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DEPARTMENT OF PLANT BIOLOGY AND BIODIVERSITY MANAGEMENT

ECOLOGICAL STUDY OF THE NATURAL REGENERATION OF THE WOODY SPECIES IN ENCLOSED AREAS IN RAYA AZEBO WOREDA, SOUTHERN ZONE, TIGRAY

BY

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ADDIS ABABA, ETHIOPIA

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DECLARATION

I, the undersigned declare that this dissertation is my original work and it or part of it has not been presented in any other University, college or institution for a degree or other purpose. All sources of materials used for the dissertation have been duly acknowledged.

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LIST OF ABBREVIATIONS

Term	Description
AAS	Atomic absorption spectrophotometry
ANOVA	Analysis of Variance
ASTM	American Society for Testing And Materials
CBD	Convention on Biological diversity
CCA	Canonical Correspondence Analysis
CEC	Cation exchange capacity
C/N	Carbon to Nitrogen Ratio
CSA	Central Statistical Agency
CSH	Circumference at Stump Height
DBH	Diameter at breast height
DSH	Diameter at Stump Height
EARO	Ethiopian Agricultural and Reseadrch Organization
EFAP	Ethiopian Forestry Action Program
EMSA	Ethiopiaian Meteorological Services Agency
EPA	Environmental Protection Authority
EWNHS	Ethiopian Wildlife and Natural History Society
FAO	Food and Agricultural Organization
GFRA	Global Forest Resources Assessment
GPDRE	Government of the Peoples Democratic Republic of Ethiopia
GPS	Global Positioning System
HTS	Hunting Technical Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
IVI	Importance Value Index
MEA	Millennium Ecosystem Assessment
MEF	Ministry of Environment and Forest
OM	Organic Matter
pH	Power of hydrogen
REST	Relief Society of Tigray
SAC	Species Accumulation Curve
SER	Society for Ecological Restoration International,
SOM	Soil Organic Matter
TFAP	Tigray Forestry Action Program
TWINSPAN	Two Way Indicator Species Analysis
UNDESA	United Nations Department of Economic and Social Afairs
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute
WCMC	World Conservation Monitoring Center

ABSTRACT

The study was conducted in Raya Azebo Woreda, Southern Tigray at about 662 km from Addis Ababa. It is under severe pressure due to grazing, anthropogenic activities and rainfall fluctuations. Floristic composition, natural regneration and soil analysis were assessed. Data were collected from three area closures and their adjacent grazed lands using preferential and systematic sampling procedures. Vegetation data were collected from a total of 90 sampling plots and each field site comprised of 30 plots. In each of the study sites, sample plots having an equal size of 20 m x 20 m were designated as the main plots used to investigate the densities and distribution of woody species. Moreover, each main plot was divided into five smaller sub-plots of sizes 5 m x 5 m for regeneration counts (seedlings and saplings) and sizes of 2 m x 2 m for measuring cover abundance of herbaceous layers (grasses and forbs) in the woodland. In each sampling plot diameters of each woody species and environmental variables were recorded. From each plot, soil samples were collected to analyze the following edaphic parameters: soil pH, soil texture, available phosphorus, total nitrogen, cation exchange capacity, exchangeable bases and soil conductivity. A total of 133 species representing 45 families were recorded. Fabaceae followed by Poaceae, Asteracae and Euphorbiaceae were the most dominant families in the study area. Five plant community types were identified from the hierarchical cluster analysis and named after two dominant species in each cluster. The density of all seedlings were 410 individuals/ha while the total sapling density was about 212 individuals/ha. The overall regeneration status of the study area was found to be good regeneration (5.56%), fair regeneration (55.56%), poor regeneration (22.22%) and no regeneration (16.67%). The major factors affecting the regeneration of species in the woodland are frequent rainfall fluctuations, anthropogenic distrubances and grazing pressures. The influential environmental variables of the study area were altitude, pH, EC, Na, K, Ca, Mg, CEC, TN, OM, P, Sand%, Silt% and Clay%. The proportion of sand, silt and clay contents of the study area was 66.58%, 21.66% and 11.78% respectively which impliess the soils in the area was sand dominated. The five textural classes of soil identified in the study areas were sandy loam followed by sandy clay loam, clay loam, loamy sand and loam. The soil pH in the area ranges from neutral (7.0 - 7.3) to strongly alkaline (8.5 - 9.0) because the pH of dryland soils could be affected by the deposition of unleached exchangeable cations on the soil surface due to insufficient rainfall, hence, keeping the soil pH high.

Keywords: *natural regeneration, ordination, area closures, anthropogenic activities, species diversity, soil texture*

1. INTRODUCTION

1.1. Background Information

1.1.1. Trends in Changing Vegetation Diversity

Ethiopia is a country with great geographical diversity ranging from high mountains, flat-topped plateau, deep river gorges, rolling plains and the Great Rift Valley runs from the northeast to the southwest which separates the south-eastern and south-western highlands of the country (Ensermu Kelbessa *et al.*, 1992; EFAP, 1994; Zerihun Woldu, 1999). The highlands on each side of the Great Rift Valley give way to extensive semi-arid lowlands to the east, west and southern parts of the country (EFAP, 1994). The altitudinal variations of the country ranges from the highest peak at Ras Dejen 4533 m above sea level, in the Simien Mountains, down to the world's lowest point, Danakil Depression, which is 125 m below sea level in Afar National Regional State. The country has a large area of land with an altitude of over 2000 m above sea level that covers 40% of the land mass than any other country in Africa (Friis *et al.,* 2010). These physical conditions and variations in altitudes give the country a wide range of climatic features, soil variability, water availability and flora heterogeneity (Zerihun Woldu, 1999; Friis *et al.,* 2010). Hence, these heterogenous landscapes and climatic features of the country are suitable for the evolution of various plant species (EWNHS, 1996).

In addition, the various vegetation types are distributed from the afroalpine to the desert plant ecosystems i.e. from the arid lowlands in the east to the tropical rainforest in the west and the afroalpine region in the central highlands and the Bale Mountains in the southeast (Friis *et al.,* 2010). However, this rich vegetation diversity is severely threatened by conversion of woodlands into permanent farmlands, over-grazing, fuelwood collection, new settlement and unwise exploitation. These trends are the major causes for the decline of the country’s vegetation diversity (IBC, 2005; Friis *et al.,* 2010). Therefore, restoration of the vast degraded landscapes will have a valid and important role in facilitating the overall sustainable development of the country (Million Bekele, 2000). According to some authors (UNEP, 1992; EFAP, 1994; IUCN, 1999), over 60% of the Ethiopian land surface is covered with a huge mass of drylands where 12% of human and 20% of livestock populations reside. Accordingly, ecological studies of the Ethiopian dryland ecosystems are extremely important since they support high biodiversity, endemism and livestock grazing (Tefera Mengistu *et al.,* 2005).

Grabherr *et al. (*1994) and Chapin (2000) reported that changes of vegetation diversity are currently linked to the potential of trends which aggravate the current declining vegetation. For instance, the warming trends, together with changes in local rainfall are major features of arid and semi-arid areas throughout the world (Stephenson, 1990). The most recent report from the IPCC (2001) described that most of the observed warming over the past 50 years is likely to have been due to the increase in greenhouse gas concentration. As a result, the trends to wards warmer temperatures appear to have already reduced vegetation diversities (Stone *et al*., 1996). When the local rainfall decreases, factors such as high solar radiation energy causes high temperature and high evapotranspiration rates which in turn affects the hydrological budgets of several ponds, lakes, rivers and streams. All these trends have significant influence on the vegetation composition, abundance, distribution, diversity and phenology of a wide range of species (Hughes, 2000).

Historical estimates suggest that close to 40% of the country's land area was covered with high forests at the turn of the 19th century (EFAP, 1994). However, through rapid population growth, extensive vegetation clearing for cultivation, over-grazing, movement of political centers, new settlements, extraction of fuelwood and construction materials without replanting have reduced the forest area of the country to 16% in the 1950's (UNEP, 1983). Further estimates of the distribution of forest and woodland areas have revealed that the size declined to 5.6% by the early 1980s, 2.7% in 1989 and this figure dropped further to 2.4% by

1990 (Sayer *et al.*, 1992). As noted by the Ethiopian Forestry Action Program (EFAP, 1994), there is about 3% annual loss of forest resources in the country due to deforestation and degradation through high demand for fuelwood, agricultural expansion and grazing, hence, the disappearance of forests and woodlands have been the most drastic in the past 100 years.

The high forests of Ethiopia may be categorized into Dry Evergreen Montane Forest and Moist Evergreen Montane Forest (MEF, 2015). Dry evergreen forests occur in the northern and central parts of Ethiopia where the dry sub-humid climate dominates while the moist evergreen forests occur in the southern and southwestern parts of Ethiopia where humid climate prevails. The dry evergreen montane forests of Ethiopia with *Juniperus procera, Olea europaea subsp. cuspidata* and *Podocarpus falcatus* occur scattered irregularly as remnant forest patches such as at church yards and settled margins whereas the moist evergreen forests with *Pouteria adolfi-friedericii, Albizia* and *Ficus* species occur more extensively. For a long period of time, forests with canopy cover exceeding 75% were considered as high forests (MEF, 2015). Accordingly, the current high forest cover of Ethiopia is between 3 and 2.5% depending on different estimates (MEF, 2015).

FAO has provided a new definition of forests which includes areas that met earlier to be understood as woodlands. According to FAO (2011), forest is defined as a land with a canopy cover of more than 10 percent of the ground includes area of exceeding 0.5 ha with trees higher than 5 metres at maturity. The new forest definition includes the broad-leafed deciduous *Combretum-Terminalia* woodlands, *Acacia-Commiphora* woodlands and the *Acacia* woodlands are recognized as forests. Thus, according to the new forest definition by FAO, the total forest cover in Ethiopia is 13% (FAO, 2011). However, this estimation is not supported with ground truth. On the other hand, recent reports estimated that the Ethiopian forest cover has reached about 15% (MEF, 2015).

According to Millennium Ecosystem Assessment (MEA, 2005) and WCMC (1992), over the past 50 years, human beings have changed ecosystems more rapidly and widely than in any comparable period in human history resulting in a broad and largely irreversible loss in the diversity of life on Earth. The problem becomes even more severe and interlinked in sub-Saharan-Africa where the prevailing climate influence accelerates the expansion of desertification and aggravates land degradation which consequently leads to the loss of biodiversity (Uitto and Manshard, 1993). According to Mackenzie and Mackenzie (1995), on the global basis, the vegetation resource degradation is caused primarily by overgrazing (35%), deforestation (30%), agricultural activities (28%), exploitation of fuelwood (7%) and industrialization (4%). These patterns are different in various regions of the world. For instance, in North America, 66% of the soil loss has been responsible for the gricultural activities while in Africa, overgrazing is responsible for about half of the soil degradation. In addition, the United Nations Framework Convention on Climate Change (UNFCCC, 2007) described that the main cause of deforestation is agriculture. For instance, subsistence farming is responsible for 48% of deforestation; commercial farming 32%; logging 14% and fuelwood extractions 5%.

According to FAO (1994), in Ethiopia more than 80% of deforestation or vegetation resource degradation is primarily due to expansion of agricultural land. On the other hand, the preliminary estimates of the Global Forest Resources Assessment (GFRA, 2010) shows that natural forest loss in tropical Africa appears to have accelerated, while in Central America and Europe it has remained constant, and has declined slightly in tropical Asia and South America. The establishment of plantations (reforestation activities) in industrialized countries has increased and led to a decline in deforestation rates. GFRA (2010) suggested that most of the forest conservation awareness occurs in developed countries than in developing countries due to their high population growth and more concerned with basic necessities such as food, clothing and shelter than long-term issues such as species extinction prevention. FAO (1990) proposed that forest density, diversity, and population structure should be further studied and the quality of forest resource inventory and database information is useful in understanding the vital status of vegetation resources but still effective inventory remained too poor in many developing countries to draw strong conclusions for planning and implementation of conservation strategies.

In Ethiopia, especially in the Northern Regions, the unwise exploitation in the past and the current growing demand for agricultural expansion associated with the grazing pressure by livestock have subsequently worsened the vegetation degradation (Hurni, 1990; Azene Bekele *et al.*, 1993; Demel Teketay, 2001). Tigray Region covers the largest degraded area in Ethiopia due to a long history of extensive land clearance, early human settlement, poor farming practices, growth in population and frequent droughts (Nyssen *et al.,* 2007). The vegetation of Tigray is highly degraded and more than half of the highlands are severely eroded, water resources have been greately depleted, and soils have lost 30-50% of their fertility and productive capacity compared to their original state some 500 years ago (Hurni, 1988). Pollen fossil and buried soil charcoal analysis studies have suggested that in northern Ethiopia, particularly in Tigray, forest disturbance has a 3000-year history and soil erosion as a result of vegetation clearance may have occurred in the middle Holocene (Bard *et al.,* 2000; Darbyshire *et al.,* 2003).

Around 50 B.C, the natural pre-disturbance vegetation of the area was *Podocarpus-Juniperus* forest which converted into a secondary vegetation of *Dodonaea* scrub that dominated the northern Ethiopia for 1800 years while *Olea, Juniperus* and *Celtis* spread around AD 1400 to 1700 (Darbyshire *et al.,* 2003). The travertine deposition in the plateau of Tigray implies the presence of dense vegetation cover that once covered northern Ethiopia during the middle Holocene (Bard *et al.,* 2000). As a result of this age-old history of intensive agriculture and deforestation, this region has been very vulnerable to soil erosion, land degradation and frequent droughts (Descheemaeker et *al.,* 2005).

According to the Ministry of Agriculture (MOA, 2003) report, the natural forest cover in Tigray was only 0.2% of the total land mass of the Region which is the indication of the severe forest degradation. In addition, Hamilton (1977) pointed out that over the last 2000 years, there has been progressive deforestation, which is still increasing steadily as the population of the country is growing at a faster rate. Mitku Haile and Kindeya Gebrehiwot (2000) have further stated that Tigray is characterized by a low degree of vegetation cover, over-cultivation a relatively high population density, unpredictable rains and frequent droughts, and severe soil erosion and steep slopes. The authors also noted that crop residues commonly used as fodder for livestock and manure (dung) is burned for heating and cooking, thus removing almost all organic litter from the soils and their use as fertilizers is a common trend.

The natural vegetation of the central plateau of Ethiopia may have been dry evergreen montane forest and trees such as *Juniperus procera* and *Olea europaea* subsp. *cuspidata* were the dominant species (Pichi Sermolli, 1957; Friis *et al.,* 2010). Because of the high demand by the society, this vegetation type has disappeared from most parts of the highlands except in a few remnant patches around holy places and inaccessible areas (Tamrat Bekele, 1993, 1994). In addition, records from the early travellers in the 15th and 16th century (Almeida, 1954; Alvarez, 1970) indicated that agro-climatic conditions of the Ethiopian highlands about 500 years ago were similar to the present day conditions, except that the density of trees in the earlier times was higher in the cultivated fields. However, Mitku Haile and Kindeya Gebrehiwot (2000) described that the environmental degradation attracted the attention of researchers to find strategies for sustainable rehabilitation and improving the rural livelihood in the 1980’s. Stocking (1992) suggested that an important development in researches would improve the collaboration between researchers, administrators and local communities for joint efforts to solve the various problems of deforestation. Therefore, the fundamental understanding of the joint efforts can be used to evaluate the causes of deforestation and the opportunities for restoration.

According to Chadhokar and Solomon Abate (1988), Tigray has lost almost all of its forest over in the past decades due to serious environmental degradation caused by deforestation. Nyssen (1997), on the other hand noted that recently there has been a growing interest by the regional government to prevent environmental risks such as further deforestation, soil erosion and biodiversity loss over much of the degraded lands. Among the many rehabilitation and conservation options, area closures have gained great attention from conservation workers at various levels. Nyssen (1997) further suggested that vegetation studies should concentrate on the small amounts of natural vegetation remaining in areas such as church forests, since these remnants are key elements that can save the native vegetation or as seed sources in the area. Hence, as a part of the strategy of preventing vegetation degradation, combating desertification and alleviating poverty from getting worse, the Tigray National Regional State has been delineating steep slops and degraded grazing lands as area closures. This method has been useful to rehabilitate the degraded lands with reduced costs and time for recovery to increase benefits to the local community through ecological servces (Kindeya Gebrehiwot, 1997; Emiru Birhane, 2002). This idea has been supported by Cairns (1994) who indicated that if the influences of ecological conditions for rehabilitation (e.g. rainfall and adequate environmental protections) are fulfilled, less than ten years may be enough for nature to recover from the damage. However, since area closures in the regional state are still relatively new evolving ecosystems, the processes and functions leading to restoration remain relatively unstudied. Therefore, the contribution of area closures in terms of biodiversity conservation, land rehabilitation and natural regeneration needs to be properly investigated and documented. Based on this, the current study was conducted to address the natural regeneration status, floristic composition and soil physico-chemical analysis to provide appropriate information on the ecological conditions of the study area.

According to the World Resources Institute (WRI, 1997) report, deforestation refers to the extensive and wide spread cutting of forests and woodlands making an area devoid of its vegetation cover. The report went on to suggest that priorities have to be seriously considered to stop unplanned deforestation. Accordingly, in Ethiopia deforestation is a common trend, for instance, the annual rate of deforestation ranges from 100,000 to 200,000 ha (FAO, 1988), 150,000 to 200,000 ha (EFAP, 1994), 160,000 to 200,000 ha (Reusing, 1998) and greater than 200,000 ha per year (FAO, 2001). These data show that thousands of hectares are destroyed every year which implies that the vegetation resources are under continuous threats of destruction and degradation. This continous deforestation is the result of human mismanagement and over-populatiion growth (CSA, 2004) compared to 11.8 million in 1900; 36 million in 1960; 47.3 million in 1988 (UNDP, 1997); 65 million in 2001 (CSA 2001) and 85 million in 2010 (CSA, 2010). The rate of deforestation has been accelerating in recent years due to expansion of agricultural investements and industrialzation associated with unsustainable utilization. Several authors e.g., Reusing (1998), Friis (1992), Friis and Sebsebe Demissew (2001) have reported that the large natural forest stands are mainly restricted to the southern and south-western regions of the country. However, most of these remain as part of the natural forest ecosystems of the country are being transformed into rapid land-use changes in the last few years for large-scale commercial agricultural farms of coffee, tea, banana and sugarcane plantations, and crop production activities by domestic and foreign companies for export markets (Kumelachew Yeshitila and Taye Bekele, 2003; Kumelachew Yeshitila and Simon Shibru, 2004; Getachew Tesfaye, 2008).

Unfortunately, most of the investments are carried out in the forest sectors and woodlands of the country. If investments are widely carried out in forest and woodland areas, they cause tremendous impacts on vegetation regeneration. These agricultural and industrial expansion practices have caused intensive clearing of woodlands and forests often associated with the loss of high productive ecosystems and huge biodiversity erosions. Hence, deforestation in Ethiopia has resulted in serious ecological degradation, loss of socio-economic benefits and caused the disappearance of various indigenous wild plants (Tewoldebirhan Gebre Egziabhere, 1989). Because of the unique geophysical locations and ecological areas, Ethiopia's forests and woodlands are characterized by their rich floral diversity estimated of 6000 plant species of which 10% are considered to be endemic (Sebsebe Demisew *et al.,* 2003; Ensermu Kelbessa and Sebsebe Demissew, 2014). The geographical distribution of the centres of endemism is high in the central plateaus, Afro-alpine and sub-alpine mountains, in the south-eastern escarpment (Ogaden region) and in the western and southwestern woodlands (Leipzig, 1996; Friis *et al.,* 2010). However, Ensermu Kelbessa *et al.* (1992) noted that the endemic plant species of Ethiopia were threatened by the massive deforestation. Hence, these threatened endemic species require special attention because they are only found in these particular habitats. If their specific habitats are destroyed, these plants could be lost forever and consequently the loss of native fauna depends on them would be very difficult to replace. An earlier study by Brandis (1906) estimated that the disappearance of one plant species through disturbance would result in the loss of several species of insects, animals and even other plants which depend on it. On the other hand, the Environmental Protection Authority (EPA, 1997) noted that massive deforestation has the greatest impact on rural communities, which depend primarily on forest and woodland resources for construction materials, farm implements and fuelwood collections for their personal needs and selling in towns and cities to generate income. Fuelwood accounts for a high proportion of the total household energy requirements in the country. Moreover, more than 85% of the Ethiopian population lives in rural areas, hence, more than 90% of the energy consumption of the country depends on fuelwood extraction (EFAP, 1993).

Tigray Region is located in the northern part of the country which lies between 12°0'0" to 15°0'0"N latitude and 39°0'0" to 40°0'0"E longitude. Centuries of erosion, deforestation, overgrazing, settlement and frequent droughts have left the landscape of the region with forest area coverage of less than 1% (Hurni and Perich, 1992). The landform is complex composed of lowlands ranging from 500-1500m above sea level, moderate relief hills ranging from 1600-2200m above sea level and highlands ranging between 2300-3200m above sea level (Araya *et al.,* 2010; Gebre Hadgu *et al.,* 2013). The soil has been depleted because of many centuries of cultivation. The climate is sub-tropical with an extended period of 9 to 10 dry months and often a relatively short rainy season of 50 to 60 days. The rainfall pattern is seasonal and erratic predominantly unimodal (June to early September) with the exception of the highlands of the southern and the eastern zones, where there are little showers during the months of March to mid May. Considering the rainfall, temperature and evapotranspiration, 90% of Tigray region is categorized as semi-arid (Kindeya Gebrehiwot *et al.,* 2002; Kindeya Gebrehiwot, 2004). The remaining areas of the region can be categorized as dry submoist including highlands of the central and southern zone and arid including the lower areas of Erob and Hintalo Wajerat woredas (Belete Taffere, 2002).

In Tigray, the native vegetation has been depleted and rainfall has declined, and as a result, re-establishment of the native vegetation is difficult in most areas of the region even though many efforts are being made to do this. Shukla *et al.* *(*1990) explained that restoration of native vegetation is made easier if most of the rain fall originates from water transpired by existing inland forests rather than moisture derived from the sea. According to research carried out by Woodwell (1994) the re-establishment of the original flora of an area may not be attainable for centuries, particularly in dryland areas, where inland moisture is a limiting factor. Hayden (1998), in his study of vegetation suggested that if the native vegetation of an area was cleared, most of the rain water would run off or drain to a depth below the root zone where it would not be used by plants, and would not be available for rapid circulation back to the atmosphere through evapo-transpiration. Hence, the northern part of Ethiopia, Tigray in particular, is highly exposed to the long-term impacts of droughts, thus, the region may no longer support the native vegetation cover and many notable species have now disappeared or are under threat of extinction (Nyssen *et al.,* 2007).

According to Mooney (1955) Ethiopia was densely wooded in ancient times, but there is no way of establishing how much of the country was actually forested, or specifically at what period and at what rate deforestation has occurred. Similarly, Nyssen *et al.* (2007) pointed out that most of the landscapes in Tigray were once covered with extensive forests even though deforestation had occurred for thousands of years, because in most parts of the region scattered remnants of *Juniperus procera, Olea europaea* subsp. *cuspidata, Cordia africana, Podocarpus falcatus, Croton macrostachyus, Ficus spp., Boswellia spp., Balanites aegyptiaca, Oxytenanthera abyssinica* and other species were abundant in pre-settlement times (Nyssen *et al.,* 2007).

Considering the land use related reports of the region, the Tigray Forestry Action Program (TFAP, 1996) noted that the present use of the term forest refers to the much localized groves around numerous churches throughout the highlands, in sparsely settled margins of the plateau, in deep valleys and inaccessible areas. As Chojnacki (1963) and Pankhurst (1995) stated that deforestation took place mainly in areas of extensive settlement, especially in the vicinity of towns or moving capitals such as Gondar and Adwa.

At present, closed forests, although highly impoverished, can be found in some localities such as Dese'a, Hugumbrda and Gratkahsu together with the thousands of groves around the churches; strengthen the view that most of the landscapes of the region were once covered with forests. Hence, the effects of deforestation on the socio-economic and ecological conditions of the region can easily be observed (TFAP, 1996). Several authors e.g., Friis (1986), Friis and Mesfin Tadesse (1990), Tamrat Bekele (1993) have reported, these the highlands of Ethiopia were once forested and this indicated by the numerous patches of forests or woodlands which have approximately the same species composition as in the areas still having closed forest as well as old trees found in many church yards. Vegetation in church yards were protected and conserved because of religious beliefs and cultural practices of local communities as a whole. Much of the forested areas were transformed into agricultural fields and shrub lands which have to be confirmed with evidences from other studies. For instance, in the northern part of the country, particularly in Tigray, houses are built of stones, which is different system compared to the tradition in the rest of the country which implies that there is scarcity of local timber for at least a few hundred years (Tamrat Bekele, 1993).

Nyssen *et al.* (2007) conducted a study which made a multi-scale assessment over a time span of 30 years of environmental rehabilitation in the most degraded areas of the Tigray highlands of northern Ethiopia. The study showed that the area in 1975 was bare; but, in 2006 sheet and rill erosion rates decreased, infiltration and spring discharges were enhanced, and consequently vegetation cover and crop production have improved due to the soil bunds constructed on the contour. These impacts are evidenced and quantified by a comprehensive comparison of the current landscape with what is seen in 30-year old photographs and substantiated by field investigations. The authors assessed the changes in the environmental conditions and observations were deduced from the comparison of the historical photographs taken in 1975 with the 2006 status. The combination of a variety of methods allowed for a holistic analysis of observed environmental changes between 1975 and 2006 incorporating details on the effectiveness of conservation measures in this marginal semi-arid area, which is representative for mountain dryland environments. On the contrary, despite the fact that vegetation cover improved, some areas still show ongoing deforestation due to fuelwood extraction and this gully erosion has expanded dramatically since 2006 due to enhanced runoff as a result of the decreased vegetation cover.

Repeat photography is an excellent tool for comparison and interpretation of changes between historical and current landscape patterns (James *et al.,* 2014) or particularly valuable for assessing and understanding the history of the sites to get a common sense of how the vegetation has changed (Pankhurst, 1976). As the name suggests, repeat photography means retaking photographs from the same site at different dates. It requires precise repositioning of the camera (Johnson, 1984) which is obtained by identification of unique landscape features such as mountain peaks, drainage ways, and their relative position.

Nyssen *et al.* (2007) have obtained fifty one landscape photographs of the environment in Tigray (HTS, 1976; Virgo and Munro, 1978) in the dry season of early 1975 revisited the same area in the same season in 2006 and took a new set of photographs. The photographs were taken at exactly the same place, in the same season and under the same angle (Nyssen *et al.,* 2007). This technique involved comparing the conditions of 2006 to these of 1975 and determining whether the various indicators were still relevant or not. When evaluating the environmental changes using the landscape photographs, the authors interpreted various indicators which showed changes of vegetation cover and land management practices in Tigray between 1975 and 2006. The authors agreed that the situation had improved with respect to visible erosion phenomena, vegetation cover on non-arable lands, land management as well as herb and shrub status between uncultivated areas and cultivated farm plots.

1.2. Statement of the Problem

The availability of accurate information on vegetation resources is an essential requirement to determine the regeneration status of plant species in order to assess to what extent species are threatened, play a crucial role in the local-climate and to provide a wide range of ecological benefits. In addition, botanical assessments such as floristic composition, population structure and natural regenerations are useful in identifying the rate of vegetation degradation, the degree of anthropogenic impacts and the disturbance elements in the vegetation. Various attempts have been made to study the forests and woodlands in different parts of the country. However, the assessment of vegetation composition has not been studied as far as Raya Azebo woreda is concerned. Most of the natural vegetation of this woreda has been severely and unwisely exploited by anthropogenic activities and grazing pressures, hence, there is a need to document species and carry out the ecological study of this area. The lack of such basic information is what hinders the conservation and sustainable utilization of the vegetation resources in the area. Therefore, this study aimed at generating primary information on the vegetation regeneration through analysis of the age and diameter structure of woody species, floristic composition of the vegetation stand, species diversity and soil physico-chemical analysis.

1.3. Research Questions

It is obvious that behind every research there are research questions that the researcher would like to answer. The research questions were:

- How is the regeneration status of the species in the woodland?
- What are the major factors that impact on the vegetation regeneration?
- What are the major trends in changing vegetation diversity and composition?
- How are the species diversity, abundance and frequency in the study areas?
- Do area enclosures contribute to regeneration of the woodland?
- Are there restoration efforts conducting in the area?

1.4. Objectives of the Study

1.4.1. General Objective

The general objective of this study was to investigate the natural regeneration status of the woodland vegetation, floristic composition, soil physical and chemical properties, and provide information on the ecological conditions of the study area.

1.4.2. Specific Objectives

The specific objectives of this study were:

- to describe the status of natural regeneration of the woody species through seedlings and saplings, and thereby identify the major factors that affect the natural regeneration potential of the vegetation.
- to describe the floristic composition, species population structure and plant community types of the study area.
- to analyze the species richness, species evenness and species diversity and assess the impacts of anthropogenic disturbances on the species composition and vegetation structure in the study area.

- to analyze the soil physical and chemical properties of the study area and evaluate the soil textural types and exchangeable bases to understand the changes in the vegetation diversity and richness

2. LITERATURE REVIEW

2.1. The Vegetation of Ethiopia

Ethiopia has a wide range of landscapes with very heterogeneous flora. However, conservation and sustainable utilization has been insufficient due to various reasons including low-level of community awareness, poor concern to the conservation problems and high level of poverty (EFAP, 1994; Ensermu Kelbessa, 2005; IBC, 2005). Many authors (Khan *et al.,* 1987; Maram and Khan, 1998; Rosser and Manika, 2002) have suggested that woodlands and forests have been lost as a result of various causes; however, anthropogenically-induced impacts have changed the ecosystems and their natural resources at a faster rate and are responsible for the current high rates of extinction. Rosser and Manika (2002) further explained that humans have caused many undesirable and unexpected changes in the environment. Of course they often have tried to reverse the rate of unexpected changes but the processes of reversing have been estimated to be very costy once changes have been established. For instance, once soil has been eroded from an area it cannot be easily restored and similary, once deforestation has occurred it is difficult to reforest and again once a species has become extinct it cannot be brought back. Thus, anthropogenic factors are responsible for the rapid decline in the natural vegetation cover of Ethiopia because about 85 % of the population is rural and mostly depend on natural resources for their food security.

