae*) takes off their leaves (Rosenholm, 1993). In addition, change of NDVI values not only notice biological productivity but also to the differences on environmental conditions where it is located (Guyot, 1990). Thus, the results of satellite imageries can not be generalized.

In Amboseli National Park (Kenya), aerial counts did not offer detailed data on pasture conditions which largely dictated animal distribution (Griffiths-Norton, 1978). In this respect, the major problem with identifying land cover with remotely sensed data is to understand the dominant land cover depicted in each pixel (Burrough and McDonnell, 1996), although its importance to wildlife foraging decisions is well documented.

1.4. **Habitats heterogeneity and Elephant feeding behaviour**

Habitats refer to the interacting systems of living and non-living components found in nature that form structural (e.g. topography, soil, water sources, vegetation) and functional (e.g. breeding, feeding, shelter, shade grounds) units (MICOA, 1997), which vary in time and scale. Habitats are not homogenous due to the variability of these interacting biotic and abiotic factors added to the fact that resources extraction, whether from agriculture, mining, gas drilling or from construction of infrastructure impact on habitats total extent resulting on edges, patches, ecotones (Cranston, 2006; TAWIRE, 2007). A reduction of total area to smaller and isolated patches affects population size (species abundance) and cut-off migration corridors (Wilcove *et al.*, 1986; Wiens, 1989; AWF *et al.*, 2002; Wilson *et al.*, 2006) and with ever growing population and increase of their needs on land, reflects on species extinction. These associated factors acting on habitats give us the responsibility of controlling habitats quality (availability and security). Resources availability model describes the parameters that attract species such as food (type, abundance/greenness, moist content, age, toxic effects, height, weight, distance to edges); water (quantity, purity and distribution), cover (canopy closure, leaf area, density, concentration, dispersion, distance to edges) and dinning sites as a function of slope, aspect, solar radiation, soil wetness, rainfall, temperature, human land uses variability (Kernick, 1980; Behnke, 1999; Core, 2006; Cranston, 2006).

Habitat security is based on human-caused impacts such as encroachment that cause species death as a mean of fire, forest edges, density and distance to roads, settlements (Behnke, 1999; Cranston, 2006).

Each of the variables can be represented, in GIS, by raster surfaces and combined using spatial analyst. The models use multivariate regression analysis of species location overlaid with habitat maps (Core, 2006; Cranston, 2006; Jessen, 2006). The results of this activity varied in time and place:

A study on human-elephant interactions in the Sebungwe ecosystem (Zimbabwe) found that density of elephant were lower on communal lands due to agricultural expansion and human settlements, which led to suggest that elephant and human coexist at variable abundance until a threshold of land cover transformation is reached in the natural habitat matrix, where after elephant disappear (Hoare, 1998).

In northeastern Ghana scientists studied elephant and human ecology and noted that as human continues to grow there is a pressure on land that results on soil fertility decline due to over-use. This affects the habitat quality for elephant. If elephant are survive in a crowded landscape, and then there must be a land-use plan, which requires a detailed study on agriculture, human ecology, and assessment of how many people the land can support (Barnes, 1996).

A research in Sengwa Wildlife Research Area (SWRA) analysed the ecology of crop raiding elephant and have concluded that although elephant are attracted by crops in the communal lands, as they decline in quality the species remain in the area due to the quality of wild grass. In addition, elephant feed on wild browse in the communal lands because fire and elephant have reduced the availability of preferred tree species within the SWRA (Osborne, 2005). The same conclusion was found in Malawi where crop raiding by elephant was attributed to the small number of adult bulls (Bhima, 1998). The issue behind adult bull elephant crop-raiding was reported in Kenya and scientists advocate that if they are to succeed in sexual contests for females, they need high-quality food to build up their strength.

In Malawi, a study found that higher density of elephant occurred in the mixed woodland/thicket, the floodplain and the scrub mopane due to the richest vegetation in terms of species numbers. Thus availability of suitable forage in the protected areas may keep the elephant away from the crops (Bhima, 1998).

In Kenya, researchers used GPS radio collars to track Elephant movements between Amboseli National Park and Longido Game Controlled Area and have found that they have moved to areas which contain *Acacia xanthophloea* woodland of mixed age. This woodland is heavily browsed by elephant on the edge of a swamp filled with nutritious swamp grasses with high activity pattern early morning to a maximum at 09:00 and 10:00, which then dropped off rapidly as the day warmed to reach another minimum from l5:00 to 16:00. In the late afternoon and early night movements increased rapidly, tending to walk throughout the night until about 04:00. Thus, elephant prefer dense vegetation and its night use due to high diurnal human activities (Douglas-Hamilton, 1998).

In Congo scientists used remote sensing for mapping habitats and predict species distribution and abundance. Unfortunately, the animal species were less correlated with habitat type identified through remote sensing. A species must be either common enough and/or habitat-specific enough to exhibit a significant relationship with one or more remotely sensed habitat types" (De Sherbinin, 2005). In addition, NDVI was not correlated at all with the presence of animal species unless the higher density of species was found in areas with higher NDVI.

A study of Elephant habitats use applied satellite tracking in northern Cameron and reported that elephant select habitats not based on vegetation diversity but due to water availability and distribution. During the wet season elephant preferred the floodplain, due to perennial grasses. When water is scarce, in the dry season, elephant use *Acacia seyal*, resulting on reduction of vegetation cover and consequently increase of flooded land when new rain come (Tchamba *et. al.*, 1994).

Similar findings were found in northern Botswana when using aerial survey data to monitor trends of elephant population and reported that elephant range differed from dry and wet seasons. Wet season range extent was high, shrinking in response to the drying up of seasonal pans and streams when the animals concentrate near the permanent rivers (Gibson *et. al*., 1998).This cause more degradation of around water point areas resulting on forage reduction, erosion, sedimentation, seasonal flooding and the costs of getting forage increase as the distance from water points increase.

Similar to Kernick (1980); (Tchamba, 1998); Behnke (1999); in wet season water and pasture are available and located near permanent and temporary water points that will result on pattern of concentration of herbs. As the dry season progresses herbs are forced to quit temporary water to concentrate around permanent water points. In this season there is no good pastures left around used permanent water points and as the dry season progresses animals must walk increasingly long distances between permanent water points and peripheral pasture areas. This pattern persists until the first strong rains of the new wet season, when the herbs shift to far-flung pasture areas. Later in the wet season when rainfall has become more general and the grazing around permanent settlement has recovered, the herbs will return to their home areas and the cycle begins again. Therefore needs of herbs; forage conditions, nature of rains in different years, distribution of water points bound herbs movement and resources uses.

1.5. **Elephant conservation issue in Mozambique**

Abiotic ecological change and the way the distinct land use are practised, are modifying the natural environment and the impact of the environmental change in biological diversity is increasing (IUCN, 1998; Baillie, *et al.,* 2004). For example, until May 1998 about 5-20% of forests and invertebrates were condemned to the extinction in the world (IUCN, 1998). In 2004 the *IUCN Red List* identifies 12% of birds as threatened, 23% of mammals, and 32% of amphibians (Baillie, *et al.*, 2004).

In order to regulate the human land use practices and to prevent massive extinction of biodiversity, since 1932, conservation areas have been gazetted, covering 8.83% (13,232,275 km^2) at worldwide level (IUCN, 1998). Many African countries have been dedicating their land to protection strategies. In Mozambique 15.81% (126381.978 sq km) of the total land (799380 sq km) is somehow protected of which 4.69% National Parks dedicated to tourism activities, 5.84% reserves and 5.28% hunting areas where any human activity is allowed such of the open areas (84.19%) (MITUR, 2003).

Despite these efforts, lack of systematic data collection has influenced poor design of Protected Areas (PAs), as it was only based on the presence of large game populations in particular area for the purpose of controlling their utilization (Severre, 2000; Songorwa, 2004; Goodman, 2004). This rose doubt on the suitable location and real boundary of those PAs; sometimes there is a use of administrative and economic boundaries whereas landscape units and components do not recognize it (Cumming, 1999; Sandwith, 2001).

The boundaries of such PAs were therefore more often based on economic considerations than ecological requirements (Kideghesho, 1999).

As a result, much of the biodiversity most in need of protection has not been protected and now there is a strong loss of unprotected biological diversity (Campbell and Hofer, 1995; New, 2000; Severre, 2000; New, 2000; Scherl, *et al.*, 2004; Songorwa, 2004; Margules, 2005). For example, Protected Areas have no enough land for species requiring extensive areas. As a consequence, a mere 1.5% of the total African elephant is adequately protected and an approximately 76% of the range of these species are not protected at all they are most found on private land where sometimes are killed by humans (Ogilvie, 1992; Miller, 1996; Dublin and Taylor, 1996; Blanc, *et al*., 2003; Hien, 2005). In that regard, there is a need to identify, evaluate, select and monitor the habitats in the ecosystems, which are not conserved (Margules and Pressey, 2000; Margules *et al.*, 2002; Margules, 2005; Smith *et. al., 2006*).

Systematic conservation planning (SCP) and gap analysis have been successfully applied in improvement of representativeness and effectiveness of PAs (Margules and Pressey, 2000, Smith *et al*, 2006). Although gap analysis provides an overview of the distribution and conservation status of biodiversity components, one of critical issue is that it operates on a relatively large geographic area and at a coarse spatial scale (1:100,000) (Zimmerman, 2002). The use of small scale in gap analysis falls in several limitations due to its large minimum mapping unit (100 ha to 1 sq km), and can fail to identify small habitat patches, and gradual ecotones (New, 2000; Zimmerman, 2002). Furthermore, gap analysis does not consider cost-effective and cause-effect analysis and this is very critical in the current economical and ecological sustainable development approach. Because PAs design and expansion must address issues at a finer spatial scale (1:24 000 to 1:50 000), to achieve the representativeness of PAs it is considered that an ecological landscape gap analysis must be combined with GIS and RS as a tool in systematic conservation planning.

Planning for Elephant conservation is a priority for this study because elephant utilize a wider landscape than just a Protected Area, so that their survival may depend on much broader protection of the habitats they need. This knowledge could be important to decision-makers when data required for objective decisions as to what should be protected and in what order of priority. With the results of this study it is possible to predict what will happen to the distribution and numbers of species in various conditions and with predictions, it is possible to determine which areas to include in the PAs system if there is a constraint on the area available. In addition, the study will contribute in information for enlarging conservation beyond Protected Areas as the way towards human-wildlife conflict mitigation. Moreover the study will ensure proper natural resources management and monitoring plans (NRMMP), crucial activity to achieve the initiated comprehensive National Strategy for the Management of Elephant (NSME, 1999) in Mozambique.

1.6. **Objectives**

This research activity designed to plan areas for Elephant conservation using Geographic Information System (GIS) and Remote Sensing (RS) technologies in Mozambique.

1.6.1. **Achieved objectives to date**

(a) Determine; by use of transects, GPS, kernel density and home range; the Elephant spatial distribution;

(b) Map; by use of satellite imagery NDVI, GPS, quadrats, Shannon index; the habitat diversity spatial distribution;

(c) Examine; by use of statistics and spatial correlation analysis; the relationship between habitat types and Elephant spatial distribution;

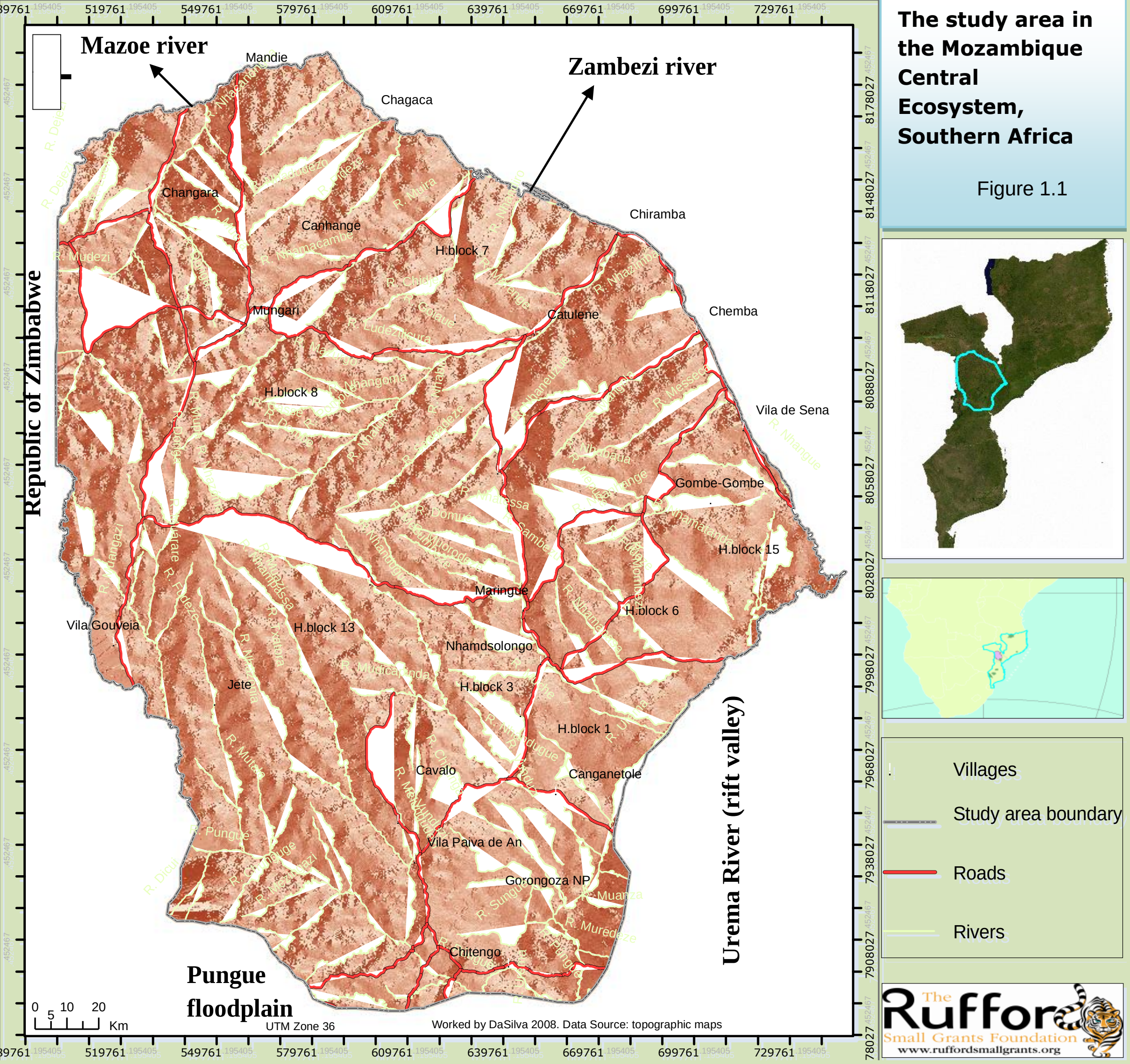
(d) Determine; by use of coefficient of determination; the key variables that explain the seasonal habitat selection or avoidance by elephant;

(e) Design; by use of queries, scores-ranking, numerical clustering analysis, quantile method, kriging geostatistics, satellite imagery derived NDVI; the candidate habitats for Elephant conservation.

1.6.2. **Ongoing objectives**

Monitor, by comparison of satellite imagery data and surveys, wildlife habitats gains, losses and persistence within and outside Protected Areas;

To assess, by use of multiple ring buffer, overlays analysis, spatial statistics tools, the implications of those changes for Elephant conservation in Mozambique central ecosystem.



The study area in the Mozambique Central Ecosystem, Southern Africa

Figure 1.1

1.7. **Study Area**

1.7.1. **Location**

Mozambique is a developing country located in Southern Africa with an area of 799380 sq km and a population of more than 20530714 inhabitants (INE, 2007).

The economy of the country is based on agriculture, pastoralism, and exploitation of natural resources such as Cahora Bassa Dam hydroelectric power.

The study area occupies 49342.96 sq km of the vast Mozambique Central Ecosystem (see figure 1.1). It's bordered with the Tete Province in north by the Mazoe and Zambeze Rivers, with the rift floodplains in south by Pungue River flood plains, with Zambeze Delta in East by Urema floodplains and with Republic of Zimbabwe in West by the Mahomboe highlands (see figure 1.1).

1.7.2. **Climate, soils and vegetation**

Characterized by different environments, the study area represents a cross ecological link between Malawi, Zimbabwe and Mozambique ecosystems. This ecological connectivity is sustained by differential hydrologic systems such as Zambeze river, Nhamacamba river, Pompue river, Nhadugue river and modified by altitudinal ranges such as the Mahomboe highlands and Gorongoza escarpment, Chivuli and Macossa plateaus and Gorongoza floodplain (vide figures 1.1; 1.2).

The landscape of the study area is mostly moderate; altitude ranges from 14.9 m to 1811.8 meters registering the difference of 1796.9 meters (see figure 1.2). Soils are mostly developed on a granite substrate and are of the tropical brownish lithic soils type (INIA, 1995).

Climate is tropical sub-humid; rainfall averages 300 to 500 mm annually and falls in a unimodal pattern from December to May (INAM, 2008). The average monthly temperature ranges between 5 and 25°C (INAM, 2008).

Combination of acid soils, moderate topography and sub-humid climate result on two main types of habitats, the mopane and miombo woodland, dominated by woody grassland vegetation (see appendix 3.1).

Plate 1.1

1.7.3. **Population and conservation**

The conservation status of the study area varies from national parks; communal lands and coutadas (hunting areas). Although the hunting areas, much of them are characterized by higher biodiversity indexes, the Forests and Wildlife Act of 1999; the Forestry and Wildlife CoP14 Doc.37 regulations of 2002 and the Wildlife hunting legislation of 1972 favour sport hunting within coutadas. At the same time human activities such as settlements, pastoralism, infrastructure development, bee keeping and shifting cultivation have been taking place in the coutadas, the same as in communal lands (see plate 1.1). As a result, habitats are being encroached. Human population is linearly distributed in small concentric villages along the roads. Higher population densities occur in urban areas (521 inhabitants/sq km) (INE, 2007). Although the study area land is mostly suitable for maize and sorghum farming (FAO, 1999), the presence of game on farms, crop-raid and food storage damage leave many households vulnerable to famine.

These conservation issues are integrated on three distinguished landscape units ranging from highlands, plateaus and floodplains (see figure 1.3).

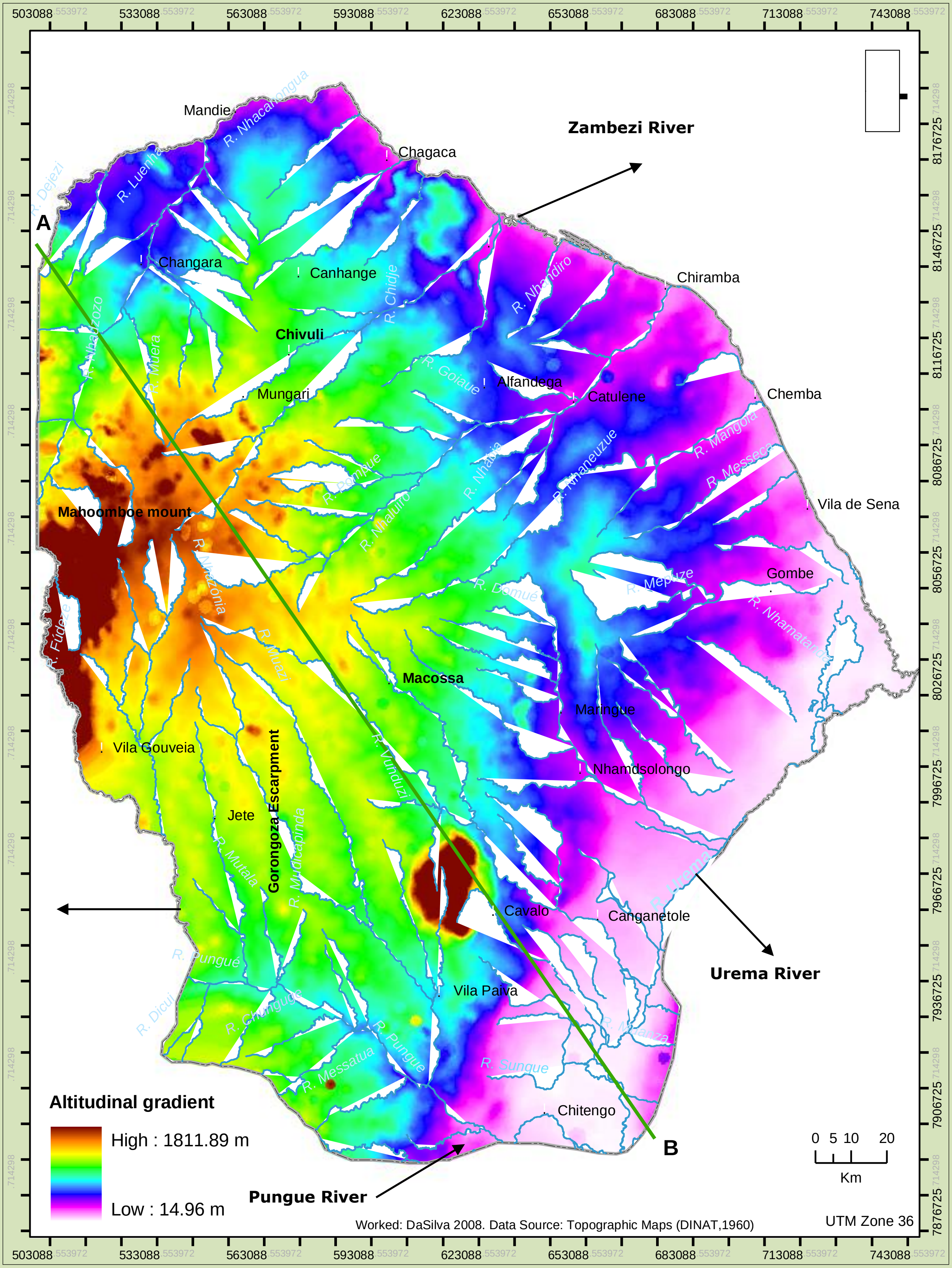


Figure 1.2: The study area is zoned (using altitudinal gradient) by different landscape units

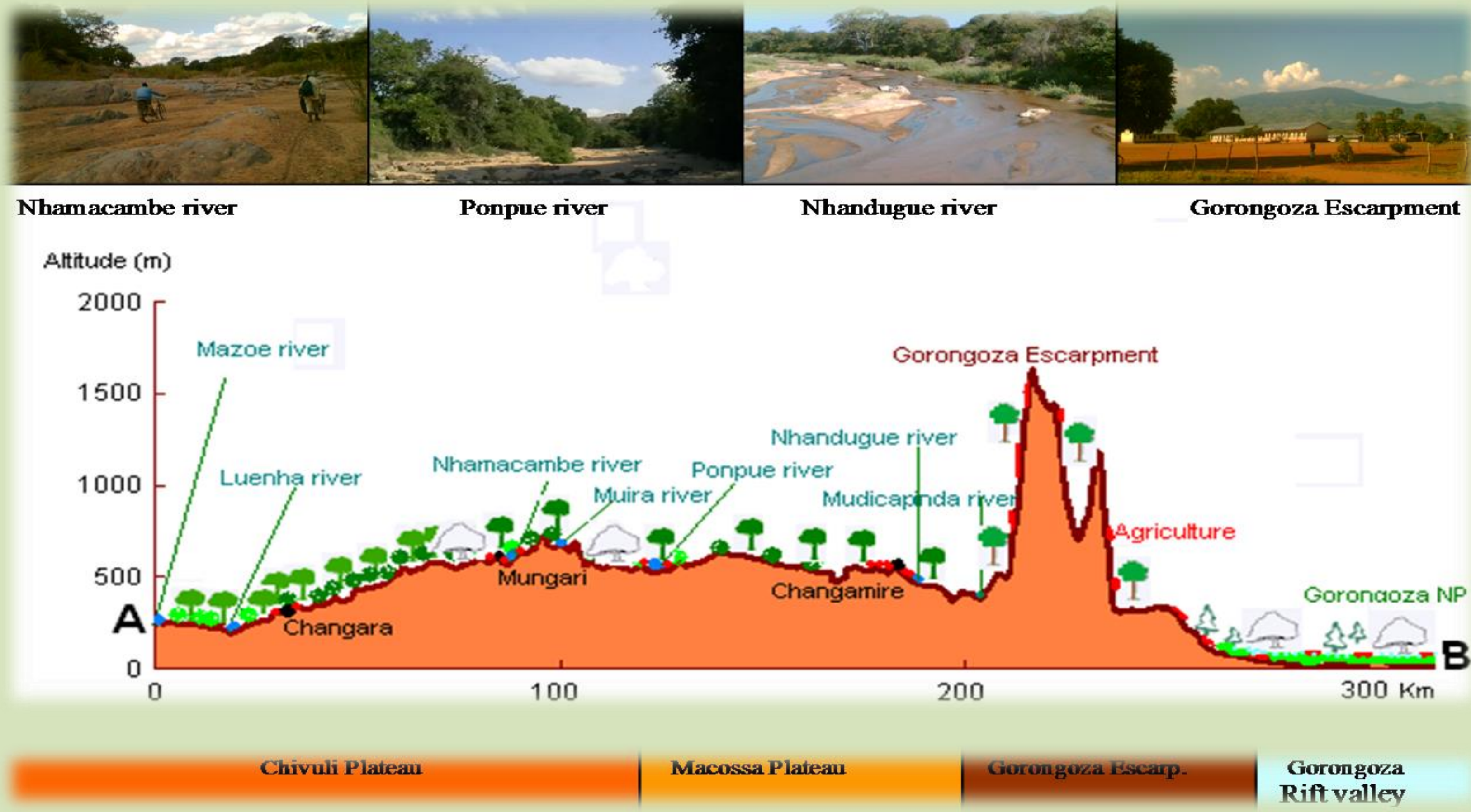


Figure 1.3: Topographic profile of the study area. ©DaSilva 2008 based on figure 1.2

1.7.4. **Landscape units**

*a) **Mahomboe highlands***

Mahomboe eastern highlands are southwards of Inyangani Mountain and northwards of Chimanimani heights remarking the boundary between Mozambique and Zimbabwe (see figure 1.2). Ranging from 700 to 1811.89 meters, altitudinal differences result on the steepest slope (>30%) of the study area **(**see figure 1.1**)**, which in turn (due to its orientation) result on drier areas in the west (Zimbabwe) and humid areas in Mozambique (Manning, 2004). At the highest areas (1811.89) the brownish lithic soils cover the acid eroded granite parental rocky material (INIA, 1995) and represent a smaller deeper layer (0-30m), with no salting minerals layer covered by open woodland vegetation. This vegetation type is of evergreen small shrubs of cypress, protea with little herbaceous ground cover (Manning, 2004). At the Mahomboe highlands the Mupa, Muarare and Nhazonia rivers follow a dendritic pattern of high risk of erosion (see figure 1.1). The eastern highland ends in the northern part by Mazoe and Zambezi depression while in the southeast creates the floodplains of Urema (see figure 1.2).

b) Urema and Zambezi floodplains

The Urema and Zambezi floodplains, at the southern end of the great African rift floodplains in the hurt of central Mozambique (see figure 1.4), remark the beginning of the Zambezi Delta Wetland. This landscape unit ranges from 14.96 to 299.9 meters, on flat to gentle slopes (0% -14.96 %), where seasonal flooding and water logging of the floodplains is of alluvial substrate of sedimentary material covered by *vertsoils* (black cotton soils), silted on texture, very deeper layer (>100 m) and salty, resulting on variety of micro-habitats in the grassland. Grassland of the Gorongoza is one of the examples and it's dotted with patches of acacia trees, savannah, dry forest on sandy and seasonally rain-filled pans and termite hills thickets (White, 1983). The Urema floodplains provide land for agriculture, hunting and grazing (Da Silva, 2005). It also provides habitats for diverse and abundant population of wildlife such as buffalos (*Syncerus caffer*), African elephant (*Loxodonta africana*), impala (*Aepyceros melampus*), waterbuck (*Kobus ellipsiprymnus*), hippopotamus (*Hippopotamus amphibious*), crocodile (*Caiman crocodiles*), lion (*Panthera leo*), wildebeest (*Connochaetes taurinus*), eland (*Taurotragus oryx*), sable (*Hippotragus niger*), hyaena (*Crocuta crocuta*), cheetah (*Acinonyx jubatus*) and numerous threatened and endangered species including wattled crane (Beilfuss et. al., 2001). Large number of these species has been reducing due to Mozambique's 16 years civil war particularly at the boundary with the casa-banana village and Maringue District.

Between the Urema floodplains and Mahomboe highlands there is a sloppy transitional area described as the Chivuli and Macossa plateaus (see figure 1.4).

c) Chivuli and Macossa plateaus

Located between Mahomboe highlands and Urema floodplains, the Chivuli and Macossa plateaus range from 300 to 699.9 m creating a moderate slope (15% - 29.9%) of granite and gneiss substrate covered by brownish and redness moderate acid and alkaline soils of miombo vegetation habited by diverse wild fauna species such as eland (*Taurotragus oryx*), greater kudu (*Tragelaphus strepsiceros*), porcupine (*Hystrix cristata*), impala (*Aepyceros melampus*), bushpig (*Potamochoerus lavartus*), buffalo (*Syncerus caffer*), zebra (*Equus burchelli*), lion (*Panthera leo*), elephant (*Loxodonta africana*). The acid and alkaline soils of the plateau are alternated with small patches of lithic soils at the

Gorongoza escarpment where human have encroached vast areas for *Canabis sativa* drug farms. The reminiscent evergreen vegetation covers the montane forest of Gorongoza escarpment and gives a spectacular view of the site.

The presence of villages such of mutchaiabande, massara, nhaurire, nhamacheta, cavalo, sixpence, moguene, nhandare, casa-banana with land use practices not compatible to wildlife conservation e.g. agriculture and modern hunting tactics reduces the hypothesis of associating the Gorongoza NP with the Chivuli-Macossa plateaus and Mahomboe highlands up to Zimbabwe. Indeed, before the civil war large mammals such as elephant and Buffalos have been coming to Gorongoza NP from Nyanga NP, but with the establishment of casa-banana RENAMO army house the connection was far stopped (said the *Mussangadze Regulo, see video nr*.2). After the civil war, in 2006, a herb of buffalos were sighted watering in the Nhadugue river and seven years before (1999), three buffalos were killed by the villagers when trying to access the Gorongoza NP using Nhandare corridor (said *the Gorongoza Regulo*). Thus, will Gorongoza NP survive from the danger of becoming a smaller isolated "island" (see figures 1.4; 1.5).