Even though many efforts are being made, a number of vegetation conservation issues remain challenging and unresolved. According to several authors (Desta Hamito, 2001; Rezene Fessehaie *et al.,* 2012; IBC, 2012) reports, out of the many threats, the following factors may be the most critical challenges facing the conservation of vegetation in the country: *Anthropogenic impacts:* as the long-term experience shows that the elimination of human-induced impacts is impossible unless the vegetation management mechanism is improved. *Poor knowledge of vegetation conservation issues by the society:* the insufficient public awareness concerning the vegetation conservation issues and the inadequate puplic role in conservation efforts should be raised. *Transition period* of a political situation aggravated the loss of vegetation and habitat fragmentation occupied by refugees and displaced persons. *Expansion of agriculture and settlement:* the major conservation challenges of vegetation are habitat disturbances by conversion of woodlands to agricultural fields and settlement. *Inadequate financial resource:* is one of the challenges affecting vegetation conservation due to failure to link research to funds and effective protection to enough budget allocation. *Introduction of exotic species:* is another major challenge to vegetation conservation and its use in development. Degraded lands allow exotic species to increase their presence in an area. For example, *Prosopis juliflora* is aggressively invading pastoral areas of Afar and Somali national regional states, *Parthenium hysterophorus* is invading rapidly many arable lands and rangeland fields, and *Lantana camara* shrub is also replacing the other degraded scrubland areas of the country. *Low in capacity for vegetation conservation and management:* Ethiopia is rich in vegetation diversity but the challenge is low in capacity for conservation and sustainable management because the majority of the rural population is almost completely dependent on natural resources for their livelihoods, hence, affect the vegetation type of the country.

2.1.1. Classification of the Natural Vegetation Types

Several authors (EPA, 1997; Zerihun Woldu, 1999; Friis and Sebsebe Demissew, 2001 and Sebsebe Demisew *et al.,* 2004) have made considerable contribution to the classification of the Ethiopian natural vegetation based on physiognomic approaches into eight types. However, a recent study by Friis *et al.* (2010) has further classified the various natural vegetation of Ethiopia into 12 major types with some modifications and they are now considered as natural ecosystems of the country. These 12 include: *Desert and semi-desert scrubland (DSS), Acacia-Commiphora woodland and bushland (ACB), Wooded grassland of the western*

Gambella region (WGG), Combretum-Terminalia woodland and wooded grassland (CTW), Dry evergreen Afromontane forest and grassland complex (DAF), Moist evergreen Afromontane forest (MAF), Transitional rainforest (TRF), Ericaceous belt (EB), Afroalpine belt (AA), Riverine vegetation (RV), Fresh-water lakes vegetation including lake shores, marshes, swamps and flood plains vegetation (FLV) and Salt-water lakes vegetation including lake shores, salt marshes and pan vegetation (SLV). Of these six are categorized as forest vegetation, i.e., *the Ericaceous belt, the Dry Evergreen Afromontane Forset and grassland complex, the Moist Evergreen Afromontane Forest, the Transitional Rainforest, the Combretum-Terminalia woodland and wooded grassland, the Acacia-Commiphora woodland and bushland, and the Riverine vegetation.*

I) *Afroalpine and Subafroalpine:* This ecosystem includes areas with altitudes higher than 3200 m. The sub-afroalpine areas occur between 3200 and 3500 m, while the afroalpine areas occur between 3500 m and 4620 m (Tewolde Berhan Gebre Egziabhier (1988). This ecosystem is a very important source of water for the permanent streams and rivers. The vegetation of this ecosystem is characterised by the most conspicuous giant Lobelia, *Lobelia rhynchopetalum* and evergreen shrubs including the heather, *Erica arborea* and perennial herbs such as *Helichrysum*, *Kniphofia*, *Alchemilla* and *Festuca* species. Ethiopia has the largest range of afroalpine and subafroalpine habitats in Africa which are peculiar in that there are no seasonal variations in temperature, frequent frost leaving on bare soil all year round. The Simien and Bale Mountains are found in this ecosystem. As indicated by Vivero *et al.* (2005), both Mountains are the most important centres of plant biodiversity. In addition, Zerihun Woldu (1986) described that the Ethiopian plateau forms part of the Afroalpine and Afromontane region and show remarkable endemism due to the long period of spatial isolation of the mountains from each other since their origin (Miocene to upper Pleistocene).

II) *Dry Evergreen Afromontane Forest and Grassland Complex:* This ecosystem covers much of the highland areas and mountainous chains of Ethiopia. The

Ethiopian highlands are the largest mountain complex in Africa and comprise over 50% of the African land area covered by Afromontane vegetation, of which dry afromontane forests form the largest part (Tamrat Bekele, 1993; Demel Teketay, 1996). The altitudinal range of this complex vegetation type is 1500 m to 3200 m with average annual temperature and rainfall of 14-25°C and 700 - 1100 mm, respectively (Friis, 1992; Zerihun Woldu, 1999). This ecosystem usually dominated by *Juniperus procera,* followed by *Olea europaea* subsp. c*uspidata, Podocarpus falcatus* tree species and the shrubs occurring in this vegetation type include *Carissa spinarum* and *Dodonaea angustifolia* (Zerihun Woldu, 1999). The ground cover is rich in grasses, sedges and forbs (Friis, 1992). Degradation in this ecosystem is very high and particularly severe in the northeastern highlands, most of the mountains are bare, valleys have been gullied, springs and streams are mainly dry in the dry season. This type of ecosystem develops relatively high humidity, but not much rain, and where there is a prolonged dry season, 4-8 months (Abate Ayalew *et al.,* 2006). During the dry season, not only moisture stress but also temperature increases and daytime humidity decreases (Demel Teketay, 1996). The forests have diminished due to anthropogenic interference and replaced by grasslands in flat areas with deep soil and by bushlands on steeper slopes with thin soil as a result of soil erosion (Ensermu Kelbessa *et al.,* 1992; Zerihun Woldu, 1999).

III) *Moist Evergreen Afromontane Forest:* This ecosystem is characterised by one or more closed strata of evergreen trees, which may reach a height of 30 to 40 m. The vegetation type in this ecosystem can be further divided into two (Friis, 1992; Sebsebe Demissew *et al.* 2004). The first type includes the Afro-montane Rainforest which occurs in the southwestern part of the Ethiopian highlands in between 1500 and 2600 m elevation and the Harenna Forest on the southeastern slopes of the Bale Mountains (Ermias Lulekal *et al.,* 2008). These forests characteristically contain a mixture of *Podocarpus falcatus,* and *Pouteria adolfi-friederici, Celtis africana*, *Schefflera abyssinica*, *Mimusops kummel, Millettia ferruginea, Croton macrostachyus, Syzygium guineense, Ekebergia capensis, Olea welweitschii* and the mountain bamboo (*Arundinaria alpina).*

The second type includes the Transitional Rainforest, which occurs in the western escarpment of the Ethiopian Highlands, in Wellega, Illubabor and Kefa. The forest type occurs between 500 and 1500 m elevation. The characteristic species in the canopy includes *Pouteria altissima, Anthocleista schweinfurthii, Ficus mucuso* and species of *Garcinia, Manilkara* and *Trilepisium*.

IV) *Acacia-Comiphora Woodland and Bushland:* According to Friis *et al.* (2010), floristically, the *Acacia-Comiphora woodland and busland* is the most diverse vegetation type. Because of its variation, this vegetation type is distributed into two. The extensive and large coverage is in the eastern and southern parts of Ethiopia which is physiognomically varied due to many unique species. The other distribution is restricted to the rift valley part of the country which is physiognomically uniform due to very few unique species. This vegetation type is characterized by drought resistant trees and shrubs occurring between 400-1900m a.b.s. In general, it occurs in the northern, eastern, central and southern parts of the country but widespread in the southern, southeastern lowlands and the western part of the Afar rigion. The trees and shrubs include species of *Acacia, Balanites* and *Commiphora*. The ground cover is rich in species of *Barleria* and succulents with a number of *Aloe* species; the expansion of exotic invasive species such as *Prosopis juliflora* in this ecosystem is threatening the biodiversity. This ecosystem is currently under strong environmental stresses because of the fuelwood extraction and charcoal production for the major cities and towns in the country. In addition, clearance for rain-fed agriculture and irrigation has further enhanced its vulnerability, hence, the rate of deforestation and natural resource depletion has increased (Friis *et al.,* 2010).

V) *Combretum-Terminalia Woodland and Wooded Grassland:* This ecosystem is characterised by small to moderate-sized trees with fairly large deciduous leaves. These include *Boswellia papyrifera*, *Anogeissus leiocarpa* and *Stereospermum kunthianum* and species of *Terminalia*, *Combretum* and *Lannea*. The solid-stemmed lowland bamboo (*Oxytenanthera abyssinica)* is prominent in river valleys of western Ethiopia. The vegetation type occurs along the western escarpment of the Ethiopian Plateau. It is the dominant vegetation in Benshangul-Gumuz and Gambella Regions, and the Dedessa Valley in Wellega, where it occurs between 500 and 1900 m. The vegetation in this ecosystem has developed under the influence of fire. Although it is not demarcated, the Gambella National Park is the only protected area in this ecosystem.

VI) *Lowland, Semi-evergreen Forest:* This ecosystem includes forests that are restricted to the lowlands of western Gambella Region in Abobo and Gog Woredas. They occur between 450 and 650 m on sandy soils. They are semi-deciduous, with a 15-20 m tall, more or less continuous canopy in which *Baphia abyssinica* is dominant, mixed with less common species including *Celtis toka, Diospyros abyssinica, Malacantha alnifolia*, and *Zanha golungensis* and species of *Lecaniodiscus, Trichilia* and *Zanthoxylum*.

VII) *Desert and Semi-desert Scrubland:* This ecosystem is characterised by highly drought tolerant species of *Acacia brichettiana, A. stuhlmanii* and *A. walawlensis, Boswellia ogadenenesis, Commiphora longipedicillata* and *C. staphyleifolia* as well as succulents such as species of *Euphorbia* and *Aloe*. Grasses such as *Dactyloctenium aegyptim* and *Panicum turgidum* are also characteristic species. This ecosystem type occurs in the Afar Depression, the Ogaden, around Lake Chew Bahir and the Omo Delta below an altitude of 500 m. The semi-desert parts are found in the northwestern and northeastern parts of the Country. The northern parts of Afar and northestern Tigray are predominantly deserted. This ecosystem is being threatened by bush encroachment and the failure to manage the expansion of invasive exotic species, such as *Prosopis juliflora* (Ensermu Kelbessa *et al*., 1992).

VIII) *Aquatic Ecosystem:* This ecosystem consists of both running (lotic) and standing (lentic) inland water bodies, which include r*iverine vegetation, Fresh-water lakes vegetation including lake shores, marshes, swamps and flood plains vegetation and Salt-water lakes vegetation including lake shores, salt marshes* *and pan vegetation*. The swamps, reservoirs and shores of lakes are dominated by species of sedges and grasses.

2.2. Natural Regeneration

Natural regeneration refers to the natural process by which plants replace them selves by means of self-sown seeds (Evans, 1992), or vegetative recovery (sprouting from stumps, rhizomes or roots) after disturbances such as fire, cutting and browsing (Petrie, 1999). Natural regeneration dynamics is an extremely complex process which depends on environmental factors such as distribution of rainfall, topographic variation, edaphic factors, solar radiation, soil characteristics, seed viability and herbivory (Gerhardt and Hytteborn, 1992; Khurana and Singh, 2001; McLaren and McDonal, 2003; Enoki and Abe, 2004). Natural regeneration in large degraded areas is accepted and recognized as a low cost restoration technique since it alleviates many of the problems associated with seed collecting, storing, sowing and raising seedlings in a nursery (van der Valk and Pederson, 1989). Moreover, in natural regeneration, transplanting shock is avoided (Vesikallio, 1981), root distribution is better and much longer in depth and, insect and disease attack problems are also few (Petersen and Mohr, 1984). Therefore, an increased understanding of the patterns of natural regeneration enables to undertake proper vegetation information and this information in turn would help to utilize a given ecosystem wisely or sustainably.

A report by Society for Ecological Restoration (SER, 2004) noted that the prominent demand is not only restoring forests and landscapes but also how can be brought about restoration which is feasible, affordable and profitable to society through the practice of ecological restoration. In addition, Zobel and Talbert (1984) have suggested that the question facing is how to use the forest resources wisely and widely for long-lasting benefit to humans. Therefore, long-term thinking is a key step to rebuilding landscapes in ways that will improve human well-being and reducing environmental risks and scarcities.

2.2.1. Factors Controlling Natural Regeneration

According to Berg (1975) several factors are believed to be involved in the control of natural regeneration. Some of the factors are:

Seed supply: Lack of seed sources due to the absence of fertile plants with viable seeds; seed predation by insects, birds and mice. *Soil condition:* Seed germination and establishment will be prevented by conditions such as soil compaction that reduces air spaces and water absorption. *Competition:* Competition from herbaceous plants may prevent the success of natural regeneration due to competing spaces, nutrients and water availability. *Predation:* seed predators and herbivores often limit regeneration of natural and planted populations (Holl *et al.* 2000; Holl *et al.* 2003). Seedlings may be destroyed by predators such as insects, domestic and wildlife animals due to the lack of natural deterrents such as unpalatable chemicals and thorns compared to matured plant species. *Moisture stress:* Regeneration is sensitive to moisture stress, hence, high mortality rates of seedlings are common due to high temperatures and high soil moisture stresses (Pereira and Kozlowski, 1977; Barnes *et al.,* 1998). *Natural hazards:* Natural hazards due to natural factors such as fire, flood, drought and solar radiations cause damage upon natural regeneration.

2.2.2. Factors Stimulating Natural Regeneration

Stimulation of natural regeneration can be achieved in many ways including the removal of ecological disturbances, establishing area closures (Tefera Mengistu 2001), and implementing environmental education programmes and raising community awareness and economic incentives (Holz, 2003). Janzen (1988) further suggested that community understanding should be linked between the environment and development, reforestation programmes should be linked with the reversing the effects of deforestation and loss of biodiversity. Encouraging natural regeneration is usually a cheaper and effective restoration technique than other restoration strategies (e.g,. artificial plantations with nursery-raised seedlings) due to its acceptable option of restoring large degraded areas (FAO, 2003). Vallejo *et al.* (2003) suggested that the first step in the process of vegetation recovery involves identifying the principal factors that are acting as barriers or as facilitators to natural regeneration. Most studies have identified competition, moisture stresses and poor soil conditions are the most important barriers for species re-establishment (Holl, 1999). According to Bendz (1986) and Janzen (1988) areas deforested due to cultivation, livestock grazing and anthropogenic activities can be restored in a short period of time through natural regeneration. In addition, FAO (2003) suggested that in order to succeed with the process of natural regeneration, ecological succession will undergo by adequate protection of the area alone. At the same time, for sufficient conservation of locally remnant species, surrounding areas should be expanded step by step over to create continuous conservation area coverages.

2.2.3. Natural Regeneration of Woody Vegetation

Natural regeneration assessment serves to evaluate the availability of young species (seedlings and saplings), competition problems and the composition of the vegetation in order to make a decision whether the area is well established with the desired species or not (Ackzell, 1994). For most woody plants, lack of seedlings affect the formation of a vegetation structure on the forest floor (Demel Teketay and Granstrom, 1997). As explained by Khan *et al.* (1987), regeneration is a critical factor of vegetation restoration because it is an extremely important future situation and maintains the desired species composition after intensive anthropogenic disturbances. Several authors have suggested that the regeneration status of species in a vegetation community can be predicted from the population dynamics of seedlings and saplings (Pritts and Hancock, 1983; Uma Shankar *et al.,* 1998; Bhuyan *et al.,* 2003). Saxena and Singh (1984) on the other hand noted that the population structure characterized by the presence of sufficient number of seedlings, saplings and adult species show satisfactory regeneration behaviour, while inadequate number of seedlings and saplings of woody species in a vegetation indicates poor regeneration.

The successful regeneration of woody species can be determined by its ability to produce large number of seedlings, and the ability of seedlings to survive and grow (Good and Good, 1972). However, the presence of sufficient number of seedlings, saplings and adult trees is greatly influenced by the interaction of biotic and abiotic factors of the environment (Augspurger, 1984; Khan and Tripathi, 1989). Moreover, the intensity, magnitude and frequency of disturbances are also largely determined by the structure and composition of plant communities in many natural vegetation ecosystems (Armesto and Pickett, 1985; Khan and Tripathi, 1989; Bhuyan *et al.,* 2003). Clements (1936) observed that forest disturbances have negative impacts that destroy climax assemblages and bring instability in the system, while Paine (1966) and Huston (1979) considered disturbances to have positive impacts that might increase species diversity in the community by preventing competitive exclusion by dominant species. Several authors have carried out studies on population structure and the regeneration status within different ecosystems and shown that the success of regeneration can be controlled by anthropogenic pressure (Bhuyan *et al.* 2003), light intensity (Clark *et al.,* 1996), soil moisture availability (Lawrence and Oechel, 1983; Wyant *et al.,* 1983), soil nutrient availability (Beckage and Clark, 2003), pathogen and herbivory (Khan, 2004), burning (Khan and Tripathi, 1989) and micro-environmental factors (Whitemore, 1975; Gause and Stone, 1979).

2.3. Ecosystem Restoration

The Society for Ecological Restoration (SER 2004) has defined ecological restoration as the process of assisting the recovery of ecosystems and habitats that have been degraded, damaged, or destroyed. It is an intentional activity that accelerates the recovery of an ecosystem with respect to its stable and sustainable state through active human intervention (SER 2004). The practice of ecological restoration includes a wide range of tasks such as erosion control, removal of exotic species, re-vegetation of disturbed areas and re-introduction of native species, inorder to improve the ecosystem processes such as carbon sequestration, nutrient cycling, nitrogen fixation, pollination of flowering plants, decomposition of organic matter and water infiltration into the soil (Daily *et al.,* 1997). According to Wilson (1991) conservation biologists are concerned with how to conserve remnants of small populations and how to prevent habitats before degradation but greatly concerned with how to restore the remnants of the crisis. Several authors have suggested that restoration attempts primarily to return an ecosystem back to its past state or prior to disturbance but not necessarily to return the historic ecosystem conditions due to some constraints such as lack of funds, below average rainfall and grazing disturbances (Aronson *et al.,* 1993; Parmesan, 2006; Vaughn *et al.*, 2010).

2.3.1. The Need for Ecosystem Restoration

The current environmental degradation and destruction of many of the earth's vegetation is great and taking place on a short timescale (Novacek and Cleland, 2001). An estimate of the current extinction rate is 1,000 to 10,000 times more than the mass extinction of historic times (Wilson 1988). According to Daily *et al.* (1997) and Hobbs (2008), fundamentally, natural ecosystems provide human society with goods and services such as the purification of air and water, fuelwood and timber, detoxification and decomposition of wastes and regeneration of soil fertility. Habitat loss is the leading cause of both species extinctions and the decline of ecosystem services (Daily *et al.* 1997; Wilson 1988). The two methods to reverse the trends of habitat loss are conservation of currently viable habitats and restoration of degraded lands. The Society for Ecological Restoration (SER 2004) stated that restoration of ecosystems provide ecological, economical, educational and scientific benefits. The fundamental difference between restoration and conservation efforts is that conservation attempts to maintain and protect the existing habitats and biodiversity, whereas restoration attempts to reverse the degraded habitats and declined populations through direct human intervention. Conservation is a better to prevent original habitats and their biodiversity than restoration because the latter does not provide an extremely valuable original habitat. It is generally less effective and more expensive than conservation since it cannot always restore the vegetation to its pre-disturbance state because some habitat and biodiversity losses are permanent (SER, 2004).

According to Bradshaw (1997) and Daily *et al.* (1997), ecosystem restoration re-establishes natural capital (e.g. potable water and wildlife populations), modifies carbon sequestration through afforestation and improves the production of goods and services (e.g. fuelwood and timber). Compared to other forms of capital, ecosystems are poorly understood, not quite supervised, and undergoing rapid degradation and depletion. Since ecosystems are not considered as vital capitals, the importance of ecosystem services is widely appreciated or valued only upon their loss (SER, 2004).

2.3.2. The Major Challenges of Ecosystem Restoration

In many parts of the world, ecosystems are no longer providing essential goods and services due to biodiversity degradation. According to Alpert (2002) and Hilderbrand *et al.* (2005), many failures have occurred restoration times because people may not know how to manage natural systems effectively and assumptions which worked in one area may not work while applied to another area. Various authors have suggested that the large and growing human population on earth, mechanized agricultural investments, mining industries and infrastructures together with the rapid technological advancements cause extensive damages and challenges inorder to restore ecosystems (Cairns, 1994; Wilkins *et al.,* 2003).

Currently, the forest and woodland sector in Ethiopia can not attain natural regeneration due to large-scale disturbance as a result of investment activities happening in all parts of the country, particularly in the south and southwestern regions where the remaining part of the natural forests occured. According to the Ministry of Environment and Forest (MEF, 2015), these disturbances will be the main cause in future of ecosystem unsustainability. Hence, increasing the disturbances on the existing natural forests and woodlands is a problem. Some of these are as follows:

Mechanized agricultural investments in forest areas: Currently, the government and private investors engaged in mechanized agriculture to produce sugar and food crops to the foreign markets. The government invests on large scale sugarcane plantations in different parts of the country such as *Kuraz sugar* factory in south Omo, where the lage area of forests and woodlands cleared for the sugarcane plantations, establishment of the factory, building for the offices and place of residences. Similarly, the private investors involved in mechanized agricultural investment practices dominantly in Gambella, Southern Nations, Nationalities and Peoples Region (SNNPR) and Benishamgul-Gumuz in food crop production and Pulses Farming for international (export) markets as well as cotton farming for domestic textile factories (MEF, 2015).

Coffee plantations in natural forest areas: Coffee plantations and wild coffee growing in the natural forests have reduced the forest regeneration, density and diversity. In the coffee forest, the larger trees can provide as shading for the coffee plants. Moreover, the coffee growing farmers clearing any understory (shrubs, tree seedlings and saplings) and ground layers (grasses and forbs) to reduce space, moisture and nutrient competitions. Consequently, the natural regeneration of the rich biodiversity of the southwestern and southeastern forests is reduced (MEF, 2015).

Enset plantation practices in forest areas: The high forests in the southwest Ethiopia are additionally suffering from the traditional enset plantation practices. However, unlike the coffee forest, Enset plantations do not need shading trees. As a result, Enset plantations are involved in the total woodland clearances which leades to the failure of seedling establishments (MEF, 2015).

Mining activities in forest areas: Ethiopia has high potential reserves of mineral resources but those explored so far are unfortunately found in woodland or forest areas. For example, Laga Dembi gold factory as well as Yayu potash mineral resources is found under the forest areas (MEF, 2015). Therefore, the impact of mining industries carried out on forest areas retard the growth of seedlings and saplings.

Expansion of small-scale agriculture in forests: Over 85 % of the Ethiopian population is rural and mostly depend on farming subsistance which is rain-fed agricultural livelihoods. As a result, expansion of small-scale agriculture togather with the fuelwood extraction and charcoal production are the major drivers of deforestation. In addition, farmers respond to the unproductive lands by moving to the new forest lands resulting in habitat loss and fragmentation because most of the nutrients of the woodlands are held in the biomass of larger trees (MEF, 2015).

Fuelwood extraction and charcoal production in forests: Fuelwood and charcoal are important sources of energy for both the urban and rural populations. Depending on this demand, most farmers are dependent on selling fuelwood and charcoal products for both economic and food security, and in many cases this dependence is increasing with improved living standards and increasing population. Therefore, these stresses are critical problems in the regeneration of the woodland and forestry sectors.

Infrastructures in forest sectors: Various development activities such as road building activities, hydro-electric dam constructions (e.g. the Renaissance dam) and high electric power transmission lines that passe through forests and woodlands caused considerable deforestation thereby reduces regeneration (MEF, 2015).

2.3.3. Contribution of Area Enclosures to Regeneration

Area enclosures are areas closed off to human and livestock interferences in order to promote natural regeneration and reduce environmental degradation (Betru Nedessa *et al.,* 2005). Area enclosures are usually established for site rehabilitation in steep, eroded and degraded areas normally identified together with the local communities and governmental offices (Descheemaeker *et al.,* 2006) to increase or further improve plant and animal biodiversity (Kindeya Gebrehiwot, 1997; Emiru Brihane, 2002). To avoid the environmental problems, communities have started to limit human and domestic animal interference in some degraded areas to prevent further degradation and promote natural regeneration. The primary objective of establishing area closures is to improve the overall ecosystem conditions so that they can reverse ecosystem goods and services. Moreover, establishing area closures is advantageous since it is a quick and cheap method for the rehabilitation of degraded areas (Bendz, 1986; Tefera Mengistu, 2001).

In Ethiopia, closures started with the introduction of large-scale land rehabilitation, and soil and water conservation programmes in the 1980s (Betru Nedessa *et al.,* 2005). According to Tefera Mengistu (2001) establishing area closures is becoming a promising alternative to combat desertification, to protect severely degraded landscapes, to minimize surface run-off and to create conducive atmosphere for human, livestock and wildlife by conserving the vegetation resources such as trees, shrubs, forbs and grasses.

In addition, CBD (2001) considers area closures as cornerstones for improving local microclimate and biodiversity conservation of an area, and as major tools for reducing the current loss of species and habitats in all types of ecosystems. From the historical point of view, some authors, e.g., Feoli (1996) and Alemayehu Wassie (2002), remarked that the practice of area closures in Ethiopia was not a new and it had been traditionally exercised for centuries around church boundaries by restricting the use of forests and woodlands. Recently, area closures have been widely established with the general aim of restoring degraded areas through plantation, natural regeneration and land protection (Emiru Birhane, 2002). According to FAO (2001), area closures improve medicinally, ecologically and economically important plant species, soil organic matter stability and provides habitats for various beneficial species such as pollinators. Practising conservation activities, ecosystem restorations and establishment of area closures will remain the main important roles in ecologists; however, climate influences may make these practices impossible task (Heller *et al.,* 2009).

2.4. Plant Community

A plant community is a group of species within a given area which interacts with each other and with their environment (Tamrat Bekele, 1993). Plant communities may vary in appearance, abundance, distribution and species composition from location to location due to abiotic (soil, climate and topography) and biotic factors (competition, grazing and anthropogenic disturbances) (Walter, 1985; Goldsmith *et al.,* 1986; Kent and Coker, 1992; McCune and Grace, 2002). Clements (1905) was the first to define the term ecotones (edges or boundaries) as a stable delineation between distinct vegetation communities. Curtis (1959) and Van der Maarel (1990) described ecotones as ecological transition zones such as the intersection between vegetation types of both sides which are narrow and unstable zones possessing a mixture of two different homogeneous community types.

2.4.1. The Plant Community Theories

At the beginning of the 20th century, two contrasting views of the community prevailed among certain groups. These were the Clementesian view (Organismal concept of community) by Frederic Edward Clements, which considered plant communities as discrete units and Gleasonian view (Individualistic concept of community) by Henry Allan Gleason that considered plant communities as continuous entities (Lewis and Tayler, 1979). These community concepts are briefly summarized below:

2.4.1.1. The Discrete Community Concept

The discrete community theory was popular during the 1930s and 1940s. In this concept, the distinctive vegetation of each area represents a distinct community, which is separated by sharp or clear vegetational boundaries (ecotones) from other adjacent communities (Ricklefts, 1997). Clements assumed the community as a superorganism in which the functions of various species are connected like the parts of the body (Clements, 1916). Each species represents an interacting, integrated component of the whole. They have similar environmental requirements, similar distributions along environmental gradients, common evolutionary history, and similar responses and tolerances. The entire vegetation develops together as a single unit like an organism.

2.4.1.2. The Continuum Community Concept

The continuum concept implies the gradual change without clear boundaries along environmental gradients due to many factors like moisture, temperature and soil conditions (Ricklefts, 1990). Gleason (1926), in his individualistic continuum approach proposed that species combinations or communities were created by the indivdual responses of species independently to the environmental conditions and by chance events of dispersal and disturbances. In addition, each species is distributed depending on its own traits such as genetic make up and physiological requirements; hence, there are no two species with completely overlapping (similar) distribution. The early theory of Gleason (1926) gave emphasis to the traits of individual species, which allows each species to live within specific habitats or specific geographic ranges. Furthermore, Gleason states that the relationship between co-existing species is the result of similarities in their requirements and tolerances at that point in space. However, neither Gleason nor Clements appeared to be concerned with collecting and analyzing field data for the specific purpose of testing their respective hypotheses (Mclntosh, 1975).

According to Roberts (1987) and Claessen *et al*. (1994) both concepts gave very little emphasise on environmental factors for the modification effect of the vegetation and subsequent influence on the pattern of community. Gleason's concepts were misunderstood from 1926 to the early 1950s until Whittaker and others began developing the idea of continuum approach. The current view about the nature of community is much closer to Gleason's opinion (Begon *et al*. 1996). In the 1950s, Whittaker investigated patterns of vegetation along elevation gradients in the Smoky Mountains which showed that the distribution of vegetational change along environmental gradients was a continuum due to gradual change in composition without sharp boundaries (Whittaker, 1967).

The modern synthesis of plant communities recognizes that both Gleason and Clements views have validity and application for different aspects of community analysis. Chapman and Reiss (1992) stated that discontinuity in community association could also occur if the environmental variables change a sharply as in the case of cliffs and lake shores. While Collins *et al*. (1993) and Huston (1994) observed that species with a wider range of distribution were not used in association analysis for community classification (discrete community concept). In the case of the continuum concept, normal distribution is not considered a universal case since resource pattern is not always continuous.

2.4.2. Techniques in Vegetation Classification

Among the many multivariate techniques developed, classification and ordination are the two main basic techniques, which are employed to study the complex nature of communities (Ricklefts and Schuluter, 1993).

2.4.2.1. Classification

Classification is the process of grouping similar species together into classes based on selected shared characteristics (Tart *et al.,* 2005). Accordingly, classification begins with the assumption that communities consist of distinct units. Various techniques of vegetation classification have been discussed by several authors like Gauch (1962) who divided classification techniques into hierarchical and non-hierarchical which are briefly described below:

Non-hierarchical method: When there is no particular advantage in the groups being arranged in a hierarchy, a non-hierarchical method of classification may be chosen (Gauch 1962; Dingby and Kempton, 1994). In this case species are arranged in clusters, bringing similar species together (Pielou, 1969) to optimize structure of individual species. If homogeneity of species is of a prime importance in the application process, the non-hierarchical techniques are best fit.

Hierarchical method: In such a classification technique, samples having the same properties are arranged into classes and the classes at any level are subclasses of classes at higher level (Pielou, 1969). A strategy for hierarchical clustering technique is generally divided into two types: *Agglomerative:* this is a "bottom up" approach, where each observation starts in its own cluster, and pairs of clusters are merged as one moves up the hierarchy. Agglomerative methods start with individual items and group them together in a series of steps (Dingby and Kempton, 1994). *Divisive (splitting):* this is a "top down" approach in which one starts with the whole set of data and progressively splits are performed as one moves down the hierarchy. *Monothetic divisive:* This technique begins with all the samples in a single group and then divides them hierarchically into smaller groups on the basis of the presence and absence of a single species (Williams and Lambert, 1964). *Polythetic divisive:* In this case information on all species is used. It begins with all samples together in a single cluster and successively divides the samples into a hierarchy of smaller and smaller clusters until finally each cluster contains only one sample (Dingby and Kempton, 1994). In general, the *monothetic* type is one in which all members are identical in all characteristics whereas the *polythetic* type is one in which all members are similar, but not identical.

2.4.2.2. Ordination

Oridination in plant ecology is a means of analyzing field observations for the purpose of recognizing the factors which determine the distribution of vegetation (Goodall, 1954) and is also widely used as a tool for examining relationships between environmental factors and community floristic composition (Chapman and Reiss, 1992). On the other hand, ordination is a data reduction procedure when the obtained data has a large number of variables and one believes that there is some redundancy in those variables, possibly due to then measuring the same concept (ter Braak, 1986). Because of this redundancy, the purpose of carrying out an ordination analysis is to reduce these observed variables into a relatively smaller number of components that are simpler, more space-efficient and visual (ter Braak, 1986). Mueller-Dombois and Ellenberg (1974) described ordination as a noise reduction technique, which visualize multiple dimensions simultaneously as a single multivariate analysis which aims at saving time and graphical results also lead to interpretations of species distribution with environmental factors thereby demonstrating the relationship.

In order to establish the main links between environmental factors and vegetation variations, a redundancy analysis (RDA) can be performed (ter Braak, 1986, 1994). In addition, Ter Braak (1994) and Legendre and Legendre (1998) pointed out that RDA is an ordination technique that produces a multivariate direct gradient which aims to analyze and visualize community variation, and the features of species distribution along environmental variables. Regarding its final output, ordination allows community to be arranged on a graph (Lambert and Dale, 1964) and aims at representing the individuality of each stand. As opposed to the use of classification in describing discrete plant communities, ordination techniques have evolved which can relate continuous variables. Ordination enables one to obtain information on both the continuity and discontinuity of the data studied as well as to recognize the number of possible clusters and their shapes (Goodall, 1973; Kershaw, 1973). It emphasizes the occurrence of a predictable association of species under a particular set of environmental variables and their common trend, which are most important in sorting out a group (Begon *et al*., 1996).

2.5. Soil Physical and Chemical Properties

2.5.1. Soil Texture

Soil texture refers to the relative proportions of the various mineral particles namely: sand, silt and clay found in the soil which differs in terms of size. Particles that range in size from 0.05 to 2.0 mm are sands, 0.002 to 0.05 mm is considered as silt and the smallest particles are found in clay, with size less than 0.002 mm. Their abundance or scarcity affects nearly every aspect of soil use. Settling rates of primary particles are based on the principle of sedimentation as stated by Sanchez (1976), that the larger the particle, the more quickly the particle will sink (settle) out of suspension, hence, most of the sand particles in the soil will settle to the bottom in about 40 seconds. The silt and clay particles will take quite a bit longer time, perhaps as long as 2 hours. A more robust scientific approach to measure the quantity of particles in an aqueous solution (suspension) is by using a soil hydrometer (ASTM 152H). The hydrometer uses the Bouyoucos scale, expressed as the percent by mass (g) of soil in suspension implies how many grams/liter of particles are in the suspension. Thus, the 40 second reading gives the grams of silt and clay still suspended after the sand particles have settled. The soil texture largely determines factors such as the soil's water holding capacity, organic matter content, air supplying capacity, soil drainage, nutrient availability and plant rooting depth (Sanchez, 1976; Donahue *et al. 1*983).

Over a very long period of time, pedological processes such as land use system, erosion, deposition, eluviation and weathering can alter soil horizon textures (Foth, 1990; Brady and Weil, 2002). As soils get older sand weathers to silt and silt weathers to clay, and therefore, old soils will have more clay. Soil texture can determine the amount of pores and the pore size distribution (Brady and Weil,

2002) which in turn affects the infiltration rates, aeration status and water holding capacity of the soil. Sand soil particles fit together in a way that creates large pores so that infiltration rates and permeabilities to water are high and retain little water. In contrast, clay soil particles fit together in a way that creates small pores so that infiltration rates and permeabilities to water are low and retain much water in available forms and may be poorly drained. Therefore, a soil made of clay particles will have more total pore spaces than sand soil particles. Soils of intermediate textures such as loams are intermediate in porosity, water retention and drainage. Specific surfaces and cation exchange capacities of sands are low as compared to clays (White, 1997; Wakene Negassa, 2001; Ward, 2008). The water-holding capacity is determined in large measure by the particle size distribution (PSD) of fine textured soils (silt and clay) than coarse textured soils (sands) (Ward, 2008).

2.5.2. Soil Chemical Properties

2.5.2.1. Soil pH

The pH value reflects the relative number of hydrogen ions (H^+) in the soil solution which tells whether or not the soil is acidic or alkaline (FAO, 2006). A pH of 7 describes a neutral solution when the hydrogen and hydroxide ions (OH) are present in equal concentrations. When the pH is below 7, the soil solution is described more acidic due to a higher concentration of hydrogen ions than that of hydroxide ions. On the contrary, when the pH is above 7, the soil solution is described more alkaline because of a higher concentration of hydroxide ions than that of hydrogen ions. The rate of pH in the soil normally ranges from pH 3 to pH 9 (Londo *et al.*, 2006). Descriptive terms commonly associated with certain ranges in soil pH are described by Foth and Ellis (1997) as follows: soils with pH < 4.5, the soil solution is extremely acidic; very strongly acidic soils (pH 4.5-5.0), strongly acidic soils (pH 5.1-5.5), moderately acidic soils (pH 5.6-6.0), slightly acidic soils (pH 6.1-6.5), neutralized soils (pH 6.6-7.3), slightly alkaline soils (pH

7.4-7.8), moderately alkaline soils (pH 7.9-8.4), strongly alkaline soils (pH 8.5-9.0) and soils with pH > 9.1 is very strongly alkaline.

Leaching due to high rainfall leads to soils being acidic soil, which in turn retards the decomposition of organic matter as a result of the intolerance of soil micro-organisms to strongly acids (Lewis and Taylor, 1979). Forest soils tend to become acidic as a result of carbon dioxide production from decomposing organic matter and root respiration dissolving in water to form organic and inorganic acids such as nitric and sulfuric acids in the soil. As a result, microbial activity is slowed down in acidic soils and these prevent organic matter from decomposing, causing accumulation of organic matter and tie up of nutrients, particularly nitrogen, in the undecomposed organic matter (Etherington, 1975; Pearcy *et al.*, 1994; Eylachew Zewdie, 1999).

According to Barnes *et al.* (1998), most nutrients are more soluble or available in basic soils than in acidic soils. As soil pH decreases (pH 4.0-5.0), the content and availability of nutrients such as phosphorus to plants usually decreases because of precipitate reactions with iron and aluminum. As Tamirat Tsegaye (1992) has shown that soil pH is mostly related to the nature of the rainfall, soil organic matter and topographic situations. Where there is high rainfall, there is a high tendency of soils to be acidic, which contributes to substantial loss of basic cations (Ca^{2+}, K^+, Mg^{2+} and Na^+) below the root zone due to leaching down and accumulation of acidic cations like H^+, Al^{3+}, and Fe^{3+} in the soil surface (Smith *et al.,* 1995). Soil pH tends to rise particularly in the semi-arid and arid regions where rainfall is insufficient to leach soluble salts away and evapotranspiration exceeds the amount of precipitation which leads to the accumulation of salts in the soil surface. As reported by Miller and Donahue (1995), the extreme rising (> 8.5) and lowering (< 4.5) of soil pH affect the biological, physical and chemical properties of the soil, thereby affecting plants by disturbing the activity of soil micro-organisms and altering the solubility and availability of the essential plant nutrients. According to Sparks (2003) alkaline soils have a high saturation of base cations due to the accumulation of soluble salts dominated by sodium, calcium and magnesium (Miller and Donahue, 1995; Brady and Weil, 2002).

2.5.2.2. Soil Organic Matter (SOM)

Vegetation cover usually contributes organic matter to the soil. This is the most important indicator of soil quality which affects the water holding capacity, soil structure, nutrient contributions (Prasad and Power, 1997), oxygen holding capacity, distribution of pore spaces, reduces soil erosion and stores organic carbon (Gregorich *et al.,* 1995; Keith, 1997; Lal, 2001). In addition, as these authors reported that a properly structured soil, with good levels of soil organic carbon, allows greater infiltration and retention of rainfall. For instance, every gram of carbon in the soil can retain up to eight grams of water. Hence, by improving soil structure through increasing organic matter in the soil, it is possible to effectively capture and retain any rain that falls, making it available to plants for a long period of time (Gregorich *et al.,* 1995).

2.5.2.3. Total Nitrogen

Total nitrogen (TN) is the sum of all forms of nitrogen found in the soil including inorganic nitrogen such as nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3), and organic forms of nitrogen (Tisdale *et al.,* 1995). Plants usually absorb nitrogen in its cationic form (ammonium, NH4+) and anionic form (nitrate, NO3-). Available nitrogen can also be obtained from sources such as biological fixation by free living soil bacteria and symbiotic bacteria of legume root nodules, atmospheric fixation by lightning (breaks nitrogen bonds) which enables the free atoms to combine with oxygen in the air forming nitrogen oxides which dissolves in rain to form nitrates that are carried to the soil by precipitation and decomposition of organic nitrogen by decomposers into available inorganic forms such as $NH4^+$ or $NO3^-$ (Tisdale *et al.,* 1995). The availability of nitrogen through biological fixation is influenced by soil pH because decomposition of organic nitrogen into the inorganic forms depends on temperature, soil moisture and supply of oxygen (Tisdale *et al.,* 1995).

2.5.2.4. Available Phosphorus

Phosphorus (P) is unique among the anions in that it has low mobility and low solubility which is the most inaccessible nutrient required by plants (Moody and Bolland, 1999). In order for phosphorus to be available for plants, soil pH needs to be in the range of 6.0 to 7.5. If the soil pH is < 6, phosphorus starts forming insoluble phosphate compounds with iron (Fe), aluminium (Al) and manganese (Mn) and if the soils pH is > 7.5, phosphorus starts forming insoluble phosphate minerals with calcium (Ca) in the soil. The plant available forms of phosphorus are limited primarily to solution $HPO4^{-2}$ and $H2PO4^{-}$, with the dominant forms determined by the soil pH (Tisdale *et al.,* 1995).

2.5.2.5. Cation Exchange Capacity

Cation exchange capacity (CEC) soils is a measure of the quantity of negatively charged sites on soil surfaces that can retain positively charged cations (Foth and Ellis, 1997) such as Ca^{2+}, Mg^{2+}, and K^{+} by electrostatic forces. This attraction is important because it prevents the cations from being leached away with excessive rainfall. In order to be available to plants, cations adsorbed electrostatically on clay and organic matter surfaces are easily exchangeable with other cations present in the soil solution and are thus readily available for plant uptake (Foth, 1990; Kimmins, 1997). Plant roots facilitate this process by releasing hydrogen ions (H^{+}) into the soil solution in order to exchange for cations. The cation exchange capacity will vary with changes in the soil pH, organic matter and clay contents. The process of cation exchange is considered to be of great importance to soil fertility than anion exchange because the majority of essential minerals are absorbed by plants as cations (Poritchett and Fisher, 1987). The exchangeable cations are desirable form of nutrients, being quickly brought into solution and made accessible to roots by the exchange with proton (Curtis and Courson, 1981). According to Landon (1991), CEC can be classified as high (> 25 cmol (+)/kg), medium (15-25 cmol (+)/kg), low (5-15 cmol (+)/kg) and very low (< 5 cmol (+)/kg).

2.5.2.6. Exchangeable Bases

Soils in high rainfall areas are characterized by low contents and deficiencies of exchangeable bases such as Ca, Mg and K (Saikh *et al.,* 1998). However, high OM containing soils retain more basic cations mainly dominated by exchangeable Ca and Mg (Eylachew Zewdie, 2001). According to Berhanu Debele (1985), some high pH soils can be saturated with base elements, for instance, soils could be saturated with potassium 1 to 5%, magnesium 5 to 25%, calcium 50 to 85% and sodium 1%. The predominant exchangeable cation, which accounts for up to 80% of the exchange complex is calcium followed by magnisum. In clay minerals, the most common exchangeable cations, in order of relative abundances are Ca^{2+} > Mg^{2+} > K^{+} > Na^{+} (Grim, 1968). However, deviations from this order can create problems of ion imbalance. For example, high Mg in soils inhibits Ca uptake by plants (Malpas, 1992) because the magnesium binds the clay together so that water and nutrients do not penetrate well. On the other hand, high Na creates problems of low water flow in soils and availability for plants (Szabolcs, 1969; Sposito, 1989; Bohn *et al.,* 2001) because exchangeable Na changes soil physical and chemical properties mainly by inducing swelling and dispersion of clay and organic particles, resulting in restricting water permeability, air movement and nutritional disorders by decreasing solubility and availability of calcium and magnesium ions. Soils in semi-arid and arid areas have less potential to be affected by leaching of cations than soils of humid areas (Jordan, 1993; Mesfin Abebe, 1998; Eylachew Zewdie, 2001).

3. THE STUDY AREA

3.1. Geographical Location and Description

Raya Azebo woreda (Figure 1) is located in the south eastern part of Tigray between $12^{o}20'0''$ - $13^{o}0'0''$ N latitude and $39^{o}40'0''$ - $40^{o}0'0''$ E longitude. The woreda town, Mehoni, is about 644 km north of Addis Ababa and 128 km south of Mekelle, the capital of Tigray Regional State, and about 18 km east of the south zone capital Maychew. Raya Azebo woreda is bordered on the south by Alamata, on the southwest by Ofla, on the north by Hintalo Wajirat, on the northwest by Endamehoni woreda and on the east by Afar Region.

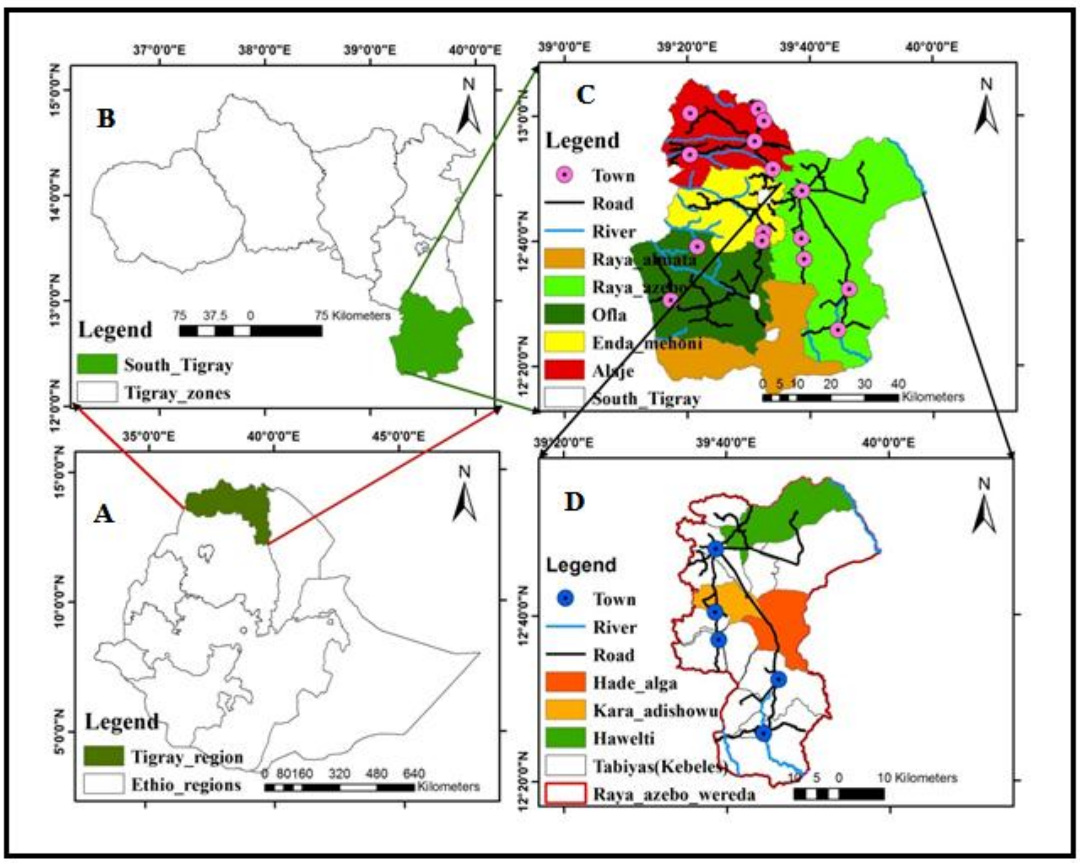


Figure 1: Map showing the location of the study area ***A)*** *map of Ethiopia showing Tigray Regional State;* ***B)*** *map of Tigray showing the Regional Zones* ***C)*** *map of Southren Zone showing the bordering woredas* ***D)*** *map of Raya Azebo woreda showing the study sites*

3.2. Climate

The temperature and rainfall data of this study area for the year 2008 - 2014 was obtained from the Ethiopian Meteorological Services Agency (EMSA, 2014) as shown in Figure 2. The study area receives bimodal type of rainfall distribution. The two wet seasons lie between March to April and July to September, and the dry season lies between October to February. The big prolonged wet season (*Kremt)* begins in July to September and a short dry spell season (*Belg*) during March to April. However, yearly fluctuations in amounts and distribution of rainfall are very common. Based on the 7 years data, the mean annual rainfall is about 590 mm but varies greatly from year to year and the mean annual temperature is about 22.5°C. The hottest months (dry season) were from February to June, with a mean maximum temperature of about 33.7°C recorded in June. The coldest months occur from July to December with the mean minimum temperature of 11.6°C being reached in December.

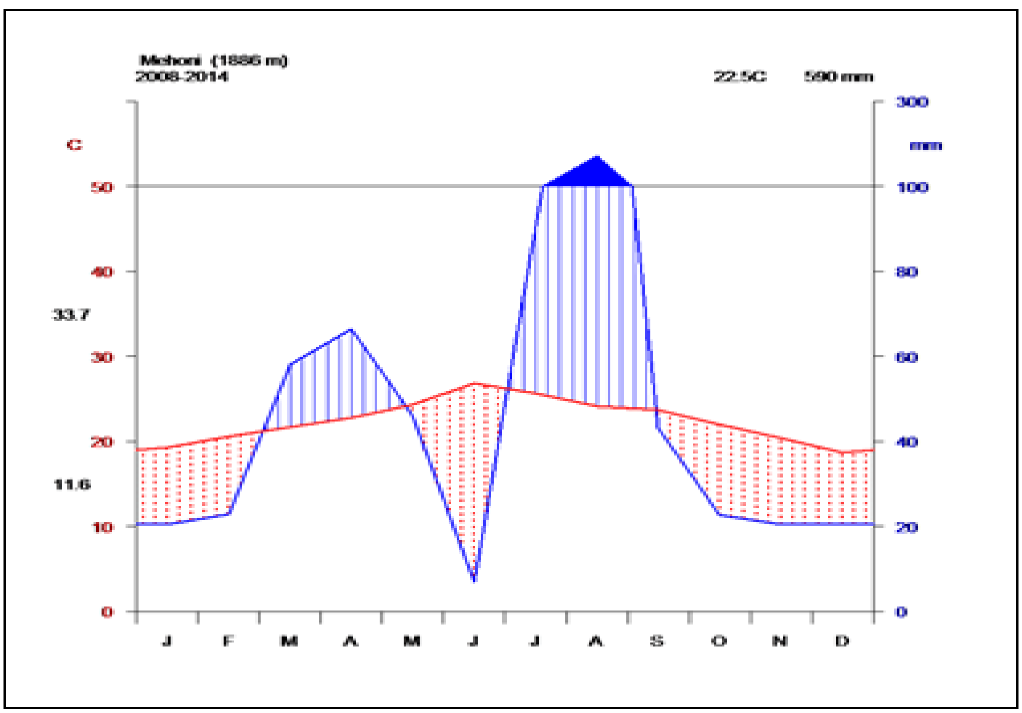


Figure 2: Climate diagram of the study area (source: EMSA, 2014)

3.3. Population and Economic Activities

Raya Azebo woreda has a total population of 135,870; of whom 67,687 are men and 68,183 are women; 16,056 (or 11.82%) are urban inhabitants (CSA, 2007). With an area of 2,132.83 square kilometers, this woreda has a population density of 63.70 per square kilometer, which is greater than the zone average of 53.91 persons per square kilometer. The four largest ethnic groups reported in Raya Azebo are the Tigrayan (87.21%), the Amhara (9.77%), the Afar (1.55%), and the Oromo (1.4%); all other ethnic groups make up 0.07% of the population. 8.44% of the population is considered literate, which is less than the zone average of 15.71%; 0.31% of the inhabitants aged 15-18 were in senior secondary school, 0.9% of the children aged 13-14 were in junior secondary school and 14.64% of children aged 7-12 were in primary school (CSA, 2007). . The economy of the woreda is mainly based on agriculture (crop production and livestock rearing). The farming system is mixed farming with special emphasis on production of crop such as *sorghum, teff, barley, maize* and *wheat*. However, agriculture is characterized by subsistence farming where farmers employ traditional technologies of farming over centuries (REST, 1996).

3.4. Geology and Soil

Geologically, a large point of the landscape in the area is characterized by the presence of poorly compacted sedimentary basic fill. The rock formation is mainly composed of Tertiary Volcanic Rocks. The soil of the lowland area is mostly loamy and silt loam to clay loam (Water Works Design and Supervision Enterprise, 2008), whereas the soils in the uplands are mainly dominated by sand and silt clay and characterized by the presence of crystalline rocks (Igneous and metamorphic), which are covered by alluvial and colluvial deposits, residual soils and flood plain deposits (REST, 1996). Water erosion and sedimentaion is a serious problem due to flooding on the mountain foot slopes where gulleys are already formed. This calls for the construction of physical conservation measures such as terraces and check-dams which are crucial to reduce soil erosion and landscape resilience (Wolde Mekuria *et al.,* 2007).

3.5. Vegetation

The main causes of vegetation changes are natural and socioeconomic in nature, including drought, unwise use of the woody vegetation and over-grazing. This woreda is covered with various vegetation types including degraded bushland, shrubland, cactus land, scrubland and woodland. According to Friis *et al.* (2010), the vegetation cover of the study area falls under the *Acacia-Comiphora woodland and bushland* vegetation type. The trees and shrubs include species of *Acacia etbaica, A. tortilis*, *Balanites aegyptiaca* and *Cordia monoica*. The ground cover includes species of *Barleria* and succulents with a number of *Aloe* species.

3.6. Livestock Resources

According to the Raya Azebo Woreda Agricultural and Rural Development Office (2007), the total number of livestock in the woreda is estimated to be about 207,301 out of which the largest proportion (69.2%) constitutes cattle and the smallest (0.3%) mule and horse (Table 1). The major sources of livestock feed in the woreda are crop residue and natural pasture.

Table 1. Livestock resources in the woreda

Livestock type	Number	Percent
Cattle	143,510	69.2
Goat and sheep	36,257	17.5
Donkey	15,088	7.3
Mule and horse	646	0.3
Camel	11,800	5.7

4. MATERIALS AND METHODS

4.1. Reconnaissance Survey and Site Selection

Reconnaissance field survey was carried out in September to October 2012 in order to identify the general ecological conditions of the study area and gather information on the natural vegetation types. Three sites were selected to represent each of the three geographic areas and the species composition of the sites. The first site, *Kara-Adishowu:* is located in Kara village which lies between 12°35'0" - 12°45'0" N latitude and 39°30'0" - 39°60'0" E longitude. It is about 15 km south of Mehoni, on the road to Addis Ababa with an altitude ranging from 1720 to 1805 and overing an area of 123 ha. The vegetation of this area is dominated by *Acacia tortilis* and other species including *Acacia asak* and *Cadia purpurea*. The second site, *Hawelti:* is situated near the *Rakata* village which lies between 12°40'0" - 12°55'0" N latitude and 39°40'0" – 39°50'0" E longitude. It is about 13 km north of Mehoni town on the road to Mekelle with an altitude ranging from 1730 to 1780 m and covering 89.5 ha. The vegetation of the area is dominated by woody species including *Acacia etbaica,* and *Cadia purpurea* and the third site, *Hade-alga:* is situated in *Atsmi-harmaz* village which lies between 12°35'0" - 12°45'0" N latitude and 39°50'0" – 40°0'0" E longitude. It is about 20 km away from Mehoni to the east, along the road to Chercher town. The altitude ranges from 1530 to 1747 m, covering an area of 115.75 ha. The common woody species in this area are *Acacia hockii* and *Acacia oerfota*. Each site has been closed from human and domestic animal interfrences since 2007. In general, the study area lies in an elevational range between 1530 and 1805 m above sea level.

After the reconnaissance survey and selection of the study sites, data collection was largely undertaken from April to May, 2013; September to November, 2013; April to May, 2014 and September to November, 2014. These periods were the best time for vegetation study because after the rainy seasons most of the shortlived annual species or herbs flower and can be clearely observed in these seasons.

4.2. Sampling Designs

Vegetation inventory has been defined by Husch *et al.* (2003) as the procedure for obtaining information on the quantity and quality of the vegetation resources. Akindele (1990) also gave some reasons for which a complete enumeration of the entire population present in a given area is almost an impossible and unachievable goal in practical applications due to the constraints of time, money, labour and access to suitable sites. Hence, a very important technique in vegetation inventory is sampling of a part of the vegetation, the result of which is to get a reliable estimate of the needed parameters for the whole vegetation. Thus, sampling is an accepted short cut since the population size to be measured is comparatively small and it becomes possible to make the measurements easier, quicker and cheaper with accuracy. In addition, this point has been supported by Magurran (2004), the best way to get information about a particular ecosystem would be to count every individual of every species, however, complete enumeration of species richness is difficult and may not be successfully carried out. It is necessary to estimate species richness by taking enough representative samples is a fundamental activity in studies of biodiversity.

To achieve the proposed objectives in this study, preferential and systematic sampling methods were used in order to locate the sample plots. Systematic sampling is a convenient and useful technique for developing samples. In addiion, there are circumstances in which preferential sampling is still the preferred method. Many authors (e.g., Muller-Dombis and Ellenberg, 1974; Greig-smith, 1983) have suggested that preferential sampling method is the most useful sampling design when the vegetation of the area being studied has a relatively higher density in some remnant patches than in others, whereas systematic sampling is used when the area being studied has varied or heterogeneous vegetation. Therefore, it appears that the choice is not necessarily between entirely systematic and entirely preferential sampling, rather using a combination of both sampling methods is advantageous.

In the Braun-Blanquet approach, the sample plots were selected subjectively in the field to find the most typical examples. This has been critizised as being too subjective. Most of the historical phytosociological data on vegetation composition have been sampled preferentially and thus belong to those ecological data that do not fulfill the statistical assumption of independence of observations necessary for valid statistical testing and inference (Lájer 2007).

In preferential sampling methods, some one can place his sample plots where he prefers or assums a particular patch of remnant vegetation sites. The advantage is that it is quick and easy, important considerations in field work. The disadvantage is that it is unfair to draw inferences to the parts of the vegetation not next to turnouts (Merckx *et al.,* 2011; Michalcová *et al.,* 2011). Rolecek *et al.* (2007) argue that in a systematic sampling design, a sampling interval is better to select the individuals that will comprise the sample. That's why systematic sampling is the preferred sampling technique because these interval sampling processes end up with less time-consuming and less expensive, whereas preferential sampling yields data sets that cover a broader range of vegetation variability to ensure fair representation of species. As a result, systematic sampling may fail to allow rare types to be included.

According to Cerdà, 1997, many dryland areas present a patchy distribution of vegetation. This vegetation patchiness can make available a measure of the landscape capacity to conserve water and nutrients. Preferential sampling methods have traditionally based on purposive sampling in which the researcher chooses sample locations based on knowledge of the study area. In this sampling method many pocket areas of field included deliberately that are known to be considerably different from the rest of the field (Francis and Schepers, 1997). Because of the vegetation patchiness, therefore, the combinations of both sampling methods were considered the most appropriate for this study area.

In each of the study sites, sample plots measuring 20 m x 20 m were designated as the main plots used for sampling of tree and shrub species. Each main plot was further divided into smaller sub-plots of sizes 5 m x 5 m for regeneration counts (seedlings and saplings), 2 m x 2 m for measuring cover abundance of herbaceous layers (grasses and forbs) and 15 cm x 15 cm for measuring soil samples (Table 2). These measurements were taken to estimate the vegetation status of the species (Abayneh Derero *et al.,* 2003*;* Taye Bekele *et al.,* 2003). The plots were marked using plastic ribbon and four wooden pegs. Data were collected from 90 sampling plots covering an area of 3.6 ha.

Table 2: Sample plot sizes

Measurements for square plots	Study plot area	Where to use them
15 cm × 15 cm	225 cm^2	sampling soils physico-chemical analysis
2 m x 2 m	4 m^2	sampling herbaceous vegetation
5 m x 5 m	25 m^2	sampling of seedlings and saplings
20 m x 20 m	400 m^2	sampling of shrubs and trees

4.3. Field Data Collection

4.3.1. Vegetation Sampling

For this study, vegetation data was collected from 90 sampling plots measuring 20 m x 20 m. Therefore, each field site comprised of 30 plots (20 plots from each closed site and 10 plots from their respective adjacent grazed lands). More plots were sampled in the closed areas since the adjacent grazed areas had less vegetation and these spatially less heterogeneous or less variability compared to the closed areas. In each site, the number of plant species in each plot as well as the number of individuals of each species was recorded. In addition, in each sampling plot, heights and DBH of each woody species were recorded using a measuring tape following Abayneh Derero *et al.* (2003) and Taye Bekele *et al.* (2003). Seedling and sapling diameters were meaured at 30 cm height (Muller-Dombis and Ellenberg, 1974; Corral-Rivas *et al.,* 2007). Stems with height $\leq$ 1 m and diameter of $\leq$ 3 cm size considered as seedlings; stems with height > 1 m and diameter of $\leq$ 3 cm as saplings and stems with height > 2 m and diameter of > 3 cm as trees or shrubs. Individuals with multiple stems (shrubs) and branches arising below breast height were treated as individuals of the same tree but the diameter was measured separately for the branches and averaged. The heights of species were measured using a long stick and the very tall species were estimated visually. The causes of disturbance in the woodland were recorded in each plot through observation. For the measurement of diameter, the circumferences of the woody species were measured at breast height using a measuring tape. The circumference measurements were then converted into diameter values by dividing the circumference values by pi (π = 3.142). Therefore, diameter values were calculated from circumference measurements using the following formula: $C = \pi d$, Where, C = *circumference,* π = *3.14* and d = *diameter. Therefore,* $d = C/\pi$.