This study methodologically considered visual interpretation and spectral analysis of satellite imageries, literature review, field survey and cartographic evaluation. Data analysis was done in ArcView 3.2 (Spatial Animal Movement and image analysis Extensions); ArcGIS 9.1 and ERDAS spatial packages. Statistical Package for Social Science (SPSS) assisted these spatial packages for elaboration on graphs, cross tables and models testing. The results are presented in form of maps, graphs and this report.

2.1. **Data collection, storage and processing**

2.2.1. Land use/cover

Landsat 7 imageries were acquired at the National Center of Remote Sensing-CENACARTA. The images were geometrical corrected to Universal Transversal Mercator-UTM System, spheroid of WGS 84, Zone 36S and analysed using digital processing and visual interpretation techniques in ERDAS and ArcView 3.2 image analysis. Because different tasks of nature conservation and landscape protection need different levels of land use/cover data, it was necessary to perform several interpretations of the same image at different levels of resolution.

Visual interpretation method (desktop computer interpretation) was used to prepare satellite imagery pre-field maps. This activity was based on photo elements interpretation such as tone, texture, size, shape, pattern, aspect and association.

After imagery quality analysis (image enhancement-standard deviation), the near infra-red (TM3) and the red (TM2) bands were processed accordingly to the Normalized Difference Vegetation Index (NDVI) in ArcView 3.2 image analysis (equation 1).

$$NDVI = \frac{NIR - R}{NIR + R} \qquad (1)$$

Source: Tucker, 1979

Where NIR is the near infrared spectral band and R is the red spectral band. Resulted value of pixel varies among 0.01 to 1.00 for vegetation. The higher values correspond to dense vegetation, decreasing with decline of digital values (ESRI, 1998). The use of NDVI contributes on discrimination of land use/cover, therefore the NDVI denotes vegetation distribution in the imagery and how the association of certain types of vegetation can be related with certain wild animals.

One of critical issue in mapping land use/cover using Landsat 7 imagery is the detection of rural settlements and vegetation types. For the first case, 2007 Population and Housing Census tracks (Enumeration Areas) were combined with satellite imagery to identify and locate human settlements.

2.1.2. **Vegetation data**

For vegetation data both satellite imagery and quadrats count were used. This was practical for mapping and monitoring the Elephant habitat diversity spatial distribution.

Quadrats of 10 m x 10 m were applied for trees (Higher Normalized Vegetation Index-NDVI) and shrubs (Moderate NDVI) counting and quadrats of 1 m x 1m for grasses and herbaceous (Low NDVI values) estimation. Accordingly to man power factor, research time (12 months) and confidence level (95%), a total number of 386 quadrats were sufficiently representative for the study area of 49342.96 sq km. Stratified random sampling assisted this research on determining the distribution of samples (see also De Sherbinin, 2005; Da Silva and Kwasamila, 2007). For this matter a Landsat ETM+ NDVI was computed. From this four classes were identified ranging from bare areas 6408.01 sq km (12.99%); Low NDVI-19 436.44 sq km (39.39%); Moderate NDVI-16657.48 sq km (33.76%) and High NDVI-6 408.01 sq km (13.86%). A simple mathematical assignment was done to know how many quadrats to sample in each NDVI strum; for example:

$$\text{Number of quadrats for trees (High NDVI)} = \frac{Tota\ln umberquadrats * highNDVI\%}{100\%} \qquad (2)$$

$$\text{Number of quadrats for trees (High NDVI)} = \frac{386\,quadrats * 13.86\%}{100\%}$$

Number of quadrats for trees (High NDVI) = 53.4996 approximately 54 quadrats.

Using the same method was estimated the number of quadrats corresponding to shrubs (Moderate NDVI) = 130.3136 ≈130 quadrats; grasses and herbaceous (low NDVI) = 152.0454

≈152 quadrats; bare areas 50.1414 ≈50 quadrats. The last was conducted in order to survey the invasive plant species within/along water points, important indicators of water quality. Thus, a map of the study area (habitat types based on NDVI) was divided in 10 km x 10 km grids and systematically selected for future sampling (see figure 3.16). Selected grids where then divided in small numbered grids of 10 m x 10 m for moderate and high NDVI and 1 m x 1 m for low NDVI. A random number table was then used to select which squares to sample. Each sample point was located using GPS and by taking a random number between 0 and 54 for trees; 0 and 130 for shrubs and 0 and 152 for grasses/herbs; 0 and 50 for bare areas, to give a compass bearing, followed by another random number which indicates the number of paces which should be taken in that direction. Stratified random sampling was carried out because the study area is fairly uniform and very large. The use of 1 m x 1m quadrats for grasses/herbs and 10 m x 10 m for trees/shrubs are due to the facility of getting manageable sites. Data was collected from samples in each habitat, identifying each species present in the quadrat, counting the number of individuals of each species, recording all data on the data sheet, GPS and plant press. Plant press was very useful for plant museum specimen collection and this data combined with GPS records is baseline information for future ecological monitoring activity. All data was compiled and processed in ArcGIS 9.1, Excel and SPSS.

Data on vegetation survey was processed using diversity indices such as proportion, dominance, relative dominance, evenness, abundance and species richness, accordingly to the following estimators:

Shannon Index (H')

$$H = -\sum_{i=1}^{s} (Pi) * (\log_e Pi)$$

$$Pi = \frac{n_i}{N}$$

Species Evenness (J)

$$J = \frac{H'}{H_{max}}$$

$$H_{max} = \ln S$$

Simpson index of dominance (D)

$$D = \frac{\sum ni(ni-1)}{N(N-1)}$$

Relative dominance (RD)

$$RD = \frac{d_i}{DA} * 100$$

Margalef's index or total sample size (I)

$$I = \frac{(S-1)}{\ln N} \qquad (3)$$

Species Richness (S_R)

$$S_R = \frac{S}{N}$$

pi = proportion of total sample represented by a species

S = total number of species in each plot

ni = number of individuals of the ith species

N = total number of individuals in a plot

Source: Spllerberg, 1999; New, 2000; Pullin, 2002.

The use of this technique helped on elaboration of habitat diversity maps (see figure 3.5); prediction of plant richness (see figure 3.6; tables 3.2; 3.3; 3.4). These data were used for better understanding of elephant food distribution.

2.1.3. **Elephant data**

Data on Elephant spatial distribution was acquired using field direct observation and line transects counts. The use of transects is to avoid overlapping counts. With transects its easy to calculate area and density of Elephant. Transects are based on the visual contact distance that is estimated basing on vegetation density, visibility and terrain conditions. In order to place transects during the field survey, the study area was divided in three landscape units (see figure 1.2**)**. Basing on a random number tables 452 transects of 1 km were selected and perpendicularly sampled to the main rivers. The allocation of 452 transects within the landscape units were proportionally to their extent. However, basing on participatory sampling transects were North-South walked in order to cover higher diversity of habitats. Walking transects was mostly between 06:00 and 10:00 and between 15:00 and 18:00. The results of walking transects constitute a location and count of signs which elephant leave behind when passing through the bush, grassland, riverine vegetation, such as dungs, feeding signs, mud-wallowing, rubbing posts, trails and foot prints (see also Stuart and Stuart, 1994; Walker, 1996).

Thus, 6 observers for both sides (left and right) were walking along the centre-line of the transect *(—)* and whenever they see a dung-pile, trails, foot prints, feeding signs, mud-wallowing, rubbing posts or an Elephant (●), they recorded the location and perpendicular distance *(----)*. This method was successfully applied by Barnes (1996) for assessing the seasonal movement patterns of elephant. The results were then compared with these obtained through GPS collaring system of the Gorongoza National Park.

Data on Elephant sites location was interpolated accordingly to the kriging method in ArcGIS 9.1 geostatistical analyst to predict Elephant distribution (see figure 3.3). Variogram models were computed to understand the spatial dependence of samples.

Home range estimation was done using animal movement extension of ArcView 3.2 GIS software by applying Kernel and minimum convex polygon tools (see figure 3.4). The size of an

Elephants home range was estimated using Xtools in ArcView 3.2 and is an indicator of the availability of essential resources, restrictions imposed by the size of the respective conservation area, and the degree of disturbance to which the animal is exposed. Where water and food are abundant and disturbance is minimal, it can be expected that home ranges will be small.

Elephant density was estimated using kernel density function available in ArcGIS 9.1 Spatial Analyst as it's referred on figure 3.1. Kernel density option employs a circular search neighbourhood around each point and calculates each cell value by adding the values of overlapping neighbourhoods. This data helped us on understand patterns of dispersion and concentration of elephant that might not be apparent when viewing sites locations. Further, this information and that provided throughout home ranges and kriging prediction was useful to select Elephant preferred habitats as it's shown on figure 3.16.

2.1.4. **Topographic data**

Topographic maps were acquired at National Directorate of Land (DINAT) and projected to UTM system; WGS 84 and zone 36S using Arc tool box (see also Croiser *et al*. 2004). Using ArcCatalog a point feature class with altitude attribute field data in meters was created in a geodatabase. Adding the feature class over the topographic map, altitude data was digitized using Edit tool, and later interpolated at 100 meters using universal kriging method in ArcMap spatial analyst tool for rigorously representing the variation of the surface (relief). A 100 meters interpolation unit was used for easy estimation of area; since one grid represented 100m x 100m that is 100 square meters. After grid computation, a map of contours at 5 m, 10 m, 25 m and 100 m was derived using ArcMap spatial analyst. A 5 m contours was loaded on 3D ArcGIS 9.1 spatial analyst to generate a Triangular Irregular Network (TIN) model that is the emphasized form of representing terrain aspects.

From TIN model new grids representing the maximum reason of altitude variation (slope) and the maximum altitude variation (aspect), of which the direction, the length, the movement of the relief gradient and the degree of exposure to sun radiation was estimated as its shown on figures 1.1; 1.4. Also the TIN model allowed us to derive the topographic profile of the study area as it's shown on figure 1.5.

Slope percent is related to the rate at which water would run off a site, influencing soil moisture and soil development (Zimmerman, 2002). The slope function determines the rate of change from each cell's elevation to its neighbour's elevation (ESRI, 1998). For example, a rise of 2 meters over a distance of 100 meters describes a 2% slope with an angle of 1.15 (ESRI, 1996). Aspect is the direction of slope and it shows the wind-eroded material in a specific direction, which is prone to cause landslides. Furthermore, local climate influenced by sun exposure is likely to affect the vegetation and dependent wildlife (Klingseisen, 2006). Hillshade determines the hypothetical solar radiation of the earth's surface at a specific location due to variations in slope angle, aspect and position. Daily maximum solar radiation occurs on south to southeast facing slopes (Smith, 1995).

Slope percent grid derived from TIN was reclassified into three classes: flat to gentle slopes (0% -14.96 %), moderate slopes (15% - 29.9%), and steep slopes (≥ 30.0%) (see also Strahler and Strahler, 1992; ESRI, 1996; ESRI, 1998). And hillshade data was reclassified into three classes: shaded north to northeast (NNE) facing slopes, moderately exposed slopes (flat to gentle rolling areas), and exposed south to southeast (SSE) slopes. The success of each classification was tested using ANOVA analysis. Thus, topographic data is important for landscape units' analysis, estimation of water and food availability, costs of travelling in search of food, cover and security of elephant. In addition topographic data was used to predict NDVI, climate and wildfire variability and consequently plant richness distribution and corresponding wildlife type variability.

2.1.4. **Wildfire data**

Wildfire was mapped using Landsat ETM+ and Modis satellite imageries during five months (July, August, September, October and November). Modis satellite seemed to be more accurate on fire mapping, since provided detailed data up to 500 metres of spatial resolution and everyday than Landsat which its over 29 metres and during 16 to 21 days.

2.1.5. **Aridity Index**

Aridity index (AI) is a numerical indicator of the degree of dryness of the climate at a given location (UNEP, 1992). It combines potential evapotranspiration (PET), temperature (T) and rainfall (R). This data were acquired at the National Meteorological Institute, corresponding to 52 years (1955-2007) and for all National meteorological stations. Data were processed accordingly to the equation 4: $AI = \frac{R}{PET}$ (4)

The result of this equation was then interpolated using a kriging method present in ArcGIS 9.1 geostatistics analysis and classified accordingly to the table 2.1.

Table 2.1: Aridity Index Classification

	Aridity Index
Hyperarid	AI < 0.05
Arid	0.05<AI<0.20
Semi-arid	0.20<AI<0.50
Dry subhumid	0.50<AI<0.65

Source: UNEP, 1992

A spatial query of the study area aridity index was then computed. Aridity index was correlated to water, wildfire and elephant distribution.

2.1.6. **Geodatabase creation, editing and management**

Data obtained during field survey and cartographic evaluation processes were topologically verified, edited and loaded in a geodatabase (see also Joselyn, 2002). Geodatabase building process consisted on dividing the study area on 10 km x 10 km numbered grids. From this, all feature classes were assigned to each numbered grid. For example in each grid the number of elephant signs were counted and entered. For this exercise, a spatial join between elephant signs and grid were done. Second the number of signs per grid code was summarized. This process was repeated for all variables with some particularities for vegetation, normalized difference vegetation index, aridity index that were based on utility values. For the case of settlements, roads and water sources a distance to elephant location was estimated by means of selection by location. The result of this process is a geographic matrix (see also Berry, 1964; Hansen, *et. al*.2006) table showing elephant (location, abundance, frequency, probability, class), population (location, density, distance from settlements to elephant location), dung piles (location, ecological density), altitude (average altitude), wildfire (frequency, intensity), NDVI (average, standard deviation, variance, coefficient variability), water sources (density, size, availability, distance to elephant location), roads (density, distance to elephant location), aridity index and vegetation (diversity, utility, fragmentation, availability). Thus, geographic matrix table shows an identification of grids, its location and corresponding biological, anthropogenic, environmental and topographic variables.

Geographic matrix table helped in correlating the biological, environmental and anthropogenic features to provide an identification of different habitats used by elephant, common and rare plant species, representative and flexible habitats, sites used by elephant but in otherwise threatened by human being or vulnerable habitats.

Metadata for the final shape file (Geographic matrix table) was built using FGDC and ESRI format available in ArcCatalog.

2.2. **Data analysis and modelling**

Data analysis was based on the geodatabase (geographic matrix table). From it we performed maps categorization, spatial interpolations, spatial correlation, general linear models, multivariate regression analysis, cost allocation and spatial queries.

2.2.1. **Shape files area estimation**

Area was calculated by utilizing the Xtools extension of ArcView 3.2, where the area of selected polygon shapefiles was calculated in a chosen unit (hectares, acres, square meters, and square kilometres). After Xtools calculates the area of each selected shapefile, it adds this calculation to the associated attribute table. This is useful because each layer's attribute table can be viewed as a database file in Microsoft Excel. By transferring this data to Excel, total area of unprotected habitats, Elephant home ranges extent were obtained by summing the appropriate column using Excel sum tool ($\sum$).

2.2.2. **Maps categorization**

Future change analysis activities will be based on comparison of accurate maps produced accordingly to the same methods. Thematic maps, for this research, were based on suitable data classification (categorization). This process is the way to represent several features that have similar values by the same graphical symbol (United Nations, 2000).

Categories depended on the mean, variance, class ranges, data distribution and standard deviation (normal distribution or lower variance). The categories or classes were determined by subtracting and adding the standard deviation to the mean. The class ranges were constant if the data assign to the uniform distribution (equal intervals method) unless the quantiles method was used for the data uniformly distributed (higher standard deviation). However, the choose of which classification method to use was based on data distribution and the real situation of the field observation.

The critical issue in maps categorization is assigning similar values to different classes. In this respect, a student *t-test* was computed in SPSS in order to test if there is a statistical difference between map units.

The square of standard deviation is variance. The variance was computed within class and the total variance of all observations. A relationship between within class and total variance is relative variance. The lower (<10%) relative variance, the better is the classification. Therefore, the significance of the classification was tested using *F-test* on the variance ratio with degrees of freedom m, n-k; using One-Way Analysis of Variance (ANOVA). If $p > 0.05$ was interpreted as the map classification demonstrates that no statistical significance can be attributed to the differences between classes. ANOVA analysis was computed in SPSS. Similar methodology has been used by Burrough and McDonnell (1996) when analysing the zinc concentration and noted that the standard deviations per class are larger because of the non-normal distribution.

2.2.3. **Spatial correlation analysis**

Relationship between Elephant spatial distribution and habitat types was determined using overlay of maps of Elephant distribution and habitat types.

Through the comparison of spatial variables using spatial correlation analysis it was possible to denote the spatial relationship of elements (cause-effect relationship). Using spatial correlation analysis combined with neighbour analysis and dissolve of unnecessary features it provided preferred habitat and avoided habitats by elephant. These areas are represented in our geodatabase as elephant classes.

Habitat types are not the single factor influencing Elephant population. Matters related to governance (illegal killing of species, law enforcement effects, policy and legislation, ivory trade and bush meat need) were also accessed but these results were not included in our statistical analysis due to smaller sample size, that means needed more time than that available.

Thus, a comprehensive elephant spatial model as a cause effect relationship could include spatial modelling of Elephant, habitat and governance (see figure 2.1).

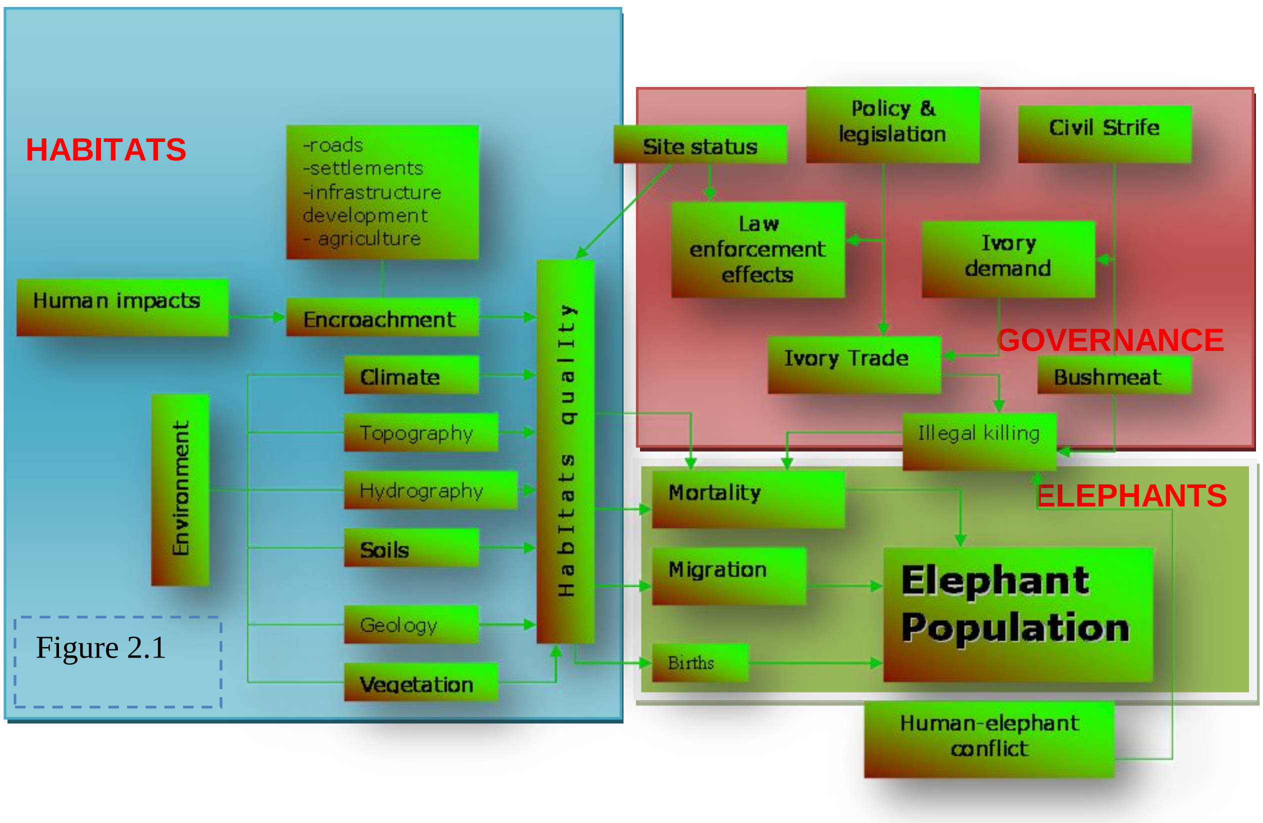


Figure 2.1

2.2.4. **General linear model: Repeated ANOVA**

We used General Linear Model-GLM to compute the mean difference between habitat types and their use by elephant. We examined the mean performance between habitats and the efficiency of elephant habitat use. The significance of the difference was tested using the Mannchly's test of sphericity. Partial Eta squared value was used to analyse the effect size variability. The significance of the difference was tested using multiple mean comparisons between habitats and efficiency of use. The marginal means between habitats and habitats efficiency of use by elephant were then represented on graphs (see figure 3.8).

2.2.5. **Multivariate regression analysis**

Multiple regression analysis was based on linear regression where r (spearman coefficient of correlation) R square (coefficient of multiple determination) and Adjusted R square (standardized R square based on the sample size and degrees of freedom) was computed in SPSS and ArcView 3.2 theme regression extension, for the matter of data analysis complementarity.

This helped us to know whether the distribution of elephant vary over a range of values of the habitat independent variables. In addition, Adjusted R square denotes how much any factor explains the variability on another (see equation 5).

$$Y_i = \beta_0 + \sum_i{}^{p} \beta X_{ij} + \varepsilon_{ij}$$

$$R^2 = \frac{SS_R}{SS_r} = 1 - \frac{SS\varepsilon}{SS_r} \qquad (5)$$

$source: Nie, 1985$

Where Yi is the response variable, β0,...,βp are unknown coefficients; X1,...,Xp are p regressors, and εi is a mean zero error term. Adjusted R square is calculated by:

$$R_A^2 = 1 - (1 - R^2)\left(\frac{n-1}{n-p}\right) \qquad (5)$$

where n = sample size

p = degrees of freedom due to regressio

source: Jenness 2006

Multiple linear regression tool available in ArcView 3.2 theme and grid regression extension was used to compute the relationship between spatial features both raster and vector, probability distribution of elephant, prediction of new elephant observations, scatter plot showing the relationship between elephant and landscape variables as its referred on figures 3.9; 3.10; 3.11; 3.12

Using identifier tool was possible to select a particular point on scatter plot and view the attribute value on table and map. In addition, it allowed quickly and easy queries in order to find out where features shown on scatter plot lay on the landscape as it's shown on figure 3.14. In addition, descriptive statistics and ANOVA table with both the F-values and P-values were performed to estimate the confidence of the linear relationship and the *P*-value was computed to indicate if the relationship is linear at all or not (see tables 3.6; 3.7; 3.8; 3.9). Thus if *P-value* <

0.00001 it was interpreted as there is indeed strong evidence of a linear relationship between the two variables at 0.99 of confidence level. However, different layers required different models. For this situation a scatter plot was important in identifying the suited model and this was performed using a Define model tool present in grid and theme regression analysis of ArcView 3.2.

This method has been successful applied by Jenness (2006) when analysing the factors behind fish productivity; Da Silva and Kaswamila (2007) when estimating elephant of Tanzania Conservation Lands Trust.

Care was taken in interpreting adjusted R square, as a casual relationship is not necessary implied; the underlying, causal agent governing the animal distribution could be a different factor. For instance, the distribution of wildebeest on the Serengeti plains may be more strongly related to the availability of calcium than to grass greenness or grass height (Grimsdell, 1978; Campbell and Hofer, 1995). In that respect, once it was discovered that, for example, water is the factor of core habitat use, further multivariate regression analysis and Analysis of Variance (ANOVA) were performed in order to understand which water parameter is most important (water size, availability, distance, density). Further the factors related to the influencing cause were computed. Thus, all this research activity helped us in answering why elephant choose some habitats and avoid others by time and space.

2.2.6. **Cost allocation and spatial queries**

One of the critical issues on selecting priority areas for conservation is the complementarity of selected sites to existing protected areas networks. For this issue spatial analyst tools provided cost weighted and shortest path analysis tools. Thus, it was assumed that Elephant searching for their suitable habitat will not travel straight forward; they will find altitudinal and longitudinal obstacles. To calculate the cost of travelling to near source pool the cost allocation tool considers its nearest source based on the least accumulative cost over a cost surface. Using cost weighted tool all sites were given (based on different factors) a distance for travelling to the nearest source pool. The shortest path analysis provided a better way (corridor) for elephant travelling to the source pool as it’s referred on figure 3.4.

Spatial queries were computed in ArcMap 9.1 based on: (i) areas used by elephant but threatened by human being; (ii) areas of unique and common plant species; (iii) avoided and preferred site; (iv) representative and flexible sites; (v) sites connecting PAs in less than 5 kilometres; (vi) sites of features used by elephant but at research time not used; (vii) sites used by elephant and found in the same landscape unit.

Therefore the boundaries of such candidate sites for Elephant conservation are the sum of different functional and hierarchical units. Delineation of landscape units were based on shared slope and altitude and described in terms of land use/cover (see also Haines-Young *et al.,* 1993; Petch, *et al.,* 1995); the delineation of biogeocenoses were based on Elephant spatial distribution, home ranges and density (Petch, *et al.,* 1995); the habitats were delineated in terms of the sites which elephant use more frequently out of all available, e.g. high kernel density of Elephant spatio-temporal variables (see also Osborn, 2005). Then the habitats were classified as core habitat, peripheral habitat and unsuitable habitat categories.

Some authors use vegetation types as habitat types (Grimsdell, 1978). In this study we cannot assume at all this statement since the distribution of elephant is also determined by water availability that in turn depend, for example, on climatic variables rather than vegetation types.

2.2.7. **Score ranking analysis and numerical clustering**

From correlation and multiple regressions analysis critical factors determining the distribution of elephant were identified as it's referred on figure 3.14. The presence (1) and absence (0) analysis of these factors per grid were performed. From this a total sum of utility measure resulted by factors attracting elephant were computed as it's shown on figure 3.16[2]. Also a total sum of repulsive elephant factors were obtained as it's referred on figure 3.16[1]. Then the differential between the attractive and repulsive factors were obtained by subtracting the figure 3.16[2] by 3.26[1] grid by grid, as it's referred on figure 3.16[3]. This figure 3.26[3] was then categorized using a quantile method to find out the associations (sites with the same management techniques). The kriging interpolation was then used to predict future elephant habitats associations as it's referred on figure 3.16[4]. In order to highlight which factor make the sites as associated, a spatial join of critical factors and NDVI followed by categorize based on factors were used to generate the figure 3.17.

Chapter 3

Results and analysis

3.1. Elephant's patterns of distribution

Elephant locations were identified by means of global positioning units. Elephant positions record was based on the signals which they leave when pass through the bush such as footprints, tracks and trails, foraging, watering, barking, probing, carcasses and dung-piles. These records were based on transects placed within different landscape units (see figure 1.2). Transects on the landscape units were 1 km length and perpendicularly oriented to the main rivers. The results of this sub-chapter encompass: i) calculation of the presence and absence of elephant's patterns of distribution; ii) elephant home ranges and iii) ecological dung density. Droppings location were recorded and classified in fresh (no older than 24 hours), dry (24 hours to 30 days) and degraded (3 months ago). From calculation of patterns of distribution, all signals indicating the absence of elephant were coded as 0 and subsequently 1 to indicate the presence of the specie. Using simple kernel density and varonoi tool the dispersion, concentration and stratums of elephant were, respectively determined (see figures 3.1; 3.2). Dividing the number of droppings obtained per transect (square kilometre) per the extent of each strata of which each transect is located, the ecological dung density were statistical obtained. Ordinary kriging were, then, applied to compute the spatial autocorrelation of measured samples, and to predict new locations on overall spatial arrangements. In addition, kernel probability and minimum convex polygon were used to calculate elephant home ranges (see figure 3.4).

3.1.1. Presence and absence of elephant

A total number of 404 sites were located to validate different sources of secondary data. Between these samples 124 (30.7%) represented other signals (footprints, tracks and trails, foraging, watering, barking, probing and carcasses) and 280 (69.3%) were dung-piles. In defecations, many samples 107 (26.5%) registered the occurrence of three dungs; 26 (6.4%) five dungs; 25 (6.2%) twelve dungs; 24 (5.9%) four dungs; 17 (4.2%) three teen dungs; 16 (4.0%) seven dungs; 15 (3.7%) nine dungs; 12 (3.0%) eleven dungs; 11 (2.7%) six dungs; 10 (2.5%) two dungs; 9 (2.2%) eight dungs; 7 (1.7%) ten dungs; decreasing the probability of finding dungs as the quantity of dungs were increasing per site, 1 (0.2%) fourteen dungs. In fact, some transects stated higher defecation index than others. But if the values of these samples were regularly distributed through the ecosystem and habitats, it was expected to encounter 6.03 dung-piles per sq km. Due to the variability of resources needed by elephant for their survival, a variance of 13.05 of their defecations was computed, which denotes the heterogeneity on species distributions. The same was validated by the coefficient of relative variability which is more than 20% (C.V= 59.86%), indicating higher variations and less stability on the elephant conservation environment. Of course, the values of defecations were dispersing on a ratio of 3.61 from the mean (6.03) that indicates some points stated more dungs (max=14) than others (min=2), although a total number of droppings (sum=1689) would be enough to distribute 6.03 dungs per transect. These areas of higher quantity of dungs might be coinciding with water points near to patches of elephant preferred vegetation and far from human settlements. At the same time it was expected to observe the distribution of such pachyderms (only) within the protected areas, unfortunately this did not happen due to the lack of symmetry (skewness= 0.772, more than zero) on the distribution of resources which make some areas sanctuaries than others, even if stability (flat distribution) could be observed within the protected habitats (kurtosis = -0.918). Although, in terms of statistical data analysis a significant coefficient of relative variation and skewness could indicate that care must be taken on classic tests, requiring natural logarithm technique to normalize all data set, at the other hand, combining the information of both direct sightings and indirect evidences on figure 3.1 it is possible to assume that 56.60% (26220.54 sq km) of the study area was utilized and 43.40% (23122.42 sq km) was not used throughout the year.