To capture the floristic composition and species richness, plant specimens were collected, pressed, dried and identified at the National Herbarium (ETH), at Addis Ababa University, using published volumes of the Flora of Ethiopia and Eritrea in addition to comparing with already identified (authenticated) plant specimens. Nomenclature follows that of the published volumes of the Flora of Ethiopia and Eritrea. An attempt was made to record the vernacular names of species encountered in the study during collection whenever possible.

Natural regeneration of species was determined based on the population of seedlings and saplings following Khan *et al.* (1987), Uma Shankar (2001), Bhuiyan *et al.* (2003), Khumbongmayum *et al.* (2006). A species was considered to have a good regeneration, when seedling density > sapling density > adult density; fair regeneration, when seedling density > sapling density ≤ adult density; poor regeneration, when the species survive in only the sapling life forms (i.e., there are no seedlings, number of saplings may be >, < or = adults) and no regeneration, for species with no sapling or seedling stages but individuals of species are present only in the adult tree stages.

Vegetation classification (community) analysis is a powerful tool employed for several purposes including organizing and interpreting information and contextualizing it to the situation that it exists. To analyze the data, hierarchical agglomerative clustering was used. This method of vegetation clustering classifies both samples and species simultaneously using the cover abundance values as an input source. Clusters were identified from the output of the hierarchical clustering which represents the plant communities in the study area. The plant communities were named using the two dominant species based on the highest mean cover abundance value within a cluster. To determine the vegetation community of the study area, percentage cover abundance values of trees, shrubs and herbs were estimated in the field by visual observation and latter converted to cover abundance of a floristic approach of Braun-Blanquet (1932) scales transformed into the (1-9) ordinal scales as modified by Van der Maarel (1979) as follows: (1) Rare-generally only one individual, (2) Sporadic (few) –less than 5% cover of the total area, (3) Abundant with < 5% cover of the total area, (4) Very abundant and < 5% cover of the total area, (5) 5-12% cover of the total area, (6) 12.5-25% cover of the total area, (7) 25-50% cover of the total area, (8) 50-75% cover of the total area and (9) 75-100% cover of the total area.

4.3.2. Soil Sampling

The soil samples for the physico-chemical analysis were collected from each plot used for vegetation sampling and analyzed at the ecology and ecophysiology soil analysis laboratory. Soil samples were collected from surface layer down to a depth of 15 cm with the help of soil auger in each plot following Mahler and Tindall (1914), Wilding (1985), FAO (2007) and Cools and De Vos (2010). A depth of 15 cm was chosen because topsoil has greater temperature fluctuations than the sub soil (Gent *et al.,* 1983). The reasoning for taking the soil samples were used to examine if there has any variation of soil within and among the closed and the adjacent grazed areas.

These collected soil samples from each plot were carefully stored in clean plastic bags separately and transported to the lab for analysis. The soil sample information sheet for each sample container was labeled in order to identify the sample with the information including: name of the study site, plot number, sample depth and date of sampling. Accordingly, a total of 90 soil samples were collected from the 90 plots of the study area. In each of the plots, five sub-plots measuring 15 cm × 15 cm were laid down, one at the center and the other four at each corner. The soil samples of the five sub-plots were mixed very well to form a composite sample in order to reduce variability within the plots and divided it into five equal parts, out of which one was randomly taken as the working sample for the laboratory analysis.

The collection of soil samples was excluded from areas with dead plants, furrow, manure piles, wet spots and areas near trees in order to minimize unusual differences between the plots. The soil samples or aggregates were crushed and ground to particles of uniform size by using hardened steel mortars (Van Reeuwijk, 1992; Tan, 1995). After grinding, the soil samples were sieved through a 2 mm diameter mesh size to remove root particles and other organic debris before chemical analyses and stored in clean plastic containers. The purpose of grinding was to reduce heterogeneity and to provide maximum surface area for physical and chemical reactions. The soil samples collected from each plot were brought to Addis Ababa University Ecology and Ecophysiology Laboratory for analysis to determine edaphic parameters such as the soil pH, soil texture proportions (i.e., sand, silt, and clay), available phosphorus, soil conductivity, total nitrogen, organic matter content, exchangeable bases and cation exchange capacity.

4.4. Soil Laboratory Analysis

Of these edaphic parameters such as soil pH, soil texture and soil conductivity were analysed at the ecology and ecophysiolgy laboratory at Addis Ababa University. However, due to shortage of some laboratory equipment and chemicals, the estimation of organic carbon (Walkely-Black wet oxidation), total nitrogen (Kjeldahl method), available phosphorous (Olsen method), cation exchange capacity (extraction with ammonium acetate at pH 7) and exchangeable bases (extraction with ammonium acetate) were carried out at the Ethiopian Agricultural Research Organization (EARO).

Soil texture analysis was determined by the standard Bouyoucos hydrometer method of mechanical analysis (Bouyoucos, 1962) and USDA system textural triangle was used for the classification of soil textural classes (Soil Survey Staff, 2009). The soil particles (sand, silt and clay) got cemented together into aggregates or granules by organic matter, clay and salts ($CaCO_3$) and were dispersed or break down by sodium hexametaphosphate (NaPO3)6 for soil texture assessment and shaken on the automatic stirrer for 3 hrs. After the soil size completely dispersed, the suspension was transferred to a measuring cylinder of 1000 ml, the different size fractions were sorted out by sedimentation using the Bouyoucos hydrometer. The first hydrometer and temperature readings were taken after 40 seconds. The second hydrometer and temperature readings were taken two hours after the first reading. The percentages of the soil particles were determined using the standard formulae (Landon, 1984).

Soil pH was measured potentiometrically on the upper part of the supernatant suspension of a 1:2.5 soil to water ratio mixture after an hour settlement by using a glassrod electrode pH meter (Van Reeuwijk, 1992), *EUTECH* instruments, *PH510, PHmvoC* meter. Electrical conductivity (EC) measures the total quantity of soluble salts in soil solution. The EC of soils was measured from a soil water ratio of 1:5 and shaken on the automatic stirrer for 30 minutes as described by Sahlemedhin Sertsu and Taye Bekele (2000). EC is determined by using conductivity meter, *SX713* model, cond /TDS/sal/Res meter.

The total organic carbon content was determined by the Walkley-Black wet digestion method (Walkley and Black, 1934). After that the percentage of soil organic matter content in the soil samples was estimated by multiplying the percent soil organic carbon values obtained with a constant 1.724 (%OM = %OC x 1.724, the factor 1.724 = 100/58) following the assumptions that, on average, organic matter contains about 58 percent organic carbon, which was based on the oxidation with chromic acid and the use of an indicator solution (Black, 1965). The Walkley-Black method is dependent upon the oxidation of the active organic content of the soil sample by chromic acid in the presence of excess concentrated sulphuric acid. The remaining chromic acid is then back titrated with a ferrous sulfate (indicator) solution.

Determination of total nitrogen available in the soil samples was analyzed using the Kjeldahl technique which consists of three main procedural steps: *digestion, distillation* and *titration* as described by Black (1965). 1) *The digestion process:* complete breakdown of the soil organic matter by heating it in the presence of concentrated sulphuric acid (H2SO4) solution to produce ammonium sulphate (NH4)2 SO4 solution. 2*) The distillation process:* by adding an excess of concentrated sodium hydroxide (NaOH) solution into the ammonium sulphate (NH4)2 SO4 solution. As a result, NH3 gas is released into a receiving solution of boric acid (H3BO4) to form ammonium borate. 3) *The titration process:* of the ammonium borate with standard H2SO4 gives a quantitative determination of the amount of nitrogen in the soil sample (the concentration of H+ required to reach the end point is equivalent to the concentration of N that was in the original soil).

Available phosphorous in soil extracts can be determined using two methods. The Bray's method is used for acid soils and Olsen's method for neutral, alkaline and high base saturation soils. The Olsen's method is suitable for soils having pH more than 6.5 (Landon, 1991). Available soil phosphorus was analysed according to Olsen *et al.* (1954) extraction method. Because of the alkaline nature of this study area ranged from neutral to strongly alkaline, Olsen's method was considered the most appropriate phosphorous test for this study.

Cation exchange capacity and exchangeable bases were determined after extracting the soil samples by ammonium acetate (NH4OAc) at pH 7.0. Exchangeable Ca and Mg in the ammonium acetate leachate were analysed using Atomic Absorption Spectrophotometry (AAS) after the removal of ammonium acetate and OM whereas exchangeable K and Na were analysed by using Flame Photometer Apparatus (Chapman, 1965). In addition, soil cation exchange capacity was determined by the summation method of the exchangeable bases and exchange acidity estimated titrimetrically by distillation of ammonium that was displaced by Na from NaCl solution (Chapman, 1965).

4.5. Data Analysis

4.5.1. Statistical Analyses

Most statistical analyses were performed using appropriate statistical packages in R. R-system can do a multitude of statistical analysis including analysis of variance (ANOVA) and other quantitative applications. Analysis of variance (ANOVA) was used to detect variations in the environmental variables and compare the means of more than two populations based on the same data type. For instance, compare the density of seedlings from more than two different sites. The data sets that were being compared must be presented in the same unit. Analysis of variance also indicates the significant differences among the treatments but impossible to know which of the treatments are responsible for the significant differences. Therefore, ANOVA can follow up with multiple comparison procedures to determine which means are different namely, Tukey Honest Significant Difference (Tukey HSD) pairwise comparison test was used to differentiate the factors that are responsible for the significant differences among the treatments.

The correlations of the various environmental variables with each other were evaluated by calculating Pearson's product moment correlation coefficient in a pair-wise matrix. Redundancy analysis (RDA) defined as a method of direct ordination which optimises the relationships between environmental factors and species data was performed (ter Braak, 1988). The analyses were done using R version 2.14.0 program software, vegan and labdsv packages (The R core Team, 2011).

4.5.2. Plant Diversity Analysis

The basic idea of plant diversity analysis is to obtain a quantitative estimate of plant variability that can be used to compare discrete components in an area. Among the many species diversity indices, the widely used indix include Shannon-Wiener index for species diversity, richness and evenness. Sorensen's coefficient index was used to measure the similarity in species composition among communities and sites (Mueller-Dombois and Ellenberg, 1974).

A. Shannon-Wiener diversity index: Shannon-Wiener index is the most commonly used index of diversity for plant species in a community (Grieg-Smith, 1983; Barnes *et al.,* 1998). Diversity combines two quantifiable measures; the number of species within the community (species richness) and the relative abundances of individuals within each of these species in a community (species evennes). If there is only one species in a community the diversity (H') is equal to zero and when H' increases, communities increase in diversity (Krebs 1999). In addition, H' is maximum (H_{max}) whenever all species are represented by equal number of individuals in a community (Pielou, 1975). The Shannon-Wiener Diversity Index, H', can be calculated using the following equation:

$$H' = -\sum_{i=1}^{S} pi \ln pi$$

Where,

H' = is the Shannon-Wiener Diversity Index;

S = is the total number of species;

*p*i = *ni/N (*sample/sum)*, i.e. ni is the number of individuals of species i;* and *N is the total number of individuals of all species;*

ln = log base;

∑ *= sum from species 1 to species S.*

The Shannon evenness measure: Based on Shannon's Index, evenness (J') is a measure of the relative abundance of the different species making up the richness of an area. Evenness compares the similarity of the population size of each of the species present. All measures of evenness range from 0 to 1, with 1 being complete evenness. The maximum diversity (H_{max}) that possibly occurs in a situation where all species have equal abundances, if H' = H_{max} = lnS. The ratio of observed diversity (H') to maximum diversity (H_{max}) can therefore be used to measure evenness (Pielou, 1975), as follows:

$$J' = H'/H_{max} = H'/\ln S$$

Where,

J' = evenness;

H_{max}= Maximum diversity possible (*lnS)*;

H' = is the Shannon-Wiener diversity Index;

S = is the total number of species in the sample.

B. Sorensen's Coefficient of Similarity: The Sorensen's Coefficient of Similarity was used to calculate the similarity within communities and sites (Sorensen, 1948). It gives weight to the species that are common to both plots rather than to those that only occur in only one plot (Kent and Coker, 1992). It gives a value between 0 and 1, the closer the value is to 1, the more the communities have more species in common. A Complete community overlap is equal to 1 whereas complete community dissimilarity is equal to 0. The Sorensen's Coefficient of similarity (Ss) can be defined using the following formula:

$$Ss = 2a/ (2a+b+c)$$

Where,

Ss = Sorensen's coefficient of similarity;

a = number of species common to both samples;

b = number of species unique to sample 1;

c = Number of species unique to sample 2.

Sorenson's coefficient gives a value between 0 and 1, the closer the value is to 1, the more the habitats have in common. A complete habitat overlap is equal to 1 while complete habitat dissimilarity is equal to 0. Sorenson's index of similarity was used to calculate the floristic similarity between different sites (habitats) is to use shared species to group related areas (Sorenson, 1948; McCune and Grace, 2002). Mostly the coefficient is multiplied by 100 to give percentage similarity index. Dissimilarity (DS) is then computed as $DS = b+c/ 2a+b+c$ or $1-Ss$ (Kent and Coker, 1992).

4.5.3. Analysis of Vegetation Structural Data

The DBH, density, height, basal area, frequency and IVI were used for the description of the woody species structures. These parameters were calculated to determine the vegetation structure of the woodland using the following formulae:

Species frequency: frequency indicates how the various plant species are dispersed in sample plots. However; dispersion patterns would not be uniform for all species due to competition, inefficient mode of seed dispersal, natural and anthropogenic disturbances (Armesto *et al.,* 1985; Elzinga *et al.,* 1998).

Frequency = number of plots in which spp occurs/total number of plots sampled

Species density = Total number of stems of a given species/Sample size in hectare.

Basal area (BA) = $(d/_2)^2$ x π, where, π = 3.14, d = diameter.

Importance Value Index (IVI): This index represents the contribution that a species makes to its community in respect of the number of plants within the plots (abundance or density), its influence on the other species through its shading or competition (dominance) and its contribution to the community through its distribution (frequency) (Kent and Cooker, 1992). The Importance Value Index is the cumulative value of the three parameters (relative frequency + relative density + relative dominance), to prevent biased approach (Lamprecht, 1989) (Appendix 9). According to Kent and Coker, (1992), IVI is the most realistic aspect in vegetation study and useful to compare the ecological significance of species.

Where,

Relative frequency (RF) = (Frequency of a single species x 100)/Total frequency of all species.

Relative density (RD) = (Number of individuals of a single species x 100)/ Total number of individuals of all species.

Relative dominance (RDO) = (Basal area of a single species x 100)/Total basal area of all species.

5. RESULTS

5.1. Floristic Composition

A total of 133 plant species belonging to 45 families were recorded in the 90 plots (Appendix 1). Out of the total species recorded in the study area, 24 species were recorded in *Kara,* 36 species in *Rakata* and 13 species were in *Atsmi-harmaz*. In addition, 28 species were common to the three sites. Ten species were found common in both *Kara* and *Rakata*. Eight species were found common in both *Kara* and *Atsmi-harmaz* whereas only 14 species were common between *Rakata* and *Atsmi-harmaz* (Appendix 2). In terms of the actual number of the species recorded, *Rakata* was the most species rich site followed by *Kara* and *Atsmi-harmaz*.

When the overall data set is considered together (Table 3), the most species-rich family was *Fabaceae* represented by 18 species, which makes up 13.53% of the total number of species recorded. This was followed by the family *Poaceae* (14 species), *Asteraceae* (11 species), *Euphorbiaceae (*8 species), *Boraginaceae (7* species) and *Cappariadaceae* (6 species).

Table 3: Familie recorded and number of species represented in them

Family	Number of species	Percent	Family	Number of species	Percent
Acanthaceae	4	3.01	*Malvaceae*	2	1.50
Agavaceae	1	0.75	*Moraceae*	1	0.75
Aloaceae	1	0.75	*Nyctaginaceae*	1	0.75
Amaranthaceae	5	3.76	*Olacaceae*	1	0.75
Anacardiaceae	1	0.75	*Oleaceae*	2	1.50
Apocynaceae	3	2.26	*Oxalidaceae*	1	0.75
Asclepiadaceae	3	2.26	*Papaveraceae*	1	0.75
Asteraceae	11	8.27	*Poaceae*	14	10.53
Balanitaceae	1	0.75	*Polygonaceae*	2	1.50
Boraginaceae	7	5.26	*Portulacaceae*	2	1.50
Brassicaceae	1	0.75	*Ranunculaceae*	1	0.75
Burseraceae	1	0.75	*Rhamnaceae*	2	1.50
Cactaceae	1	0.75	*Rutaceae*	1	0.75
Capparidaceae	6	4.51	*Santalaceae*	1	0.75
Celastraceae	2	1.50	*Sapindaceae*	1	0.75
Chenopodiaceae	2	1.50	*Simaroubaceae*	1	0.75
Commelinaceae	1	0.75	Solanaceae	5	3.76
Crassulaceae	1	0.75	*Tiliaceae*	3	2.26
Cucurbitaceae	2	1.50	*Verbenaceae*	2	1.50
Cyperaceae	3	2.26	*Vitaceae*	1	0.75
Ebenaceae	1	0.75	*Zygophyllaceae*	1	0.75
Euphorbiaceae	8	6.02			
Fabaceae	18	13.53			
Lamiaceae	3	2.26			

The total number of families observed was 45. Of these, 22 had only one species represented in them while on the other extreme one had 18 species (Table 3). It has been observed that nearly half (48.89%) of the families recorded had only 1 species in them. Rarity of species can be caused by factors such as anthropogenic influences and natural factors rather than a single reason (Schwartz, 1993).

Of the 133 species recorded, 19 (14.29%) were trees, 50 (37.59%) were shrubs, 59 (44.36%) were herbs and 5 (3.76%) were climbers. The common tree species were *Balanites aegyptiaca, Euphorbia candelabrum, Acacia asak, Acacia etbaica,* and *Acacia tortilis* whereas the common shrub species were *Justicia shimperiana, Carissa spinarum, Maytenus senegalensis, Acacia oerfota, Cadia purpurea* and *Ziziphus spina-christi*. The common herb species were *Barleria eranthemoides, Tribulus torrestris, Parthenium hysterophorus, Chenopodium ambrosioides* and *Argemone mexicana*. While the common climber species were *Cissus quadrangularis, Senecio hadiensis* and *Sarcostemma viminale*. The most abundant species recorded in the area were *Cadia purpurea* (245/ha), *Acacia hockii* (197.22/ha), *Acacia etbaica* (114.22/ha), *Acacia tortilis* (97.78/ha) and *Acacia asak* (94.17/ha).

5.2. Natural Regeneration Status

The overall natural regeneration status of the plant species were estimated from the relative amount of seedlings, saplings and adults in the total population of the different species. Thirty six woody species were selected to represent the larger population for the analysis of natural regeneration status depends on fuelwood, construction purposes, economic contributions and relatively good frequency. These woody species as a reference to natural regeneration and their regeneration status is shown in Appendix 3 and 4 respectively. The natural regeneration status was analyzed based on the features of good regeneration, fair regeneration, poor regeneration and no regeneration (Table 4).

Table 4: Natural regeneration status when the overall data set is considered

Regeneration status	Number of species	Percent
Good regeneration	2	5.56
Fair regeneration	20	55.56
Poor regeneration	8	22.22
No regeneration	6	16.67
Total	36	100

The overall natural regeneration status in the study area 55.56% of woody species displayed fair regeneration, 22.22% poor regeneration, 16.67% no regeneration, while 5.56% showed good regeneration (Table 4). The 36 representative woody species recorded from the three sites were distributed as follows: four species were recorded only in *Kara,* 6 only in *Rakata* and 2 species only in *Atsmi-harmaz* (Appendix 4). Whereas 12 species were common to all the three sites, 3 common in both *Kara* and *Rakata,* 4 in both *Kara* and *Atsmi-harmaz* while 5 were common both in *Rakata* and *Atsmi-harmaz*. The number of species recorded in *Rakata* was higher than that recorded in *Kara* and *Atsmi-harmaz.*

Table 5: The status of regeneration of woody species in the three closed sites

Study sites	Good regen	Fair regen	Poor regen	No regen	Total
Kara	1	17	3	1	22
Percent	1.47	25	4.41	1.47	32.35
Rakata	2	14	3	6	25
Percent	2.94	20.59	4.41	8.82	36.76
Atsmi-harmaz	0	15	5	1	21
Percent	0	22.06	7.35	1.47	30.88
Total species	3	46	11	8	68
Total percent	4.41	67.65	16.18	11.76	100

The regeneration status of woody species in the closed areas is shown in Table 5. In *Kara*, only 1 species (1.47%) showed good regeneration, 17 species (25%) fair regeneration, 3 species (4.41%) poor regeneration and 1 species (1.47%) was no regenerating at all. In *Rakata,* 2 species (2.94%) showed good regeneration, 14 species (20.59%) fair regeneration, 3 species (4.41%) poor regeneration and 6 species (8.82%) showed no regeneration. In *Atsmi-harmaz,* no species were showed good regeneration, but 15 species (22.06%) were showed fair regeneration, 5 species (7.35%) showed poor regeneration and 1 species (1.47%) showed no regeneration.

In general, the regeneration status of the closed area maximum (67.65%) species showed fair regeneration, 16.18% poor regeneration, 11.76% no regeneration and 4.41% good regeneration. In *Kara* the one species which had good regeneration was *Grewia tembensis* even though it was highly defoliated. In *Rakata* there were two species *Grewia tembensis* and *Acacia asak* which showed good regeneration and in *Atsmi-harmaz,* there was none at all. The species that displayed poor regeneration in *Kara* were *Boscia salicifolia, Euclea racemosa* subsp. *schimperi* and *Osyris quadripartite*. In *Rakata*, there were *Cordia sinensis* and *Olea europaea* subsp. *cuspidata* and in *Atsmi-harmaz, Cordia* *monoica, Euclea racemosa* subsp. *schimperi, Maerua angolensis* and *Olea europaea* subsp. *cuspidata*. Some of the woody species did not showing regeneration at all. These include *Acacia seyal* in *Kara; Acokanthera schimperi, Commiphora schimperi, Cordia sinensis, Teclea simplicifolia* and *Ximenia americana* in *Rakata* and *Commiphora schimperi* in *Atsmi-harmaz*.

Table 6: The status of regeneration of woody species in the three grazed sites

Study sites	Good regen.	Fair regen.	Poor regen.	No regen.	Total
Kara	0	8	6	1	15
percent	0	18.61	13.95	2.33	34.89
Rakata	1	5	5	5	16
percent	2.33	11.63	11.63	11.63	37.22
Atsmi-harmaz	0	7	5	0	12
percent	0	16.28	11.63	0	27.91
Total species	1	20	16	6	43
Total *percent*	2.33	46.51	37.21	13.95	100

The regeneration status of woody species in the grazed areas is shown in Table 6. In *Kara* grazed land, no species showed good regeneration, 8 species (18.61%) showed fair regeneration, 6 species (13.95%) poor regeneration and 1 species (2.33%) showed no regeneration. In *Rakata,* 1 species (2.33%) showed good regeneration, 5 species (11.63%) showed fair regeneration, 5 species (11.63%) showed poor regeneration and 5 species (11.63%) showed no regeneration. In *Atsmi-harmaz,* no species has shown good regeneration, 7 species (16.28%) fair regeneration, 5 species (11.63%) showed poor regeneration and none of the species showed no regeneration.

In general, the regeneration status of the grazed area was found to be 46.51% fair regeneration, 37.21% poor regeneration, 13.95% no regeneration and 2.33% good regeneration. *Acacia asak* showed good regeneration in *Rakata* but in *Kara* and in *Atsmi-harmaz,* no species displayed good regeneration. In *Kara Acacia etbaica, Acacia oerfota, Boscia salicifolia, Dichrostachys cinerea, Grewia mollis* and *Ziziphus mucronata* displayed poor regeneration while *Acokanthera schimperi, Cordia monoica, Dichrostachys cinerea, Ehretia cymosa* and *Olea europaea* subsp *cuspidata* in *Rakata. In Atsmi-harmaz, Balanites aegyptiaca, Cadaba farinosa, Cordia sinensis* and *Rhus natalensis* had poor regeneration. S0me of the woody species such as *Rhus natalensis* in *Kara; Commiphora schimperi, Cordia monoica, Euphorbia candelabrum* in *Rakata* and none of the species showed any regeneration in *Atsmi-harmaz* grazed area. In general, the regeneration of woody species in the study areas could be catagorized as fair.

5.2.1. The status of seedlings and saplings

When the number of seedlings and saplings were analysed separately, a total of 22 mature woody species belonging to 10 different families were recorded with seedling stages. However, 14 others belonging to 12 different families do not exhibit any plants in the seedling stage (Table 7). The total density of seedlings in the study area was 410 individuals/ha. The five woody species that had the highest number of seedlings were *Acacia hockii* (105/ha), *Cadia purpurea* (77.78/ha), *Acacia asak (48.06*/ha*), Grewia tembensis* (41.67/ha) and *Acacia etbaica* (37.78/ha) (Appendix 3).

Table 7: Number of families and species in which seedlings and saplings were recorded

Present/absent of seedlings	Number of families	Number of species	Percent
Present	10	22	61.11
Absent	12	14	38.89
Total		36	100
Present/absent of saplings	Number of families	Number of species	Percent
Present	13	30	83.33
Absent	6	6	16.67
Total		36	100

On the other hand, a total of 30 woody species belonging to 13 families were recorded in the plant saplings while in 6 species none were present (Table 7). The total sapling density of this woodland was about 212.78 individuals/ha. The five species that had the highest sapling density were *Cadia purpurea* (60.28/ha), *Acacia asak* (26.11/ha), *Acacia etbaica* (22.50/ha), *Acacia hockii* (21.11/ha) and *Grewia tembensis* (16.11/ha) (Appendix 3).

Table 8: Number of woody species with seedlings and saplings in the closed and grazed areas of the woodland

Closed area				Grazed area		
Sites	Seedlings (present/absent)	No of spp	%	Seedlings (present/absent)	No of spp	%
Kara	Present	19	27.54	Present	7	16.67
	Absent	4	5.80	Absent	7	16.67
Rakata	Present	16	23.19	Present	6	14.29
	Absent	9	13.04	Absent	10	23.81
Atsmi-harmaz	Present	15	21.74	Present	7	16.67
	Absent	6	8.70	Absent	5	11.91
Total		69			42	
Closed area				Grazed area		
Sites	Saplings (present/absent)	No of spp	%	Saplings (present/absent)	No of spp	%
Kara	Present	22	31.88	Present	13	30.95
	Absent	1	1.45	Absent	1	2.38
Rakata	Present	19	27.54	Present	11	26.19
	Absent	6	8.70	Absent	5	11.91
Atsmi-harmaz	Present	20	28.99	Present	12	28.57
	Absent	1	1.45	Absent	0	0
Total		69			42	

As shown in Table 8, when considering the seedling and sapling abundances in the closed areas of *Kara, Rakata* and *Atsmi-harmaz,* a total of 19 (27.54%), 16 (23.19%) and 15 (21.74%) woody species were represented by seedling stages and a total of 4 (5.80%), 9 (13.04%) and 6 (8.70%) species were absent as seedling stages respectively. In addition, a total of 22 (31.88%), 19 (27.54%) and 20 (28.99%) woody species were represented by their sapling stages and a total of 1 (1.45%), 6 (8.70%) and 1 (1.45%) mature woody species were absent as saplings. Moreover**,** the abundance of seedlings and saplings in the grazed areas of *Kara, Rakata* and *Atsmi-harmaz* showed that a total of 7 (16.67%), 6 (14.29%) and 7 (16.67%) woody species were present as seedlings and a total of 7 (16.67%), 10 (23.81%) and 5 (11.91%) woody species were absent as seedlings respectively. On the other hand, a total of 13 (30.95%), 11 (26.19%) and 12 (28.57%) woody species were represented by sapling stages and a total of 1 (2.38%), 5 (11.91%) and (0%) species were absent as saplings.

When the closed and grazed areas were compared, the closed areas had the highest number of seedlings and saplings. In *Kara* and *Rakata* the grazed areas had more seedlings than in *Atsmi-harmaz.* The grazed areas also had lower species lacking saplings than the closed area. The densities of the seedlings, saplings and adults in the closed and grazed areas are shown in Figure 3. Generally the seedling densities were higher than these of the sapling. In the closed area, the density of seedlings was 301 individuals/ha, saplings 136 individuals/ha and adults 294 individuals/ha. While in the grazed area, were 109 individuals/ha, 77 individuals/ha and 133 individuals/ha respectively. As a total of both closed and grazed areas, density of seedling was 410 individuals/ha, saplings 213 individuals/ha and adults 427 individuals/ha.

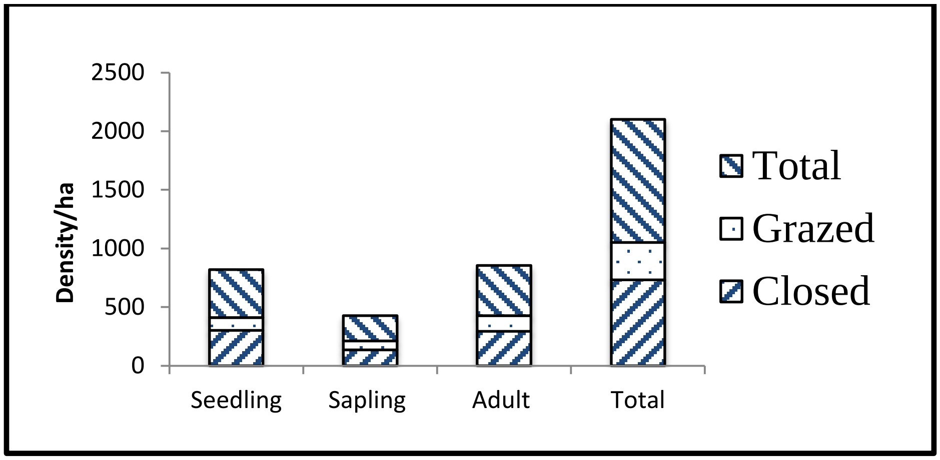


Figure 3: Seedling, sapling and adult density/ha in the closed and grazed areas

Species that had plants both in seedling and sapling stages were 22 (61.11%) species. These were *Acacia tortilis, Cadia purpurea, Grewia tembensis, Acacia hockii, Acacia etbaica, Dichrostachys cinerea* and *Grewia villosa* (**Figure 4**). These that only had plants in the sapling stage were 8 (22.22%) and included *Cordia sinensis*, *Acokanthera schimperi*. Six *species* (16.67%) had no plants in the seedling or sapling stages. These recorded *Acacia seyal, Teclea simplicifolia* and *Euphorbia candelabrum*. None of the species were represented only by plants in the seedling stage.

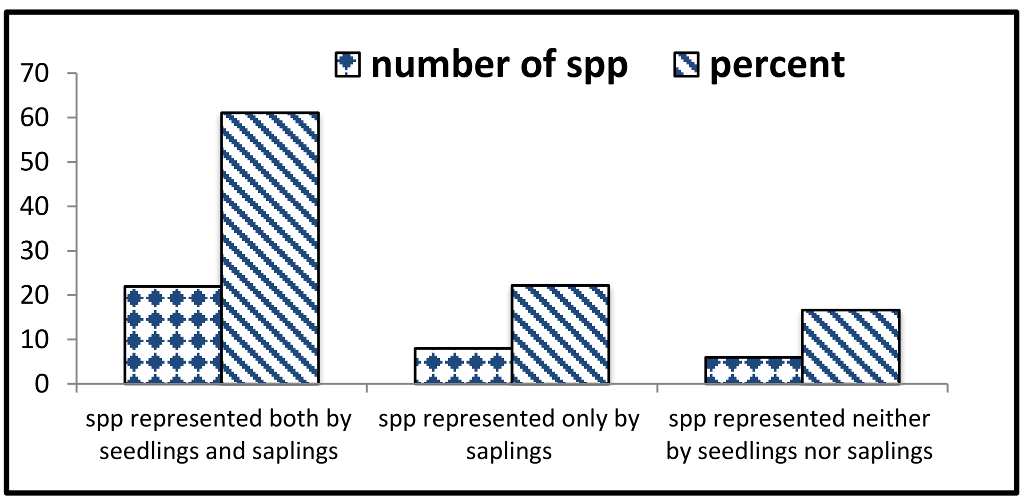


Figure 4: Seedling and sapling representative species and their percent.

Seedling, sapling and adult species rank abundance distributions have been plotted in terms of species against plots to compare the diversity of each of the closed and grazed sites (Figure 5). There was a difference in the distribution (evenness) of species between the closed and grazed areas. For instance, the rank abundance for grazed areas indicated that the distribution of the species approaches a little because of a steep slope indicates low evenness as the high ranking species have much higher abundances than the low ranking species. According to Wilson (1991) such steepness is a common pattern of species abundance occurred in species poor and relatively disturbed habitats. Similarly, the rank abundance for closed areas resemble a normal series pattern (Preston, 1948), clearly representing relatively even distribution and high species richness probably due to the gradual increase in the number of various species in the closed area. A shallow distribution (i.e., a horizontal graph) indicates high evenness as the abundances of different species are similar.

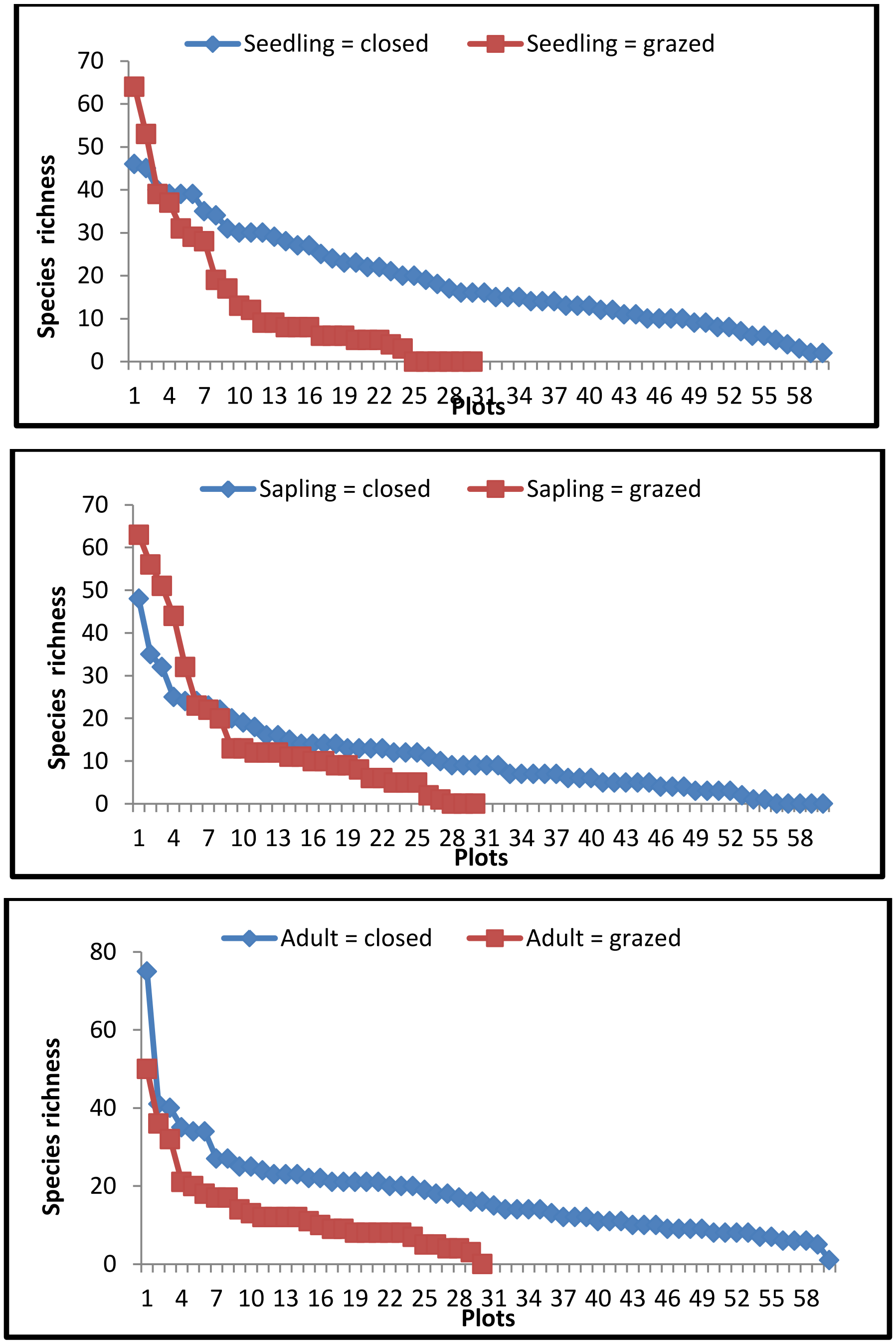


Figure 5: Rank abundance of woody species in the closed and grazed areas

5.3. Vegetation Structure of the Woodland

Vegetation structure of the woodland had the highest density in the lower DBH and lower height size classes, and decrease in density towards the higher DBH and higher height classes. The absence of tree species in the higher DBH classes indicated that the site represents young vegetation type may be due to deforestation of old trees in the past. According to Singh and Singh (1992), a greater percentage of individuals in lower size classes compared to higher size classes indicates frequent reproduction or resulting in fair survival of seedlings and saplings.

5.3.1. Diameter Class Distribution

The overall diameter class structure of the study area is given in **Figure 6**. Diameter size classes were determined as 3 cm increments in each DBH size classes. For instance, size class 1 = ≤ 3 cm, 2 = 3.1 - 6 cm, 3 = 6.1 - 9 cm, 4 = 9.1 - 12 cm, 5 = 12.1 - 15 cm, 6 = 15.1 cm and above. All stems ≥ class 6 were combined in a single size class.

The highest densities of the woody species were recorded in the lowest DBH size classes of 1 and 2, which together constitute 81.71% while the species in the rest size classes were combined constitute only 18.28%.

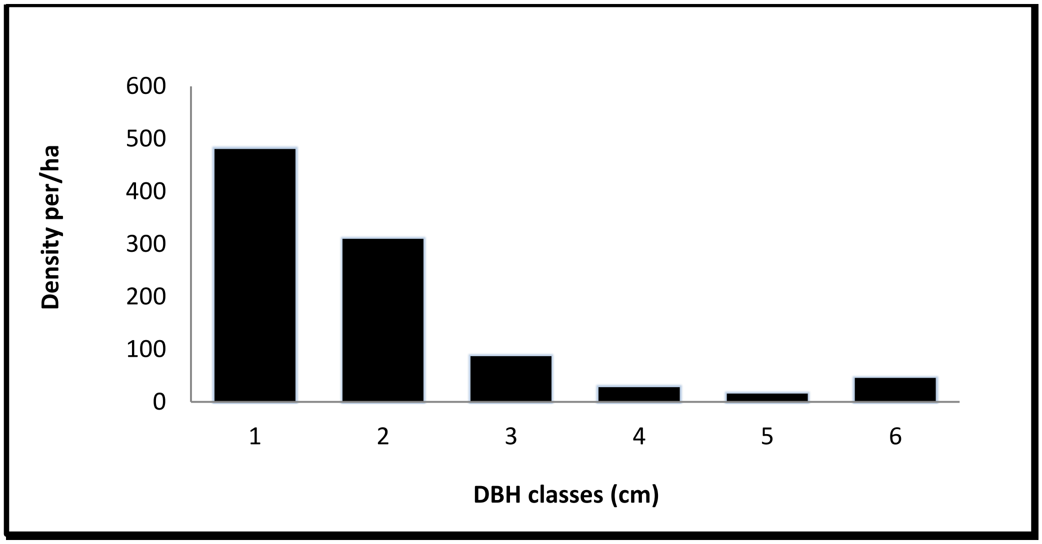


Figure 6: Diameter class distribution of the woody species.

The distribution of woody species interms of density in the various size classes consistently decreased with increase in DBH classes. This is evident in Figure 6 where the diameter class distribution of the woody species shown an almost inverted 'J' shape with the greatest numbers of individuals occupying the lower DBH classes, which is an indication of a fair regeneration in the woodland. Such a higher density of small-sized individuals can be contributed to the open canopy cover and lower densities of the larger individuals. However, the study revealed that the number of woody species decrease at higher diameter (DBH) classes.

A comparison of the closed and grazed areas (Figure 7) with respect to the ditribution diameter classes shows that the DBH decreased with increase in the density of individuals in the higher density size classes. The denity of most of the woody species were concentrated in the lower DBH size classes and consistently decreased with increase in DBH size class.

In the closed areas 90.14% of the individual plants fell in the lower size class of 1 and 2 whereas classes 3-6 only had 9.86% individual plants. In the grazed areas the 95.17% of the individuals fall in the lower size class 1 and 2 which is 83.58% and 11.59% respecively whereas classes 3-6, 0.48%, 3.54%, 0.16% and 0.64%

respectively together constitute only 4.82%. The closed areas have better distribution of dbh in the size classes than the grazed areas.

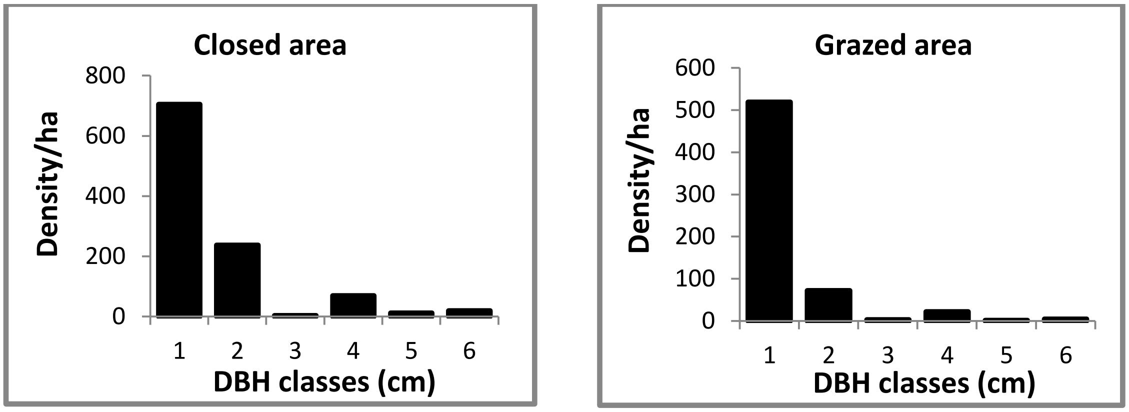


Figure 7: Comparison of the DBH class distribution in the closed and grazed areas

When the three sites were compared with respect to their DBH class distribution at *Kara,* 71.02% of the individual plants fell in the lower size class 1 and 15% in size class 2 (Figure 8) size classes 3-6 constitute only 13.62% of the total number of individual plants. At *Rakata,* there was a more even distribution of individual plants between size class of 1 and 2 which took 38.72% and 35.89% of the total number of plants in the site respectively. The rest of the size classe, i.e., 3-6 classes constitute of 25.35% of all individual plants in this site. At *Atsmi-hamaz* the distribution of the size classes was more or less even size classes 1 to 3, had 35.25%, 47.17% and 14.59% of the total number of individual plants respectively. The plants densities declined in the higher DBH classes.

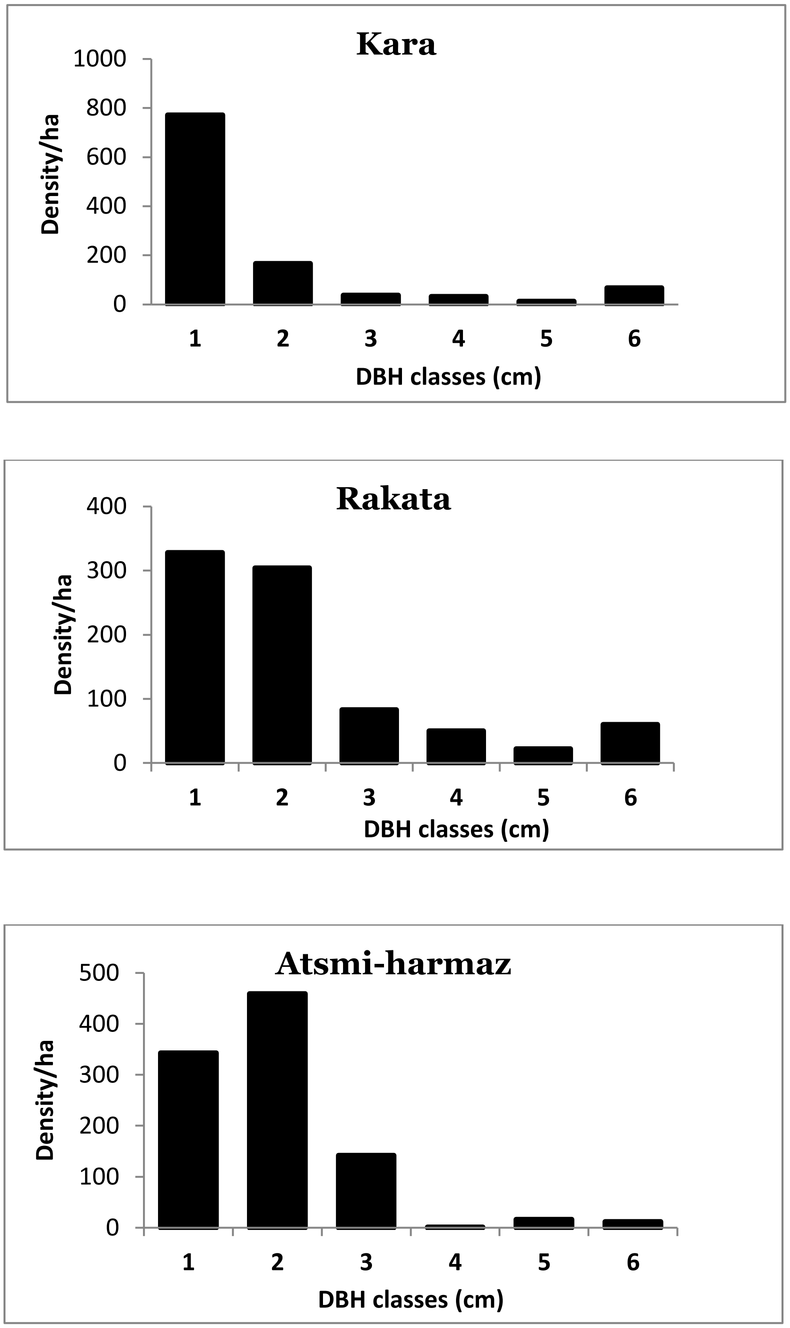


Figure 8: Comparison of the diameter class distribution in the three sites

5.3.2. Height Class Distribution

The distribution of tree height classes in the study area is shown in Figure 9 and Appendix 6. Height classes were determined as 2 m increments in each height class. For instance, size class 1 = $\leq$ 2 m, 2 = 2.1 - 4 m, 3 = 4.1 - 6 m, 4 = 6.1 - 8 m, 5 = 8.1 m and above. All stems $\geq$ class 5 were combined in a single height class.

Most of the woody species in the study area were concentrated in the height class sizes 1 and 2 together constitute 92.52%. The plants in the remaining size classes (3-5) 7.48% constituted of the total number of plants recorded. The overall height class density distribution showed a decreasing trend in the number of individuals with increasing height (Figure 9), i.e., there were a greater number of individuals in the lower height class sizes and a gradual decrease towards the upper height class sizes. There were very few individuals in height clases greater than size class 3.

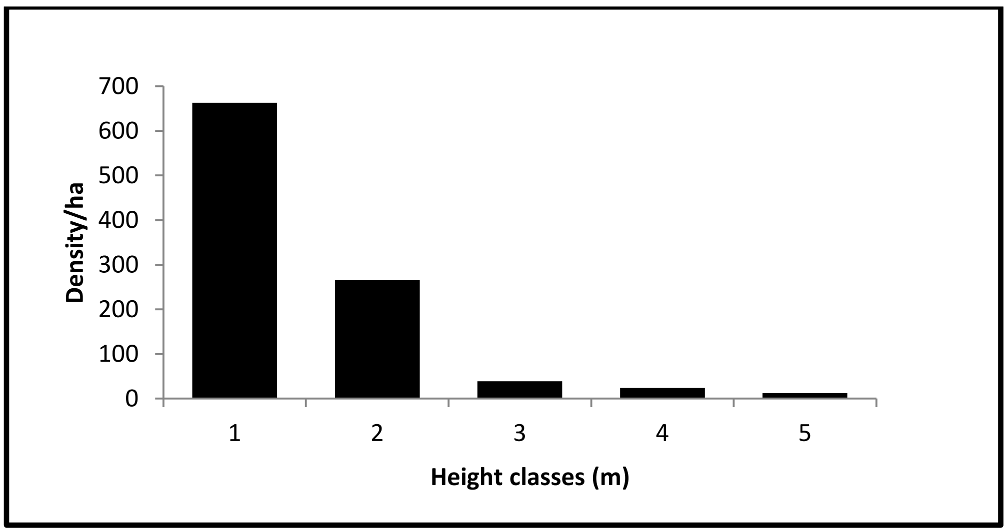


Figure 9: Overall height class distribution of the woody species.

When the three sites are compared with respect to their height class size distribution is shown in Figure 10. At *Kara* 74.94% of the individuals at *Kara* were found to fall in size class 1, 13.61% in size class of 2 and the rest in size classes 3-5. At *Rakata,* classes 1 and 2 contained 53.88% and 39.62% of all individuals respectively while the remaining size classes 3-5 allocated for 6.50% of all individuals. At *Atsmi-harmaz more* individuals (96.54%) were in height size 1 and 2, but the number declined in the upper height classes (3-5).

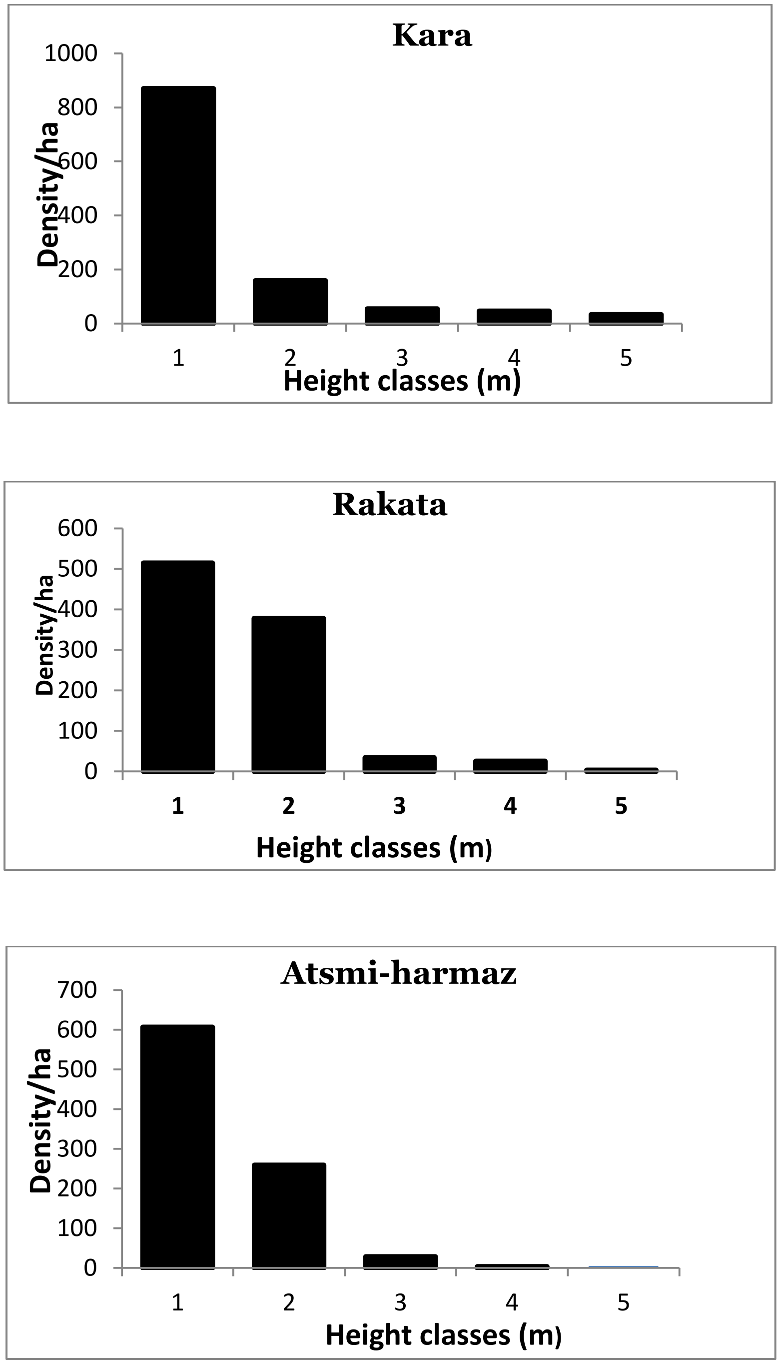
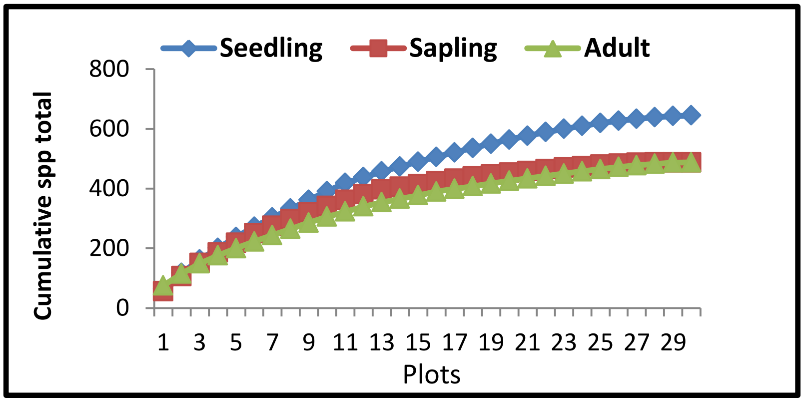
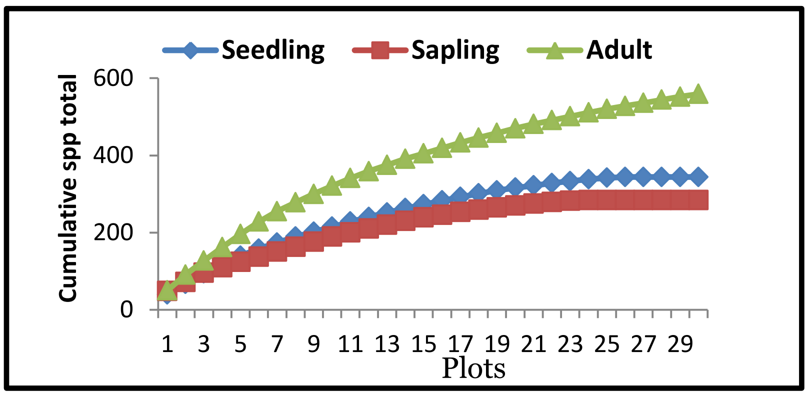


Figure 10: Comparison of height class distribution in the three sites

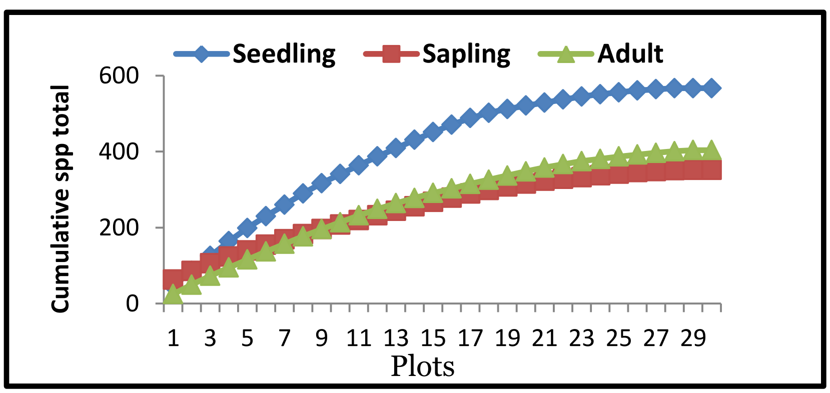
The cumulative curve of the richness of the seedlings, saplings and adult species of the three sites is shown in Figure 11. Whenever richness of each site is observed, *Kara* has 40% seedlings, and overlapped of sapling and adult species richness (30%) were observed at the end of the graph. Adult species in *Rakata* has the highest proportion of richness (47%) followed by seedlings (29%) and saplings (24%). *Atsmi-harmaz* is rich in seedlings (43%) followed by adults (31%) with slight difference of saplings (27%).



Kara



Rakata



A. harmaz

Figure 11: Shows cumulative curves of seedlings, saplings and adults in the three sites

5.3.3. Basal Area

Tree basal area (BA) is the cross-sectional area measured in meter squared (m^2) which can be used to estimate woody species volumes**.** The basal area of all the tree and shrub species in the study area is shown in Appendix 7, which recorded the lowest basal area (0.0238 m^2/ha).

5.3.4. Frequency

The frequencies of all the species are shown in Appendix 8. Frequency indicates how the various species were dispersed in all the sample plots. The six most frequently occurring species were *Grewia tembensis*, *Acacia tortilis*, *Barleria eranthemoides*, *Acacia etbaica*, *Cadia purpurea* and *Aloe camperi* (Table 9)

Table 9: The six most frequently occurred species in the study area (FR = frequency, %FR =Percentage frequency, RFR = relative frequency).

Species name	FR	% FR	RFR
Grewia tembensis	70	77.78	7.76
Acacia tortilis	60	66.67	6.65
Barleria eranthemoides	54	60.00	5.99
Acacia etbaica	50	55.56	5.54
Cadia purpurea	46	51.11	5.10
Aloe camperi	43	47.78	4.77

5.3.5. Importance Value Index (IVI)

The importance value gives an overall estimate of the importance of plant species in their community. Because of their abundance, frequency and dominance in the woodland, they comprised 53.645% of the total importance values whereas the remaining percentage (46.355%) was shared among the other species. Based on their higher IVI value (Table 10), *Cadia purpurea, Euphorbia candelabrum, Acacia tortilis*, *Acacia hockii*, *Acacia etbaica* and *Grewia tembensis* were the most dominant and ecologically most significant woody species in the study area (Appendix 9).

Table 10: Importance Value Index of the six most commom species (RF=Relative frequency, RD= Relative density, RDO= Relative dominance).

Species name	RF	RD	RDO	IVI	IVI %
Cadia purpurea	9.2369	23.6457	0.7001	33.5828	11.1943
Euphorbia candelabrum	0.6024	0.4334	30.1050	31.1408	10.3803
Acacia tortilis	12.0482	9.4529	8.0513	29.5524	9.8508
Acacia hockii	6.0241	18.4995	1.5169	26.0405	8.6802
Acacia etbaica	9.8394	10.6717	3.9673	24.4784	8.1595
Grewia tembensis	9.2369	6.2026	0.7001	16.1397	5.3799
Total					53.645

On the other hand, the importance value of each community is shown in table 11. In this regard, from each community 12 species which have the highest importance values were selected. The importance value gives an overall estimate of the importance of plant species in a given area. Species which had the highest ecological significance in each community were *Cynodon dactylon*, *Cadia purpurea*, *Pennisetum pedicellatum*, *Acacia etbaica* and *Acacia hockii*. The total percentage of the highest 12 species in each community were 52.4%, 37.3%, 47.3%, 55.5% and 58.2% respectively. The highest importance value was recorded in community 5 and the lowest in community 2 (table 11). Some of the species were distributed in most of the communities but others restricted to only one community. For instance, *Pennisetum pedicellatum* was found in all the 5 communities, *Cadia purpurea* in 4, *Aloe camperi, Barleria eranthemoides, Cynodon dactylon, Cyperus bulbosus* and *Cyperus rotundus* in 3, *Acacia asak, Acacia etbaica, Acacia hockii, Acacia mellifera, Acacia tortilis, Andropogon* *commutatus, Pennisetum villosum, Setaria verticillata* and *Tribulus terrestris* in 2 and *Acokanthera schimperi, Aerva javanica, Alternanthera pungens, Amaranthus caudatus, Cadaba farinosa, Eragrostis papposa, Euphorbia nubica, Euphorbia candelabrum, Grewia villosa, Heliotropium cinerascens* and *Maytenus senegalensis* only in one of the communities.