No significant elephant’s signals were observed at the Mahomboe highlands (700 to 1811.89 m); at the Guro, Macossa, Maringue and Chemba District headquarters, Gorongoza escarpment, Sena small town, Cavalo, Jet villages (see figures 1.4; 3.1). At the time of survey the elephant were chiefly utilizing some areas at the lowlands of the floodplains (14.96 to 299.9 m) and middle lands of the plateaus (300 to 699.9 m) in the dry and wet seasons, respectively (see figures 1.4; 3.1). Comparing the mean ($\overline{X}$ = 6.03) and variance (S^2 = 13.05), it becomes clear that at these landscape units (plateaus and floodplains), elephant obeyed to an aggregated pattern of distribution ($S^2 > \overline{X}$) in the northern part of the study area (see figure 3.1). Sighted elephant on these areas were ranging from 1 to 30 and frequently seen groups number was 1, 2, 3, 5, 8, 12 which indicate that their spatial clustering might be a survival response to the human negative impact. At this aggregated pattern of distribution, a solitary bull was sighted near Nhamaropa village exhibiting a linear pattern of distribution along the unpaved road to Tambara. Villages are located along the roads (see figure 1.1) and cultivate along it. Thus, it might be expected that the solitary adult bull was crop-raiding. Contrary to the linear pattern of bull, a female with cow-calf were roundly concentrating in Nhatunduluco swamps network, 7 kilometres from Chivuli headquarters (see figure 3.1). This might be justified by the presence of nutritious grasses on the edge of swamps. The same has been observed along the Pompue river at the Macossa plateau where three females and their cow-calves were intensively utilizing the Pompue swamps, as the same in Chitengo. At these areas the abundance of elephant and sex-ratio was not only indicating the scope for a growing population but also indicating that habitat disturbance can result on scarcity of food, migration and dispersion of elephant. A dispersal distribution pattern of elephant were observed particularly along the Zambezi river banks near to Chagaca villages on a connection between Nheluire and Pompue rivers, down to Changara village, around the Alfandega village, western Maringue, on edges of the Mohoomboe highlands near to Guro District headquarters, on Muira river banks and at eastern and northern parts of the GNP sanctuary (see figure 3.1). This might be due to the overlapping distribution of resources both important for human and elephant, such as water and preferred vegetation.

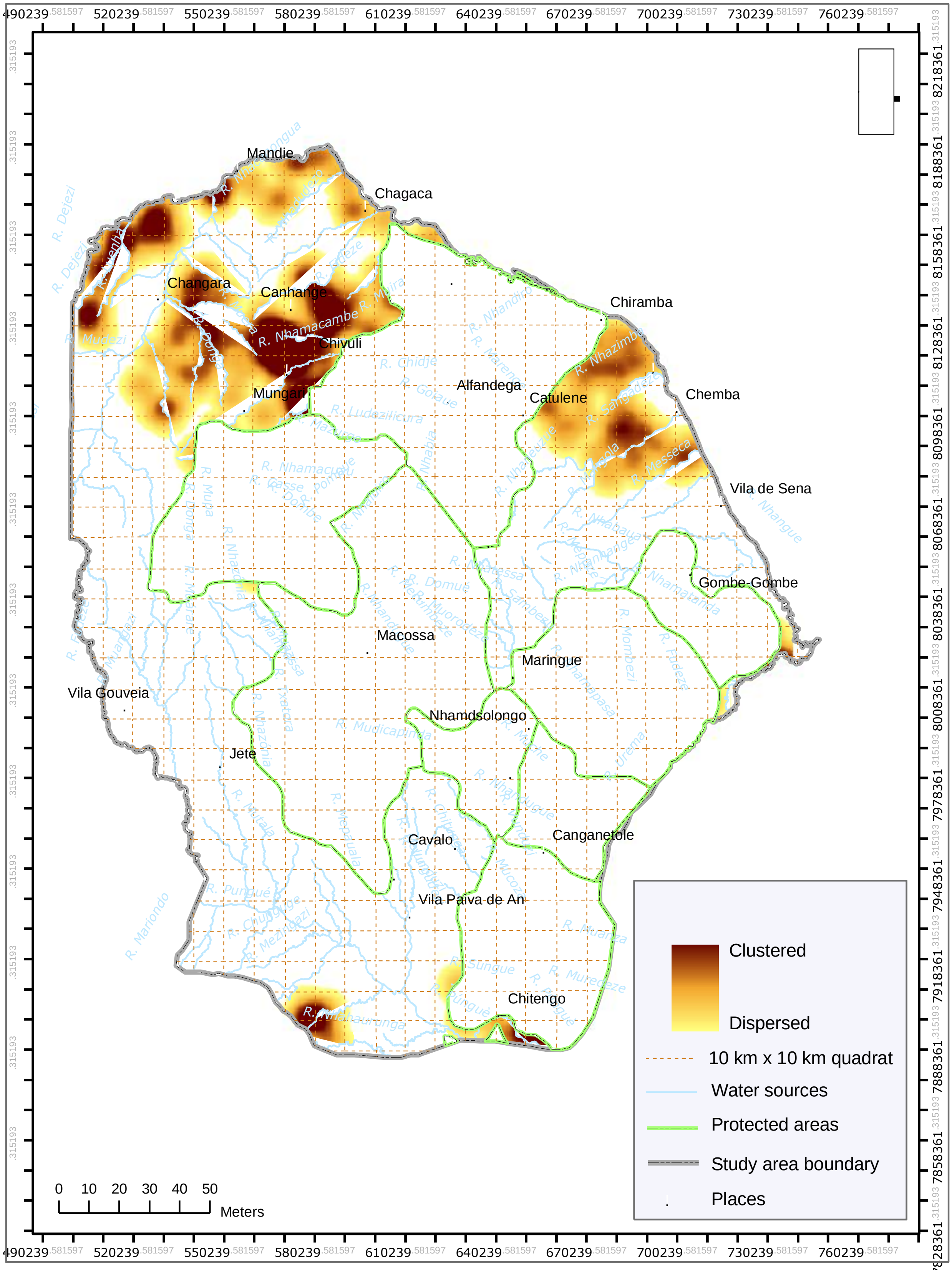


Figure 3.1: Kernel density of elephant patterns of presence and absence. The figure 3.1 indicates the sites which elephant use more frequently out of all available (see also Osborn, 2005). Thus, is there any significant difference of dungs' density between Elephant's stratums?

3.1.2. **Ecological dung density**

The overall dung density, at the time of survey, was estimated at 0.0644 per sq km, varying from 0.00 to 0.0346 dungs per sq km. Within this range three distinct classes were identified: high (0.0245-0.0346); medium (0.013-0.0173) and low (0.000-0.0012) dung densities. *Student's t-Test* was computed to test whether the values of low, medium and high densities are the same (H_0). Comparing the low and medium classes it was found a t = -10.8; sdev=0.00336; degrees of freedom = 283, for $p=0.0001$. These figures indicate that for the probability of this result ($t = -10.8$), assuming the null hypothesis (H_0), is less than *0.0001*. Thus there is a significant difference between the values of low and medium dung densities classes. The same was observed from a comparison of medium and high density classes, where t = -19.1; sdev = 0.00380; degrees of freedom = 252 and $p = 0.0001$, which indicate that the probability of this result ($t=-19.1$), assuming the null hyphothesis (H_0), is less than *0.0001*. Therefore, the H_0 is rejected that can mean the values of medium and high dung density differ significantly. Both cases are clearly represented on figure 3.2:

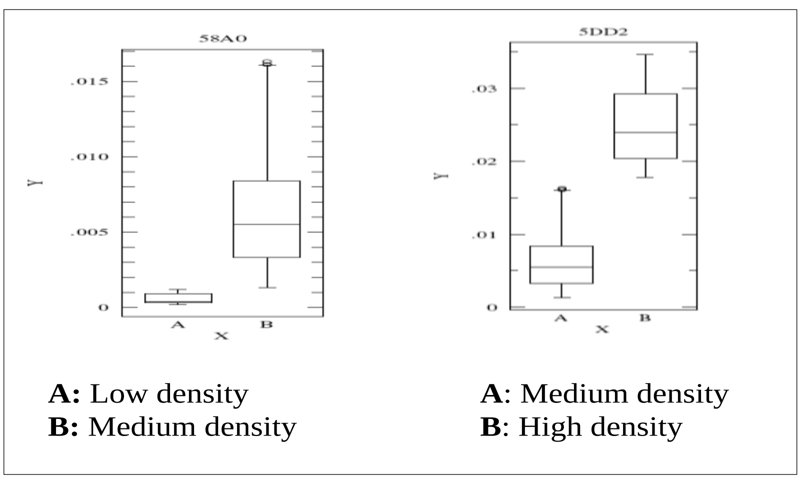


Figure 3.2: Significant difference between the ecological dung density classes values

The lower ecological dung density (0.000-0.0012) was observed at the south-western Alfandega (southern part of stratum 019), neighbour of Chiramba headquarters (stratum 016), Mahomboe ridge (stratum 022), eastern Nhamdsolongo village along the Urema River (stratum 028) and northern GNP sanctuary (see figure 3.3). These patterns coincide, majority, with settlements. And probably they are due to the fact that during the dry season (August), burning of grasslands is frequent and as a result elephant move into dense vegetation in search for food and shades. During the wet months (January), the grasses become unpalatable the elephant prefer to move in the moist and evergreen forest located far from roads access. Apart of this, the lower dung-piles density maybe indicating that elephant were avoiding areas where poachers were active. These areas were spatially related to bee keeping activities on *Kigelia africana* riverine forest. The said activities have been pulling elephant to concentrate on saved sites that could be characterized by higher dung density (see figure 3.3).

The higher ecological dung-density (0.0245-0.0346) was observed at the Mazoe and Zambeze rivers connecting floodplains (stratums 003 and 004), at the northern part of chivuli-Nhamassonge (stratums 006 and 012), along the Muira river near and within hunting block 7 (stratums 013 and 014) and along the Ponpue river particularly within hunting block 9 (stratums 023, 024 and 025) (see figure 3.3).

At the same time, the medium ecological dung-density (0.013-0.0173) characterized the overall study area particularly at the Nhamacamba river and Nhatunduluco swamps of Chivuli and Muira river near Nhamaropa village (stratum 020), Nhamacamba river at the Mungari village (stratum 021), Muera river (stratum 022), Luenha-Mazoe flood plains (stratums 001, 002, 009, 010, 011), along the Zambezi river north-east Chiramba (stratums 005 and 015), at the flood plains of Urema-Pungue rivers near Chitengo village within GNP (stratums 029 and 030) and along the Nheluire and Elephant rivers (stratum 026) (see figure 3.3).

Higher and medium ecological dung densities coincided with areas where water is "permanently" available (see figure 3.3). Barnes (1996) who used droppings to study elephant emphasized that they have the habit of defaecating when approaching to water. This might be due to the need of daily water large reservoir (±120 litres). Furthermore, elephant frequent twice a day per used water point for both bathing and drinking and this might be duplicating the number of dungs per day per used point.

Thus, ecological dung density denoted to be a very good indicator of daily elephant water requirements. As water influence on forage access and efficiency of its use, then to the abundance of elephant coming to defecate in a particular site, it can be assumed that water points can be used as a predictor and estimator of the size of foraging areas, transverse distance between them and their spatial distribution. In addition, dung piles density suggested being an useful measure to monitor temporal (weekly, monthly) movements of elephant and to assess the effects of climate changes on food availability and feeding preference. Unfortunately, it was difficult to extrapolate accurate figures of individual density from faeces due to the fact that the clusters of high dung density might be an effort of defecation of the plural elephant coming for watering simultaneously, since elephant forage in groups. Further, dung density might also be indicating food availability and dietary composition in different seasons. Diet based on arboreal feeding during the dry season may decrease defecation indexes and detection rates of their dung on the ground contrary to wet season grazing on crops, fresh grasses and fruits that might contribute to higher dung density (see figure 3.3).

Thus, geostatistics are powerful GIS tools for conservators particularly when dealing with tropical ecosystems where the rate of habitats loss is more likely to be very hasty than the efforts of their protection. Probably these GIS tools might become more powerful if a range of assumptions are made around the prediction of expected samples, for example what would be the value of dung piles site if the same it's located near water point comparatively to the one near roads or settlements. The same statement made us to assume, accurately, the predictions within the stratums (see figure 3.3).

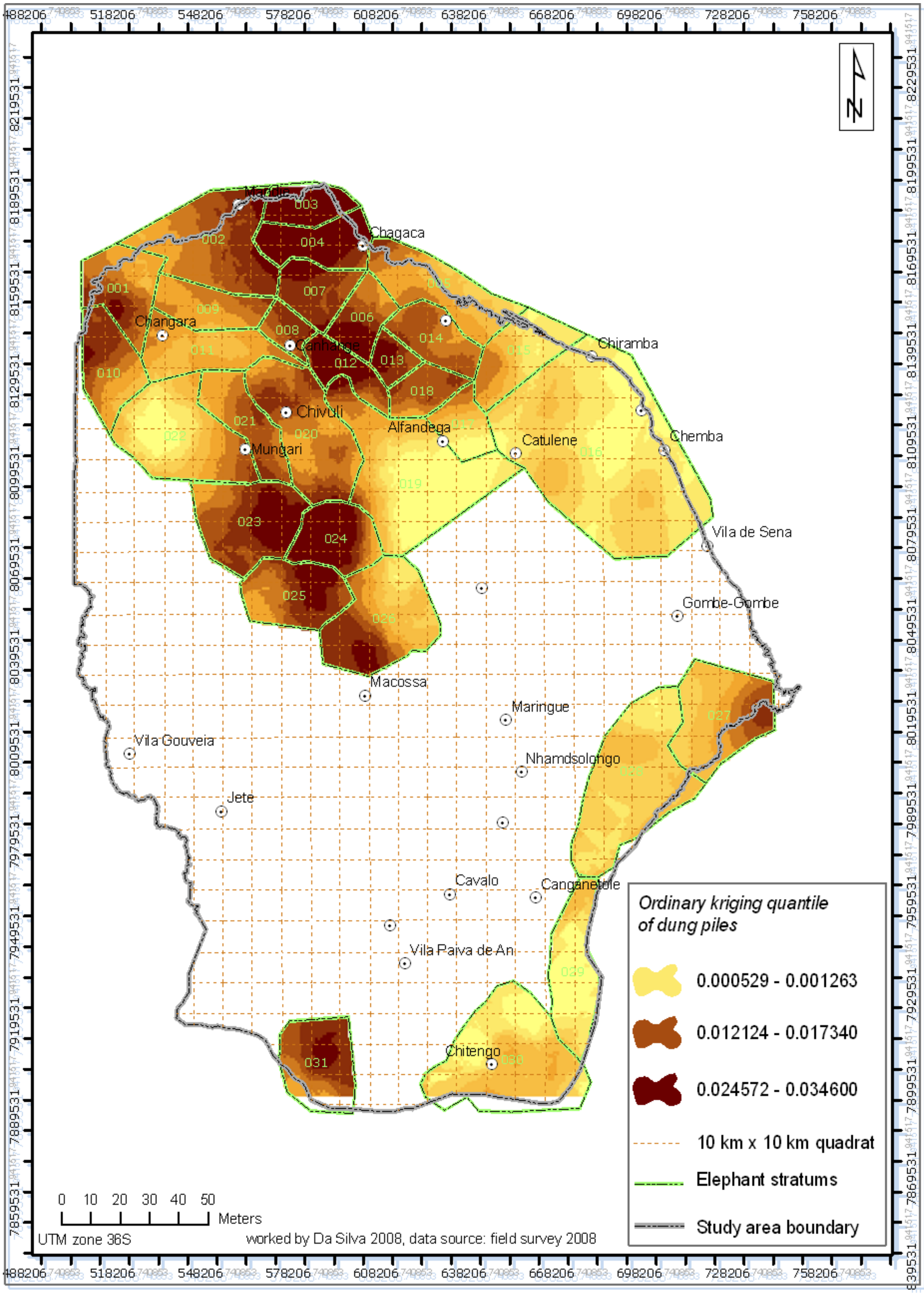


Figure 3.3: Ordinary kriging quantile of dung-piles

Although the figure 3.3 shows the utility of each area and the suggested connectivity between the stratums, the same does not explain the elephant movement trend.

3.1.3. Elephant movement and their home ranges

Two movements of elephant distribution in different landscape units were apparent throughout the year: a) March to November and b) December to February (see figure 3.4).

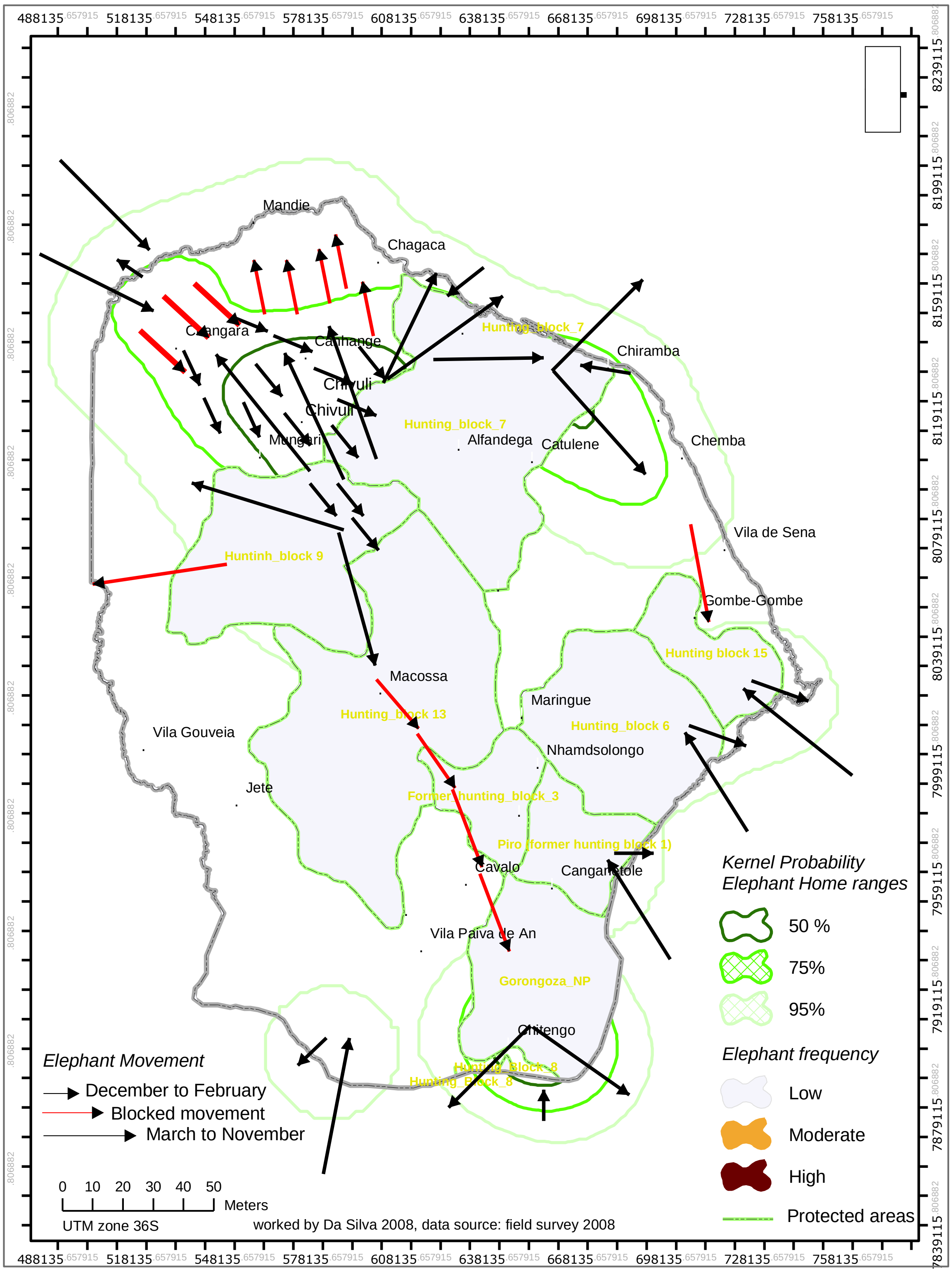


Plate 3.1

a) ***March to November***

On March one part of elephant begin the movement from the hunting blocks 7 and 9 using the corridor connecting Nhabesse, Nhatunduluco, Nhamalaca, Lolongue up to the northern part in Nhamassonge (see figure 3.4). The beginning of this movement concurs with mature crops in the community land (see plate 3.1). This exposure between elephant and human creates an overlapping negative interface. Nhamaropa villagers sleep in their fields to prevent crop raiding and the elephant is sometimes the victim of its damage as farmers do not hesitate to shoot the animal.

To prevent this negative interface the government has, ultimately, decided to offer a higher calibre firearm for tracking elephant.

Accordingly to the Chivuli stakeholders this is a new technique for chasing elephant. *I have talk to the ancestral and referred that since the past, elephant existed and were not eating even damaging crops but when human densities increased over the areas where elephant used before, their food started to disappear forcing them to change their feeding habits to concentrate on crops. Before the war, it was easy to chase elephant using fire. But these days we far use it but they never go out, this is the reason that forced the government to post one firearm in the villages densely populated by elephant*, said the Chivuli locality president (see video nr. 1). The impact of firearm both for farmers and elephant is well known. First the community ranger is not trained on the weapon ethics of use that could result on non-selective shooting of the species. Second the community ranger is chasing elephant from one farm to another and this added to the fact that elephant is simple changing its activity pattern to visit the same farm during night time; it of course perpetuates the conflict and has brought difficulties in direct observation of elephants during the day time.

During April, May and June, when crops harvesting period have ended, elephant still in the community land particularly in the Nhacafule, Chivuli and Nhamassonge may be eating the fresh grasses and watering on ephemeral swampy water of Nhatunduluco, Nhamalaca and Muira River. Studies revealed that although crops decline in quality the elephant remain in the area due to the quality of wild grass (Bhima, 1998).

In July, August and September the scarcity period begin when grasses in farms undergo and the seasonal pans experience a severe dry (see report nr.2). During this period elephant move to concentrate around rivers such as Muira, Mussangadze, Elephant and Nhadugue probably due to the presence of green riverine grasses and salt. At this time human and elephant fight for water accessibility and food storage damage. In addition, August is the month of harsh wildfire. The 2008 wildfire has killed more than 39 villagers and leaving other 30 thousand homeless. These catastrophes were more severe in Macossa and Tambara Districts. The causes of wildfire are not well known but during the survey period villagers were using fire for preparing new subsistence agricultural lands, managing tsetse fly, chasing elephant from fields, collecting honey and catching small mammals. For example within the hunting blocks 9 and 13 (Macossa) villagers were sighted burning the forest in order to capture small mammals such as cockroaches (see plate 3.2).

Of course, when August reaches the study area rainfall is scarce, vegetables farming is no longer, however indigenous people are faced with food shortage particularly for broth. The unique alternative is to burn the wild in order to seize cockroaches. This has been resulting on the development of successional plant species such as *Aristida spp*, which are less palatable for game.

There is evidence; however, that promoting conservation needs to balance with communities' needs (TAWIRI, 2005). Because these communities' needs still not balanced to date, the existing harsh environment forces elephant to move up to protected areas sanctuaries in December.

b) ***December to February***

From December little part of elephant back dispersing up to the hunting blocks (see figure 3.4). The question on why do elephants leave community land at the end of dry season (Later November) was beyond the scope of this sub-chapter. However, the hypothesis of wildfire that had cleaned all grasses and reducing food and shades availability for elephant can be put forward for elephant movement back to hunting blocks. Indeed, at this period the private hunting block authorities have yet prepared food, solar pumped water and ponds of salt in order to attract elephant for the start of sport hunting period.

Previous the establishment of these hunting companies with their *obscure* range land management tools and before the 16 years civil war when human densities were lower, elephant backing from Changara-Tambara (Nhacafula)-Nhamassonge-Chivuli (Nhatunduluca)- Nhamaropa (Nhamalaca)- Macossa (Nhamandandze-Nhandoe-Zuinga-Vorodze- Nhapsingo-Nhadungue) were reaching the Gorongoza NP (Chitengo).

Accordingly to the Mussangadze Regulo *elephant were moving up to Chitengo in search of water, genus exchange and security. With the establishment of hunting companies and setting of watering points and eco-rangers in the hunting block 9 this movement has been decreasing. But this was not any issue for genus exchange barrier; the movement was seriously stopped since the 16 years civil war and the blockage of the corridor in Zuinga, Vorodze and casa-banana. The first two obstacles were not of significant impact since elephant diverged to use the Tongonda-Elephant river-Nitandique-Nhapenpepe-Pompue-Nhadugue-casa banana-Chitengo but the* *second (casa-banana) it's very serious hence it blocks elephant when trying to diverge the Gorongoza escarpment by use of Nhadugue river* (see video nr.2).

Actually, elephant move from Southern Changara-Tambara-Chiramba-Nhamassonge-Mungari up to Macossa having limited to access the corridor to Magoe at the northern part and Gorongoza NP at the southern part; due to conflicting land uses and the presence of active poachers, respectively.

Therefore, two connecting areas in the plateau were discovered: the Nhacafula-Chivuli-Nhamassonge and the Ponpue-Nhandugue corridors. The first is located in the community land (*March to November*) and the second in the hunting blocks 9 and 13 (*November to February*) (see figures 3.2; 3.3; 3.4).

Surprising is the fact that the hunting blocks host the population of elephant particularly at the end of the dry season; but during rainy season, most of elephant and other herbivores leave the hunting blocks 7; 9; 13 and Gorongoza NP and spread into a wide area of Chivuli/Nhamassonge plateau and Urema flood plain; for more than half year, depending on the resources available in this area where communities of farmers live.

The seasonal movement of elephant has been well documented in Africa and coincides with seasonal climatic changes and the corresponding changes in food and water availability (Viljoen 1989).During the wet season, elephant distribution is widespread and usually in areas with a high abundance of vegetation and shrink in the dry season, concentrating near water sources (Osborn, 2005), where vegetation species are often evergreen (Kernick, 1980; Barnes, 1996).

A kernel spatial movement analysis has denoted that at 50% of core used area, the observed home range extent 4918.62 sq km (100%) vary in 16.45% (808.95 sq km) within strictly protected areas (national parks), 35% (1722.04 sq km) in hunting areas and 48.54% (2387.63 sq km) in the communal land (see figure 3.4).

Within the hunting blocks, the total relative proportion 35% (1722.04 sq km) was not uniformly distributed. Higher extent 17.35% (853.30 sq km) was observed in hunting block 9 (3601.89 sq km); 16.46% (809.83 sq km) in hunting block 7 (5191.64 sq km) and 1.20% (58.91 sq km) in hunting block 13 (6389.65 sq km).

The same heterogeneity was stated in the community land. Within 48.54% (2387.63 sq km); 22.23% (1093.46 sq km) was observed in Mungari/Chivuli-Nhamaropa (3239.14 sq km); 17.66% (868.68 sq km) in Nhamassonge (1404.88 sq km); 5.19% (255.21 sq km) in Nhacafula (1266.98 sq km) and 3.46% (170.28 sq km) in Chiramba (1242.74 sq km) (see figure 3.4).

A comparison between the home ranges of elephant in the protected areas of South Africa, Tanzania and Kenya that varies from 54 sq km to 2178 sq km (Estes, 1992) and the observed home ranges in the study area (4918.62 sq km), the last appear fairly larger.

Large home ranges are expected were water and food are scarce and disturbance is maximal (Douglas-Hamilton, 1971 and 1973; Kernick, 1980; Barnes, 1996). Water is not an issue in the PAs (particularly in December); maybe the reason of dispersion might be found on the art of killing animals and the stability between the size of the PA, size of elephant population and food availability. Roux (2006), who studied *feeding ecology, space use and habitat selection of elephant in South Africa* argued that smaller protected areas may not have sufficient resources to support viable elephant population year around.

For this case, a weak negative coefficient of correlation (r= -0.04959) was noticed and denoted that an increase of the size of Protected area might reflect on the decrease of home range size but this relationship was not significant (p= *0.907*). In this respect, the size of PA explained 0.25% (R^2 = 0.0025) of the variation in the size of home range of elephant of the study area and 99.75% by other factors. This comes again to confirm the habitats diversity theory hypothesizing that large areas contain more types of habitat, and so consequently more species.

3.2. **Habitats diversity distribution**

This habitats mapping activity is based on the interacting systems of living and non-living components found in nature e.g. topography, soil fertility, water sources, vegetation cover, aridity index, Normalized Difference Vegetation Index-NDVI (see appendices 3.1; 3.2; 3.3; 3.4; 3.5; 3.6). The habitats are evaluated in relation to their vulnerability to human land uses and resources extraction practices and refined by their functionality e.g. breeding, feeding, shelter, shade grounds. This approach pertains to habitats availability and security models of classification. Security model is based on human-caused impacts such as encroachment that cause species death (Behnke, 1999; Cranston, 2006). Resources availability model is determined by the parameters that attract elephant such as *food; cover.* Food and cover were accessed by means of Landsat ETM+ satellite imageries visually and digitally interpreted (Griffiths-Norton, 1978). Hence some areas were ambiguous; the combination of field surveyed data, digital terrain model, Quickbird imagery, Enumeration Areas (EAs) and water points shapefiles aided on the re-segmentation of Landsat NDVI data, which, vary on negative values of water points, swampy areas; values of NDVI equal or near to zero depicting the bare areas of agriculture, residence, rocks, fire. Apart of this, the productivity of vegetation varied in low, moderate and high values indicating the differential environmental conditions where it is located. Further, differential NDVI might also be influenced by the type of vegetation and its heterogeneity; however to confirm this hypothesis the NDVI classes were described in terms of abundance, dominance, evenness, intensity of patchy size variability and diversity of plant species (see also Chapter 2). Since our poor knowledge of the number and distributions of species can limits our understanding of ecological processes, and our ability to use this knowledge to inform biodiversity and for conservation planning, we used Generalized Linear Models (GLM) and cartographic regression to estimate potential species distributions and avoid problems arising from an incomplete sampling. Thus, three habitats were apparent within the study area: a) moist evergreen afro-montane of *Brachystegia spiciformis*; b) semi-arid plateau of *combretum spp* and *colophospermum mopane*; c) degraded wooded grassland on lowlands of Urema and Zambezi floodplains (see figure 3.5).