Table 11: The importance value of each of the community

Community 1		Community 2		Community 3		Community 4		Community 5	
species	IVI%	species	IVI%	species	IVI%	species	IVI%	species	IVI%
C.dactylon	6.1	C.purpurea	3.8	P. pedicellatum	5.0	A. etbaica	5.1	A. hockii	6.8
A. commutatus	5.8	P.foliosa	3.7	A. tortilis	4.4	C. bulbosus	5.1	A. commutatus	6.2
C.purpurea	5.2	P.oleracea	3.7	C. bulbosus	4.4	A.asak	5.0	A.camperi	4.9
A. tortilis	4.7	A.camperi	3.3	A. hockii	4.1	C.rotundus	5.0	P. villosum	4.9
E. nubica	4.2	P. pedicellatum	3.2	C.dactylon	4.1	A.camperi	4.7	A.asak	4.6
C. farinosa	3.8	C.dactylon	3.1	C.rotundus	3.7	A. mellifera	4.6	S. verticillat	4.6
E. papposa	3.8	C.rotundus	2.9	P. hysterophorus	3.7	M. senegalensis	4.5	A. mellifera	4.4
G.villosa	3.8	E. candelabrum	2.8	P. villosum	3.7	P. pedicellatum	4.5	A. javanica	4.4
O.ficus-indica	3.8	A. schimperi	2.8	P. mezianum	3.7	S. verticillat	4.5	C. bulbosus	4.4
P. pedicellatum	3.8	A. etbaica	2.7	Z.mucronata	3.7	T.terrestris	4.5	P. pedicellatum	4.4
T.terrestris	3.8	A. pungens	2.7	B. eranthemoides	3.5	C.purpurea	4.1	P. juliflora	4.4
B. eranthemoides	3.7	A. caudatus	2.7	C.purpurea	3.2	H. cinerascens	3.9	B. eranthemoides	4.2
Total	52.4		37.3		47.3		55.5		58.2

Abbreviations:* P. pedicellatum** =*Pennisetum pedicellatum;* ***P.mezianum*= Pennisetum mezianum;* ***C.purpurea****=Cadia purpurea;* ***A.camperi****=Aloe camperi;* ***B. eranthemoides*** *=Barleria eranthemoides;* ***C.dactylon****=Cynodon dactylon;* ***C. bulbosus*** *=Cyperus bulbosus;* ***C.rotundus****=Cyperus rotundus,* ***A. asak****=Acacia asak,* ***A. etbaica****=Acacia etbaica,* ***A. hockii****= Acacia hockii,* ***A. mellifera*** *=Acacia mellifera;* ***A.tortilis****=Acacia tortilis;* ***O.ficus-indica****= Opuntia ficus-indica;* ***P. juliflora****= Prosopis juliflora;* ***P.foliosa****= Portulaca foliosa;* ***P.oleracea****= Portulaca* oleracea; ***Z.mucronata****= Ziziphus mucronata;* ***P. hysterophorus****= Parthenium hysterophorus* ***A.commutatus****=Andropogon commutatus;* ***P. villosum*** *=Pennisetum villosum;* ***S. verticillat****=Setaria verticillata;* ***T. terrestris*** *=Tribulus terrestris;* ***A. schimperi****=Acokanthera schimperi;* ***A. javanica*** *=Aerva javanica;* ***A. pungens*** *= Alternanthera pungens;* ***A. caudatus*** *=Amaranthus caudatus;* ***C.farinosa****= Cadaba farinosa;* ***E.papposa****= Eragrostis papposa;* ***E.nubica****=Euphorbia nubica;* ***E. candelabrum*** *=Euphorbia candelabrum;* ***G.villosa****=Grewia villosa;* ***H. cinerascens*** *=Heliotropium cinerascens;* ***M. senegalensis****=Maytenus senegalensis.*

5.3.6. Species Population Structure

Whenever all the woody species are taken together, the population structure displays the reversed J-shaped pattern. However, the distribution of DBH classes of some selected species showed different types of population structures. Population structure refers to the distribution of individuals of each species in height or DBH to provide the overall profile of species under study (Peter, 1996). The population structure of all tree and shrub species are resulted in four different patterns (Figure 12).

The first pattern of population structure illustrated by *Acacia tortilis* could be termed as U-shaped (Figure 12a). In this pattern, DBH classes of the middle are low. Ahmed *et al.* (1991) noted that the reduction of the middle size classes was mainly due to selective cutting of the trees for different purposes rather than due to the failure of regeneration. Species included in this type of pattern are *Acacia tortilis, Acacia hockii, Acacia etbaica* and *Dichrostachys cinerea.*

The second pattern represented by *Cadia purpurea* (Figure 12b) was formed by species with positively skewed population distribution (inverted 'J' shaped). These species had the highest density in the lower DBH classes and decrease in density towards the higher size classes, which suggests continuous recruitment potential in the woodland if it is under continuous protection. Species included in this type of pattern are *Cadia purpurea, Grewia tembensis* and *Grewia mollis.*

The third pattern is represented by *Acacia asak* (Figure 12c). The density of all species in this group increases with increasing DBH up to some points and then decreases with increasing DBH. This pattern shows Gaussean curve (bell-shaped) since it contains higher individuals in the middle size class and smaller numbers in both sides. The species in this group are *Acacia mellifera, Carissa spinarum* and *Grewia villosa.*

The fourth pattern consists of species in the medium DBH classes and absent from the lower and higher DBH classes. This pattern is represented by *Cordia sinensis* (Figure 12d). In this pattern unless appropriate conservation measures are taken, they will become locally extinct from the woodland in the near future. The species showing this pattern include *Cordia monoica, Commiphora schimperi, Ficus mucuso, Ximenia americana* and Osyris *quadripartita*.

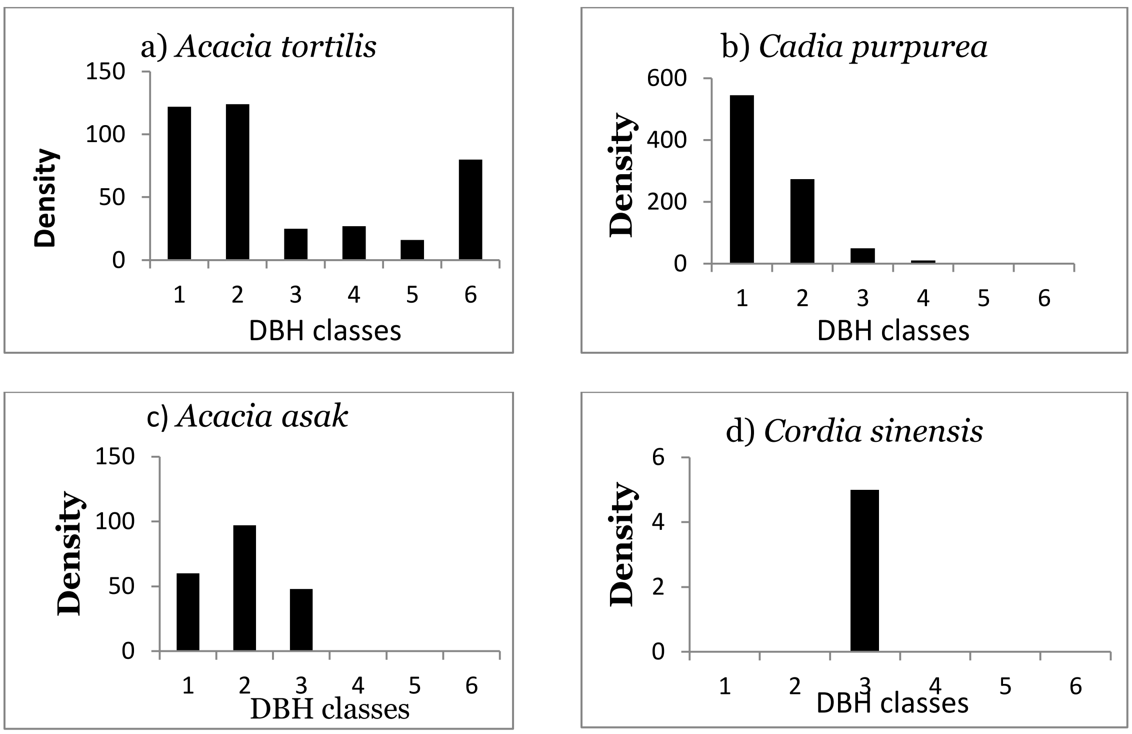


Figure 12: Population structure of species in the study area

5.4. Similarities among the Study Sites

The similarity index of woody species in the three closed sites is presented in Table 12. The results show that the three closed areas had a similarity index greater than 50% which implies that more than half of the species were common among the three habitats.

Table 12: Sorensen's Coefficient of Similarity in the three closed areas (*Kara-I, Rakata-II* and *Atsmi-harmaz-III*).

Closed area	Similarity	%	Dissimilarity	%
I and II	0.58	58	0.42	42
I and III	0.51	51	0.49	49
II and III	0.56	56	0.44	44

A similar computation of Sorenson's coefficient showed that the three grazed areas had very little overlap or similarity interms of having shared common species (Table 13).

Table 13: *Sorensen's Coefficient of Similarity in the three grazed areas (Kara-I, Rakata-II* and*Atsmi-harmaz-III).*

Grazed area	Similarity	%	Dissimilarity	%
I and II	0.41	41	0.59	59
I and III	0.53	53	0.47	47
II and III	0.50	50	0.50	50

The grazed areas surrounding the three closed areas showed a higher amount of similarity with the closed areas interms of the proportion of shared common species (Table 14).

Table 14: Sorensen's Coefficient of Similarity between the closed and the adjacent grazed areas (KC=kara closed, KG=kara grazed, RC=rakata closed, RG= rakata grazed, AC=A. harmaz closed, AG=A. harmaz grazed)

Sites	similarity	%	dissimilarity	%
KC and KG	0.76	76	0.24	24
RC and RG	0.65	65	0.35	35
AC and AG	0.59	59	0.41	41

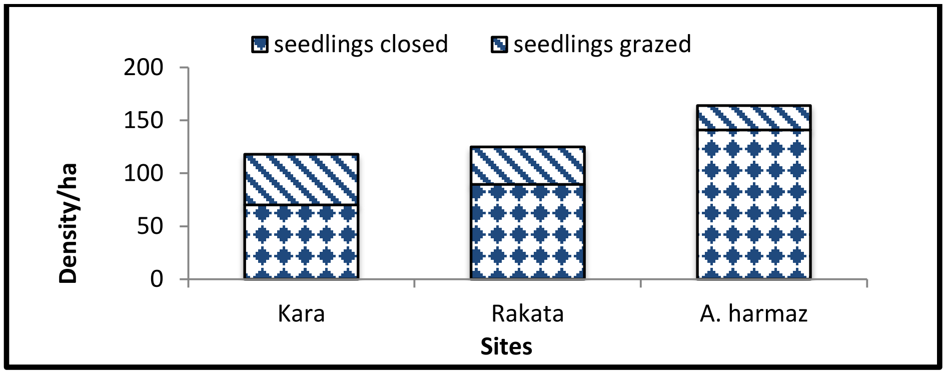
The diversity and evenness of woody species in the three closed and grazed areas were computed and the results obtained are summarized in Table 15. The K*ara* and *Rakata* closed areas had high species diversity and evenness indices compared to their adjacent grazed areas (Table 15). In the *Atsmi-harmaz* closed area the species diversity and evenness indices were lower than in its adjacent grazed area.

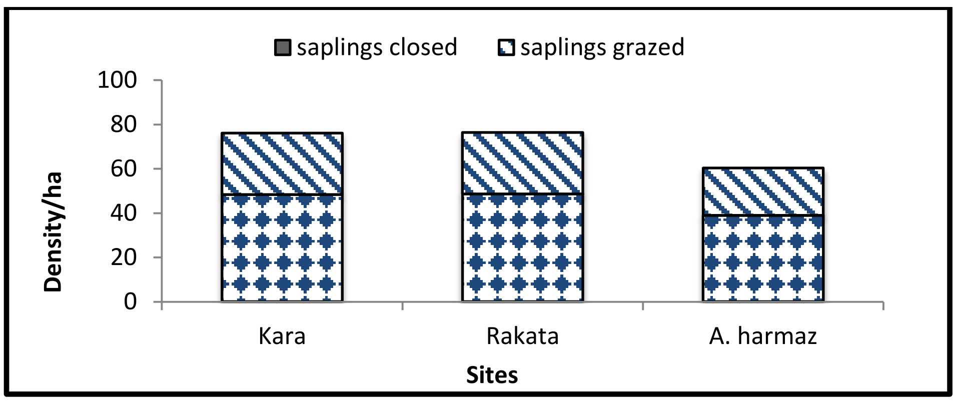
Table 15: Shannon-Wiener diversity and evenness indices of *the closed* and *grazed areas*

Closed sites	Species richness	Diversity (H')	H'_{max} (lnS)	Evenness (H'/H' max)
Kara	24	2.378	3.178	0.748
Rakata	24	2.254	3.178	0.709
Atsmi-harmaz	15	1.154	2.708	0.426
Grazed sites	Species richness	Diversity (H')	H'_{max} (lnS)	Evenness (H'/H' max)
Kara	18	1.974	2.890	0.683
Rakata	16	1.791	2.773	0.646
Atsmi-harmaz	12	2.155	2.485	0.867

5.5. Variations in Seedling, Sapling and Adult Plant Densites in the Three Sites

The seedling, sapling and adult plant densities were highest in the closed areas than in the grazed areas (Figure 13).





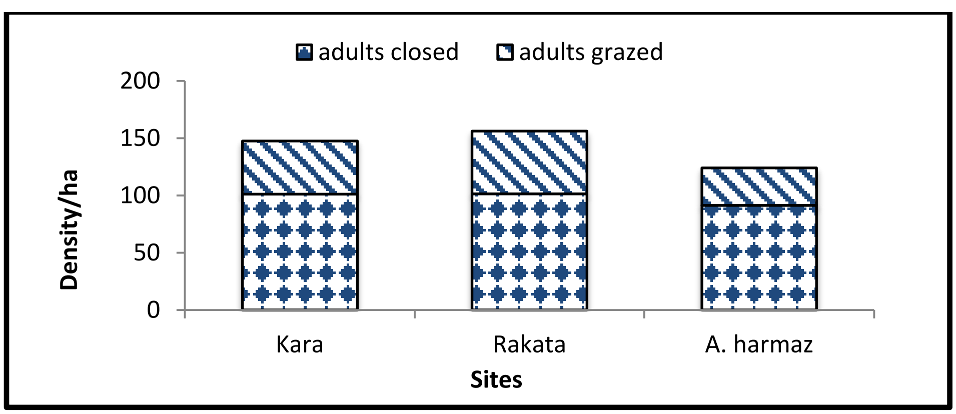


Figure 13: Comparison of the seedling, sapling and adult plant densities/ha in the three study sites

Analysis of variance (ANOVA) computed at p = 0.05 to assess whether significant differences existed between the three sites interms of seedling, sapling and adult plant densities showed there were no significant differences in the mean value of these densities in the three sites (Table 16).

Table 16: Summary of ANOVA for seedling, sapling and adult abundances of the whole data

Treatments	Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Seedlings	Between Groups	892.194	2	446.097	0.185	0.831
	Within Groups	165745.583	69	2402.109		
	Total	166637.777	71			
Saplings	Between Groups	776.083	2	388.041	0.411	0.665
	Within Groups	65149.791	69	944.199		
	Total	65925.875	71			
Adults	Between Groups	619.527	2	309.763	0.206	0.814
	Within Groups	103590.916	69	1501.317		
	Total	104210.444	71			

When this was computed for the three closed sites at p = 0.05, no significant difference was formed in the mean values of seedling. sapling, and adult plants in densities/ha in the three site (Table 17).

Table 17: Summary of ANOVA for seedling, sapling and adult abundances in the three closed sites

Treatment	Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Seedlings	Between Groups	861.08	2	430.541	0.269	0.765
	Within Groups	110256.42	69	1597.919		
	Total	111117.50	71			
Saplings	Between Groups	232.19	2	116.097	0.304	0.738
	Within Groups	26272.13	69	380.755		
	Total	26504.32	71			
Adults	Between Groups	40.11	2	20.055	0.018	0.982
	Within Groups	76886.88	69	1114.302		
	Total	76926.99	71			

A computation of the same for the three grazed sites at p = 0.05 also revealed that there was no significant difference in the mean values of seedling, sapling and adult plant densities/ha between the three site (Table 18).

Table 18: Summary of ANOVA for seedling, sapling and adult abundances in the three grazed sites

Treatment	Source of Variation	Sum of Squares	df	Mean Square	F	P-value
Seedlings	Between Groups	2656.48	2	1328.240	2.283	0.112
	Within Groups	29666.11	51	581.688		
	Total	32322.59	53			
Saplings	Between Groups	725.93	2	362.963	1.051	0.357
	Within Groups	17604.44	51	345.185		
	Total	18330.37	53			
Adults	Between Groups	696.33	2	348.166	0.881	0.421
	Within Groups	20150.50	51	395.107		
	Total	20846.83	53			

5.6. The Effect of Grazing and Anthropogenic Activities

The main factors responsible for vegetation disturbance recorded were the same in all the three study sites. They include factors such as tree cutting by humans, fuelwood collection and livestock grazing. In addition, people were not only involved in direct cutting of trees but also in the lopping of large portions of side branches or crowns of the trees. As a result, the number and diversity of tree species decreased in the higher diameter size classes and thus retarded the regeneration processes.

In the presence or absence of disturbance based on the intensity of grazing, fuelwood collection, charcoal production, tree stumps, and fencing of farms and houses on six selected specie is shown in Table 19. The magnitude of the impact was quantified as follows: 0 = nil; 1 = slight; 2 = moderate and 3 = heavy.

Table 19: Species most affected by grazing and anthropogenic disturbances in the study area

Species	stump	fuelwood collection	grazing intensity	fence	charcoal production
Ziziphus spina-christi	3	0	1	3	0
Grewia mollis	0	0	3	0	0
Grewia tembensis	0	0	3	0	0
Cadia purpurea	3	3	0	0	0
Acacia etbaica	3	2	0	0	0
Acacia tortilis	3	2	0	3	0

5.7. Vegetation Community Analysis

5. 7.1. Vegetation Community Types

Five plant community types were identified from the output of the hierarchical agglomerative clustering (Figure 14). The plant communities have been named after two species (tree, shrub or herb) in each cluster which had the highest mean cover abundance. The communities identified were: 1) The *Cadia purpurea - Acacia tortilis* community*,* 2) The *Acacia asak - Aloe camperi* community*,* 3*).* The *Acacia tortilis - Acacia etbiaca* community *4)* The *Barleria eranthemoides - Aloe camperi* community and *5)* The *Acacia hockii - Acacia etbaica* community. These vegetation communities are described below:

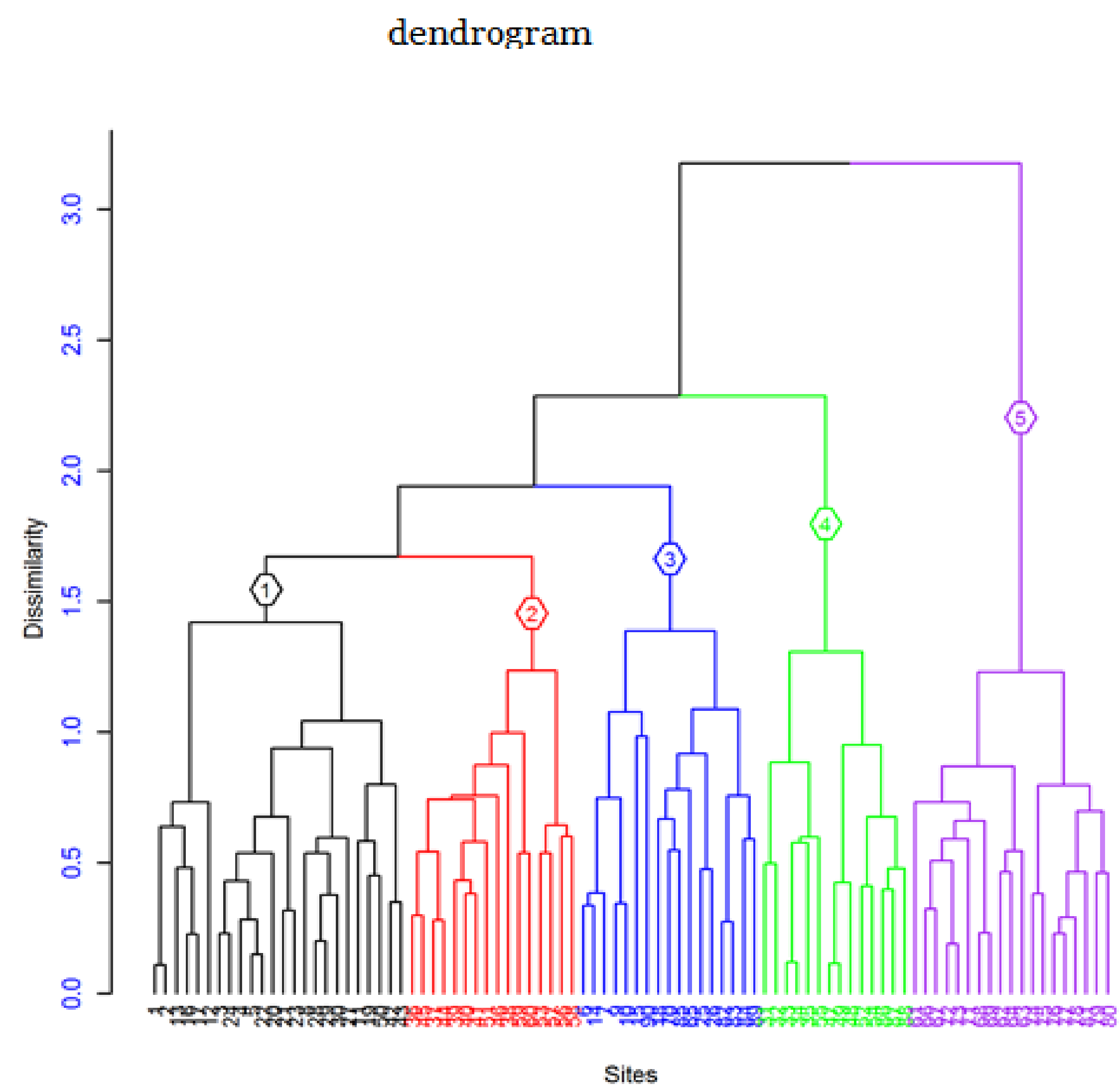


Figure 14: Dendrogram showing the plant communitie identified in the study

1. The *Cadia purpurea - Acacia tortilis* community

This community type occurs between the altitude ranges 1680m to 1805m a.s.l. In this community *Cadia purpurea* was the dominant shrub and *Acacia tortilis* is the dominant tree. Other tree species in the community included *Balanites aegyptiaca, Acacia etbaica, Acacia hockii, Cadaba farinosa, Euphorbia nubica, Carissa spinarum, Euclea racemosa subsp. schimperi, Grewia mollis, Hibiscus* *micranthus, Leucas abyssinica, Aloe camperi, Withania somnifera*, *Grewia tembensis, Dichrostachys cinerea, Ziziphus spina-christi* and Ziziphus *mucronata*. The herb layers include *Andropogon commutatus, Barleria eranthemoides, Tribulus torrestris*, *Commelina africanus, Parthenium hysterophorus, Pennisetum mezianum* and *Pennisetum pedicellatum*. The climbers *Cissus quadrangularis* and *Senecio hadiensis* were also common in this community.

2. The *Acacia asak - Aloe camperi* community

The altitude where this community type occurs ranges from 1710m to 1886m a.s.l. The dominant tree species in this community were *Acacia asak, Aloe camperi and Acacia tortils* (Table 20) whereas other less dominant species such as *Cadia purpurea, Carissa spinarum, Commiphora schimperi, Cordia sinensis, Euphorbia candelabrum, Maytenus senegalensis, Rumex nervosus, Acacia etbaica, Grewia tembensis, Ehretia cymosa, Dodonea angustifolia, Ziziphus mucronata, Acokanthera schimperi, Euphorbia nubica* and *Leucas abyssinica* were also present. The climbers *Commicarpus plumbaginus* and *Sarcostemma viminale* were common. In The herb layer *Alternanthera punges, Xanthium spinosum, Argemone mexicana, Cynodon dactylon, Datura stramonium, Kleinia odora, Amaranthus caudatus, Barleria eranthemoides, Tribulus torrestris, Setaria verticillata, Pennisetum pedicellatum, Chenopodium ambrosioides, Eragrostis papposa, Cyperus bulbosus* and *Cyperus rotundus* were recorded.

3. The *Acacia tortilis – Acacia etbiaca* community

The altitude of this community ranges from 1625m to 1790m a.s.l. It was characterized by the dominant tree *Acacia tortilis* (**Table 20**) which associate with *Acacia etbaica, Acacia hockii, Acacia oerfota, Balanites aegyptiaca, Cadaba farinosa, Capparis tomentosa, Carissa spinarum, Cordia sinensis, Dichrostachys cinerea, Grewia tembensis, Ziziphus mucronata, Grewia* *villosa, Grewia mollis, Withania somnifera, Leucas abyssinica, Opuntia ficus-indica, Heliotropium cinerascens* and other less dominant species such as *Cadia purpurea, Euphorbia nubica, Ziziphus spina-christi*. *Cissus quadrangularis* and *Senecio hadiensis* were the common climbers in the community. The herbs layer was represented by *Cyperus bulbosus, Tribulus torrestris, Cynodon dactylon, Parthenium hysterophorus, Pennisetum mezianum* and *Pennisetum villosum*.

4. The *Barleria eranthemoides - Aloe camperi* community

This community occurs at altitudes from 1654m to 1753m a.s.l. *Barleria eranthemoides* was the dominant herb while *Aloe camperi* the dominant succulent shrub (Table 20). They associated with species such as *Acacia etbaica, Cadia purpurea, Ehretia cymosa, Euclea racemosa subsp. schimperi, Grewia villosa, Heliotropium cinerascens, Olea europaea subsp. cuspidata, Acacia tortilis, Grewia tembensis, Acacia asak, Acacia mellifera, Dichrostachys cinerea, Ximenia americana, Ziziphus mucronata, Ormocarpum muricatum, Cordia sinensis, Commiphora schimperi* and *Balanites aegyptiaca*. The herb layers were well represented by *Tribulus torrestris, Eragrostis papposa, Cyperus rotundus, Setaria verticillata, Cyperus bulbosus, Huernia macrocarpa* and *Pennisetum pedicellatum*. The two climbers *Jasminum grandiflorum* and *Cissus quadrangularis* were the most common in this community.

5. The *Acacia hockii – Acacia etbaica* community

The altitude where this community occurs range from 1672m to 1745m a.s.l. It is characterized by the two most abundant trees *Acacia hockii* and *Acacia etbaica* (Table 20). The few species associated with the two was *Acacia asak* and other less dominant species such as *Cappris tomentosa, Clerodendron myricoides, Dichrostachys cinerea, Grewia villosa, Hibiscus micranthus, Ormocarpum muricatum, Carissa spinarum, Grewia tembensis, Commiphora schimperi, Prosopis juliflora* and Grewia *mollis*. The climber *Cissus quadrangularis* was the common in this community. The herb layers were dominated by *Pennisetum* *pedicellatum, Pennisetum villosum, Setaria verticillata, Tribulus torrestris, Cyperus bulbosus* and *Barleria eranthemoides*.

Table 20: Synoptic table for the community types showing with species a cover-abundance value of ≥ 1

	Communities				
Species name	**C-1**	**C-2**	**C-3**	**C-4**	**C-5**
Cadia purpurea	**6.12**	2.47	2.36	2.75	0.68
Acacia tortilis	**5.79**	2.65	3.86	1.75	1.16
Barleria eranthemoides	**3.75**	2.35	2.29	3.06	2.32
Acacia etbaica	**2.29**	2.18	2.93	2.69	3.16
Euphorbia nubica	**2.17**	1.41	0.29	0.56	0.00
Aloe camperi	**2.08**	3.47	2.14	3.05	2.79
Grewia tembensis	**2.04**	1.76	1.64	1.00	3.00
Andropogon commutatus	**1.92**	0.88	0.00	0.00	0.00
Leucas abyssinica	**1.88**	0.00	0.93	0.38	0.68
Cissus quadrangularis	**1.58**	0.88	0.50	1.19	1.05
Cynodon dactylon	**1.54**	0.29	0.00	0.75	0.00
Balanites aegyptiaca	**1.25**	1.18	0.36	0.44	0.26
Eragrostis papposa	**1.25**	0.29	1.07	0.69	0.89
Acacia hockii	**1.21**	2.65	2.43	0.38	4.42
Achyranthes aspera	**1.08**	0.59	0.00	0.31	0.11
Dichrostachys cinerea	**1.04**	0.18	1.21	0.44	0.58
Acacia asak	0.42	**3.65**	1.50	0.19	2.47
Aloe camperi	2.08	**3.47**	2.14	3.05	2.79
Acacia tortilis	5.79	**2.65**	1.07	1.75	1.16
Acacia hockii	1.21	**2.65**	2.43	0.38	4.42
Cadia purpurea	6.12	**2.47**	2.36	2.75	0.68
Barleria eranthemoides	3.75	**2.35**	2.29	3.06	2.32
Acacia etbaica	2.29	**2.18**	2.93	2.69	3.16
Grewia tembensis	2.04	**1.76**	1.64	1.00	3.00
Leucas abyssinica	1.88	**1.53**	0.93	0.38	0.68

Euphorbia nubica	2.17	**1.41**	0.29	0.56	0.00
Setaria verticillata	0.00	**1.24**	0.36	0.50	0.26
Balanites aegyptiaca	0.00	**1.18**	0.36	0.44	0.26
Acacia tortilis	5.79	2.65	**3.86**	1.75	1.16
Acacia etbaica	2.29	2.18	**2.93**	2.68	3.16
Acacia hockii	1.21	2.65	**2.43**	0.38	4.42
Cadia purpurea	6.12	2.47	**2.36**	2.75	0.68
Barleria eranthemoides	3.75	2.35	**2.29**	3.06	2.32
Aloe camperi	2.08	3.47	**2.14**	3.05	2.79
Cyperus rotundus	0.42	0.35	**1.64**	0.94	0.26
Grewia tembensis	2.04	1.76	**1.64**	1.00	3.00
Acacia asak	0.42	3.65	**1.50**	0.19	2.47
Dichrostachys cinerea	1.04	0.18	**1.21**	0.44	0.58
Acokanthera schimperi	0.21	0.00	**1.14**	0.00	0.00
Tribulus torrestris	0.42	0.29	**1.07**	0.44	0.32
Eragrostis papposa	1.25	0.29	**1.07**	0.69	0.89
Carissa spinarum	0.58	0.12	**1.00**	0.56	0.21
Barleria eranthemoides	3.75	2.35	2.29	**3.06**	2.32
Aloe camperi	2.08	3.47	2.14	**3.05**	2.79
Cadia purpurea	6.12	2.47	2.36	**2.75**	0.68
Acacia etbaica	2.29	2.18	2.93	**2.69**	3.16
Pennisetum pedicellatum	0.75	0.00	0.43	**1.94**	0.79
Acacia tortilis	5.79	2.65	3.86	**1.75**	1.16
Heliotropium cinerascens	0.08	0.06	0.5	**1.38**	0.68
Parthenium hysterophorus	0.00	0.00	0.00	**1.25**	0.00
Cissus quadrangularis	1.58	0.88	0.50	**1.19**	1.05
Acacia mellifera	0.00	0.00	0.00	**1.12**	1.26
Grewia tembensis	2.04	1.76	1.64	**1.00**	3.00
Acacia hockii	1.21	2.65	2.43	0.38	**4.42**
Acacia etbaica	2.29	2.18	2.93	2.69	**3.16**
Grewia tembensis	2.04	1.76	1.64	1.00	**3.00**
Aloe camperi	2.08	3.47	2.14	3.05	**2.79**
Acacia asak	0.42	3.65	1.50	0.19	**2.47**

Barleria eranthemoides	3.75	2.35	2.29	3.06	**2.32**
Acacia mellifera	0.00	0.00	0.00	1.12	**1.26**
Acacia tortilis	5.79	2.65	3.86	1.75	**1.16**

5.7.2. Diversity, Richness and Evenness of the Communities

Among the five communities, the Shannon-Wiener diversity results are shown in Table 21. In terms of the actual number of the species per community, community IV was the most species rich followed by community II, community III and community I. In that order Community V was the most species poor community. Similarly community IV had the highest species diversity and community V had the lowest**.** Interms of evenness community II had the highest index even though it had a lower index for species richness than community IV which had the highest.