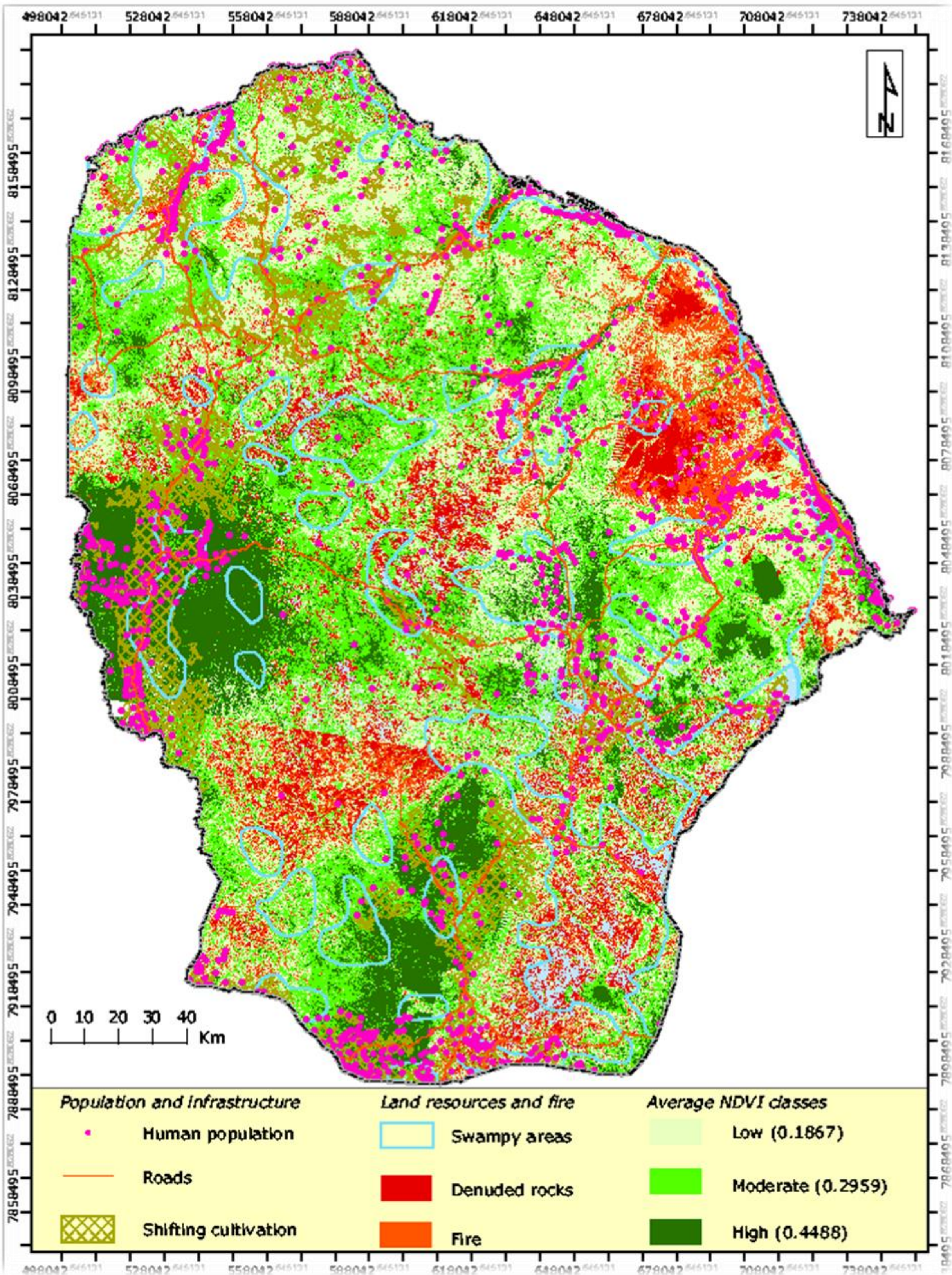


Figure 3.5: Habitat types described in terms of ecological and environmental variables and evaluated in terms of their vulnerability to anthropogenic parameters

3.2.1. Moist evergreen afro-montane of Brachystegia spiciformis

This habitat type is mostly described by high vegetation abundance (high chlorophyll concentration in leaves) in Landsat ETM+ satellite imagery. These areas in panchromatic imagery are of aggregated whitish patches associated to higher altitudes (700 to 1811.89 m) of the Gorongoza Escarpment, Mahomboe Mountain that create heavy orographic rains over 2000 mm per year (see figures 1.2; 3.5; appendix 3.3; MICOA, 1997). The whitish tonality indicates the absence of photosynthetic activity in infrared band of Landsat ETM+. This habitat type was primarily found on rocky hillsides, rocky outcrops, edges of evergreen forest, streams forest and red clay soils reflecting the minimum value of 0.3442 and maximum of 0.5853, which denote that if the capacity of solar radiation absorption by plant's leaves was uniformly distributed the mean NDVI could be 0.4488. For the reason that at the down slope, in the floodplains between mountains, human practice shifting cultivation (see appendix 3.1) on the red clay high fertile soils (see appendix 3.4), linearly inundated by small streams (see appendix 3.2) along the paved road to Tete (see appendix 3.6), where also human prefer to fix they spontaneous settlements (see appendix 3.5); there is an interference of other spectral signals (skweness = 0.550 less than zero; kurtosis 0.147 less than 3). This added to the differential location of vegetation (some on rocky hillsides and another on streams) have been causing a variance of 0.0035 and a standard deviation of 0.0593 on values of NDVI. Although these estimators indicate that there is a mixed occurrence of shifting cultivation on open forest (see appendix 3.1); at the same time the coefficient of variability C.V = 13.21% has shown a medium variability of vegetation greenness within the cluster.

The field survey based on quadrats of 10 x 10 m (100 m^2) and 1 m x 1m (1 m^2), has identified 28 specie richness, with a specie variation estimated at 0.6779 (Shannon Index), denoting unequal distribution of individuals among species (species evenness = 0.2643). This situation was expressed by the higher relative dominance of *Brachystegia spiciformis*, *Newtonia buchananii*, *Millettia stuhlmannii*, *Erythrophleum africanum*, *Afzelia quanzensis; Craterispermum chweinfurthii*, *Markhamia obtusifolia*, *Hymenocardia acida*, *Brackenridgea zanguebarica*, *Erythroxylum emarginatum* (see table 3.1).

Table 3.1: species diversity, layers, stand structure and micro-habitats of the moist evergreen afro-montane habitat

Aspect		Tree layer	Shrub layer	Herb/grass layer	micro-habitat	Plant richness
Stand structure Height Cover		10-16 (25) m 40-75 %	0.3-3 m 10-30 %	0-0.3 m <1-40 %		
Plant richness ***Plant evenness*** ***Shannon diversity***		19 0.3907 1.1504	9 0.4021 0.8835	0 0 0		28 0.2643 0.6779
Identified plant species		*Albizia glaberrima* *Balanites maughamii* *Ficus verruculosa* *Millettia stuhlmannii* *Newtonia buchananii*			*streams forest*	*5*
		Burkea africana *Erythrophleum africanum*	*Brackenridgea zanguebarica* *Craterispermum schweinfurthii* *Hymenocardia acida* *Markhamia obtusifolia*		*edges of evergreen forest*	*6*
		***Brenani**odendron carvalhoi*			*red clay soils*	*1*
		Brachys**tegia spiciformis* ***Englerophyt**um magalismontanum* ***G**arcinia kingaensis* *Rinorea ferrugin**ea	*Diplorhynchus condylocarpon* *Combretum zeyheri* *Erythroxylum emarginatum* *Flacourtia indica*		*rocky hillsides*	*8*
		Hymenocardia ulmoides *Khaya anthotheca* *Maprounea africana* *Pterocarpus angolensis* *Sclerocarya bir**rea*** *Uapaca kirkiana* *Afzelia quanzensis*	*Schrebera trichoclada*		*rocky outcrops*	*8*
Dominant plant species	1 2 3 4 5	*Brachystegia spiciformis* *Newtonia buchananii* *Millettia stuhlmannii* *Erythrophleum africanum* *Afzelia quanzensis*	*Craterispermum chweinfurthii* *Markhamia obtusifolia* *Hymenocardia acida* *Brackenridgea zanguebarica* *Erythroxylum emarginatum*			

Source: worked by Da Silva, data from field survey 2008

Spatial correlation between the patterns of dominant plant species and water points density, soil fertility, aridity index, population distribution and their land uses has shown that the higher dominance of *Brachystegia sp.* might be associated to the higher proportion of soil fertility (see appendix 3.4), higher aridity index (see appendix 3.3) and the presence of small swamps at the button of mountains slope (see appendix 3.2), although these areas are being transformed in small patches due to disturbance caused by human practices (agriculture, settlements, road) (see appendices 3.1, 3.5, 3.6). Human activity is influencing on conversion of the *Brachystegia* woodland in other competing species such as *Albizia glaberrima*.

Mapaure (2001), who studied small variations in species composition of miombo woodland in Sengwa-Zimbabwe, found that the miombo dominated by *Brachystegia spiciformis* in a hierarchical pattern of distribution is related to edaphic and disturbance factors accounted for 15.9% and 12.8% of the total variation in species composition, respectively. Similar to FAO (1999), in Mozambique, underlined that the dominance of *Brachystegia spiciformis* is associated to soil where it can be vegetated, although it is believed that the specie possesses higher limit of tolerance, occurring in environments dominated by other species such as *Isoberlinia globiflora*, *Burkea africana*, *Milletia stuhlmannii*.

Apart of this, patchy size was also estimated in order to understand the intensity of spatial variability of the *Brachystegia sp.* associations. For the total area covered by this class 13.86% (6 406.01 sq km), the minimum computed patchy size was 0.0100 sq km and max = 310.97 sq km, with a variance of 2.3463 and a standard deviation of 1.5317 from the mean = 0.0524. These results indicate a coefficient of patchy size variability less than 10% (8.03%), which can be interpreted to mean that the spatial homogeneity of soil fertility (arable land) and aridity index observed in appendices 3.4; 3.3, respectively, might be influencing on the smaller variability of the size of this habitat in highlands, although other factors might be having some explaining power, such as human practices (shifting agriculture; spontaneous settlements, roads). Human related practices also strike the future of biodiversity in the wetland areas.

3.2.2. **Degraded wooded grassland on lowlands of Urema and Zambezi floodplains**

This habitat type is mostly found in a narrow altitude band that ranges from 14.96 to 299.9 meters (see figure 1.2), on flat to gentle slopes (0% -14.96 %) wide along the mid-end of major rivers, in particular the Urema and Zambezi (see figures 1.1; 1.2). The riverine fringe primarily characterize the grassland habitat reporting higher NDVI (0.2503) values after short rains which decrease (0.1518) when surface water undergoes (dry season), on an average NDVI of 0.1867 (see figure 3.5). They are limited in their extent, being principally confined to river beds, confluences, pans and swampy areas. At these areas their productivity variance is 0.0006 from 0.0243 of the standard deviation, denoting a medium coefficient of variability (C.V=13.01%). Soil fertility and aridity index are lower at upper riverine fringe increasing at the south (see appendices 3.3; 3.4), where the rivers (due to flat slope) experience some meanders depositing alluvial materials (see figures 1.1; 1.2; appendix 3.4). These areas state a diversity of micro-habitats (Shannon index = 0.9124) ranging from patches of wooded acacia, scrublands of *Dichrostachys cinerea* on disturbed areas, seasonally rain-filled pans of *Raphia farinifera*, *Phoenix reclinata*; termite mounds of *Combretum fragrams*; *Xanthoceris zambesiaca* on alluvial soils; *Vangueira infausta* on rocky outcrops and *Faidherbia albida* on alluvial floodplains (see table 3.2; figures 1.2; appendices 3.1; 3.2; 3.3; 3.4; 3.5; 3.6). These micro-habitats are highly degraded by human, decreasing the coefficient of degradation from north (Chemba) to south (Gorongoza) maybe due to the presence of strictly protected lands at Gorongoza NP (see appendix 3.5). The species composition differs from that of surrounding semi-arid plateau habitat, and comprises a number of terrestrial and aquatic plants dominated by *Faidherbia albida*, *Markhamia zanzibarica*, *Tamarindus indica*, *Vernonia colorata*, *Sterculia apendiculata*; *Dichrostachys cinerea*, *Grewia bicolor*, *Berlinia orientalis*, *Bauhinia petersiana*, *Dalbergia melanoxylon*, *Ludwigia stolonifera*, *Lanchocarpus capass*, *Phrahmites australis*, *Eteropogon macrostachyus*, *Cyperus rotundos*. Within this group, 47 plant species were uneven distributed (0.3347) among the individual denoting a near moderate diversity of species within the habitat (Shannon index = 0.9124) (see table 3.2).

Table 3.2: species diversity, layers, stand structure and micro-habitats of the degraded grassland habitat

Aspect		**Tree layer**	**Shrub layer**	**Herb/grass layer**	**micro-habitat**	**Plant richness**
Stand structure Height Cover		 10-16 (25) m 40-75 %	 0.3-3 m 10-30 %	 0-0.3 m <1-40 %		
Plant richness ***Plant evenness*** ***Shannon diversity***		18 0.3681 1.0639	5 0.2216 0.3567	24 0.4143 1.3165		47 0.3347 0.9124
Identified plant species		*Xanthocercis zambesiaca*		*Brachiaria lachnenthe*	*alluvial soils*	2
		Annona senegalensis *Cordyla africana*			*riverine forest*	2
		Combretum fragrams			*termite mounds*	1
		Faidherbia albida *Terminalia stenostachya*		*Panicium coloratum* *Pennisetum macrourum*	*alluvial floodplains*	4
		Albizia harveyi *Diospyros kirkii* *Sterculia rogersii* *Tamarindus indica* *Vangueria infausta*	*Bauhinia petersiana* *Berlinia orientalis* *Dalbergia melanoxylon* *Grewia bicolor* *Sterculia africana*	*Andropogon gayanus* *Eragrostis nindensis*	*rocky outcrops*	12
		Acacia xanthophloea *Adansonia digitata* *Markhamia zanzibarica* *Milletita stuhlmannii* *Sterculia apendiculata* *Vernonia colorata*		*Cyanthula cylindricall* *Cyperus lavigatus* *Cyperus rotundas* *Eteropogon macrostachyus* *Hemarthria altissima* *Lanchocarpus capassa* *Ludwigia stolonifera* *Nymphaea spp* *Ocinum canum* *Phoenix reclinata* *Phrahmites australis* *Pistia stratiotes* *Raphia farinifera* *Sporobolus africanus* *Typha capensis*	*riverine fringe*	21
			Dichrostachys cinerea	*Eragrostis chapelieri* *Eragrostis rigidior* *Eragrotis trichophora* *Erogrostis clianensis*	*disturbed areas*	5
Dominant plant species	1	*Faidherbia albida*	*Dichrostachys cinerea*	*Ludwigia stolonifera*		
	2	*Markhamia zanzibarica*	*Grewia bicolor*	*Lanchocarpus capass*		
	3	*Tamarindus indica*	*Berlinia orientalis*	*Phrahmites australis*		
	4	*Vernonia colorata*	*Bauhinia petersiana*	*Eteropogon macrostachyus*		
	5	*Sterculia apendiculata*	*Dalbergia melanoxylon*	*Cyperus rotundas*		

Source: worked by Da Silva, data from field survey 2008

Patchy size extent ranged from 0.01 sq km to 38.06 sq km denoting a variance of 0.0357 and 0.1889 of the standard deviation of the mean (0.03203 sq km). These figures denote a higher intensity of patchy size variability (589.75%), which can be interpreted to mean that the larger patchy size indicate areas of wooded acacia on riverine fringe and the minimum patchy size

Thus, the major threat to this habitat type is the higher human density (see appendix 3.5) competing with game and stock on access to polluted wetland products. The polluted wetlands were chiefly characterized by the presence of aquatic opportunistic plant species such as *Ludwigia stolonifera* (see table 3.2), contrary to the semi-arid plateau where the scarcity of water might be detrimental to the development of aquatic weed plants.

3.2.3. Semi-arid plateau of combretum spp and colophospermum mopane

This habitat type is predominantly described by moderate normalized difference vegetation index (0.2282-0.3794) of *Combretum spp*, *Colophospermum mopane*, *Sclerocarya birrea*, *Aristida spp* on rocky outcrops, alkaline soils and termite mounds. The habitat falls largely on the dry summer aridity index (see appendix 3.3). This pattern is characterized by precipitation largely confined to the period of November to April, varying between 450 mm to 710 mm (White 1983). Majority of the habitat lies on the Guro and Macossa plateau landscape (300 to 699.9 m) (see figure 1.2). The panchromatic Landsat ETM+ NDVI described this habitat as an edge grey tone between whitish tones of high vegetation density in the moist evergreen afro-montane habitat and dark tones of low vegetation density in the lowlands. This transitional area occurs in coarse grained pattern of fragmentation, particularly in Macossa, Mungari, Canhange, Chivuli alternated with heavy patches of bare areas resulted from granite rocks denudated by wildfire (see figure 3.5). For this class of habitat, if the values of NDVI were regularly distributed within the group, it could be expected to observe a mean photosynthetic activity of 0.2959. Due to differential distribution of factors affecting vegetation productivity at the plateau such as the presence of small patches of shifting cultivation (see appendix 3.1), mixed tracts of moderate and low soil fertility (see appendix 3.4), unpaved roads (see appendix 3.6) and small dispersed temporary swampy areas (see appendix 3.2); the computed NDVI variance was 0.0016. At the same period, the values of NDVI for this habitat were deviating from the mean in 0.0405, indicating a coefficient of variability between 10 and 20% (C.V = 13.69%), which can be interpreted to mean that the values of NDVI tended to occur in a moderate variability. Within this variability 85 specie richness with species diversity of 1.2722 (Shannon Index) was unequally distributing among the individuals of species (species evenness = 0.3862) denoting, in part, the dominance of *Colophospermum mopane*, *Combretum hereroense*, *Combretum molle*, *Combretum imberbe*, *Combretum fragrams*; *Dichrostachys cinerea*, *Balanites aegyptiaca*, *Acacia melifera*, *Senna petersiana*, *Pterocarpus brenanii*; *Aristida congesta*, *Eteropogon macrostachyus*, *Aristida adscensionis*, *Erogrostis clianensis*, *Hyparrhenia hirta* (see table 3.3).

Table 3.3: species diversity, layers, stand structure and micro-habitats of the semi-arid plateau habitat

Aspect	Tree layer	Shrub layer	Herb/grass layer	micro-habitat	Plant richness
Stand structure Height Cover	 10-16 (25) m 40-75 %	 0.3-3 m 10-30 %	 0-0.3 m <1-40 %		
Plant richness ***Plant evenness*** ***Shannon diversity***	39 0.3887 1.4240	16 0.3595 0.9968	30 0.4104 1.3959		85 0.3862 1.2722
Identified plant species	*Acacia polyacantha* *Zizphus mucronata* *Acacia nigrescens* *Colophospermum mopane*			*alluvial soils*	4
	Senna singueana *Xanthoceris zambesiaca* *Combretum fragrams* *Combretum hereroense*			*termite mounds*	4
	Newtonia buchananii *Cordyla africana* *Bridelia micrantha* *Kigelia africana* *Acacia robusta* *Combretum zeyheri* *Combretum molle* *Combretum imberbe*	*Strychnos popatorum*	*Cissus quadrangulalaris* *Panicum maximum*	*riverine forest*	12
	Albizia adianthifolia *Acacia welwitschii* *Ziziphus mauritiana*		*Acroceras macrum* *Pennisetum macrourum* *Sorghum bicolor*	*river banks*	6
	Sterculia africana *Cussonia spicata* *Sterculia rogersii* *Kirkia acuminate* *Tamarindus indica* *Diospyros kirkii* *Sclerocarya birrea* *Albizia versicolor* *Albizia harveyi* *Pterocarpus angolensis* *Schrebera alata*	*Berlinia orientalis* *Commiphora edulis* *Bauhinia petersiana* *Grewia bicolor* *Melinis repens* *Xylotheca tettensis* *Indigofera vollansi* *Steria verticillata* *Dalbergia melanoxylon* *Pterocarpus brenanii* *Acacia melifera* *Balanites aegyptiaca*	*Heteropogon contortus* *Andropogon gayanus* *Aristida junciforms* *Centropodia glauca* *Eragrostis nindensis* *Hyperthelia dissoluta*	*rocky outcrops*	29
	Sterculia apendiculata *Tabernaemontana elegans* *Spirostachys africana* *Berchemia discolor* *Acacia xanthophloea* *Allophylus africanus* *Khaya nyasica* *Milletita stuhlmannii* *Adansonia digitata*	*Senna petersiana*	*Hemarthria altissima* *Pennisetum thunbergii* *Stenotaphrum secundatum* *Phrahmites australis*	*riverine fringe*	13
		Dichrostachys cinerea	*Cenchrus ciliaris* *Eragrostis chapelieri* *Sorghum versicolor* *Cymbopogon excavatus* *Eragrotis trichophora* *Sporobolus iocladus* *Oropetium capense* *Sporobolus africanus*	*disturbed areas (old cultivated lands, bare patches in overgrazed, trampled and eroded*	15

				Tricholaena monachne *Eragrostis rigidior* *Hyparrhenia hirta* *Erogrostis clianensis* *Aristida adscensionis* *Eteropogon macrostachyus*	*veld)*	
Dominant plant species	1 2 3 4 5	*Colophospermum mopane* *Combretum hereroense* *Combretum molle* *Combretum imberbe* *Combretum fragrams*	*Dichrostachys cinerea* *Balanites aegyptiaca* *Acacia melifera* *Senna petersiana* *Pterocarpus brenanii*	*Aristida congesta* *Eteropogon macrostachyus* *Aristida adscensionis* *Erogrostis clianensis* *Hyparrhenia hirta*		

Source: worked by Da Silva, data from field survey 2008.

Colophospermum mopane and *combretum spp* habitat patchy size ranged from 0.0064 to 0.9597 sq km. Within this range values they tended to vary in 0.0005 and deviating from the mean (0.0022 sq km) at 0.0023. These figures denote higher intensity of patchy size variability (105.99%, more than 20%), which can be interpreted to indicate that there are many factors influencing on the distribution of plant species of this habitat. These factors have their effect on plant species heterogeneity and on diversity of micro-habitats. Seven (7) micro-habitats were identified ranging from *Acacia* woodlands and *Colophospermum mopane* on alluvial soils; *Kigelia africana* along the riverine forest; *Sorghum bicolor* on river banks; *Sclerocarya birrea* and *Aristida junciforms* on rocky outcrops; *Adansonia digitata* on riverine fringe; *Sorghum versicolor* and *Dichrostachys cinerea* on disturbed lands and *Combretum spp* on termite mounds.

The dominance of *Combretum spp* patches might be attributed to the ecological function of termites (see plate 3.4).

Termite hills protect species from fire, increase soil fertility and good drainage. At the same time, the presence of *Tamarindus indica* on rocky outcrops might be replacing gradually the pioneer plant species since it possesses acid leaves. While the presence of *Aristidas spp* mixed to *Dichrostachys cinerea* might not only indicating the disturbance but also the severity of wildfires in Macossa and Tambara (see also Oudtshoorn, 2006). In addition it was expected to observe *combretum spp* occurring only near termite mounds. This did not happen at all maybe due to the fact that the study area is covered by granite materials in a gentle slope (15% - 29.9%) where certain type of debris attempt to accumulate. The debris is usually weathered to some extent and results on unconsolidated soils under intensive denudation. These soils are composed of alkaline calcareous with reduced profile (less than 2 m) that encourages the growth of *combretum spp*. Santos *et. al.* (2006) classified *Combretum spp* as terrestrial invasive plant specie due to frequent trampling of the site. *Combretum spp* indicate the transition between the terrestrial and aquatic environments (Timberlake *et.al.* 2004; Santos *et. al.* 2006), where it causes negative range land impacts, hence they create a dry dense leave profile that does not allow the development of grasses. Added to toxic effect of some plants; encroachment, wildfire, tsetse fly disease and extreme poverty are the major threats to this habitat.

3.2.4. Spatial prediction of habitats richness

One of the major goals of ecology is based on relating the altitudinal gradient, species richness and NDVI. Our results suggest that higher (85) and moderate (47) plant richness were noticed at the semi-arid plateau and grassland habitats, respectively (see table 3.4).

Table 3.4: Relationship between habitat types and ecological/environmental indicators

	Ecological and Environmental indicators							
Habitat types	Total extent	Shannon index	Plant richness	Plant evenness	Relative dominance of plant species	Micro-habitats	NDVI	Patchy size variability
Moist evergreen afro-montane of *Brachystegia spiciformis (700 to 1811.89 m)*	6408.01	0.6779	28	0.2643	*Brachystegia spiciformis (21.25%)*	5	0.4488	8.03%
Semi-arid plateau of *combretum spp* and *colophospermum mopane(300 to 699.9 m)*	16657.5	1.2722	85	0.3862	*Colophospermum mopane (23.53%)* *Combretum hereroense (23.53%)*	7	0.2959	105.99%
Degraded wooded grassland on lowlands of Urema and Zambezi valley (14.96 to 299.9 m)	19436.4	0.9124	47	0.3347	*Faldherbia albida (32.18%)*	7	0.1867	589.75%

Source: worked by Da Silva, data from Landsat ETM+ imageries and tables 3.1 to 3.3.

This was, truly, not anticipated. We expected the hypothesis that the plant richness and satellite derived NDVI are positively related. It might not happened due to the fact that higher NDVI (0.4488) values indicate higher spatial homogeneity (8.03%) of plants which contributes on lower plant richness (28) at the higher altitudes (700 to 1811.89 m) dominated by rocky hillsides. This relationship was moderate and negative (r-0.416; *p= 0.727*) to mean an increase of NDVI cause a decrease in terms of species richness. Similar to Levin *et. al.* (2007) that used NDVI to predict plant richness, found that specie richness and relative range size rarity were negatively correlated to NDVI from Landsat 7 ETM+, Aster and Quickbird images and these results were significant in most cases.

Our second hypothesis ruler that NDVI and altitude gradient are positively related.

Higher NDVI (0.4488) were documented at the afro-montane habitat (700 to 1811.99 m); moderate NDVI (0.2959) at the semi-arid plateau (300 to 699.99 m) and lower NDVI (0.1867) at the grassland of lowlands (14.96 to 299.9 m).

A spearman non parametric coefficient of correlation agreed on the above hypothesis (*p< 0.05*) confirming a stronger and positive relationship (r = 0.945) between NDVI and altitude. This was significant (*p = 0.01*) increasing linearly both parameters up to certain higher gradient and down leveling, the NDVI, at the end which indicates the presence of rocky denuded materials sometimes filled by water. Altitude explained 89.22% (adjusted R^2 = 0.8922, *p=0.000*) of the NDVI variability and 10.78% was due to other factors (see figure 3.6).

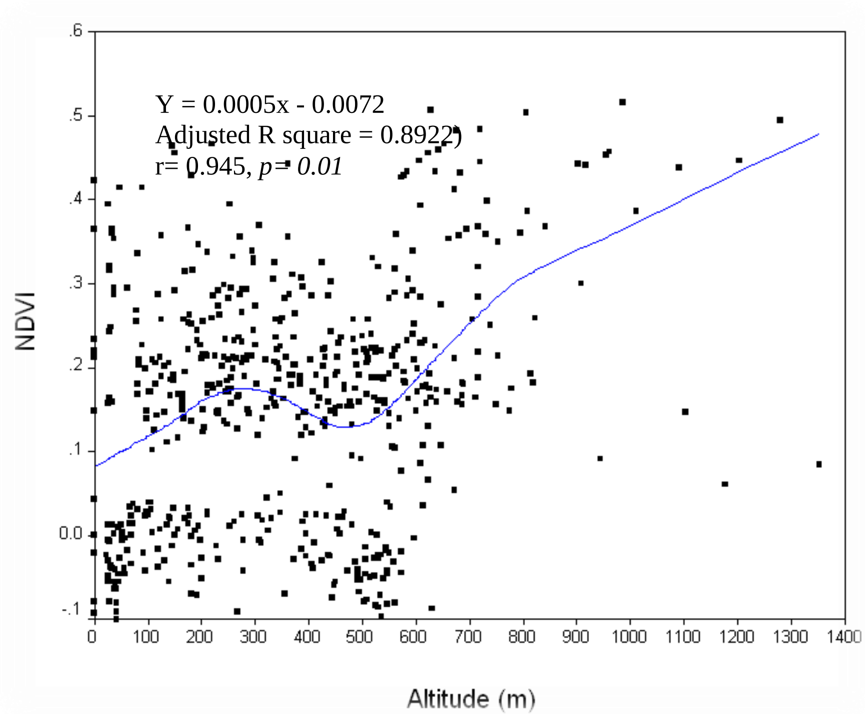


Figure 3.6: Relationship between NDVI and altitude gradient

Thus, NDVI increases with an increment of altitude and decreases with plant richness. In other words, highlands of higher NDVI will contain not as much of diversity of plant species. Higher plant richness (85) is documented at the mid-altitudes (300 to 699.99 m) of moderate NDVI (0.2959) values. This unimodal pattern of distribution showing peak specie richness at the plateau was noticed by many studies being related to ecological and evolutionary factors as well as to the size and geometry of the area (Amaral *et. al.* 2007; Levin *et. al.* 2007).

In this respect, NDVI might be a predictor not only of plant richness but also of plant relative dominance (r= 0.913; $p = 0.268$); plant evenness (r = -0.651; $p = 0.549$); intensity of patchy size variability (r= -0.895; $p = 0.294$); diversity of micro-habitats (r= -0.910; $p=0.00$). The use of NDVI in predicting specie richness spatial distribution depends on the capability of depicting moist variability along latitudinal (climate) and altitudinal (topography) gradients. Moist content is related to plant species productivity and richness. Consequently different NDVI classes will depict the diverse of environmental conditions influencing the amount of moist content that determines the composition of plant species among these NDVI classes, which vary from one area to another.

3.2.5. Do habitat types differ significantly and how larger the difference between them is?

Using the Repeated Analysis of Variance (Repeated ANOVA), we examined the NDVI performance between degraded wooded grassland on lowlands of Urema and Zambezi floodplains, semi-arid plateau of *combretum spp* and *colophospermum mopane* and moist evergreen afro-montane of *Brachystegia spiciformis*.

The means suggest that average NDVI performance was lowest at the grassland (0.1923), highest at the moist evergreen afro-montane (0.4488) and moderate at the semi-arid plateau (0.2918) (see appendix 3.7).

The Mauchly's test of sphericity indicates that the probability (*sig. = 0.000*) is less than 0.05, thus we can not assume that the variances between the scores of three habitats are equal (see appendix 3.8), there is a lack of homogeneity (equality) of variance between the three habitats and this heterogeneity was significant ($p=0.00$) somewhere between the three performance of habitats.

The effect size variability measured by partial eta squared value (0.952) is more than 0.50, indicating a larger effect of the difference between the means of habitats (see appendix 3.9). The multiple mean comparisons also denoted that there is a significant difference ($p = 0.000$) between the three habitats. The mean difference (I-J) varied in -0.00994 times less the grassland in relation to the semi-arid plateau; - 0.256 times less the grassland in relation to the moist evergreen afro-montane.

Similarly, the semi-arid plateau differed significantly ($p = 0.000$) with the grassland being 0.00994 times more than it and - 0.157 times less than the moist evergreen montane (I-J = 0.157). The moist evergreen montane mean NDVI difference was 0.256 and 0.157 times more than the grassland and semi-arid plateau habitats, respectively. This was mostly significant ($p= 0.000$) (see appendix 3.10). These results mean that semi-arid plateau and grassland are largely influenced by human disturbance (fire, shifting cultivation, infrastructure development, settlements) due to easy accessibility. Thus, they appear in aggregated and isolated smaller patches (see table 3.4).

Tucker *et al*. (1981); Rimsten, (1994); Moreira (2001) referred that the results that show 100% of crown cover are less influenced by bare soil (indicator of disturbance) but when the vegetation crown cover decreases, there is an increase in terms of bare soil spectral reflectance, that cause a decreases in the original vegetation NDVI values creating fragmented areas. The ecologists Krebs (1994); Julian and Dunster (1996) agreed that these areas are of an hierarchical pattern of distribution and their patches influence wildlife feeding behaviour due to edge effect.

Thus, it is beneficial to comprehend how elephants interact through time and space with their habitats.

3.3. **Relationship between elephant distribution and habitat types**

Spatial correlation between elephant's distribution and habitat types was performed to understand elephant habitat use patterns. Elephant patterns were obtained by generating a 10 km x 10 km numbered grid. Elephant presence signs were assigned to each grid using spatial join, summarize of the number of signs per grid. From it, density, frequency and probability of encountering the species per grid were determined. The distribution of elephant was then categorized in core habitat (higher density), peripheral habitat (moderate density) and unsuitable habitat (elephant is not present). A dissolve was then performed to each "biogeocenose" in order to eliminate unnecessary boundaries (see figure 3.7). In addition, independent variables (components of habitat types) were averaged and assigned to each 10 km x 10 km grid. Thus, a simple click on each grid will visualize the behaviour of elephant and detrimental habitat type variables (see table 2.2). This approach pertains to planning process since rare, threatened grids can simple be queried and easy located in the field. Further it's important for future elephant monitoring exercise and ecotourism activities.

Repeated Analysis of Variance (Repeated ANOVA) was then used to test whether or not there is a significant difference somewhere between elephant habitat types' use. Added to this, LSD test was computed for multiple comparisons among the means of elephant habitat use performance. Partial-Eta Square was determined to assess how large the difference between the means of elephant habitat use is. The overall significance of the differentiation was computed using the Mauchly's test of sphericity. General Linear Model was only practical to compare elephant's habitats use. For understanding why elephant habitat use differ, a spearman's non parametric correlation test was performed and weighted using multiple regression analysis of the independent variables such as food availability (NDVI), food quality (vegetation types), water availability, water density, transverse distance between water and food, altitudinal gradient, distance to settlements, distance to roads, wildfire frequency, aridity index and dependent variable (elephant density).

3.3.1. Patterns of elephant's habitat use

During the period of survey elephant used the space and resources unevenly. From the spatial correlation between elephant density and habitat types its denoted that 9 (A, B, C, D, E, F, G, Q, M) sites are being intensively selected (preferred), 10 sites (H, O, J, P, N, K, L, I, J) are relatively selected and 9 (T, T1, T2, T3, T4, T5, T6, T7, T8) are avoided, at different extents (see figure 3.7).

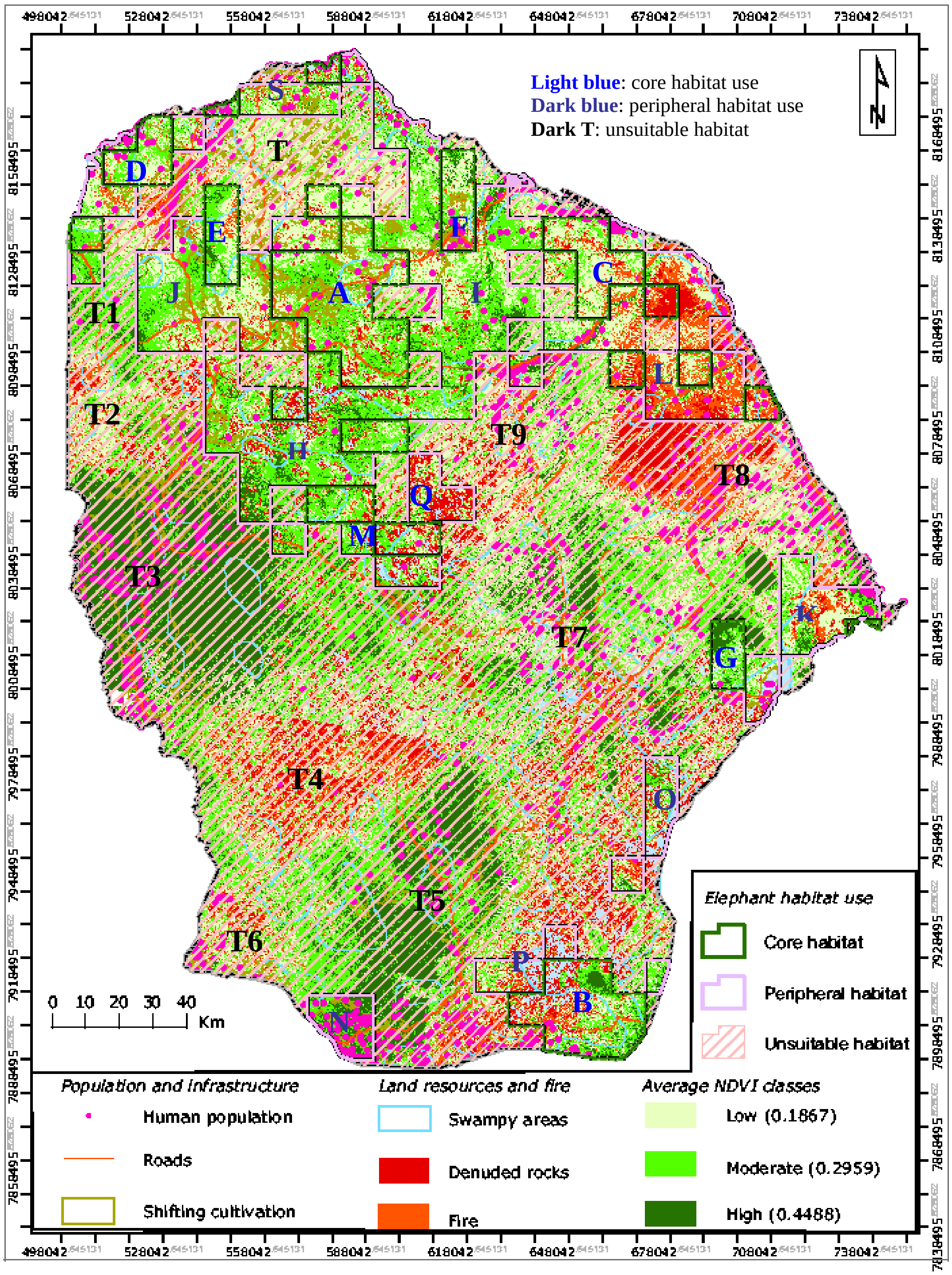


Figure 3.7: Relationship between elephant density and habitat types

Preferred sites are primarily concentrated at the semi-arid plateau of *combretum spp* and *Colophospermum mopane* where the density of elephant was 0.0100 (elephant signs/sq km), occupying 53.54% (760.41 sq km) of the core home range. Some of these sites mixed with those relatively utilized, down extent to the degraded wooded grassland on lowlands of Urema and Zambezi floodplains where the density of elephant was 0.0096 (elephant signs/sq km) at 34.92% (496.03 sq km) of core home range and western disperse and mix with avoided sites at the edge of the moist evergreen afro-montane of *Brachystegia spiciformis* (0.0078 elephant signs/sq km) at 11.54% (163.88 sq km) of core home range (see figure 3.7; table 3.5).

Table 3.5: Habitats use as a mean of elephant density and home range proportion

Habitat type	***Habitat extent (sq km)***	***Elephant signs***	***Elephant signs density***	**proportion of 50% home range**
Moist evergreen afro-montane of *Brachystegia spiciformis*	6408	50	0.0078	0.1154
Semi-arid plateau of *combretum spp* and *colophospermum mopane*	16657	167	0.0100	0.5354
Degraded wooded grassland on lowlands of Urema and Zambezi floodplains	19436	187	0.0096	0.3492

Source: worked by Da Silva, data from field survey 2008

These figures suggested that species use all habitats when available, (53.54%) semi-arid plateau, (34.92%) degraded wooded grassland and (11.54%) moist evergreen afro-montane but when the habitat influencing factor becomes more severe, their preference is narrow. For this issue, the Repeated Analysis of Variance (Repeated ANOVA) has shown a near to strong effect (partial Eta = 0.5) of the differentiation between habitats use by elephant although this segregation was not at all significant (p = 0.07). Of course, the mean habitat use difference (I-J) was -52.075 times less the grassland (78.40) in relation to the semi-arid plateau (130.47) but this difference was not significant (p = 0.422). Differently, the grassland elephant mean habitat use (78.40) was

66.43 times more than the moist evergreen afro-montane habitat (11.97) even if the probability of this difference remained not significant (*p = 0.374*). From these cases, our results also suggested that elephant habitat use was significantly (*p = 0.003*) different between the semi-arid plateau and the moist evergreen afro-montane. The first habitat was 118.51 times more utilized than the second (see figure 3.8).

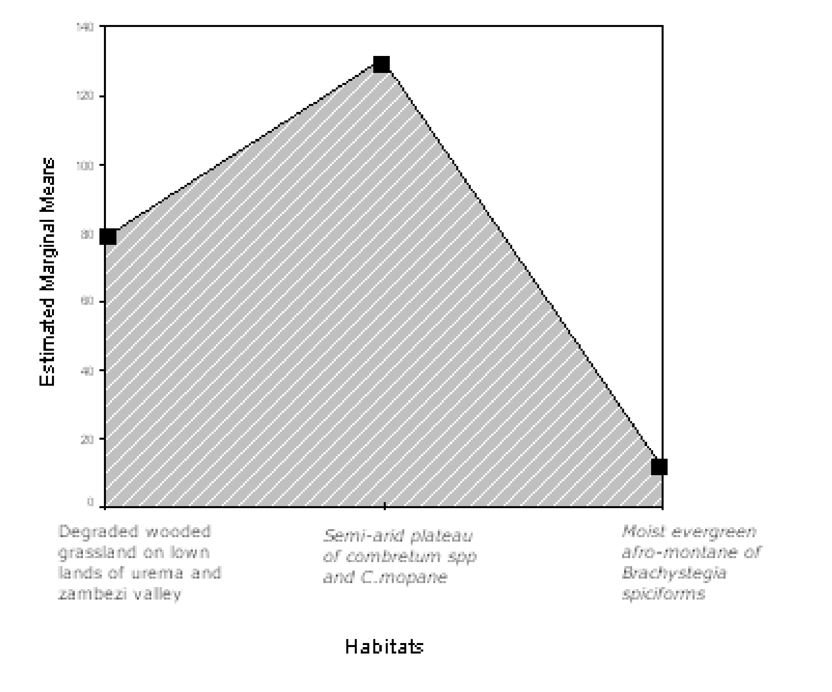


Figure 3.8: Estimated marginal means of elephant habitat use

Elephant habitat use differed at the study area. The difference was significantly between the moist evergreen afro-montane of *Brachystegia spiciformis* and the semi-arid plateau of *combretum spp* and *colophospermum mopane* (see figures 3.7, 3.8). The reasons of this differentiation are not well known.

3.3.2. **Growing plants and minerals interact with grazing/browsing elephant**

Elephant food quality varied in relation to habitat type. Higher density (0.0029 plants/sq km) of plants utilized by elephant was observed at the semi-arid plateau. At the same area the density of preferred plant species was higher (0.0012 plants/sq km). Lower density (0.0012 plants/sq km) of elephant used plants was sighted at the degraded wooded grassland (see appendix 3.11).

Similarly, the number of signs that elephant left when utilizing the vegetation classes varied significantly. 50.25% (203) of elephant was intensively utilizing the semi-deciduous forest, 19.55% (79) of elephant was sighted at the grassland, 14.36% (58) of elephant was using the regularly flooded herbaceous vegetation, 7.92% (32) utilized the closed to open forest with shifting cultivation, 6.44% (26) of elephant was observed in the semi-evergreen forest and 0.74% (3) was using cultivated areas.

Food quality and elephant density were strongly positive (r = 0.899) associated, to mean that as the species richness increases the diversity of preferred plants by elephant will linearly increase and consequently the greater the number of elephant that are likely to come for foraging. This relationship was significant ($p = 0.000$).

Thus, the observed higher intensity of semi-arid plateau habitat use might be due to higher diversity of plants. The same was documented by Barnes *et. al*. (1991) accounting for the rain forest elephant of northeastern Gabon that was strongly preferring thick secondary forest as a result of great diversity of food plants and low proportion of toxins and tannins.

Similar findings were reported in Botswana and Namib where elephants selected open secondary woodland in the wet season (Verlinden and Govor, 1998; Behnke, 1999). For this study, vegetation diversity explained 35% (Adjusted R square = 0.350; $p = 0.000$) of elephant habitat use and 65.00% by other factors.

The same was expected for vegetation greenness (NDVI). We hypothesized that because vegetation greenness is an index of food availability, elephant will be encountered in the greenest areas. Unfortunately, lower densities of elephant (0.0078) were sighted at the highest NDVI values (0.4488).

Plate 3.5

Highest densities of elephant (0.0100) coincided with moderate NDVI values (0.2959). And moderate densities of elephant (0.0096) were documented at the lowest NDVI values (0.1867).

No evidence of linear relationship between the two variables (r= 0.022), which means that vegetation greenness does not significantly imply a direct use of plants by elephant ($p = 0.602$). NDVI does not explain any variation in elephant habitat use (Adjusted R square = -0.002; $p= 0.967$). This confirms the hypothesis that vegetation tends to be more homogeny in vigorous NDVI and contribute on lower diversity of plants. Consequently, the probability of encountering game friendly species is weaker. Thus, vegetation homogeneity does not contribute directly on the observed intensity of habitat use by elephant but the diversity (heterogeneity) and multiple-functionality of some plants. For example when sampling the central ecosystem of Mozambique, elephant was intensively utilizing *Adansonia digitata* for feeding (fruits), shading (cover), watering in existing holes (trunk), digging for water (trunk), rubbing (trunk), debarking for food and stripping (trunk) (see plate 3.5).

This indicates that Elephant used *Adansonia digitata* (riverine fringe) as their major food source, particularly during the peak of wildfire months (August). This becomes a serious issue, since during the period of survey signs of degeneration of *A. digitata* due to elephant feeding behaviour were detected. Elephant were destroying these plants at alarming rates and young trees were not frequently seen. Similar destructive behaviour was known from East Africa (Tanzania), where elephant destroyed young baobab tree in Tarangire and Lake Manyara National Parks (Douglas-Hamilton, 1971). This behaviour has been noticed to affect other species and structural diversity (Western, 1975). In South Africa, the structure of woodlands changed markedly and the diversity of canopy trees and of associated birds and insects' faunas were reduced when elephant density was greater than 0.5 elephants/ sq km (Cumming *et. al.* 1997). Furthermore, the elephant-induced habitat change in Amboseli National Park contributed to the extinction of bushbuck (*Tragelaphus scriptus*) and lesser kudu (*Tragelaphus imberbis*) (Connell, 1978). In Zimbabwe changes on *Brachystegia spiciformis* resulted on dominance of *Julbernardia globiflora* due to elephant-dependent modifications (Mapaure, 2001). In the presence of such ecological behaviour, the preservation of the elephant and its habitat is likely to be a challenging and problematic.

Adansonia digitata preference was associated to *Dalbergia melanoxylon*, *Tamarindus indica*, *Cussonia spicata, Sorghum bicolor, Sorghum versicolor*, *Sporobolus africanus*, *Sporobolus ioclados*, *Stenotaphrum secundatum*, *Panicum maximum*, *Colophospermum mopane*, *Acacia melifera*, *Acacia nigrescens*, *Acacia robusta*, *Acacia welwitschii*, *Acacia xanthophloea*, *Acroceras macrum*, *Albizia harveyi*, *Albizia versicolor*, *Sclerocarya birrea.*

Fresh (left) and dry (right) dungs are indicators of elephant seasonal food preference. Elephant use marula fruits (*Sclerocarya birrea* fruits) and destroy it through the tentative of gathering the fruits located at the top. During the peak of marula elephant sometimes gets drunk and shade on it.

Halternorth and Diller (1986) reported movements of large herds over great distances (500 km) during the late dry season, in search of new growth and fruiting food plants. Baldus *et. al* (2003), in Selous-Niassa wildlife corridor noticed that the peak fruiting period of marula fruit was associated with peak occurrences of elephant along the Rovuma river where these fruits are found.

In Tanzania, Tarangire-Manyara Ecosystem (Manyara Ranch) Da Silva and Kaswamila (2007) sighted elephant feeding on *Dalbergia melanoxylon* and *Acacia xanthophloea*. They documented that its uniqueness was due to higher pressure by elephant since they prefer food of higher palatability and associated to water content. The same authors documented that the presence of *Sporobolus africanus*, *Sporobolus ioclados* indicates the occurrence of salt (see Van Wyk and Van Wyk, 1997; Coates-Palgrave, 2002). At the study area signs of elephant salting were detected (see plate 3.7).

Plate 3.7

Plate 3.7 shows elephant salting site along Muera river and as a result river's margins are eroded. The degraded lands reduce river's water flow. This associated to the seasonality of rainfall result on aquatic environment change to terrestrial. With substitution of wetlands elephant are forced to migrate or change their feeding preference concentrating on food plants that offer water, such as *Dalbergia melanoxylon, Acacia xanthophloea, Adansonia digitata, Sorghum bicolor, Sorghum versicolor*, *Sclerocarya birrea*.

In Tiger Game Reserve (India) Varma (2008) documented that the presence of salt and *Tamarindus indica* fruits stimulates elephant to get more appetite on grasses. Moreover, when *Tamarindus indica* is mixed to salt, it makes elephant stronger.

Similar findings were revealed in Kenya where diet of bull elephant was important if they are to succeed in sexual contests for females, thus they disperse on *sorghum spp* and maize farms hence they are of higher nutritional value.

Another issue of concern is NDVI and elephant. Elephant were utilizing more than one NDVI classes. But no linear evidence of association between vegetation greenness (NDVI) and elephant density (r= 0.022; $p = 0.602$) were documented. Similar findings were reported in

Burkina Faso (Hien, 2005), accounting to non evidence of a linear relationship (r = - 0.22, p = 0.45) between elephants density and NDVI. Contrary, in Kenya, high elephant densities were explained as a result of dense grass cover and green grass condition (Western, 1975). A positive correlation between NDVI and elephant density it was also very expected to occur in the study area particularly along rivers and streams of high altitude. For rivers might not have happen because of poaching in areas of riverine vegetation (*Kigelia africana* trees) where man uses fire to collect honey. For the case of streams, the influence of altitude on NDVI and consequently on diversity of food plants might be limiting the elephant of the study area. Altitude explained 89.22% NDVI variability and 10.78% was due to other factors (see figure 3.6).

3.3.3. Altitudinal gradient influence elephant food diversity and accessibility

Topography at the study area is characterized by steepest slope (>30%) at the highlands (700 to 1811.89 m), moderate slope (15-29.9%) at the plateau (300 to 699.9 m) and gentle slope (0-14.96%) at the lowlands (14.96-299.9 m). There is a difference of 1796.93 m between the lowest (14.96 m) and highest altitude (1811.89 m).

Elephant was primarily utilizing the lowlands (47.89%) and plateau (47.39%) and relatively avoided the highlands (4.71%) (see figure 3.9).

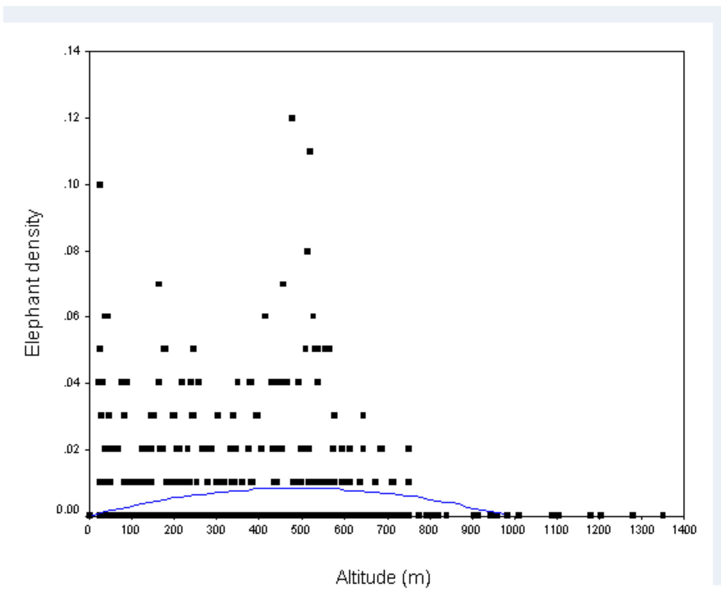


Figure 3.9: Degree of association between elephant density and altitude (m)

A weak and negative (r = -0.093) degree of association is established between elephant density and altitude. This indicates that an increase in terms of altitude might cause a linear decrease of elephant densities. This relationship is significant (*p=0.028*). Thus, altitude explained 0.6% (Adjusted R square = 0.006; *p = 0.033*) of elephant variability.

Similar findings were documented in Kenya (Smith and Kasiki, 2000) and found a weak negative association (r = -0.113) between human-elephant conflict incident density and elevation. Hien (2005), in Burkina Faso, correlated elephant density and elevation and documented a negative weak (r=-0.19) relationship between the two variables but not significant (*p=0.51*). Varma (2008), in southern India, documented that elephant was limited to altitudes ranging from 300 to 1300 m, out of which 90% was restricted to altitudes between 600 and 1200 m.

For this study, this did not happen at all maybe due to food diversity, availability and accessibility controlled by altitude gradient. Elephant preferred areas of high food plants diversity. Plant richness explained significantly ($p = 0.000$) 35% of habitat use by elephant. Food was diverse at middle (Shannon index = 1.2722) and homogeny at highlands (Shannon index = 0.6779). Lower food availability was documented at the floodplain due to dominance of temporary grasses of low leaf production due to irregular flooding system. Thus, even if food was diverse at highlands, elephant tend to spend more time and energy for accessing the resources due to the steep slope (>30%).

In addition, at the steepest slope water runoff is higher and elephant will tend to water on lowlands. Added to this, transverse distance between browsing (highlands) and watering (lowlands) places increases and consequently elephant will spend more time and energy walking than feeding. This might be the reason that made elephant to obtain plant food at the plateau (47.39%) and water at the lowlands (47.89%). However, topography does not directly impact elephant habitat use but influence on underlying factors such as vegetation diversity, availability, accessibility and water sources.

3.3.4. Water sources influence elephant's efficiency of forage use

Distribution, size, density and transverse distance were computed in order to evaluate the influence of water on elephant.

Water availability varied accordingly to topography and aridity index. Water sources located at highlands and plateau had temporary water throughout the year, particularly during rain season (November to April), experiencing a severe dry from June up to December (INAM, 2008; see figures 3.10; 3.13).

This situation becomes more severe since the study area is located on high drought risk zone (see figures 3.10; 3.13). Added to this, water sources appeared more disperse at the plateau and highlands and scattered at the lowlands. This might be a result of slope and alluvial soils (see figure 3.13).

Higher density of elephant (2.7 signs/ sq km) was observed at areas of lower density (0.06) of water points. Elephant also varied accordingly to transverse distance: 5.65% of elephant were feeding at a distance of 2-5 km from water point, 4.91% at a distance between 5.1-9.5 km, 3.19% between 9.6-15 km, and 0.25% in more than 15 km (see figure 3.10).

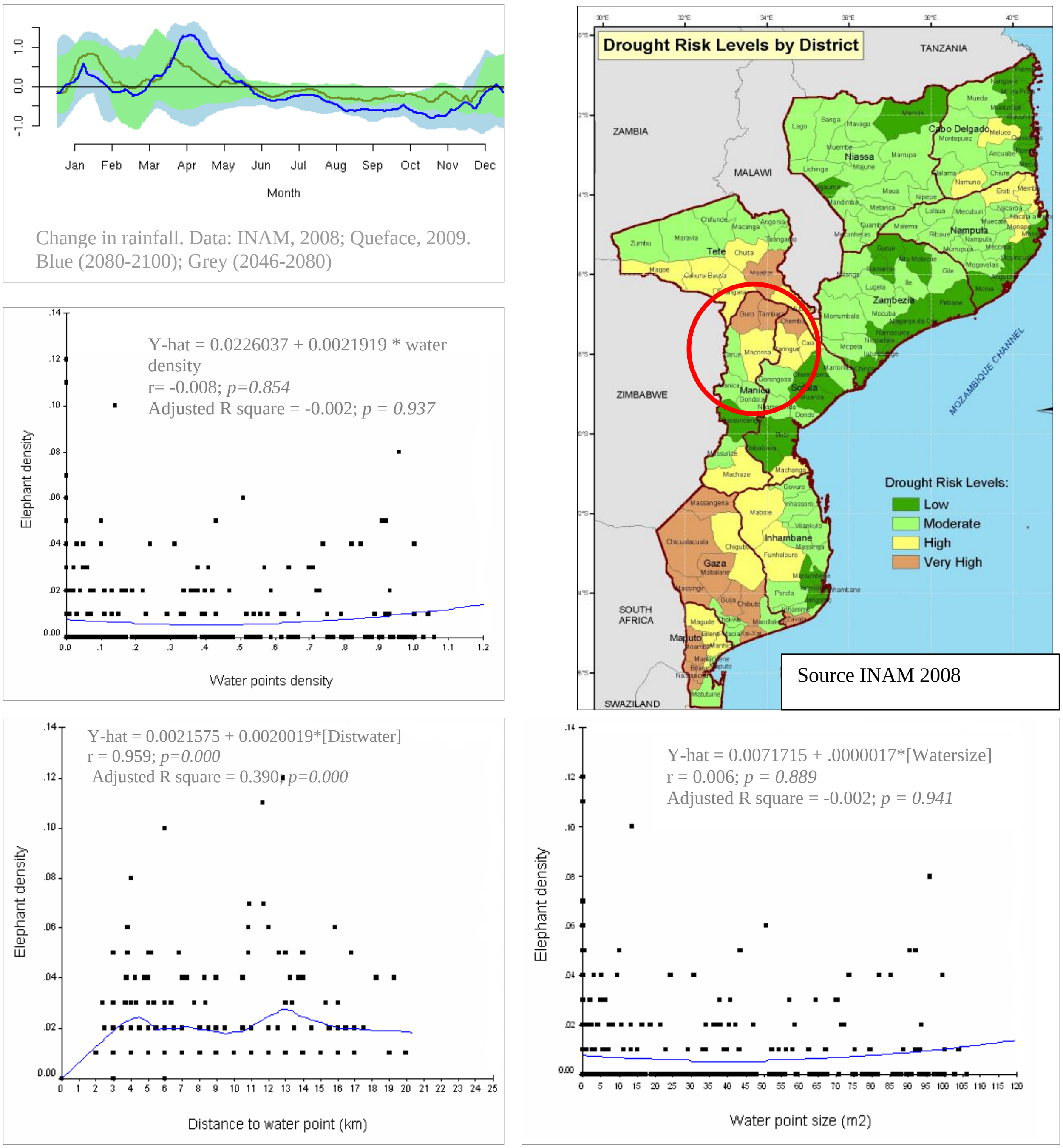


Figure 3.10: Degree of association between elephant and water

Although elephant dung was concentrated near water points, water density (r=-0.008) did not have a significant effect ($p = 0.854$) on distribution of elephant. Water density did not explain any variability on the distribution of elephant (Adjusted R square -0.002; $p = 0.937$). Similar to water point size did not show a significant degree of association with elephant (r = 0.006; $p = 0.889$). No evidence of significant amount of elephant variability (Adjusted R square = -0.002; $p = 0.941$) due to water point size.

A strong and positive relationship (r = 0.959; $p=0.000$) was depicted between elephant and transverse distance. This can be interpreted to mean that if other detrimental factors remain stable, elephant will tend to be located not far from water sources (2-5 km). As food richness and availability become scarce around these water sources, they will increase the transverse distance. Transverse distance explained significantly ($p= 0.000$) 39% (Adjusted R square = 0.390) of elephant density variability and 61% by other factors. In addition, the coefficient of multiple determination has shown that for elephant of the study area, does not matter the size and density of water points but their availability (r= 0.636; $p=0.000$). Water availability explained 40.2% (Adjusted R square 0.402) of elephant habitat use. This was significant ($p= 0.000$) (see also tables 3.6; 3.7).