Table 21: Showing the Shannon-Wiener Diversity and Evenness Indices for the Five Communities

Communities	Species richness	Diversity (H')	H'_{max} (lnS)	Evenness (H'/H' max)
I	39	2.970	3.665	0.811
II	47	3.213	3.850	0.834
III	39	2.967	3.665	0.810
IV	54	3.294	3.989	0.826
V	36	2.730	3.584	0.762

5. 7.3. Similarities among the Vegetation Communities

Sorensen's coefficient similarity of the five communities is presented in Table 22. Community I and III had the highest number of species in common based on Sorensen's coefficient similarity (Table 22). They were followed by community III and V. A relatively low species similarity was observed between communities I and II.

Table 22: Sorensen's coefficient similarity

Community types	I	II	III	IV	V
I	-				
II	0.437	-			
III	0.805	0.556	-		
IV	0.667	0.524	0.667	-	
V	0.494	0.457	0.686	0.595	-

5.8. Soil Physical and Chemical Analysis

5.8.1. Soil Physical Analysis

5.8.1.1. Soil Particle Size Distribution

The percentages of different soil particle classes were determined by using the hydrometer method. The hydrometer method of silt and clay measurement depends on the effect of particle size settling velocities within a water column are separated to permit independent settling of these particles. After the percentage of sand, silt and clay particles were determined; the soil texture was assigned the exact location of the textural name in the textural triangle using packages in R given by Lemon (2006). The textural triangle of the soil samples of each site is shown in Figure 15 and the overall data for the study area in Figure 16.

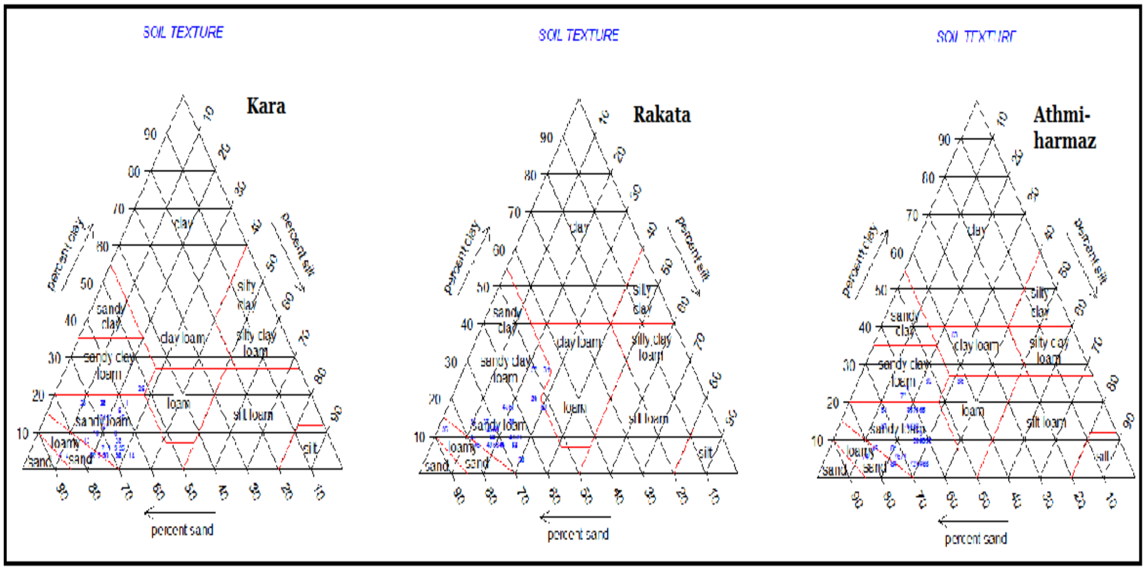


Figure 15: The textural distribution of each site in a texture triangle

The soil texture distribution of the study area was concentrated in five textural classes such as the sandy loam followed by the loamy sand, sandy clay loam, clay loam and loam. All these are associated with high erodibility due to high sand and silt proportions which cause them easily detachable without a binding agent such as organic matter.

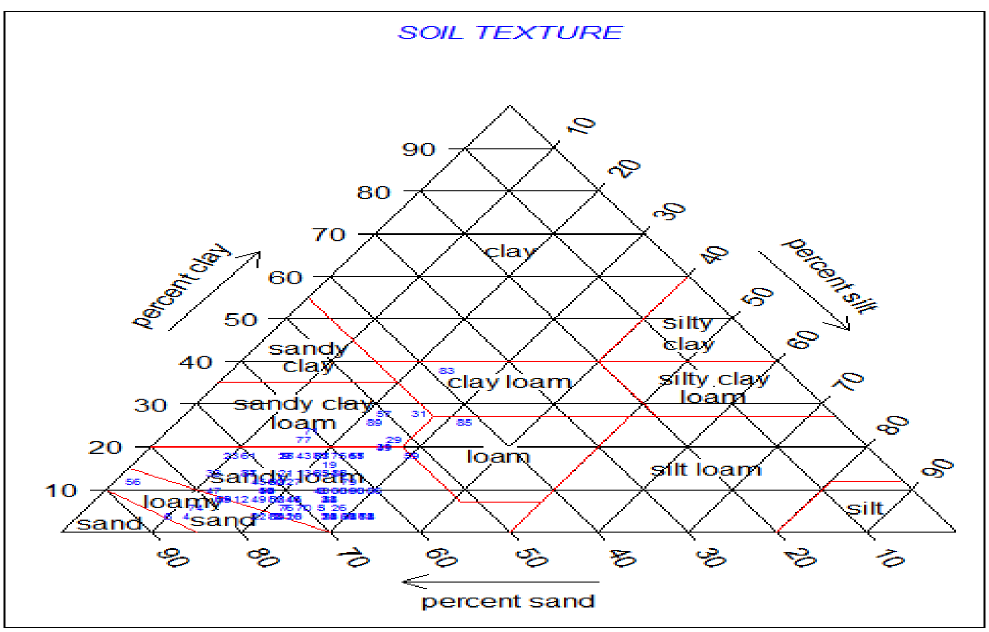


Figure 16: The textural distribution of the overall data in a texture triangle.

Sand and silt dominated soils have a tendency to be low in organic matter, moisture capacity and nutrients. Soils of this type are generally responsible to rain impact and might be aggravated through heavy grazing resulted in lower water infltration and higher soil loss (Hiernaux *et al.,* 1999). The average proportion of sand, silt and clay contents of soil at a depth of 15 cm was 66.58%, 21.66% and 11.78% respectively (Figure 17). Sand had the highest proportion in the soil; hence, the textural classes of the soil particles were sand dominated.

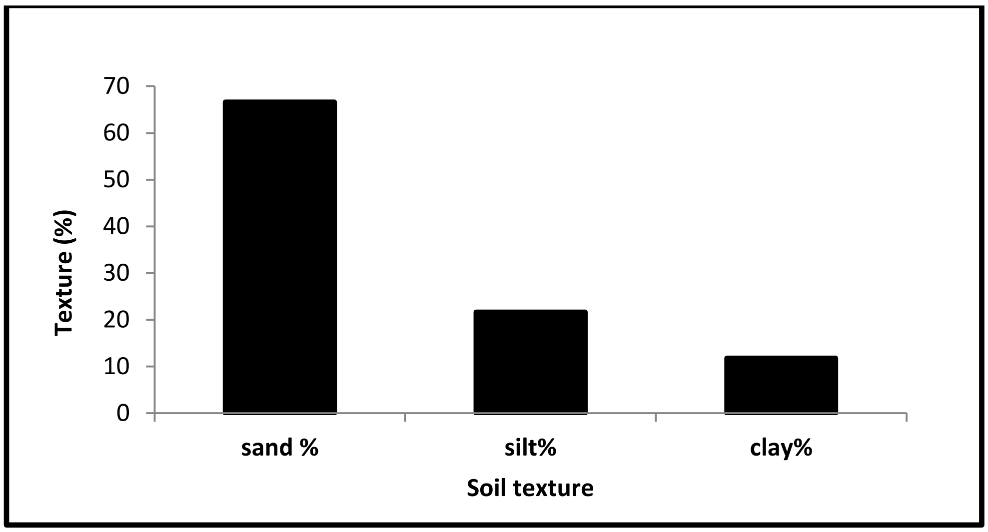


Figure 17: Percentage distrubtion of soil particle sizes

5.8.1.2. The Relation between Communities and Soil Properties

Soil physical and chemical properties influence plant growth in many ways such as moisture availability, nutrient availability and cation exchange capacity. The soil physico-chemical properties revealed that the difference between communities could be partly explained by the variations in soil texture and chemical properties. The proportion of sand particles was highets in community type 1 and lowest in community type 3 while that of silt was highest in community 3 and lowest in community 4 (Table 23). Clay particles had the highest proportion in community 2 and the lowest in community 1. The percent organic matter, the total nitrogen content and the available Phophorus in the soil also vary among the communities. Communities show in decreasing order of soil organic matter (SOM) contents are 1, 3, 5, 4 and 2 whereas total nitrogen from highest to lowest magnitude include communities 1, 3, 5, 4 and 2, and the available phosphorous (ppm) in decreasing order is community 3, 1, 5, 4 and 2.

Table 23: Relationships between soil properties and the communities

Soil properties	community 1	community 2	community 3	community 4	community 5
%Sand	68.33	65.75	64.1	67.57	66.52
%Silt	21.54	21	22.9	20.57	22
%Clay	10.08	13.25	12.9	12	11.47
pH	7.6	7.8	7.6	7.7	7.6
CEC	30.61	38.87	33.12	39.87	39.34
OM	2.83	2.00	2.48	2.27	2.36
TN	0.188	0.105	0.173	0.139	0.141
Av. P	3.43	1.64	4.51	2.96	3.03

5.8.1.3. Distribution of Textural Classes in the Community Types

The distribution of textural classes of the soil samples in the five community types are shown in Figure 18. The five textural classes identified in the study areas were sandy loam, sandy clay loam, clay loam, loamy sand and loam. Only community 3 had all the five textural classes followed by community 2 and 5 which had three and community 1 and 4 which had only two. The percentage of sandy loam was highest in community 1, community 2 and 5, and least in community 3 and 4. The dominant texture in all the communities was sandy loam followed by sandy clay loam. In general, the soil texture sandy loam occurred in all the five community types. The loamy sand in community types 1, 2, 3 and 5; the sandy clay loam in community 2, 3, 4 and 5 while the clay loam and loam soils were found only in community type 3.

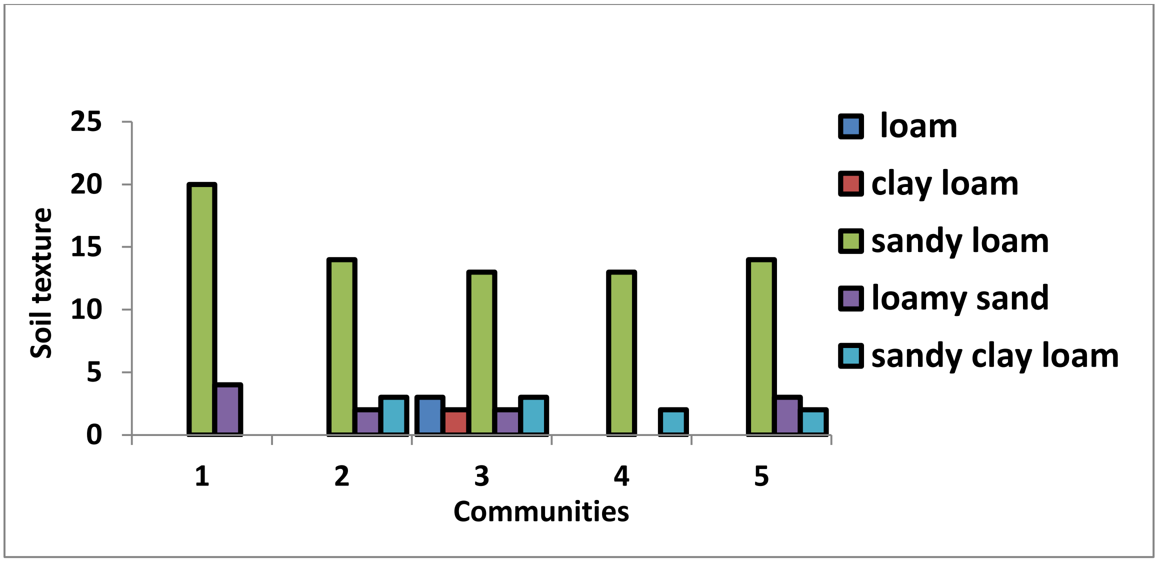


Figure 18: Distribution of soil textural classes in the community types

5.8.2. Soil Chemical Analysis

5.8.2.1. *Analysis of Variance (ANOVA) of the Soil Factors*

5.8.2.1.1. Soil pH

The analysis of variance (ANOVA) of pH indicated that there was a significant difference at p = 0.05 level (Table 24). The mean pH of the soil ranges from neutral (7.0 - 7.3) to strongly alkaline (8.5 - 9.0). pH of a soil could be affected to certain extent by vegetation mainly herbaceous species because grasses produce new growth each year, hence, they may utilize and deposit more exchangeable bases on the soil surface keeping the soil pH high (Troeh and Thompson, 1993).

Table 24: The ANOVA for pH

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.625	2	.812	4.435	.015
Within Groups	15.936	87	.183		
Total	17.561	89			

Based on the Tukey post hoc test, three comparisons were made but there were 6 test results (Table 25). *Kara* and *Rakata (p = 0.032),* and *Rakata* and *Atsmi-harmaz (p = 0.030)* were significantly different while *Atsmi-harmaz* and *Kara* were not significantly different.

Table 25: Tukey HSD for the pH of the three sites

(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.
Kara	*Rakata*	-.28333*	.11051	.032
	Atsmi-harmaz	.00333	.11051	.999
Rakata	*Kara*	.28333*	.11051	.032
	Atsmi-harmaz	.28667*	.11051	.030
Atsmi-harmaz	*Kara*	-.00333	.11051	.999
	Rakata	-.28667*	.11051	.030
*. The mean difference is significant at the 0.05 level.				

5.8.2.1.2. Soil Organic Matter (SOM)

To assess whether significant differences exist between the three area closures, analysis of variance (ANOVA) for soil organic matter was computed (Table 26). As a result significant difference (p = 0.000) in mean value of soil organic matter content was observed at 0.05 level.

Table 26: The ANOVA for soil organic matter of the three closed sites

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13.360	2	6.680	9.395	.000
Within Groups	61.860	87	.711		
Total	75.220	89			

Tukeys HSD (Table 27) revealed that there was a significant difference between the K*ara* and *Atsmi-harmaz closed* areas at p = 0.001 and also between the *Kara* and *Rakata* cloed areas at p = 0.002.

Table 27: Tukey HSD for soil organic matter of the three closed sites

(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.
Kara	*Rakata*	.78100*	.21772	.002
	Atsmi-harmaz	.84933*	.21772	.001
Rakata	*Kara*	-.78100*	.21772	.002
	Atsmi-harmaz	.06833	.21772	.947
Atsmi-harmaz	*Kara*	-.84933*	.21772	.001
	Rakata	-.06833	.21772	.947
*. The mean difference is significant at the 0.05 level.				

5.8.2.1.3. Total Nitrogen (TN)

There was a significant difference in the means of the total nitrogen present in the three closed areas at p = 0.05 (Table 28).

Table 28: The ANOVA for Total Nitrogen

Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.139	2	.070	20.029	.000
Within Groups	.302	87	.003		
Total	.442	89			

The Tukey post hoc test revealed that there was a significant difference between *Kara* and *Rakata* and *Kara* and *Atsmi-harmaz* at p = 0.05 in the levels of total nitrogen prcent in the soil of the three sites (Table 29).

Table 29: Tukey HSD for the total nitrogen of the three sites

(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.
Kara	*Rakata*	.08910*	.01522	.000
	A. harmaz	.07627*	.01522	.000
Rakata	*Kara*	-.08910*	.01522	.000
	A. harmaz	-.01283	.01522	.677
A. harmaz	*Kara*	-.07627*	.01522	.000
	Rakata	.01283	.01522	.677
*. The mean difference is significant at the 0.05 level.				

5.8.2.1.4. Cation Exchange Capacity (CEC)

Analysis of variance (ANOVA) of the cation exchange capacity of soils of the three areas revealed that there was a significant difference in the mean CEC values between the three areas (Table 30).

Table 30: The ANOVA for cation exchange capacity

Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2017.588	2	1008.794	7.125	.001
Within Groups	12318.685	87	141.594		
Total	14336.273	89			

Tuckey's Pairwise Comparisons shared that there was a significant difference between soils in *Kara* and *Rakata*, and *Kara* and *Atsmi-harmaz* at p = 0.05 in cation exchange capacity (Table 31). There was no significant difference in this aspect between *Rakata* and *Atsmi-harmaz.*

Table 31: Tukey HSD for the CEC of the three sites

(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.
Kara	*Rakata*	-9.11067*	3.07239	.011
	Atsmi-harmaz	-10.77033*	3.07239	.002
Rakata	*Kara*	9.11067*	3.07239	.011
	Atsmi-harmaz	-1.65967	3.07239	.852
Atsmi-harmaz	*Kara*	10.77033*	3.07239	.002
	Rakata	1.65967	3.07239	.852
*. The mean difference is significant at the 0.05 level.				

5.9. Ordination Analysis

The influential environmental variables in the study area were altitude, pH, TN, OM, Ca, Mg, P and CEC (Table 32). RDA is eigenvalue-based and constrained form of ordination technique, which is used for arranging sample plots along the transformed vector of environmental factors. RDA is preferred for most ecological data sets since linear relationship is common between species and environmental variables.

Table 32: Biplot scores for constraining variables

Environmental variables	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Alt.	-0.908	-0.070	-0.290	0.019	0.129	0.059
pH	0.015	0.363	-0.114	-0.099	0.223	-0.211
TN	-0.334	-0.435	0.191	-0.134	0.292	0.070
Ca	0.207	0.151	-0.274	0.193	0.082	-0.314
CEC	0.347	0.180	-0.360	0.172	0.139	0.033
Mg	-0.002	0.444	0.197	0.067	0.130	0.233
EC	-0.081	-0.001	0.064	0.543	0.232	-0.115
K	0.341	0.199	0.168	0.268	0.049	0.213
OM	-0.241	-0.380	0.002	-0.164	0.320	-0.315
Sand	-0.190	-0.031	-0.147	-0.362	-0.100	0.274
Silt	0.078	-0.201	0.126	0.261	0.251	-0.100
Clay	0.170	0.213	0.082	0.241	-0.100	-0.227
P	0.066	-0.345	0.174	0.211	0.682	0.128
Eigenvalue	12.685	5.815	4.562	2.553	1.879	1.312
Proportion Explained	0.383	0.176	0.138	0.077	0.057	0.040
Cumulative Proportion	0.383	0.559	0.697	0.774	0.831	0.871

Table 32.1: Scores of inertia and proportion of constrained and unconstrained variances

	Inertia	Proportion
Total	135	1.00
Constrained	33	0.24
Unconstrained	102	0.76

Important environmental variables that affected the distribution of species and community types are shown in Table 32 and 32.1. The tables clearly show constraining variables and their correlation with RDA axes, eigenvalue, proportion of variance explained and cumulative proportion. The RDA showed that the dominant environmental variable select the gradient correlation with the first RDA axis were altitude, CEC and K while pH, TN, Mg and OM were the most dominant that showed the greatest correlation with the second RDA axis. The presence of EC, sand, silt and clay showed the greater correlation with the third axis whereas P was highly correlated with the sixth axis (Table 32). The total inertia, or variance (in species dispersion) in the data set was 135 and the first axis had 9.52% of the total variation in species composition (12.85/135 =0.095, where 12.85 is eigenvalue of the first axis, RDA1, and 135 is total inertia). In this regard, there is a total inertia of 135 and the constraint variables explain a total of 33 of the inertia, which is about 24% leaving about 76% unexplained. The eigenvalue section allows to realize both in terms of inertia explained and proportion explained which axes contribute significantly to the explanatory power of the RDA (the constrained) and the unexplained variance (the unconstrained). The total inertia in the species data is the sum of eigenvalues of the constrained and the unconstrained axes. Thus, explained inertia, compared to total inertia, can be used as a measure of how well species composition is explained by the variables.

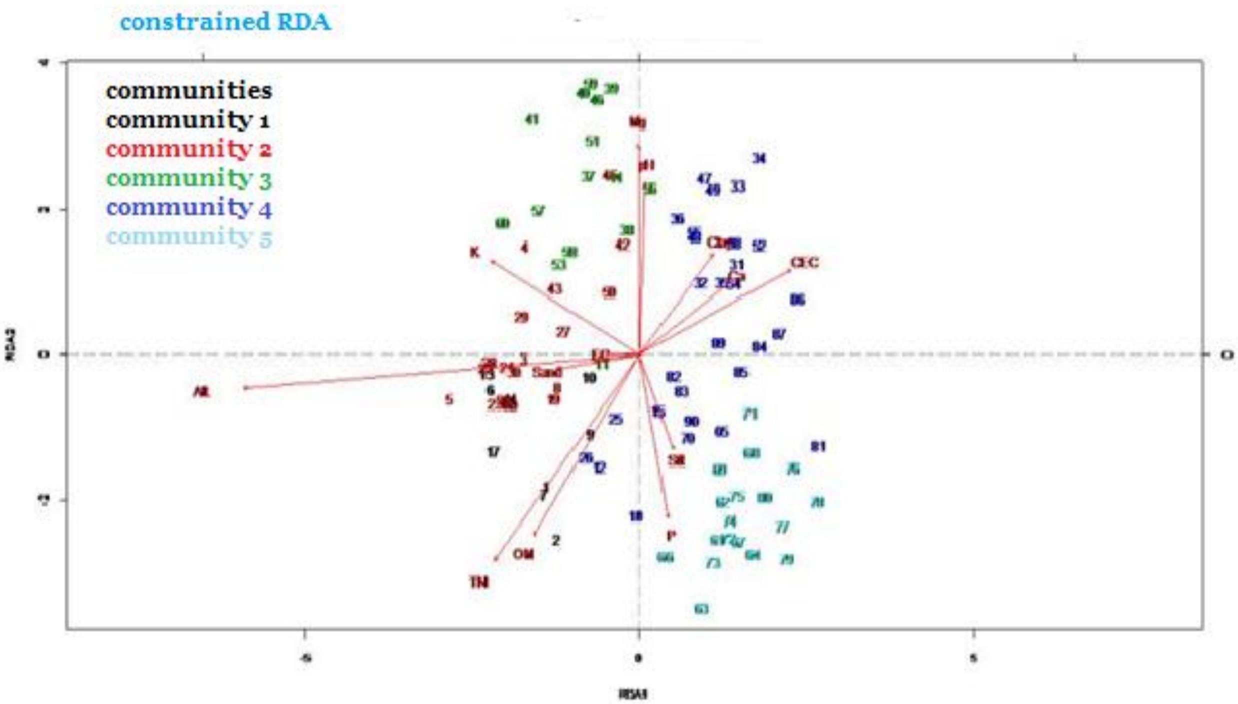


Figure 19: RDA ordination diagram of community types and environmental variables

The distributions of community type 4 was determined by CEC, clay and Ca as most of the sample plots were strongly correlated with these factors while that of community type 1 was strongly influenced by TN and OM. The distribution of community 2 was determined by altitude, K and partially influenced by EC while that of species in community type 3 was strongly influenced by pH and Mg. Along the P and silt axis, community type 5 was dominated (Figure 19). The small angle between OM and TN, between P and silt, between Mg and pH suggests a strong correlation between these environmental variables.

Table 33: Maximum significant correlation tests of vector fitting variables

Environmental variables.	RDA1	RDA2	r2	Pr(>r)
pH	0.0557	0.9984	0.1165	0.001 ***
EC	-0.9958	-0.0913	0.0066	0.736
Na	0.5836	0.8120	0.0077	0.708
K	-0.8518	0.5239	0.1564	0.002 **
Ca	0.8447	0.5352	0.0602	0.070 .
Mg	0.0113	0.9999	0.181	0.002 **
CEC	0.9130	0.4081	0.1454	0.003 **
TN	-0.6408	-0.7677	0.2795	0.001 ***
OM	-0.5790	-0.8153	0.179	0.001 ***
P	0.1832	-0.9831	0.1138	0.005 **
Alt.	-0.9995	-0.0322	0.8229	0.001 ***
Sand	-1.0000	-0.0051	0.0355	0.205
Silt	0.3196	-0.9475	0.0524	0.089 .
Clay	0.6722	0.7404	0.0651	0.060 .

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

P values based on 999 permutations.

RDA showed the maximum correlation (Table 33) significantly with the environmental variables whereas implications from the r-squared (r2) explained that the correlation can be expressed in proportions or percents.

5.9.1. Species Accumulation Curve (SAC)

Species Accumulation Curve of each site (Figure 20) shows the average number of new species included as the number of plots increased. The curve rises radically in the first 10 sample plots followed by moderate rising between sample plots 10 to 15. The curve continues to rise gradually between sample plots 15 to

20 and above sample plots 20 rises very gradual until maximum number of species is encountered.

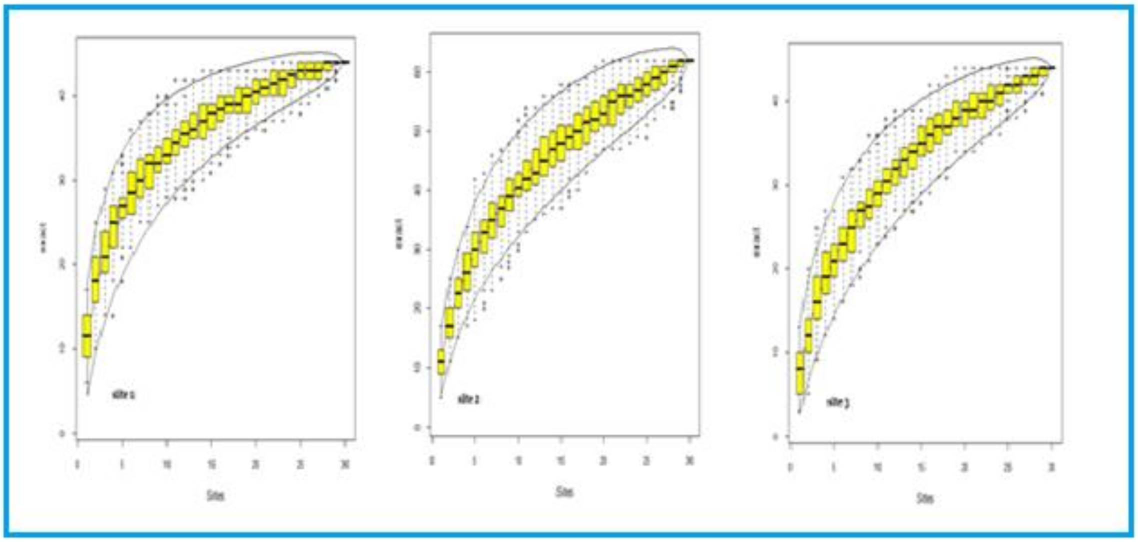


Figure 20: Species accumulation curve of each of the three sites

Species accumulation curve is useful to show how much of the species in a given area is successfully enumerated in a given area to get a reliable estimation of the species richness. According to Rice and Westoby (1983) and Oskanen (2011) as the collection increases the rate of discovery of new species declines steadily (Figure 21). Scheiner (2003) also noted that as the sampling areas increased the observed species richness gradually increased as well because more individuals get included in the sample, hence, sampling from large areas are more heterogeneous than small areas. When the samples have been sampled sufficiently or as more species are collected, the curve tends to be flatten out. However, due to the unclear boundaries of ecological communities, they often do not reach an asymptotic value because as the sampling effort increases, so is the number of slightly differing or rare species increase. Where there is high evenness the curve bends at the end, but where there is low evenness the curve is straight as shown at the beginning of the curve. The species accumulation curve tends to rise sharply at the beginning and slope very gradually towards the end of the curve. According to Fisher (1940) species never end, but the rate of increase in their numbers often slows down.