Table 3.6: Multiple determination coefficients of water availability and elephant density

					95% CI	
Coefficient	**Value**	**Std. Error**	**t-Value**	**P (>|t|)**	**Lower**	**Upper**
[Intercept]	0.000745	0.000687	1.084618	0.278557	-0.000604	0.002095
[Waterdensi]	0.197552	0.236781	0.834324	0.404454	-0.267534	0.662639
[Watersize]	-0.001910	0.002368	-0.806892	0.420070	-0.006561	0.002740
[Distwater]	0.002072	0.000106	19.514527	< 0.00001	0.001864	0.002281

Source: worked by Da Silva, data from field survey 2008

Table 3.7: Water Analysis of Variance (ANOVA)

	Df	**Sum of Sq**	**Mean Sq**	**F-Value**	**P-Value**
Regression	3	0.054	0.0178723	127.2948600	< 0.00001
Residuals	561	0.079	0.0001404		
Total	564	0.132			

Source: worked by Da Silva, data from field survey 2008

Similar findings where documented at Manyara Ranch (Tanzania) where the seasonality of water from Makuyuni river was mitigated by construction of water dams. Elephant was strictly tied to water dams (91.7%). The size and contiguity of dams influenced on the availability and quality of grazing pasture (Da Silva and Kaswamila, 2007).

Elephant of Burkina Faso (Hien, 2005) was correlated to stream density, distance to rivers and to dams. A strong negative relationship was found between elephant density and stream density (r = - 0.69, $p= 0.009$) and between elephant density and distance to dams (r = - 0.71, $p = 0.006$).

In Kenya, the greater variability in home ranges sizes of elephant was a result of the size of farms and type of crops grown and vegetation dictated by water dynamics. Dry season elephant moved between game ranches in search of water contrary to the rain season which was found grazing on communal (Less, 1998).

Studies suggested that seasonal variation in food availability and quality affect elephant ranging patterns and migration, modified by water availability, which is in turn dictated by rainfall (Western, 1975; Viljoen and Bothma, 1990; Yhodeg and Lweno, 2003). Thus, water influence habitats' use by means of distribution, distance, availability and their size (Kernick, 1980; Barnes, 1996; Behnke, 1999).

Elephant was strongly positive related to transverse distance (r = 0.959; $p=0.000$).

Similar to Barnes (1996), distance to dams was strongly associated to elephant dungs abundance confirming the hypothesis that elephant will disperse close to water because of daily requirements. Elephant of central Mozambique was concentrating (5.65%) within a distance of 2-5 km from water points and dispersing (0.25%) in more than 15 km. Literature suggests that the smaller the distances between watering points the less time and energy animals spend in walking and the more spend in eating (Kernick, 1980).

Water availability was also noticed to influence significantly ($p= 0.000$) elephant feeding behaviour (40.2%). Water availability is closely related to efficiency of forage use. Regular distributed water sources facilitate more even grazing and vice-versa (Behnke, 1999). In addition, our results denoted that larger water size (96.16 sq m) is associated to high elephant density (2.46 signs/ sq km). Although the results were not significant (($p=0.889$), studies pointed out that the larger the water source size the larger the grazing area that each serves, and the greater the number of elephant that are likely to come for use (Kernick, 1980; Less, 1998; Gibson *et al*., 1998; Behnke, 1999).

However, critical issue on water limited habitats such as of the semi-arid plateau of *combretum spp* and *colophospermum mopane* is the pull of species to concentrate on riverine micro-habitat where human burn, poach, cultivate and collect honey. For this reason, where the density of water sources was higher human diurnal activity increased and elephant consequently shifted. This is the presumably explanation of the documented weak negative degree of association between elephant and streams density (r=-0.008), although it was not significant ($p = 0.854$), since in some cases elephant killed human when trying to resist from its pressure.


Plate 3.8

3.3.4. Human dictates the security and food availability of elephant

We hypothesized that elephant will tend to avoid areas densely populated due to road traffic, wildfire effect, forest fragmentation, food abundance and quality, distance to settlements and poaching.

A spatial analysis between the presence of elephant and distance to human settlements has shown that elephant and human are competing for the same land resources (see plate 3.8; figure 3.11).

From the overall sights 403 (100%); 58 (14.22%) sights were located between 0-2 km from settlements; 122 (29.9%) between 2-4 km, 71 (17.40%) between 4-6 km; 50 (12.25%) between 6-8 km; 29 (7.11%) between 8-12 km; 13 (3.19%) between 12-14km; 10 (2.45%) between 14-16 km, 2 (0.49%) between 24-26 km.

Elephant did not utilize frequently the area immediately from the settlements (0-2km). Elephant used intensively (29.9%) habitat resources located between 2-4 km and relatively avoided (0.49%) the resources between 24-26 km from human settlements (see figure 3.11). Human occupy land suitable for their primary activity (shifting cultivation). Shifting agriculture depends on natural water availability and fertile soils, which in turn coincided with elephant refugee sites (riverine micro-habitat) (see figure 3.11). A strong positive correlation (r=0.956) was significantly (*p=0.000*) documented. This can be interpreted to mean that as human settlements tend to release the areas used by elephant, the number of the species will have to increase. Sadly, if human insists on areas preferred by elephant, they will have to find alternative sites to use. Distance to settlements explained significantly (*p=0.000*) 34.9% (Adjusted R square = 0.349; *p=0.000*) of habitat avoidance by elephant particularly from 0-2 km and 24-26 km (see figure 3.11).

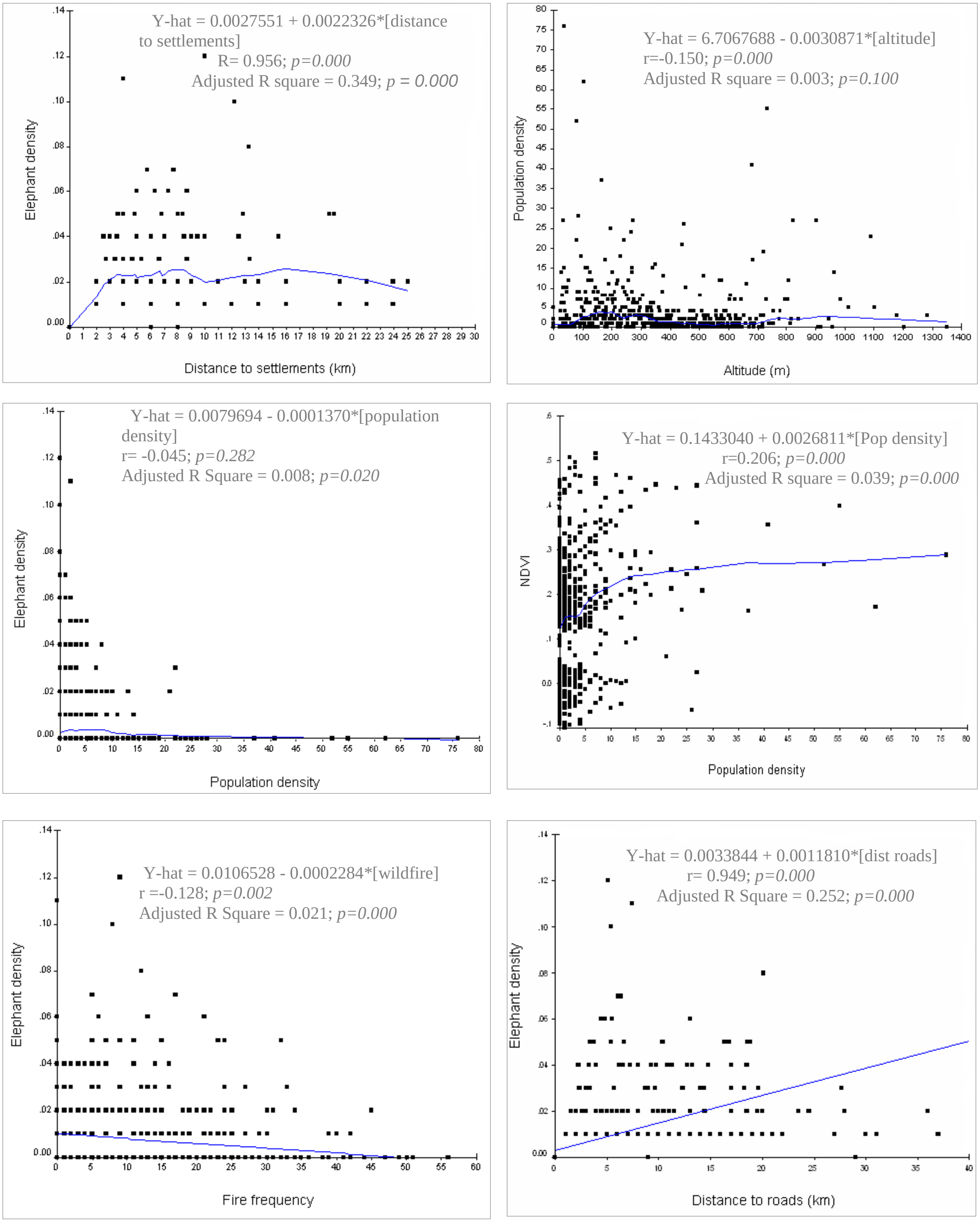


Figure 3.11: Human associates to elephant in different manners

Approximately 2 hab/sq km denoted to be not problematic for the survivor of elephant but at about 8 hab/sq km Elephant started to down levelling, confirming the hypothesis that they will tend to avoid areas densely populated. On this matter, research (du Toit *at. al.* 2004) suggested that although elephant densities do not decline in linear response to increasing human densities, “at a threshold of 16 people per sq km the elephant suddenly disappear” and also that even where human settlements are scattered, “as the cultivated area expands, the elephant habitat becomes fragmented and thus, they disappear (Songorwa, 2004). For this study, human density was not linearly correlated to elephant density (r = - 0.045; $p = 0.282$) but it was influencing elephant in other underlying forms. Human settlements have been concentrating at low and middle lands dictating the pattern of availability and use of food plants by elephant (see figure 3.11). Vegetation availability was lower at higher human densities and near human settlements due to human logging (see figure 3.11). Road accessibility and wildfire influenced the structure and composition of elephant food plants.

A weak negative correlation (r = -0.128; $p=0.002$) between elephant and fire frequency was documented, indicating that although savannah fire is interpreted as a range land management tool, an increase of fire events might cause a decrease of shade and change of the composition of elephant food plants and consequently as food decrease, elephant numbers will be forced to shrink, since they will scramble for few resources use and famine bull will be passive to matting process. Fire frequency explained significantly ($p=0.000$) 0.21% (Adjusted R square = 0.021) of elephant variability (see figure 3.12).

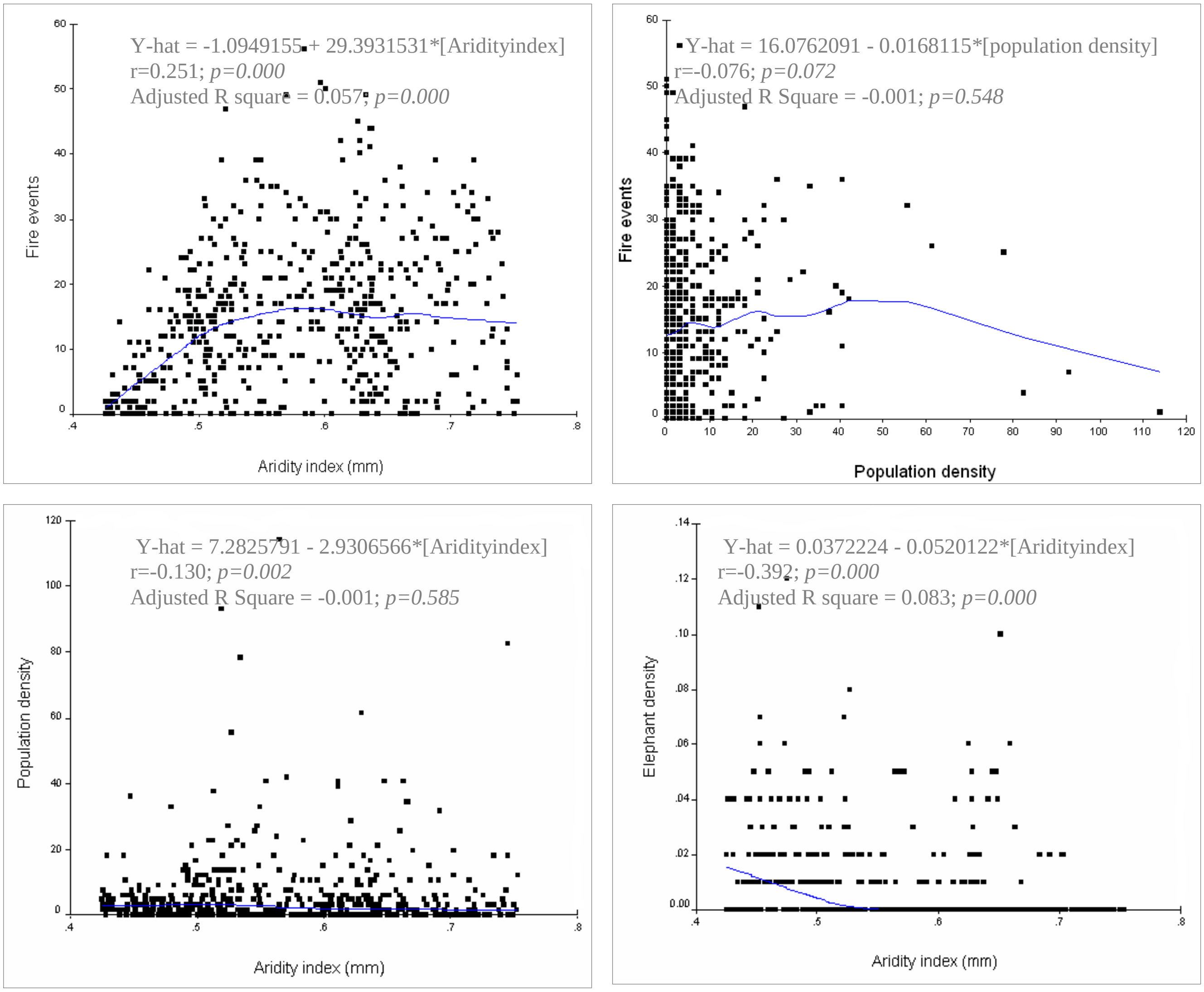


Figure 3.12: What is the root cause of fire, human or climate change?

Wildfire may occurs even without human influence (r=-0.076; $p=0.072$). Fire events decreased as human density increase, although this was not significant (Adjusted R Square = -0.001; $p=0.548$). Bushfire was more likely related to climate (r=0.251; $p=0.000$). Climate (aridity index) explained significantly ($p=0.000$) 5.7% (Adjusted R square = 0.057) of bushfire variability, particularly during August.

In addition, climate was detrimental to elephant density. A moderate negative relationship was documented (r=-0.392; $p=0.000$), and can be interpreted to mean that elephant varied accordingly to the season and this seasonality became more severe, since human activities have pulled the elephant to concentrate in water limited habitats (see figure 3.13).

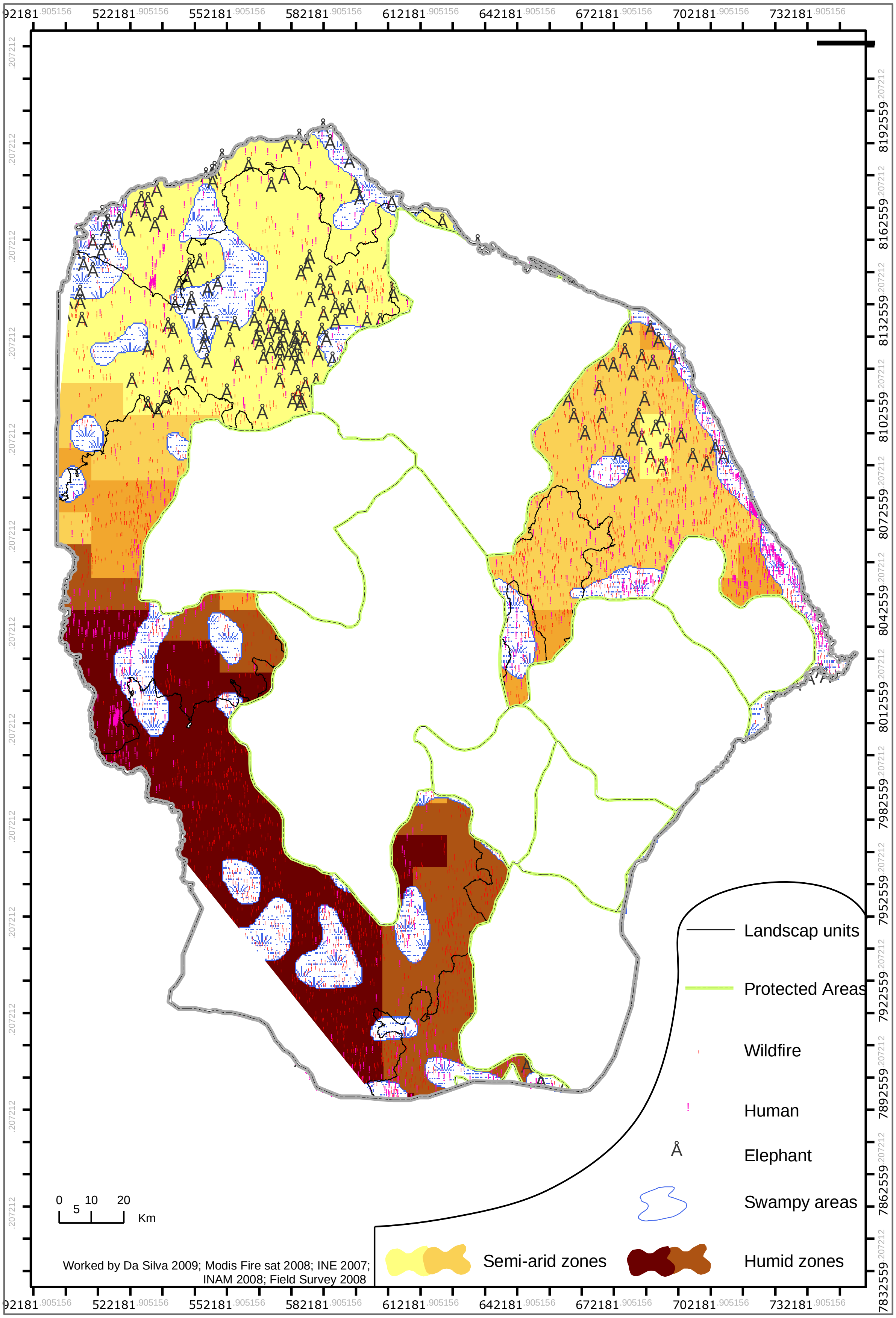


Figure 3.13: Spatial correlation between aridity index, water availability, wildfire frequency and distribution of elephant on marginal lands

This is truly harmful to elephant, since aridity index (dryness) influence not only on water availability and consequently forage pattern and efficiency of use but also on the frequency and severity of fire, which dictate food abundance and quality. Literature suggests that during wet season, the new growth of grass provide abundant forage in all habitat types. As the dry season approaches, the vast habitat undergoes changes in quality and abundance due to drought and fire (Fryxell and Sinclair, 1998). For this study, aridity index explained significantly ($p=0.000$) 8.3% of habitat use by elephant.

Adaptation of human practices to climate change effects is being cost full to elephant conservation. For example, human pulled elephant from wetlands to dry lands to cope the impact of drought during agricultural production.

This might be the reason of conservation failure in Mozambique, since protected areas have been designed accordingly to the presence of species. The location of wildlife on marginal lands is cost prohibitive to conservation due to two reasons: i) water limited habitats need investment on artificial water dams; ii) developing countries have no money for future wildlife conservation investment.

Road impact was also of concern to elephant habitat avoidance. A strong positive correlation was computed (r = 0.949; $p = 0.000$) between elephant density and distance to roads. The distance from roads explained significantly ($p=0.000$) 25.2% of elephant variability. This has relevance in three ways:

1-Traffic on the tarmac road from Manica to Tete cause high disturbance to elephant feeding behaviour, consequently there was no signs of elephant traversing the tarmac road comparatively to the unpaved road e.g. from Guro to Tambara where the elephant transverse it at different sites (e.g. 7 km from chivuli locality). Differences on road quality influence on traffic intensity and consequently on elephant habitat use behaviour;

2-Human settlements are located along the road, thus vegetation logging (caused by access to roads) creates open areas of less abundance of preferred food plant by elephant (e.g. *Combretum spp*; *Dichrostachys cinerea, Cenchrus ciliaris, Eragrostis chapelieri, Cymbopogon excavatus, Oropetium capense, Tricholaena monachne, Hyparrhenia hirta, Aristida adscensionis*). Moreover, human location is impeding the movement of elephant (e.g. Luenha river, Changara, Casa-banana, Tongonda);

3-The road increase cause more accessibility to remote areas, enhancing the chance of human-elephant interactions, causing a corresponding raise in mortality risk due to poaching (see plate 3.9).

Plate 3.9: Poaching techniques and signs in Muera and Mussangadze Villages

Table 3.8: Multiple determination coefficients of human and elephant density

					95% CI	
Coefficient	Value	Std. Error	t-Value	P (>|t|)	Lower	Upper
[Intercept]	0.004806	0.001069	4.496840	< 0.00001	0.002706	0.006906
[Distsettlem]	0.001626	0.000214	7.616326	< 0.00001	0.001207	0.002046
[Distroads]	0.000392	0.000145	2.714846	0.006860	0.000108	0.000676
[Wildfire]	-0.000139	0.000049	-2.824437	0.004926	-0.000236	-0.000042
[Popdensity]	-0.000009	0.000047	-0.192256	0.847620	-0.000100	0.000083

Source: worked by Da Silva, data from field survey 2008

Table 3.9: Human Analysis of Variance (ANOVA)

	Df	Sum of Sq	Mean Sq	F-Value	P-Value
Regression	4	0.041	0.0101722	74.331857	< 0.00001
Residuals	499	0.068	0.0001368		
Total	503	0.109			

Source: worked by Da Silva, data from field survey 2008

Our results suggested that there is no doubt to accept the hypothesis that human influence elephant habitat use (*$p<0.05$*). Human activities determined significantly (*$p=0.000$*) the habitat avoidance on lowlands of northern and eastern Gorongoza NP, Guro, Macossa, Vila de Sena, Tambara, Changara headquarters. They explained 36.8% (Adjusted R-Squared = 0.368) of habitat avoidance. This was basically due to distance to settlements (34.9%) and roads (25.2%) complemented by fire (0.21%).

Barnes (1991), in northern Gabon forest reported that elephant avoided zones within 7 km of roads because of human disturbance. In addition, there was a relationship between droppings density and distance to nearest village, which led to suggest that the most important factor determining elephant habitat use was not vegetation but human activities (see also Kideghesho, 1999).

Human activities depend on property rights and management regimes. That means there are rules under which rights and duties are exercised over the use of land resources. Thus, the duty that an individual owes defines his/her actions on the specific domain and consequently on its efficient use. Property right regimes function hand to hand with local awareness on who leave anyone mismanages his/her resources will suffer from his/her actions not just a bit but more than anybody else.

For example, at the communities of Mussangadze and Chivuli, migrants were brutally destroying habitat cover (cutting trees and farming). Nigerians are illegally caving any ever seen kilometres of land on search of diamond, tourmalines and gold in Macossa. Zimbabwean, in hunting blocks 9, 7, 13, are part time resource users and consequently are using salt and water to attract elephant for poaching. Elephant that escape from resources mismanagement migrate during half year to graze and browse in the communal land where also villagers practice different activities for cash income generation. The issue on that type of interaction is on the fact that villagers know that with any increase of their land activities, they will accrue more benefits from that increase while the same increase is detrimental to native elephant food plants. It is sad to note, that this results on pachyderms feeding preference change, concentrating on crops instead of invasive plants and during this situation the indigenous people suffer consequences of the problems caused by migrants who did not pay for any cost. However, in a land open to all (farmers, miners, poachers, bee keepers, livestock keepers) it is to be expected that each user will try to profit as much as possible on it-the tragedy of the commons (Hardin, 1968).

In fact, without solution to property rights the environmental problems will remain.

In Selous Game Reserve Buffer Zone it was cost full to control the poaching intensity that was about 2000 arrests in two years (Baldus, 2002).

A state and common properties were implemented and regulated by use of hunting quota. The meat from sport hunting was sold therein the community and the revenues where used for intensified patrols employing both community and state rangers.

Although these activities involved indigenous people on conservation of their owner resources, are the population numbers and raising density sustainable in order the demand be continually satisfied without causing the harm to the natural environment?

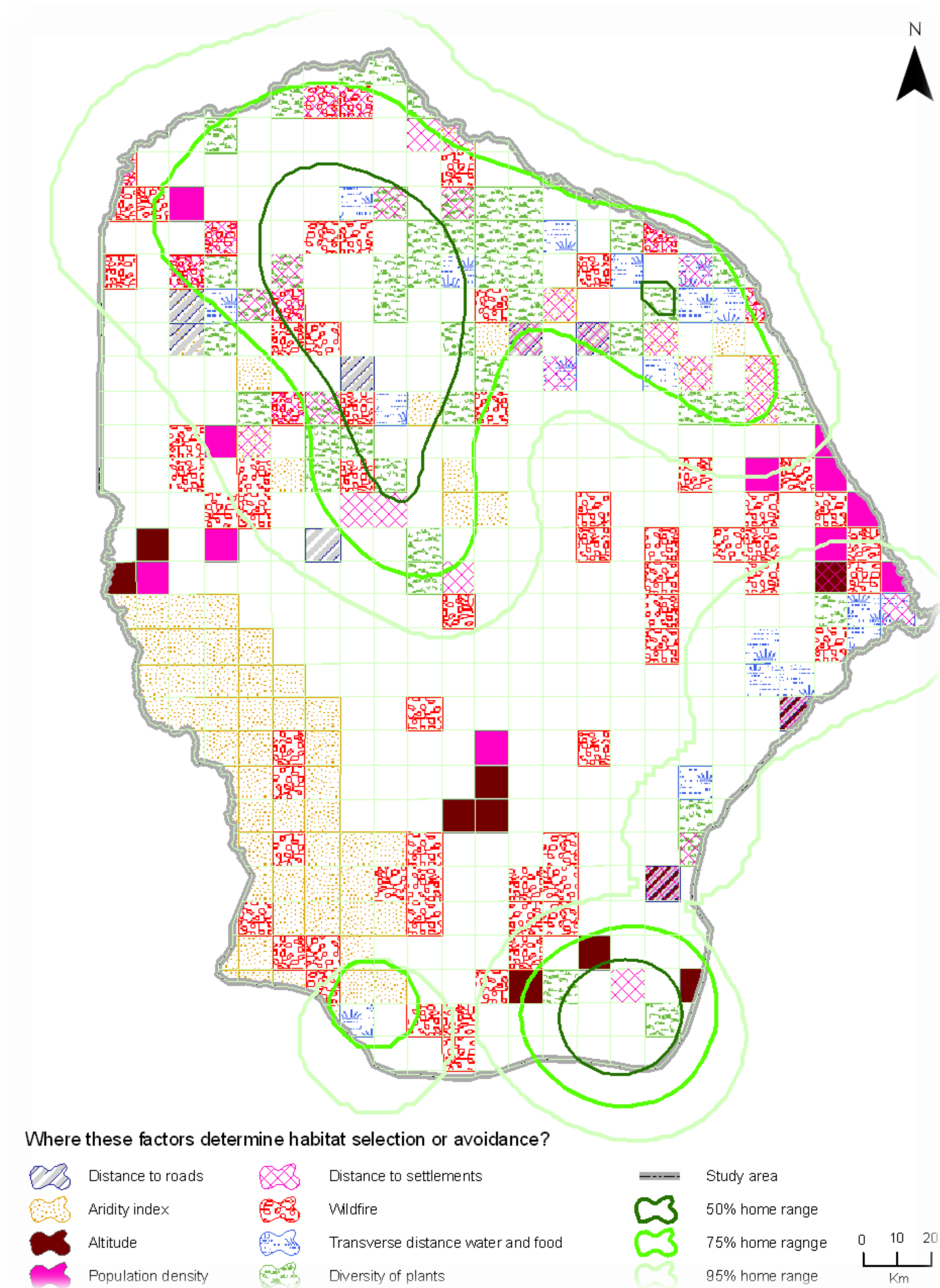
For this question scientists believed on multidisciplinarity. Thus, Wildlife Managers need to be aware on demographic issues if they want to cop the single and largest threat facing wildlife in Africa-the habitat loss due to anthropogenic factors (Kideghesho, 1999; Kideghesho *et. al.*, 2000; Songorwa, 2004; Kideghesho *et. al*., 2006).

For example, a multiple land use approach is used in Ngorongoro Conservation Authority-NCA (Tanzania). This was possible by use of management plans but up to certain period the Maasai and their land uses were multiplying at alarming rate, not sustainable for land resource. A practical mitigation measure was awarding outside scholarship to youthful.

Thus, it's urgent to identify and address critical factors (root causes) responsible for wildlife decline in each ecosystem (Kideghesho, 1999; TWFP, 1999; Songorwa, 2004).

3.3.5. Critical factors determining landscape elephant conservation

In Mozambique central ecosystem, critical factors harming elephant were identified and weighed to give the Spatial Model for Landscape Elephant Conservation-SMLEC. At micro-scale level, water availability (40.2%; $p=0.000$), human activities (36.80%; $p=0.000$) and vegetation (35.00%; $p=0.000$) influenced the existence of elephant. The macro-scale, considered altitude (0.6%; $p = 0.033$) and aridity index (8.3%; $p=0.000$) as detrimental to the factors affecting elephant at micro-scale (see figure 3.14).



N
Where these factors determine habitat selection or avoidance?
Distance to roads
Aridity index
Altitude
Population density
Distance to settlements
Wildfire
Transverse distance water and food
Diversity of plants
Study area
50% home range
75% home ragnge
95% home range
0 10 20
Km

Figure 3.14: Critical factors determine habitat selection or avoidance by elephant at 95% of confidence level

3.4. Elephant conservation priority areas

This elephant conservation priority setting activity is beyond the presence and absence of features. First, we hypothesised data sets of rich areas may contain no more species in total than would be expected from choosing the same number of areas at random (see also Reed and Alexander, 1992; Margules *et al*., 2002). Second, we premised elephant habitat use is a cause-effect relationship. Where high food quality is present elephant might not be there due to human induced practices. Thus, data sets for Elephant's conservation planning were defined in terms of grids (sites) and features. Grids are the observed different geographical units of land of 10 x 10 km. Features are the components of biological, environmental and anthropogenic units affecting elephant habitat use or avoidance (see figure 3.15).

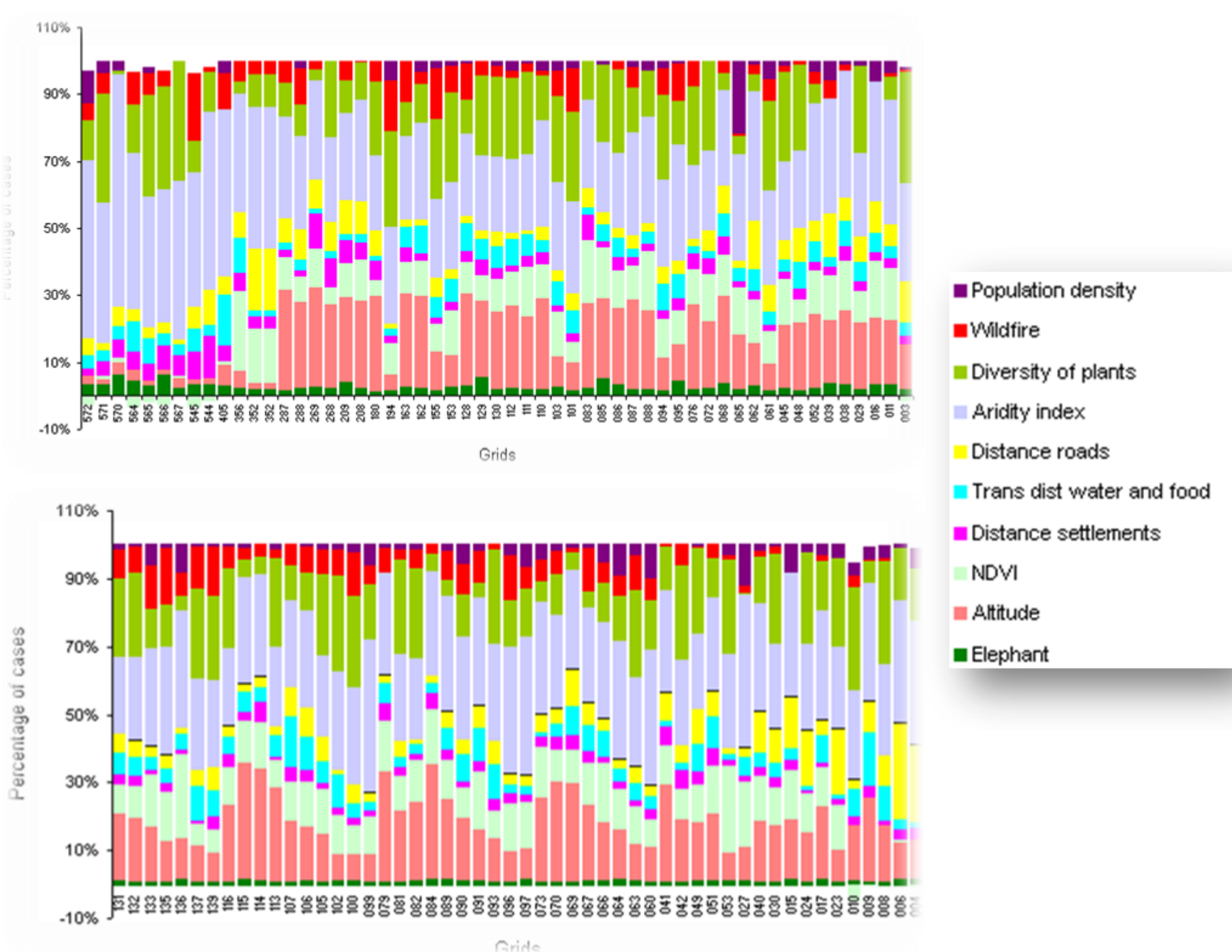
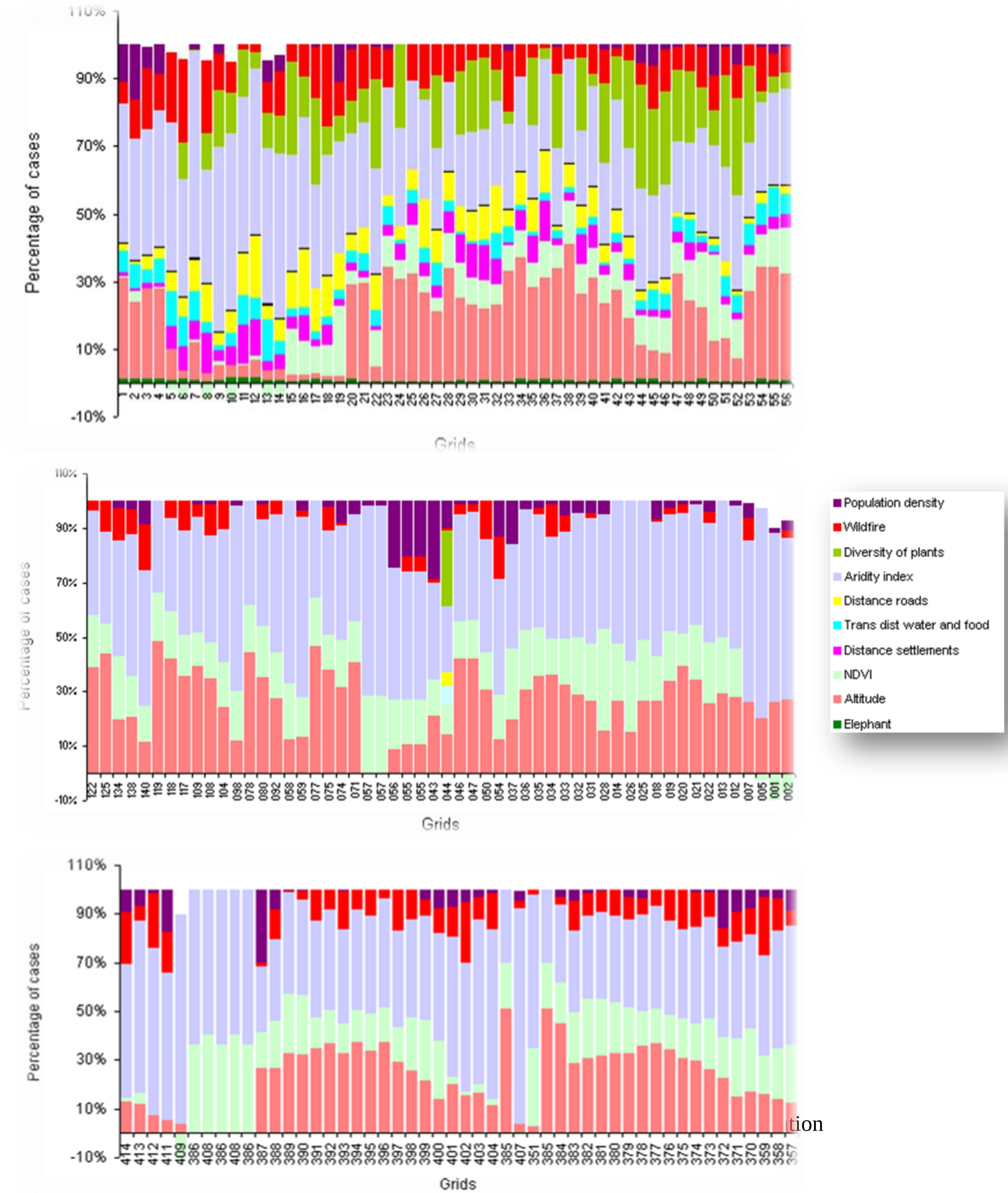


Figure 3.15: Correlation between grids and critical features for elephant conservation



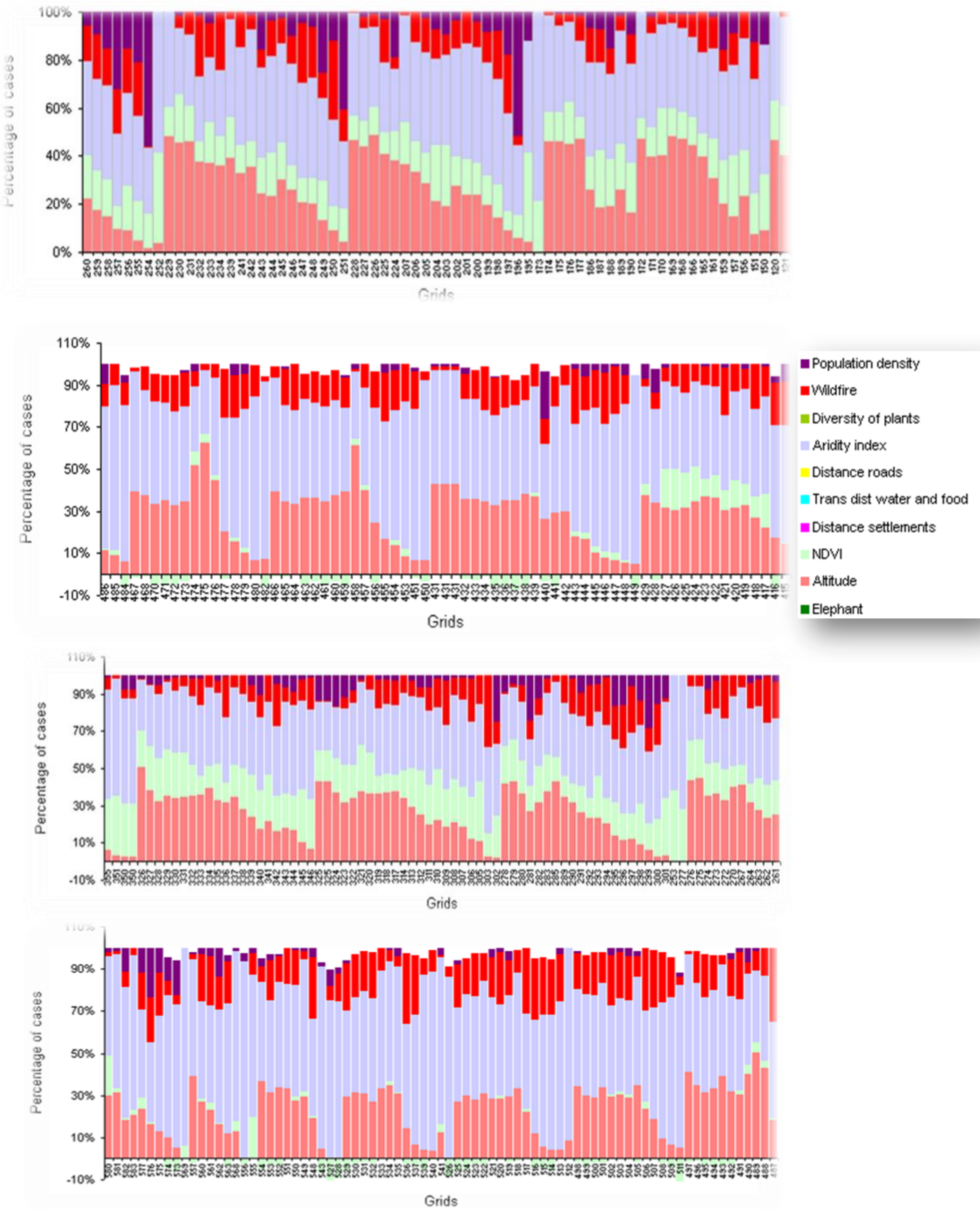


Figure 3.15: Correlation between grids and critical features for elephant conservation

Grids are represented on graphs of bars and maps. Maps encompass sites of spatial interaction of elephant critical factors and pertain to prediction of elephant habitat distribution using geostatistical models (quantile and kriging methods) and normalized difference vegetation index (NDVI) (see figures 3.16; 3.17).

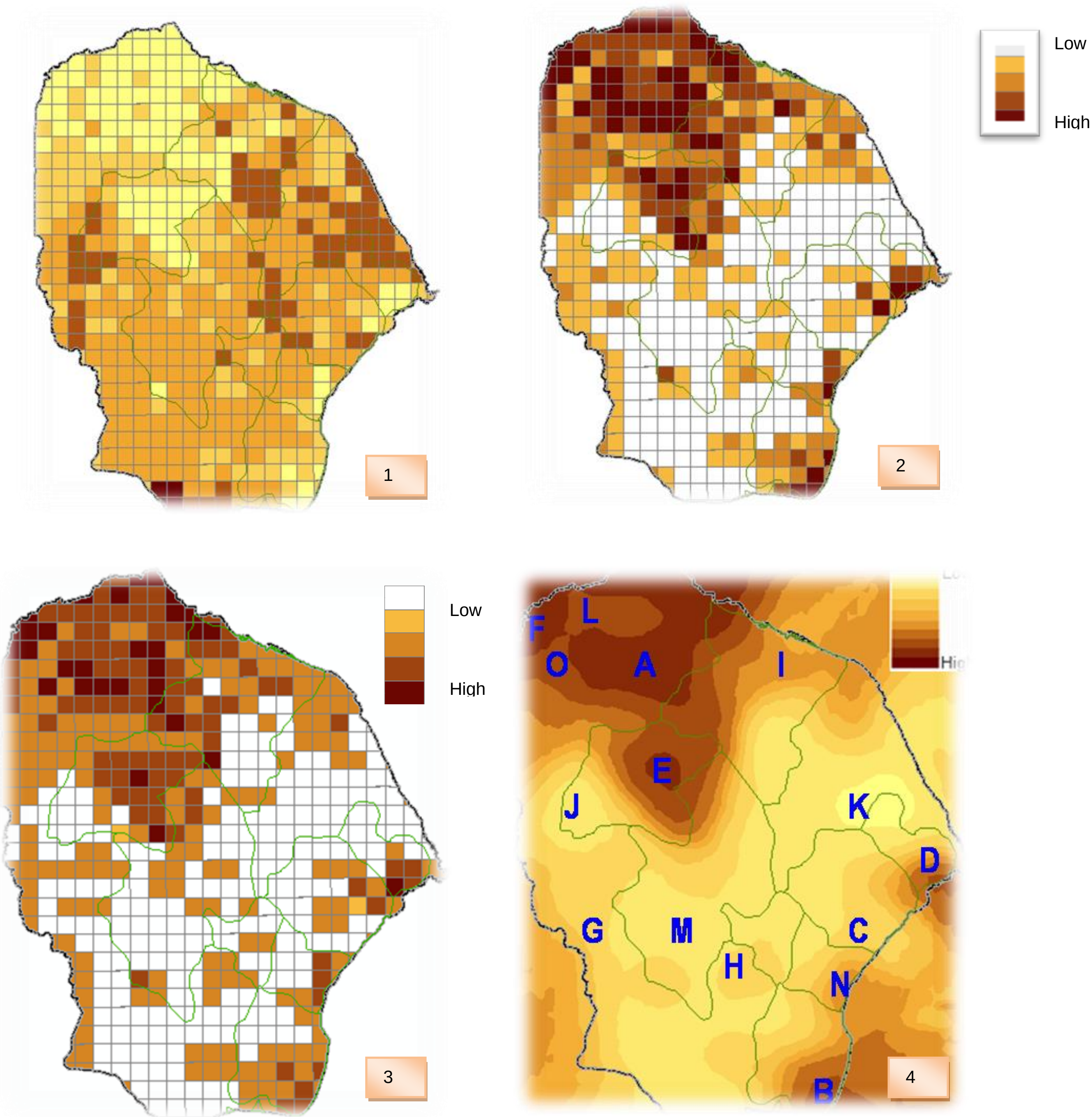


Figure 3.16: Quantile categorization and universal kriging are used to identify and predict priority sites and associations for elephant conservation, management and monitoring.
1- Degree of useless of elephant sites; 2- Variability of valuable sites for elephant; 3- Differential between useless and valuable sites; 4- kriging prediction of elephant habitat's associations.

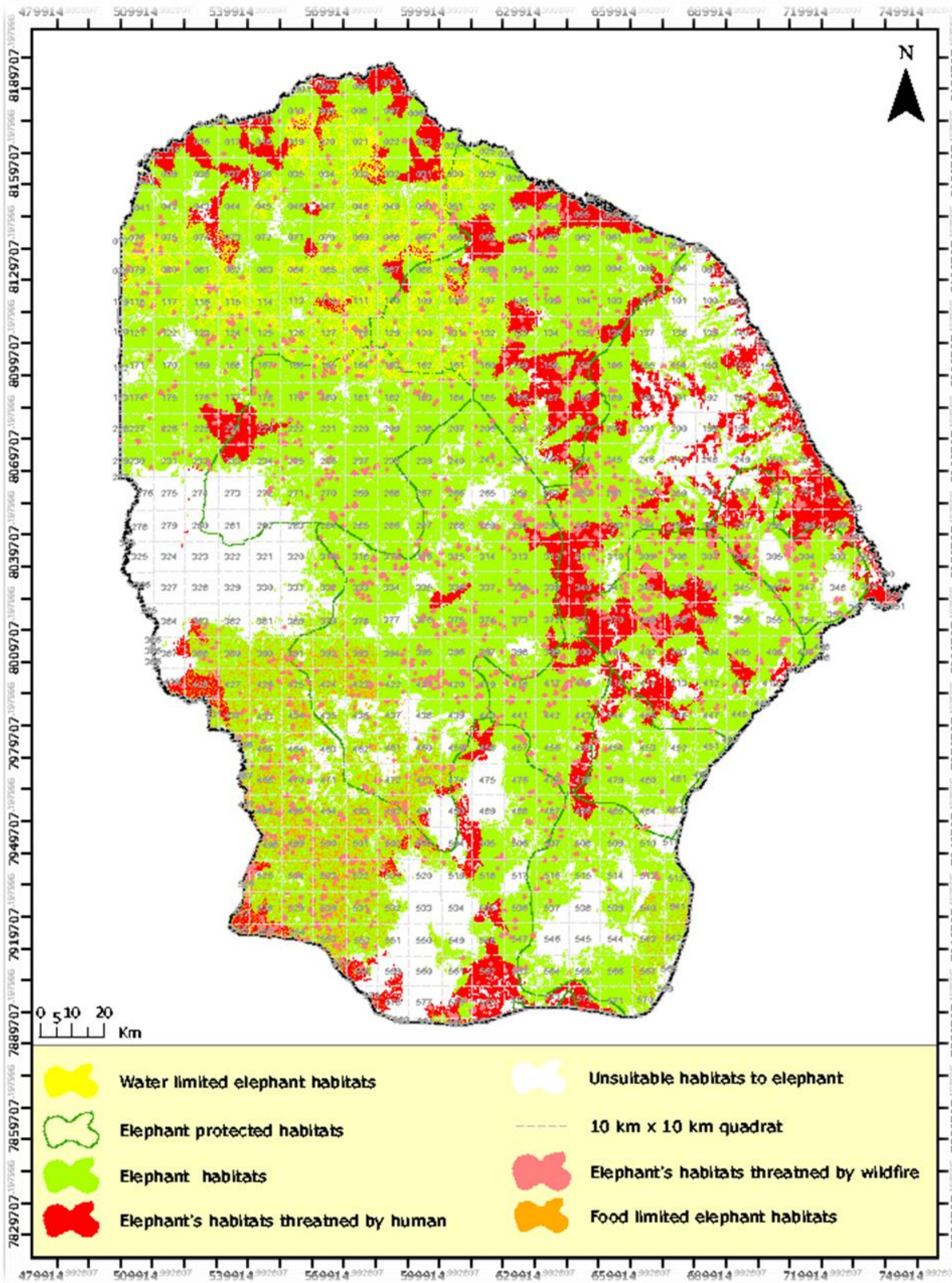


Figure 3.17: Elephant habitat distribution predicted by NDVI utility measures

Ranking scores analysis (see figure 3.16[2]), spatial numerical clustering patterns of shared features (see figure 3.16[4]) and elephant habitat prediction model (see figure 3.16) were used to prioritize elephant conservation sites. Elephant conservation sites are almost found outside protected areas with more prominence at the join area of hunting blocks 7 and 9 (see figures 3.16[2]; 3.16[3]; 3.16[4]; 3.17).

Clusters **A** and **F** are the core selected habitats outside PA’s. Elephant use them as breeding, foraging and dispersal grounds. Food diversity (1.2722), low human densities (2 hab/sq km) and proximity to hunting blocks (less than 10 km) are the key reasons for such importance. Wiens (1989) documented that because of the difficulties of long distance dispersal, successful immigration is more likely for islands near to the source pool than far away. Wildfire (0.21%) and transverse distance between watering and foraging grounds (29%) are the main threats for these promising conservation areas. One day encroachment, toxic plants and tsetse fly might be detrimental to elephant survivor.

Flexibility between **A** and **F** was expected. This might not happen due to corridor blockage in Changara village (see figures 3.13; 3.16, 3.17). If community elephant conservation awareness is raised, elephant from cluster **F** (transboundary elephant) will be accessing clusters **A** and **E**. If such efforts are expanded to cluster **M**, in hunting block 13, genus exchange will remain possible with GNP and Marromeu hunting block. This conservation willingness is plausible if clusters **H**, **N** and **C** (corridors connectors) are included in law enforcement activities (see figure 3.16[4]).

Contrary to groups **A** and **F**, the clusters **J**, **M** and **K** are acting as “empty conservation boxes” due to human induced habitat degradation (see table 3.4; figure 3.17).

B is also important to elephant of GNP due to presence of regularly flooded areas, foraging grounds and security. **B** is a food limited habitat (see figure 3.17). Location of this cluster on low lands contributes on elephant waste more time and energy feeding and watering rather than walking from one site to another. Such feeding behaviour made food plants limited (plant diversity = 0.9124; elephant food richness = 23). And without any food recovery plan; elephant will be migrating to north-eastern or southern part of the park (see figures 3.4; 3.17). Thus, its conservation status depends on refinement of the north-western boundary, evidencing more efforts at the southern to north-eastern clusters (**C**, **D** and **N**) (see figure 3.16[4]). This statement is also founded on the presence of active poachers and wildfires at the north-western boundary (see figure 3.17). Such issue has made GNP authority to place a ranger post but its efficiency on neutralizing the poachers still in “blink”. In addition, while the issue of wildfire still not solved, the area will remain useless to elephant. Wildfire reduces shade and food composition, structure and availability.

Concerns on the continuity of the same elephant habitat found in GNP (cluster **B**) and outside (cluster **H**) (see also video nr. 3) coincided with our second hypothesis favouring that food might be there but due to negative impacts, elephant will not access it. For example, at a threshold of 16 people per sq km and habitat fragmentation due to cultivated areas, elephant disappear. In addition, the Gorongoza escarpment edge effect reduces the probability of diverging the human induced impact using Nhadugue river (see figures 1.1; 1.2). Therefore, group **H** acts as a corridor connector.

Cluster **G** is of long narrow format, food homogeneity and wildfire. For our conservation priority, this cluster is excluded due to specie-shape area relationship. Long narrow protected areas will have a higher emigration rate (and therefore probability of extinction) than circular reserves (Grimsdell, 1978).

At last, this planning activity has shown that spatial pattern of high or dense populations in scattered locations represent the most favourable habitat and lower sparser populations denote areas of less favourable habitat (see figure 3.16[4]). Elephant favourable habitat varied in different sites. High valuable sites were found in **A-F-E-D-B** clusters. While low favourable sites were aggregated in **J-K-M** (see figure 3.16[4]). Low and high favourable groups are separated by intermediate clusters (**L-O-G-H-C-N) (**see figure 3.16[4]**)**. Accordingly to the theory of association it is supposed that boundaries that cut off ecological units must be reviewed in order to establish ecological processes. Hence it is not possible to protect clusters **A** and **F** without **O** and **L**. This leads to selection of intermediate clusters (**L-O-G-H-C-N)** as migratory corridors.

Generally, both kriging and NDVI models induced to the prioritization of future elephant conservation habitats. Kriging **(**see figure 3.16[4]**)** was mostly applicable to macro scale while NDVI (see figure 3.17) included site details. Both models were efficient on depicting the cause-effect interactions within and between habitats.

Chapter 4

Remarks and recommendations

4.1. **Remarks**

Ordinary kriging of dung piles density was low near settlements (0.000-0.0012) and high (0.0245-0.0346) near water source confirming the daily elephant water requirements, food availability, its efficiency of use and temporal movements. Elephant's movement varied from (i) March to November and (ii) December to February.

A kernel spatial movement analysis denoted that at core home range the first movement is located in the community land (48.54%) and the second occurs in hunting blocks (35.00%) and national parks (16.45%).

Surprising is the fact that the hunting blocks and national parks host the population of elephant at the end of the dry season; but during rainy season, most of elephant and other herbivores leave the protected areas and spread into a wide area of plateau and flood plain; for more than half year, depending on the resources available in this area where communities of farmers live.

Land resources availability, diversity and prediction were accessed by means of satellite imagery NDVI, diversity indexes and Generalized Linear Models (GLM).Average NDVI performance was higher (0.4488) at the moist evergreen afro-montane of *Brachystegia spiciformis*; moderate (0.2918) at the semi-arid plateau of *combretum spp* and *colophospermum mopane*; and lower (0.1923) at the degraded wooded grassland on lowlands of Urema and Zambezi floodplains. NDVI performance differed significantly (*sig. = 0.000*) between the three habitats, indicating a lack of homogeneity between habitats.

Higher NDVI performance was associated to high altitudes (700-1811.89 m) of low plant richness (28) and higher plant richness (85) was documented at mid-altitudes (300-699.99 m) of moderate NDVI (0.2959) values. NDVI increases with an increment of altitude and decreases with plant richness (r-0.416; $p= 0.727$). In other words, highlands of higher NDVI contain not as much of diversity of plant species.

From the relationship between elephant and habitat types evidences made us to assume that 56.60% of the ecosystem was utilized by elephant and 43.40% was not used throughout the year. Core home range denoted that elephant foremost (53.54%) utilized the semi-arid plateau of *combretum spp* and *Colophospermum mopane*; reasonably (34.92%) the lowlands of Urema and Zambezi floodplains and weakly (11.54%) the moist evergreen afro-montane of *Brachystegia spiciformis*.

Repeated ANOVA has shown that elephant habitat use differed significantly ($p = 0.003$) between the semi-arid plateau and the moist evergreen afro-montane. The first habitat was 118.51 times more utilized than the second.

Spatial Model for Landscape Elephant Conservation-SMLEC identified that habitat use by elephant was detrimental to water availability (40.2%; $p=0.000$), human activities (36.80%; $p=0.000$) and vegetation (35.00%; $p=0.000$) at micro-scale level. While the macro analysis shows that aridity index (8.3%; $p=0.000$) and altitudinal gradient (0.6%; $p = 0.033$) affected elephant habitat use factors at micro-scale. However, elephant survivor at the ecosystem was any strategy for adaptation on climate variability and human attitudes on their lands.

Diversity of food plants were strongly positive related to elephant density (r = 0.899; $p = 0.000$) and explained 35% of elephant habitat use, confirming the premise of vegetation homogeneity of highlands with higher leaves greenness does not contribute directly on the observed intensity of habitat use by elephant. Elephant were destroying *Adansonia digitata* at alarming rates and young trees were not frequently seen which can influence on the structure of vegetation, diversity of canopy trees and loss of associated faunas. NDVI as indicator of vegetation greenness suggested that elephant were utilizing more than one NDVI class depending on human attitudes and altitudinal gradient.

Elephant was primarily (95.28%) found between 14.96 to 699.9 m and relatively avoided altitudes of 700 to1811.89 meters. A weak and negative (r = -0.093) degree of association was established between elephant density and altitudinal gradient. This relationship was significant ($p=0.028$). Thus, altitude explained 0.6% (Adjusted R square = 0.006; $p = 0.033$) of elephant variability. Altitude gradient impacts elephant by means of food diversity, availability and accessibility.

In relation to water, the coefficient of multiple determination has shown that for elephant of the study area, does not matter the size and density of water points but their availability (r= 0.636; $p=0.000$) and transverse distance (r = 0.959; $p=0.000$). Water availability explained 40.2% and transverse distance 39% of elephant habitat use. This was significant ($p= 0.000$). Water influences elephant habitats' use by means of distribution, distance, availability and their size.

Human and elephant was also of concern. Our results suggested that there is no doubt to accept the hypothesis that human influence elephant habitat use ($p<0.05$). Human activities explained 36.8% of habitat avoidance at lowlands. This was basically due to distance to settlements (34.9%) and roads (25.2%) complemented by fire (0.21%).

A strong positive correlation (r=0.956) was significantly ($p=0.000$) documented between elephant density and distance to settlements. As human settlements tend to release the areas used by elephant, the number of species will have to increase. Sadly, if human insists on those areas, they will have to find alternative sites to use. Distance to settlements explained significantly ($p=0.000$) 34.9% of habitat avoidance by elephant particularly from 0-2 km from settlements. In addition, approximately 2 hab/sq km denoted to be not problematic for the survivor of elephant but at about 8 hab/sq km Elephant started to down levelling, confirming the hypothesis that they will tend to avoid areas densely populated. Higher human densities are found along the roads. As the distance increased from roads elephant more utilized the habitat (r = 0.949; $p = 0.000$). Roads quality contributed on traffic intensity and so on elephant habitat use. Human located along the road not only blocks the corridors at Changara, Casa-banana and Tongonda but also vegetation logging caused by access to roads creates open areas of less abundance of preferred food plant by elephant. In addition, roads increase cause more accessibility to remote areas, enhancing the chance of human-elephant interactions by a corresponding raise in mortality risk due to poaching.

Climate (8.3%) was also detrimental to elephant density. A moderate negative relationship was documented (r=-0.392; $p=0.000$), and means that elephant seasonal variability was a survivor strategy for adaptation of water availability and corresponding changes on plant food. This becomes more severe since human activities have pulled elephant to concentrate on water limited habitats.

Elephant Habitat Prediction Model-EHPM based on kriging analysis (critical cause-effect relationship, ranking scores analysis, spatial numerical clustering patterns) and NDVI, prioritized elephant conservation sites, which were almost found outside protected areas with more prominence at the join area of hunting blocks 7 and 9.

Elephant favourable habitat varied in different sites. High valuable sites were found in A-F-E-D-B clusters and low favourable sites were aggregated in J-K-M. Low and high favourable groups are separated by intermediate clusters (corridors) (L-O-G-H-C-N).

Generally, both kriging and NDVI geostatistics induced to the prioritization of future elephant conservation habitats. Kriging was mostly applicable to macro scale while NDVI denoted smaller site details. Both models were efficient in depicting the cause-effect interactions within and between habitats. However, a time series prediction analysis, important for adapting elephant and humans to climate variability impacts, was missed.

4.2. **Recommendations**

Elephant groups defecation rate were not observed during this study. Practical solution to this problem is to investigate the group level frequency per day. This information is important for monitoring climate change.

Elephant conservation seems to be compromised by a number of management challenges. The success of this conservation problem depends not only on eliminating poaching by increased patrols on sites intensively used by elephant; planning cultivation by organizing farms in blocks and controlling fire using fire breaks but on finding ways to reduce conflict over access to water between elephant and human. Thus, we highly recommend improving water sources availability.

Any increase of plant fruit trees diversity could reduce the pressure of elephant on crops, intensity of fire, effects of climate on water; contribute on human diversified food and fuel. Thus, it could also be plausible to raise community awareness on cultivation, certification, treatment of fruit trees both important for human, elephant and water conservation.

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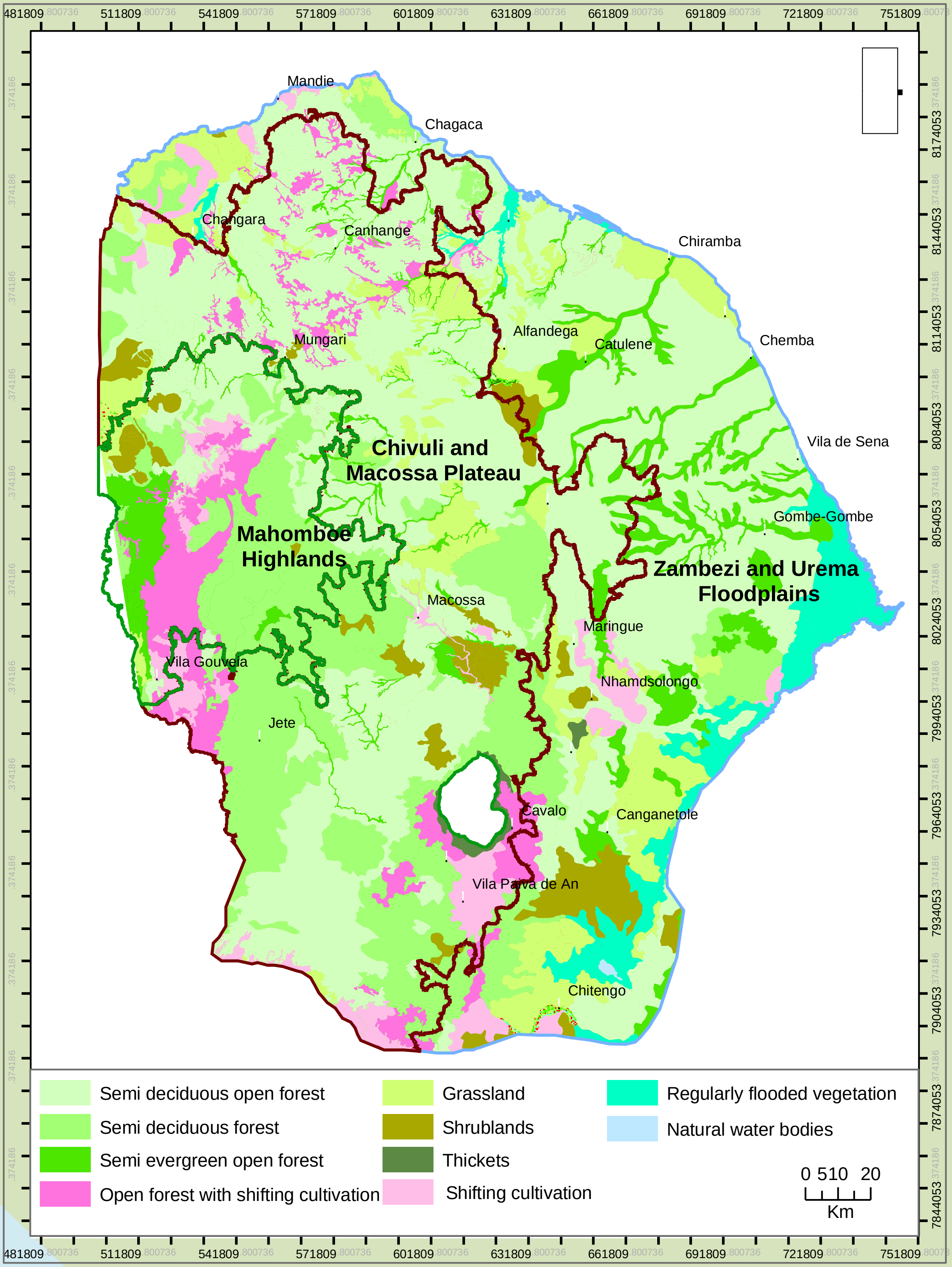
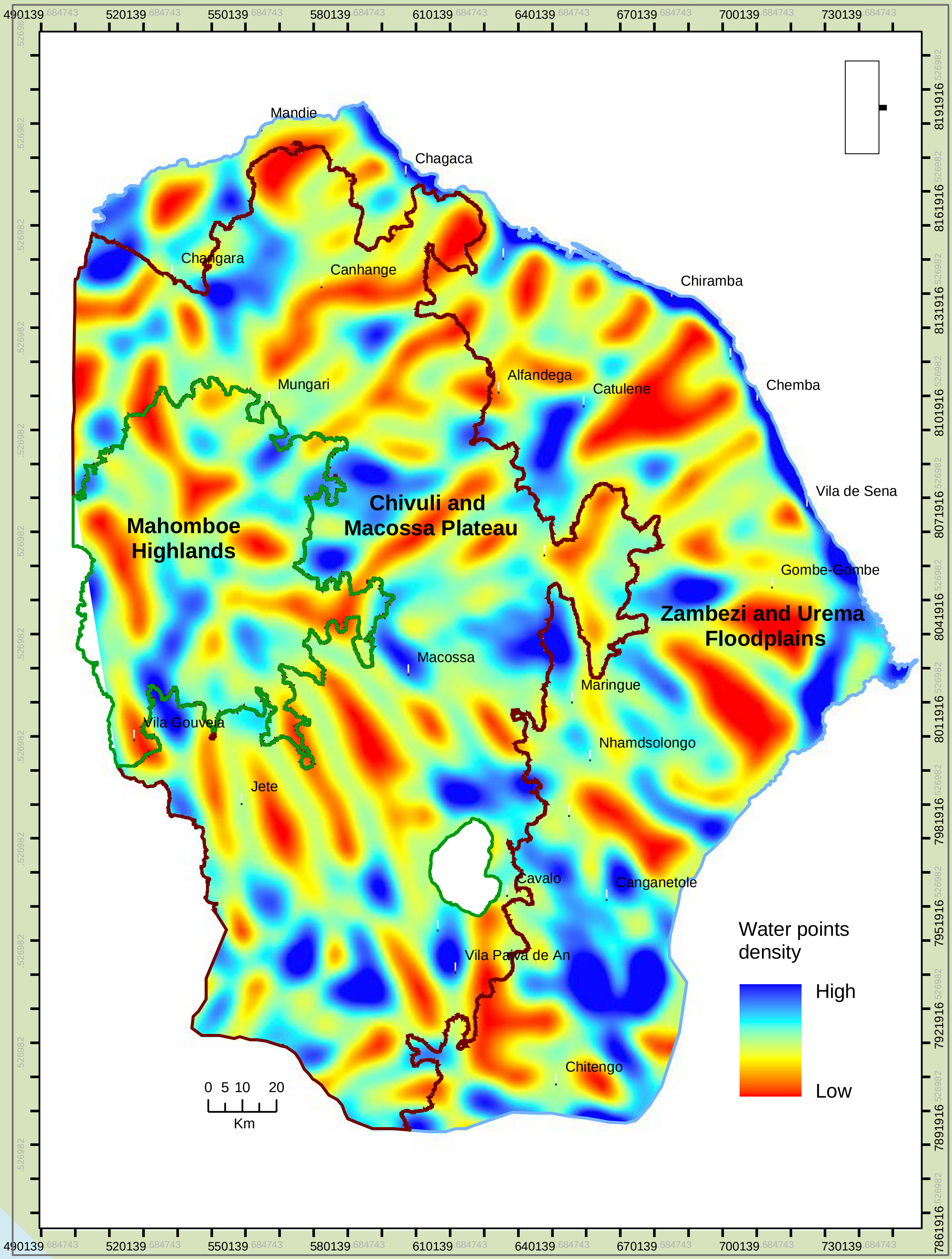
Appendices

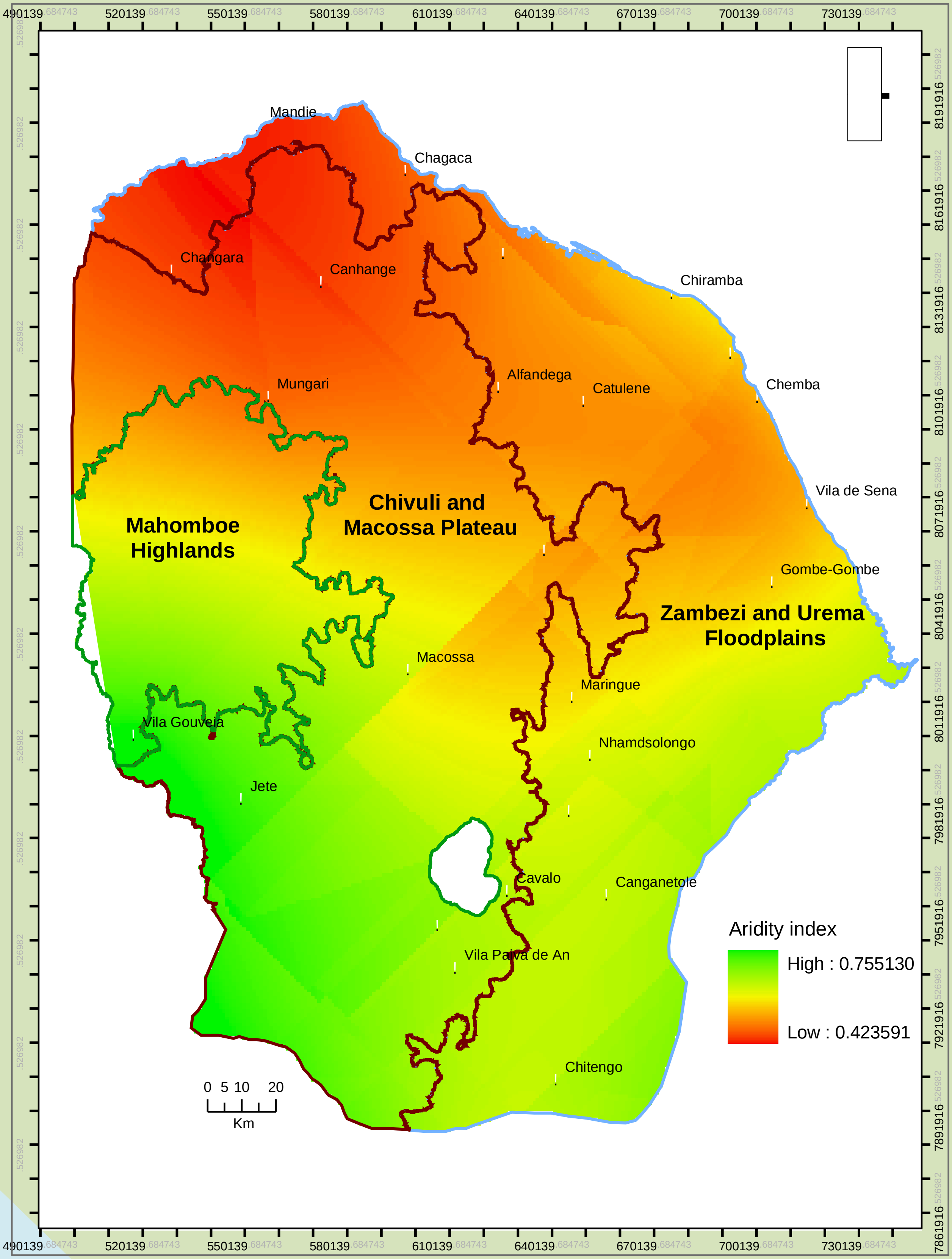
Appendix 3.1: Land use/cover



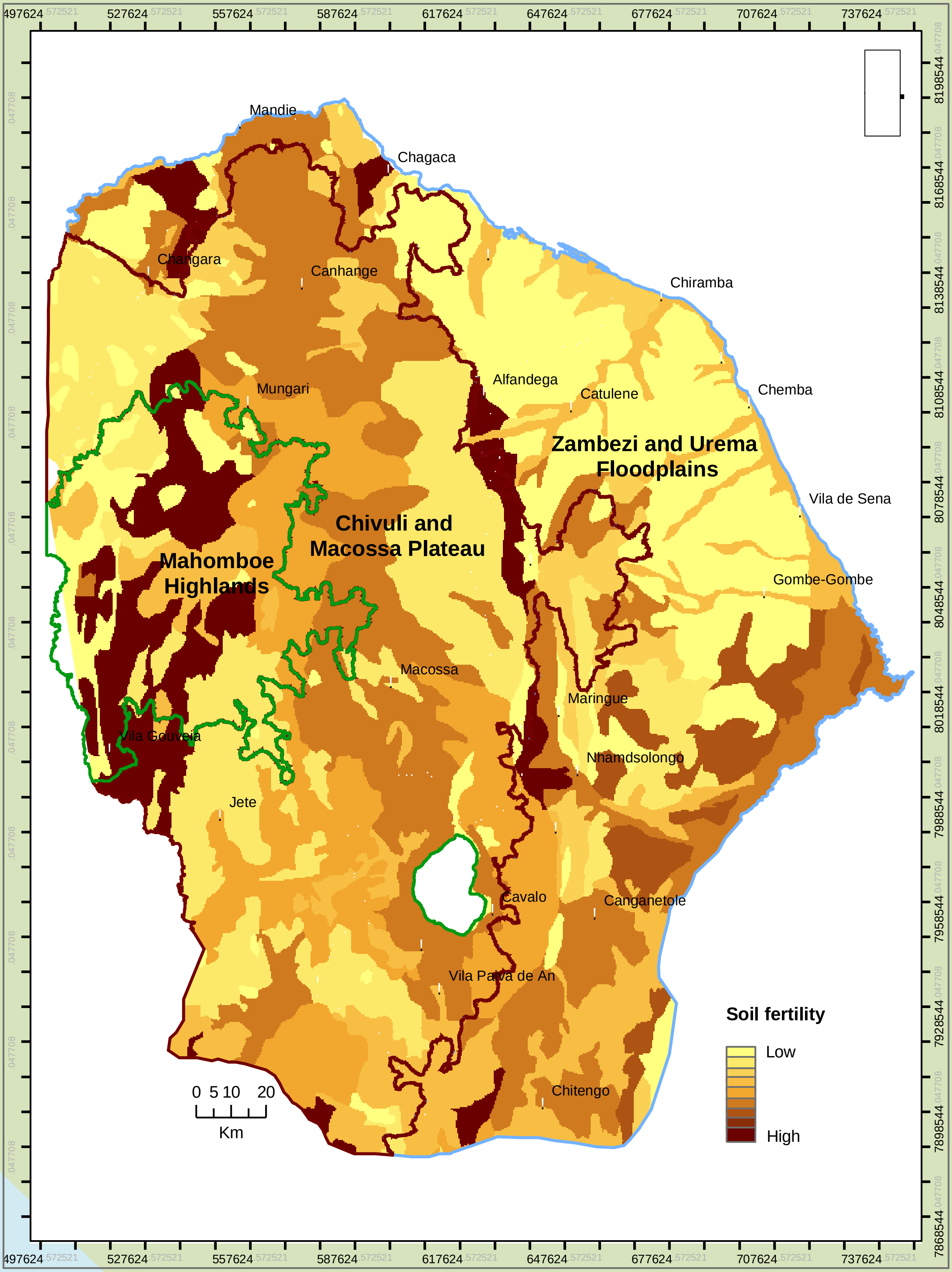
Appendix 3.2: Distribution of water sources and their density



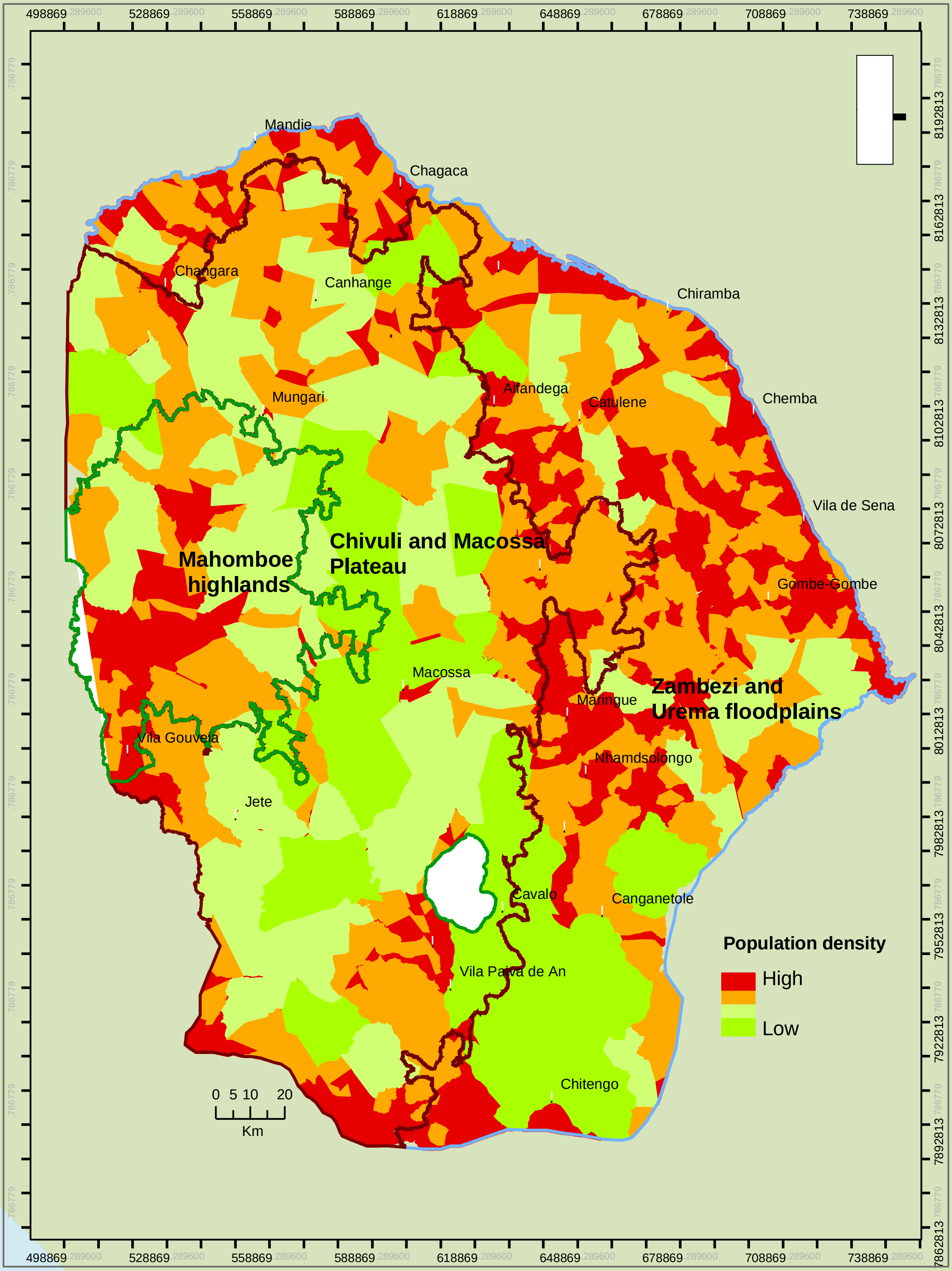
Appendix 3.3: Aridity index variability



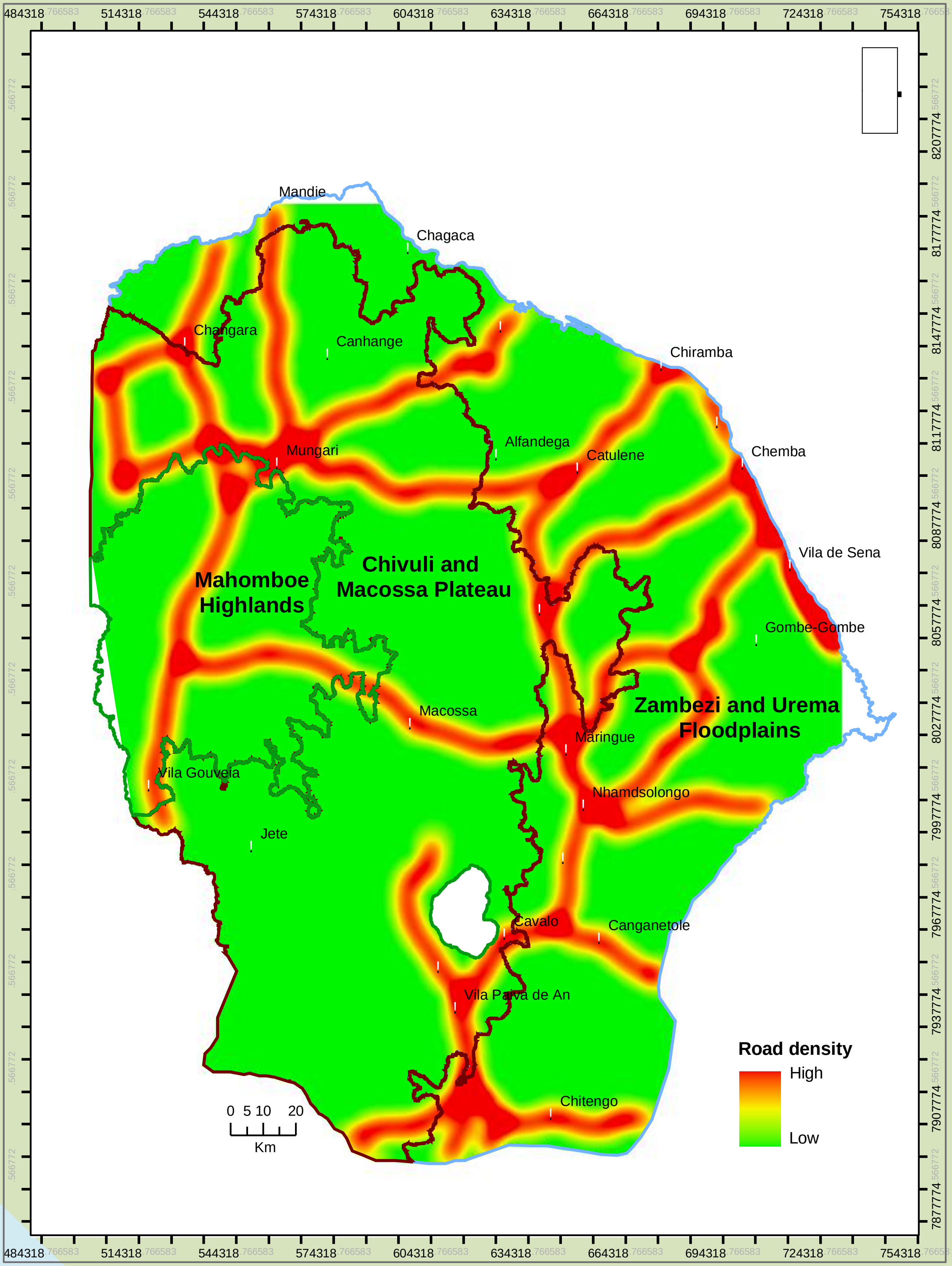
Appendix 3.4: Distribution of soil fertility



Appendix 3.5: Population density variability



Appendix 3.6: Roads density



Appendix 3.7: Descriptive statistics of mean NDVI performance

	Mean	Std. Deviation	N
SwaNDVI	-.107464	2.89E-02	50
BaNDVI	3.55E-02	6.97E-02	50
LowNDVI	.19237802	2.65E-02	50
MedNDVI	.29179400	3.89E-02	50
HighNDVI	.44880158	5.93E-02	50

Source: Landsat ETM+, dry season 2008

Appendix 3.8: Mauchly's test of sphericity

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
GREENESS	.233	69.156	9	.000	.595	.628	.250

Source: Landsat ETM+, dry season 2008

Appendix 3.9: Tests of within-subjects effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
GREENESS	Sphericity Assumed	9.406	4	2.352	976.261	.000	.952
	Greenhouse-Geisser	9.406	2.380	3.951	976.261	.000	.952
	Huynh-Feldt	9.406	2.510	3.747	976.261	.000	.952
	Lower-bound	9.406	1.000	9.406	976.261	.000	.952
Error(GREENESS)	Sphericity Assumed	.472	196	2.409E-03			
	Greenhouse-Geisser	.472	116.643	4.047E-03			
	Huynh-Feldt	.472	122.999	3.838E-03			
	Lower-bound	.472	49.000	9.635E-03			

Source: Landsat ETM+, dry season 2008

Appendix 3.10: Pairwise comparisons between habitats

					95% Confidence Interval for Difference[a]	
(I) GREENESS	(J) GREENESS	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-.143*	.011	.000	-.165	-.121
	3	-.300*	.006	.000	-.311	-.288
	4	-.399*	.007	.000	-.413	-.385
	5	-.556*	.010	.000	-.576	-.537
2	1	.143*	.011	.000	.121	.165
	3	-.157*	.009	.000	-.175	-.138
	4	-.256*	.014	.000	-.284	-.229
	5	-.413*	.014	.000	-.440	-.386
3	1	.300*	.006	.000	.288	.311
	2	.157*	.009	.000	.138	.175
	4	-9.942E-02*	.007	.000	-.114	-8.46E-02
	5	-.256*	.009	.000	-.274	-.239
4	1	.399*	.007	.000	.385	.413
	2	.256*	.014	.000	.229	.284
	3	9.942E-02*	.007	.000	8.458E-02	.114
	5	-.157*	.009	.000	-.175	-.139
5	1	.556*	.010	.000	.537	.576
	2	.413*	.014	.000	.386	.440
	3	.256*	.009	.000	.239	.274
	4	.157*	.009	.000	.139	.175

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Source: Landsat ETM+, dry season 2008

Key:
1 (swaNDVI): water points

2 (BaNDVI): bare soil (rocky outcrops, fire)

3 (LowNDVI): degraded wooded grassland on lowlands of Urema and Zambezi valley)

4 (MedNDVI): semi-arid plateau of *combretum spp* and *colophospermum mopane*

5 (HighNDVI): moist evergreen afro-montane of *Brachystegia spiciformis*

Appendix 3.11: Checklist of plant species used and preferred by elephant at different habitats

Habitat type	Habitat extent (sqkm)	Plants species used by elephant	Richness of plants used by elephant	Richness of plants preferred by elephant	Density of plants used by elephant	Density of plants preferred by elephant
Moist evergreen afro-montane of *Brachystegia spiciformis*	6408	*Balanites maughamii* *Pterocarpus angolensis* *Sclerocarya birrea** *Uapaca kirkiana* *Brachystegia spiciformis* *Diplorhynchus condylocarpon* *Englerophytum magalismontanum* *Flacourtia indica* *Brackenridgea zanguebarica* *Burkea africana*	*10*	*1*	***0.0016***	***0.0002***
Semi-arid plateau of *combretum spp* and *colophospermum mopane*	16657	*Acacia melifera** *Acacia nigrescens** *Acacia robusta** *Acacia welwitschii** *Acacia xanthophloea** *Acroceras macrum** *Adansonia digitata** *Albizia harveyi** *Albizia versicolor** *Andropogon gayanus* *Balanites aegyptiaca* *Bauhinia petersiana* *Bridelia micrantha* *Cenchrus ciliaris* *Centropodia glauca* *Colophospermum mopane** *Commiphora edulis* *Cordyla africana* *Cussonia spicata* *Dalbergia melanoxylon** *Dichrostachys cinerea* *Eragrostis chapelieri* *Eragrostis nindensis* *Eragrostis rigidior* *Eragrotis trichophora* *Erogrostis clianensis* *Eteropogon macrostachyus* *Grewia bicolor* *Hemarthria altissima* *Heteropogon contortus* *Hyparrhelia dissolute* *Hyparrhelia hirta* *Kigelia africana* *Kirkia acuminate* *Panicum maximum** *Sclerocarya birrea** *Senna petersiana* *Senna singueana* *Sorghum bicolor** *Sorghum versicolor** *Sporobolus africanus** *Sporobolus ioclados** ***Stenotaphrum secundatum**** *Strychnos popatorum** *Tamarindus indica** *Tricholaena monachne* *Xanthoceris zambesiaca* *Zizphus mucronata*	*48*	***20***	***0.0029***	***0.0012***
		Brachiaria lachnenthe *Cordyla africana* *Xanthocercis zambesiaca* *Andropogon gayanus*				

Degraded wooded grassland on lowlands of Urema and Zambezi valley	19436	*Albizia harveyi** *Dalbergia melanoxylon** *Acacia xanthophloea** *Adansonia digitata** *Bauhinia petersiana* *Eragrostis nindensis* *Grewia bicolor* *Tamarindus indica** *Vangueria infausta* *Acacia xanthophloea** *Hemarthria altissima* *Sporobolus africanus** *Dichrostachys cinerea* *Eragrostis chapelieri* *Eragrostis rigidior* *Eragrotis trichophora* *Erogrostis clianensis* *Faidherbia albida** *Panicium coloratum*	*23*	***7***	***0.0012***	***0.0004***

Source: worked by Da Silva, data from field survey 2008. *Elephant preferred plant species