The species accumulation curve rose radically with the first 20 sample plots (Figure 21), thereafter between sample plots 20 to 40 the rising become immediate gradual between sample plots 40 to 60 and finally. Above sample plot 60 the rise become very gradual until the maximum number of species was encountered.

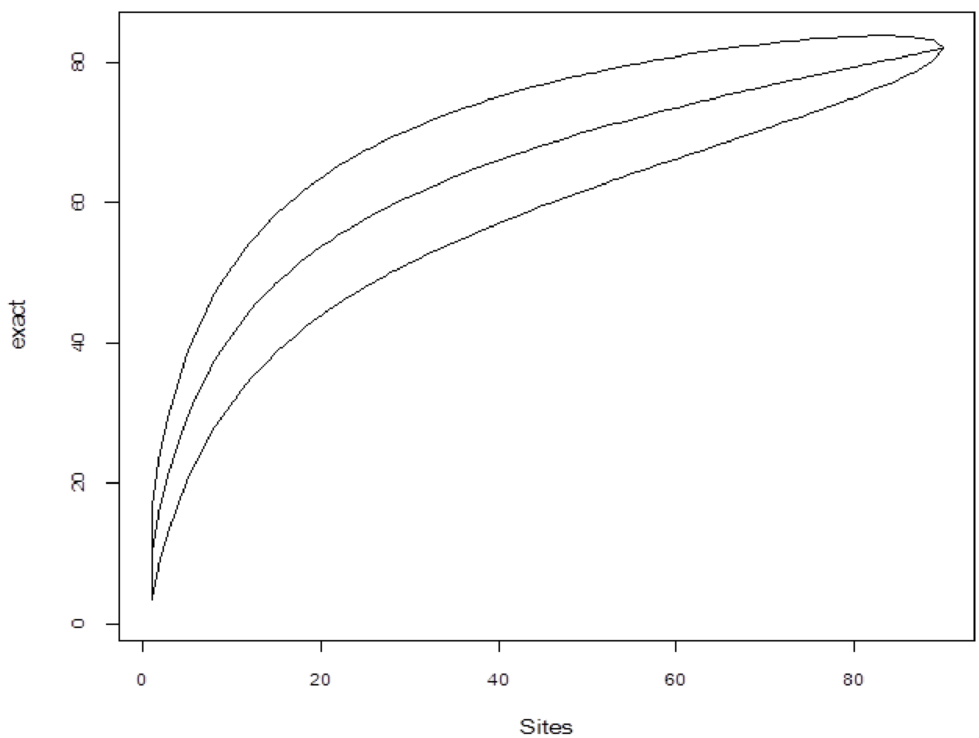


Figure 21: Species accumulation curve showing total species richness

A boxplot is a standardized way of displaying the distribution (spread) of data based on the five statistical summaries to convey the information such as the minimum, maximum, median, the first quartile (Q1) and the third quartile (Q2) data values. The box plots of the data shows that site 2 scores are more spread out relative to the median, whereas site 1 and 3 scores are clustered closer to the median (Figure 22). They have not the same average because their medians are not the same. Comparing the medians and interquartile range (IQR) shows that there is far more variation in the richness of site 2 from site 3 and site 1. Similarly, comparing the box plots also shows that site 2 is more species rich than site 1 and 3.

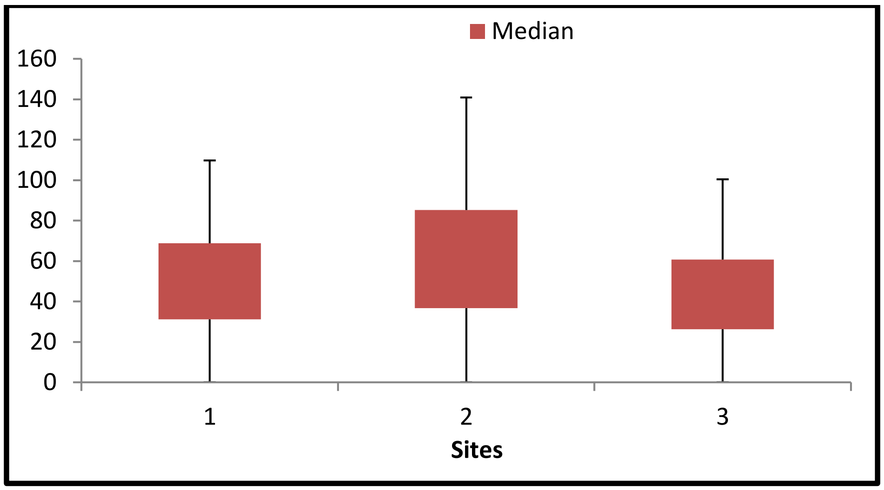


Figure 22: Shows the box and whisker plots of the three sites

The percentage of the boxplot was expressed in Table 34. Therefore, one-fourth (25%) of the data were distributed below the first (or lower) quartile (Q1), and three-fourths (75%) distributed above. One-half (50%) of the data distributed below the median and one-half (50%) distributed above and three-fourths (75%) of the data were below the third (or upper) quartile (Q3), and one-fourth (25%) were above.

Table 34: The percentage distribution of the boxplot

	Site 1 %	Site 2 %	Site 3 %
Maximum	26.71	29.11	29.04
Upper quartile (Q3)	24.89	26.17	26.24
Median	22.76	22.77	22.77
Lower quartile (Q1)	18.97	17.25	17.33
Minimum	6.68	4.69	4.62
Total%	100	100	100

5.9.2. Species Rank Abundance Curve (RAC)

A rank abundance curve provides a visually representation species richness and species evenness. Species richness can be viewed from the number of different species on the graph and species evenness can be inferred from the slope of the graph. A steep or vertical slope indicates low evenness because high ranking species have much higher abundances but fewer than the low ranking species. A shallow slope indicates high evenness because of the abundance of different species show relatively similar patterns. Species are ranked in descending order of abundances from the most abundant to the least abundant. A graph is constructed with the rank number on the x-axis and the species abundance on the y-axis. The resulted graph shows a wider curve distribution on the x-axis implies the higher the species richness (Figure 23). At the left top of the rank abundance curve, there are a few very abundant species, whereas in the middle of the curve, there are species with a moderate abundance and finally at the bottom end of the right side of the curve (tail of the curve), a few very rare species are found. *Acacia tortilis* was ranked 1st since it had the highet total abundance of 326, while *Ximenia americana* with the total abundance of 1 was ranked 82nd. In this regard, the five species with high ranking and relative abundance were *Acacia tortilis* 326 (9.52%), *Cadia purpurea* 301 (8.79%), *Acacia etbaica* 236 (6.895%), *Acacia hockii* 198 (5.78%) and *Grewia tembensis* 175 (5.11%).

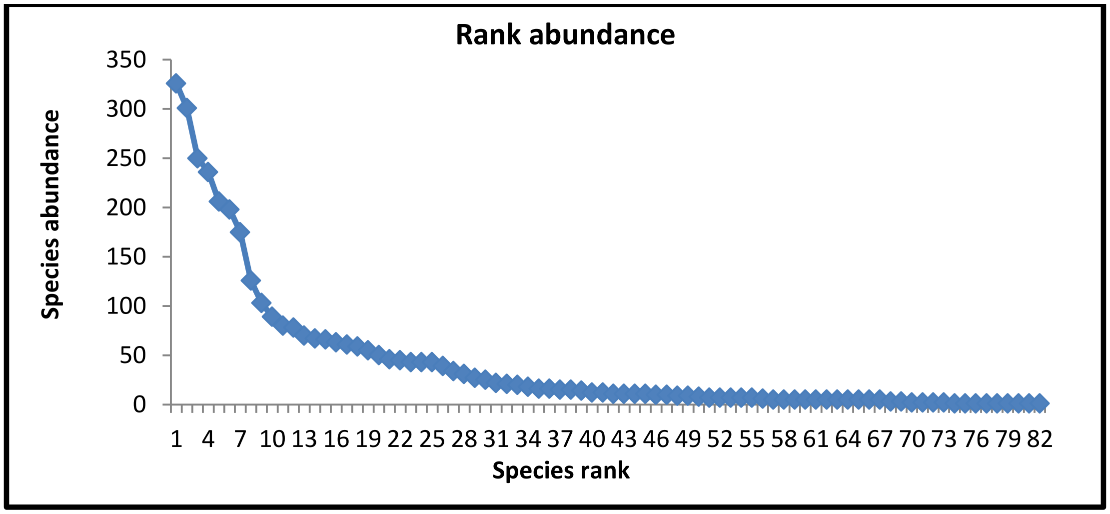


Figure 23: Rank-abundance distribution

5.9.3. The Rank Frequency Distribution Curve

Frequency distribution indicates how the various species are dispersed in sample plots. Species are ranked in order of decreasing abundance from the most frequently distributed to the least frequently distributed (i.e. from the most common to the rarest) and a graph is constructed with the rank frequency number on the x-axis and the frequency abundance on the y-axis. In the rank frequency distribution curve, usually, at the beginning there are a few very frequent species; in the middle, most species are with a moderate frequency and a few very rare species at the end of the curve (Figure 24). The result shows that *Grewia tembensis* was ranked 1st some of had the highest frequency (70), while *Ximenia americana* had the largest frequency (1) was ranked 82nd. In this respect, the five species with high ranking frequency and percentage frequency were *Grewia tembensis* 70 (78%), *Acacia tortilis* 60 (67%), *Barleria eranthemoides* 54 (60%), *Acacia etbaica* 50 (56%) and *Cadia purpurea* 46 (51%) (Appendix 8).

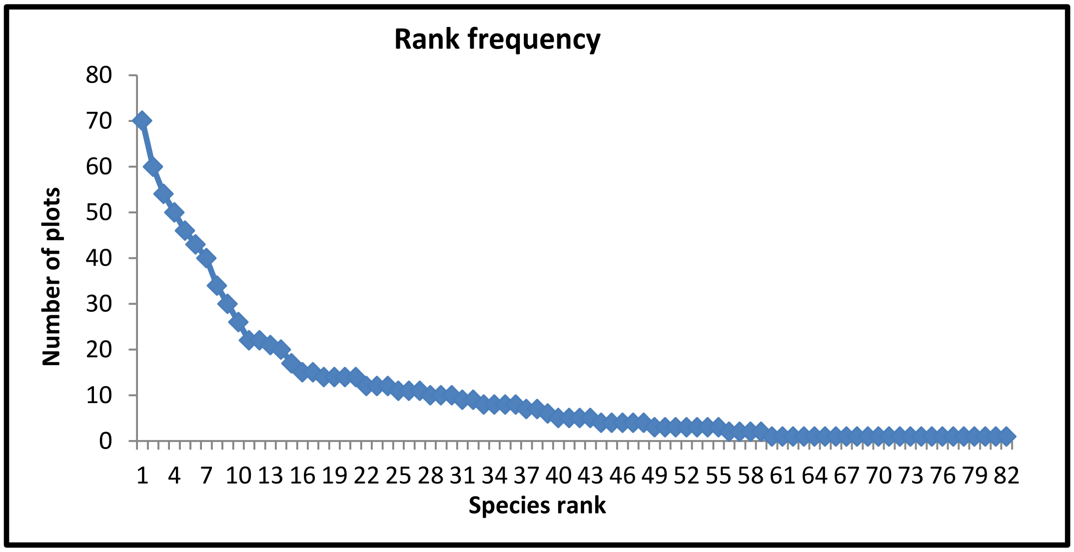


Figure 24: Rank frequency distribution

In addition, the rank abundance curve is accompanied by species richness against ranked sample plots. Figure 25 shows the distribution of species richness in each sample plot. The plots towards the beginning have the highest species richness and ranked 1st whereas plots towards the middle have high number of species with intermediate abundance and plots towards the end of the curve had the lowest species richness and showed the lowest rank. In this regard, the first five plots with high ranking were plot 7 with species richness 17, plot 46 with species richness 17, plot 21 with species richness 16, plot 23 with species richness 16, plot 37 with species richness 16.

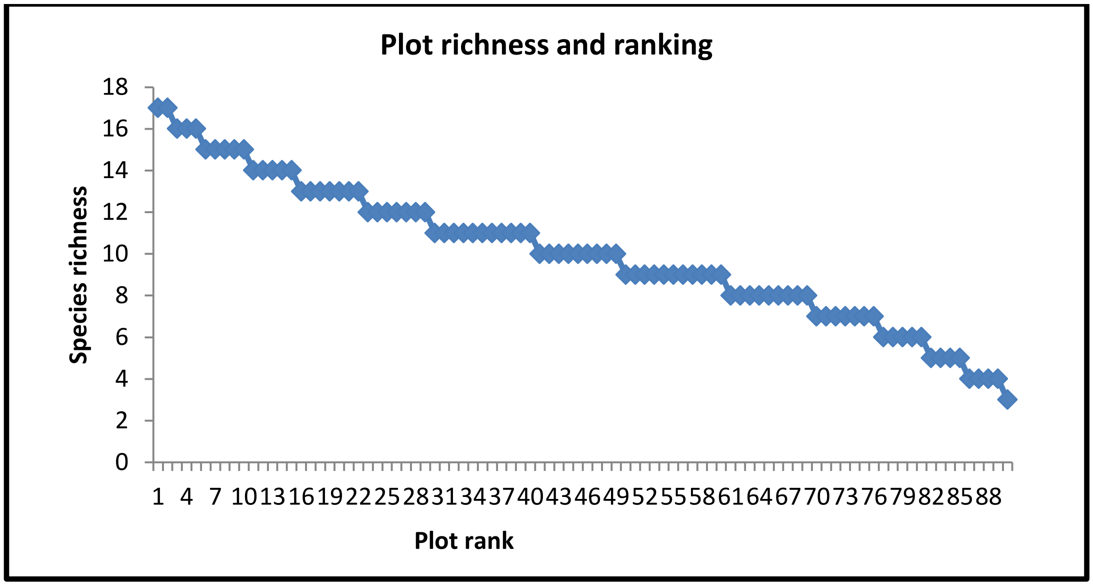


Figure 25: Species richness against ranked sample plots

5.10. Relationships among the Environmental Variables

Pearson's correlations test was applied to check if there was any correlation among the environmental variables. Relationships between the environmental variables are shown in the correlation coefficient table (Table 35). The results show that the variables which display strongly positive Pearson's correlation coefficient (r) is between CEC and Ca (r = 0.908), Ca and pH (r = 0.821), CEC and pH (r = 0.771), OM and TN (r = 0.706), Ca and clay (r = 0.655) at p = 0.01 level and the strongly (highest) negative correlation were between Ca and Na (r = - 0.841), Na and pH (r = - 0.829), CEC and Na (r = - 0.783), clay and sand (r = - 0.720) at p = 0.01 level. In addition, there was a positive significant correlation between K and EC (r = 0.270), TN and pH (r = 0 .267), P and TN (r = 0.252), P and K (r = 0.251) at p = 0.05 level and negative significant correlation between CEC and K (r = - 0.232), Ca and K (r = - 0.222) at 0.05 level.

Table 35: Pearson's product correlation coefficients (r) between environmental variables

	pH	Sand	Silt	Clay	EC	Na	K	Ca	Mg	CEC	TN	OM	P
pH	1.00												
Sand	-0.310	1.00											
Silt	-0.283	-0.588	1.00										
Clay	0.619	-0.720	-0.136	1.00									
EC	0.580	-0.315	-0.149	0.513	1.00								
Na	-0.829	0.337	0.275	-0.646	-0.644	1.00							
K	-0.073	0.040	-0.061	0.004	0.270	0.164	1.00						
Ca	0.821	-0.402	-0.193	0.655	0.606	-0.841	-0.222	1.00					
Mg	-0.385	0.237	-0.057	-0.243	-0.314	0.483	0.200	-0.437	1.00				
CEC	0.771	-0.387	-0.193	0.643	0.563	-0.783	-0.232	0.908	-0.382	1.00			
TN	0.267	-0.068	-0.080	0.141	0.364	-0.438	0.167	0.216	-0.100	0.137	1.00		
OM	0.099	0.069	-0.107	-0.010	0.207	-0.190	0.047	0.000	0.043	-0.134	0.706	1.00	
P	-0.042	-0.093	0.133	0.000	0.216	0.016	0.251	-0.050	0.021	0.004	0.252	0.086	1.00

6. DISCUSSION

6.1. Floristic Composition and Diversity

A total of 133 plant species belonging to 45 families were recorded from the study area. Considering the species accumulation curve (Figure 20), maximum numbers of species were recorded. However, the number of species is limited to 133 probably due to the observed disturbances such as anthropogenic activities, grazing pressures and frequent droughts. Some species were dominant and diverse, this could have been due to their ability to successfully exploit limited resources and adapt to grazing pressures more than other species. Some authors (Connell and Slatyer, 1977; Grime, 1979) explained that different plant species have different strategic responses to exploit different environmental resources. For instance, some plants have unique tolerances to factors like solar radiation, temperature, moisture and nutrient levels. These differences in responses or tolerances cause different species to have a competitive ability in exploiting resources over others.

Nearly half of the families recorded in the study area were rare because they were observed only once. Since greater number of rare families was observed, this indicates a richness of families and suggests great diversity in the area. The data (Table 3) suggested that many of the families in the study area were not occurred very frequently because human influence is the major factor that impacts on the occurrence of rare species through changes in habitats. Several studies (Fiedler, 1986; Fiedler and Ahouse, 1992; Cowling, 1990; Gaston, 1994)) have suggested that rarity of species can be caused by various factors such as anthropogenic pressures, overharvesting, habitat loss, grazing and long generation time.

Families that have diverse number of species might have developed mechanisms to help them to survive on different environments. The family *Fabaceae* has the highest proportion (13.53%) of species in the study area. McKey (1994) explained that the reason for this family having a number of successful species compared to other families were due to the presence of compound leaves with very small leaflets which serve as water conserving devices in some species, some are too thorny as a defence mechanism against browsers, some have deep root systems to harvest moisture and some fix atmospheric nitrogen to improve soil fertility through the symbiotic bacteria in their root nodules. Sprent (2001) noted that the unique ecological role of several members of the family was nitrogen fixation and hence they served as habitat specialists. Their strong preference for semi-arid to arid habitats is related to a nitrogen-demanding metabolism, which allows them to easily establish themselves on disturbed areas where soils are eroded and rainfall erratic habitats. In the study area, *Acacia* species were the important component of the ecosystem diversity. They were dominant on road sides, in scrub lands, and in closed and open habitats. This transformation may be aggravated by rainfall fluctuations. According to Melaku Bekele (1998), most of the northern region, particularly Tigray lost its natural vegetation cover; this might contribute for the change of plant species better adapted to the dryland habitats. Middleton and Thomas (1997) noted that in semi-arid areas, the rate of annual evapotranspiration is higher than the actual mean precipitation, hence, such areas are mainly dominated by thorny species armed with prickles or spines to prevent the challenges of rainfall fluctuation.

When the data is analysed separately in each site, the *Acacia* species is dominant and common in all the three sites and represented by different species such as *Acacia tortilis* which is dominant at *Kara*, *Acacia etbaica* at *Rakata* and *Acacia hockii* at *Atsmi-harmaz*. Currently, the earth is losing much of its precious plant diversity due to anthropogenic activities, intensive grazing and erosion while species in the *Fabaceae* are amazingly increasing; they are less susceptible to disturbances and are playing a major role in providing nutrients for many terresterial ecosystems (McKey, 1994). In addition, Marshall *et al.* (2012) also described that the *Fabaceae,* particularly the *Acacia* species dominate wide areas of the east African woodlands, wooded grasslands and bushlands in many ecosystems from low altitudes to high altitudes with erratic rainfall and they range from small shrubs to large trees.

Based on the collected data and field observations in this study, the diversity and species composition in the area is declining and progressively being replaced by *Acacia* species because they are best-adapted to the environmental conditions in the area. Several authors have reported that species diversity were relatively abundant in the past from the evidences of *scattered remnant forest patches* (Friis, 1992; Tamirat Bekele, 1993) and, *fossil pollen* and *soil charcoal analysis* (Darbyshire *et al.,* 2003). This change in vegetation type to *Acacia* species may be related to the drought resistance and better soil seed bank of its layer (Bard *et al.,* 2000; Darbyshire *et al.,* 2003; Tsige Gebru, 2007).

Consequently, the vegetation of the area has shifted towards expansion of plants adapted to survive in dryland habitats. According to several authors (e.g., Singh and Singh, 1992; Plieninger *et al.,* 2004), these plants have a variety of specialized survival mechanisms that makes them successful in dryland conditions such as highly reduced leaves to decrease loss of water by transpiration (e.g., *Acacia* species), leaves into spines (e.g., *Euphorbia* and *Opuntia* species), tiny hairs on leaf surfaces to reduce air flow thereby reducing excessive evaporation (e.g., *Grewia* species) and fleshy or succulent leaves (e.g., *Aloe* and *Kalanchoe* species). However, some of the species (e.g., *Olea europea* subsp. *cuspidata*) are threatened or not common in many parts of the study area, their populations have reached irreversible limits due to anthropogenic pressures such as demand for fuelwood, construction materials and cultural practices, and frequent droughts and long generation time.

6.2. Natural Regeneration Status

The factor which affects the population size of seedlings and saplings in the natural woodland is mainly disturbances by local inhabitants such as tree and shrub cutting for different purposes before maturation. This has led to few densities of mature trees and low seed production. In addition, the rainfall fluctuation in the area has led to severe droughts which were caused phenological disruptions and in the long run led to poor regeneration of species. The presence in low canopy trees of the woodland causes high evapotranspiration which leads to moisture stress in the soil. According to Gerhardt (1996), Demel Teketay (1997) and Vieira and Scariot (2006) tree canopies are favorable as shelters for the early establishment of seedlings, however, areas with low canopy cover may lead to complete soil dryness which hinders the establishment of young plants.

On the other hand, several authors have suggested that factors that can contribute to the poor growth of seedlings may be due to the interactive influence of biotic and abiotic factors (Demel Teketay, 1996), anthropogenic pressures (Bhuyan *et al.* 2003), solar radiation intensities (Clark *et al.,* 1996), soil moisture stresses (Lawrence and Oechel, 1983), pathogen and herbivory (Khan, 2004), soil nutrient deficiencies (Beckage and Clark, 2003; Lwanga, 2003) and microenvironmental factors (Gause and Stone, 1979). Some of the woody species such as *Commiphora schimperi, Ximenia americana* and *Euphorbia candelabrum* did not show regeneration due to the absence of both seedling and sapling stages. Species which are characterized by the presence of only adults are expected in the end to face local extinction (Dalling *et al.,* 1998) or they may be at risk in future even if they are dominant at present (Malik and Bhatt, 2016) or they may be replaced by some other non-native (exotic) tree species in the future (Saxena and Singh, 1984). In this respect, Ashalata *et al.* (2006) also noted that natural regeneration status may be reduced if the number of species represented only by adults or if the exploitation of the vegetation is faster than the natural regeneration.

6.2.1. Seedling and Sapling Status

The regeneration status of the closed and grazed areas was determined as fair (68.12% and 45.24% respectively) because the density of sapling population was less than the population of seedlings and adults. Many authors (Kozlowski, 2000; Andrzejczyk and Twarog, 2003) described that an area with low precipitation and high evapotranspiration can put extreme stresses on natural regenerations. Most of the species are concentrated on poor regeneration such as *Boscia salicifolia* and *Osyris quadripartite, Cordia monoica* and *Maerua angolensis* due to tree and shrub cutting before maturation, rainfall fluctuation (which leads to phenological delay) and low canopy trees (cause soil dryness and hinders the establishment of young plants). Currently, rehabilitation of degraded lands through area closures is receiving great attention in many parts of the country; particularly in Tigray. However, inorder to rehabilitate effectively and sustainably, the degraded areas should be well studied their remnant vegetation whether they were species-poor or species-rich ecosystems from their past history. Wondie Mebrat (2015) suggested that for an area to be selected as an area closure should understand the local species; the history of the area, local soil conditions, local microclimatic factors and the roles that the remnant vegetation would play in the future.

When compared to the closed and grazed areas, the closed areas have higher number of seedlings and saplings than the grazed areas. This may be due to the protection and grazing differences. Zerihun Woldu and Backeus (1991) suggested that rehabilitation of degraded areas can be improved through avoiding or minimizing interferences by human and domestic animals. However, in the grazed areas, the seedlings and saplings of some unpalatable species were dense due to the removal of grasses and forbs through grazing, this reducing the competiton for space, water and nutrients, hence, it leading to an increase in the numbers of woody species. For instance, C*adia purpurea* is unpalatable to browsers and for that reason in grazed areas its regeneration has increased. Several authors (e.g., Burrows and Scanlan, 1988; Burrows, 1990; César, 1992; Kebrom Tekle, 1998) have suggested that heavy grazing normally leads to the progressive increase of unpalatable species, hence, they are frequently observed and becoming common in degaded areas. On the other hand McNaughton (1985) and Huston (1994) suggested that palatable species are normally expected to be severely affected by browsers to be stored in the soil as soil seed banks and in the long run grazing resistant species become dominant. However, Zerihun Woldu and Mohammed Saleem (2000) observed that if the grazing rate is limited within the carrying capacity of the grazed area, it could be viewed as an important agent in maintaining species diversity. In general, as shown in Figure 3, even though the seedling density was higher than that of the sapling density, the main difficulty is the transformation from the seedling stages to the sapling stages and from the sapling stages to the adult stages due to the adverse conditions such as defoilation, high solar radiation and rainfall fluctuations (Mekuria Argaw *et al.,* 1999; Khumbongmayum *et al.*, 2006; Getachew Tesfaye and Abiyot Berhanu, 2006).

Moreover, seedling, sapling and adult plant densities were highest in the closed areas than in the grazed areas (Figure 12) probably due to the influence of grazing where seeds cannot be stored in the soil as soil seed banks and the seedlings and saplings could not copewith the disturbance factors. Kitajima and Fenner (2000), in their study on ecology of seedling regeneration indicated that once seeds have germinated and seedlings have established, the next challenging problem is to reach seedlings to the sapling stages again the sapling stages to the adult stages due to moisture stresses, competition and physical damages.

6.3. Analysis of Vegetation Structure

Vegetation structure of the study area has the highest density in the lower DBH and lower height size classes, and decrease in density towards the higher DBH and height classes. The absence of tree species in the higher DBH classes indicated that the site represents young vegetation type may be due to deforestation of old trees in the past. A greater percentage of individuals in the lower size classes compared to higher size classes indicate fair survival of seedlings and saplings. According to Harper (1982), in the analysis of vegetation structure, the stages of trees such as the seedlings, saplings and adult trees are the key componens of the size class distributions which are the elements of diversity that allow the chance of recovery after disturbances.

Leak (1965), in his study of J-shaped distribution suggested that inverted J-shaped distribution shows a greater number of smaller tree species than larger tree species and successive reduction of individuals from one size class to the next. This probably suggests that the reproductive capacity of the woodland may be sufficient to sustain itself, and that is why it shows a fair status of regeneration capacity. Peters (1996) also observed that an inverted J-shaped distribution pattern of structure suggests the presence of small sized DBH and short tree species that are able to sustain a constant rate of regeneration. Leak (1965) and Peters (1996) suggested that there was a possibility that the loss of adult tree species will be replaced by the growth of individuals from the small sized classes and therefore this structure represents a self-sustaining plant population.

In addition, Lieberman *et al*. (1996) noted that the absence of larger trees revealed that the past disturbances of the woody species may have been due to anthropogenic related activities and severe natural and artificial disturbances. For instance, *Cadia purpurea* is preferred for its good fuelwood value and house construction materials. Many *Acacia* species such as *Acacia tortilis* and *Acacia etbaica* have also been extensively used for fuelwood rather than charcoal production probably due to strict control. According to Friis (1992), the vegetation of Ethiopia has been affected by anthropogenic activities for centuries. Accordingly, such a long history of deforestation probably resulted in a small tree and shrub dominated ecosystems.

As Figure 12 shows that the reason for variation of population structure may be either selective cutting by the local community or unfavorable ecological conditions. This indicates the requirement of conservation and well protection of the woodland from being changed or destroyed. This result is consistent with the findings of other studies like Steininger (2000) pointed out that the population structural patterns could be interpreted as an indication of variation in population changing aspects that may arise due to anthropogenic and livestock interventions. According to several authors (Simon Shibru and Girma Belcha, 2004; Demel Teketay, 2005), the species population patterns could provide important information about their regeneration status as well as to enhance evidence-based conservation and sustainable use.

6.4. Diversity and Similarity among the Study Sites

In general, the closed areas showed more diversity than the grazed areas except for the closed area in *Atsmi-harmaz* (Table 15) which was low in diversity and evenness than its surrounding grazed area. The increasing diversity of species in grazed areas is probably due to the increasing number of unpalatable species in the vegetation (O'Conner and Pickett, 1992). An assessment of palatable and unpalatable species in the study area showed that the grazed areas had higher number of unpalatable species compared to palatable species (Appendix 12). In addition, the reduction in the competitive capacity of the dominant vegetation through selective grazing may increase the diversity of species (McNaughton, 1985; McNaughton, 1993; Howe, 1999).

Habitat similarity helps to determine what the habitats have in common in terms of species. The similarity of the three closed areas was greater than 50% (Table 12) which implies that half of the species were common in the areas. The reason for this could be similarities in moisture, altitude, soil nutrients and the intensity of grazing. According to Magurran (2004), many vegetation samples have similar species composition and relative species abundance due to their occurrence in similar environments. The similarity between site I and site II; site I and site III; site II and site III was 58%, 51% and 56% resectively (Table 13). These results show that the three grazed areas had quite a bit of overlap in species composition and probably this could have been occured by the intensity of grazing together with the moisture stress. The highest similarity index value was recorded between site I and site III. They were similar in floristic composition because they have common species accounted by 53%.

6.5. Disturbance Intensities on the Vegetation

Cadia purpurea is normally found unpalatable by browsers but preferred by humans for fuelwood collection and construction of houses since it stays for several years undecayed under the soil. *Ziziphus spina-christi* is a spiny species and usually preferred for fencing houses and farms by the local people. *Acacia tortilis* and *Acacia etbaica* are used for fuelwood collection and fencing but charcoal production is not a serious problem as it was earlier probably due to strict control. *Grewia tembensis* and *Grewia mollis* are shruby species with highly palatable leaves by browsers. Increased human population accompanied by an increase in livestock grazing has been intensified disturbances in the woodland.

In this study, defoliation was noted in many species during the field work. For example, *Grewia tembensis* a shruby species affected to have been highly defoliated by browsers (Figure 26). Defoliation together with moisture stress in the area influenced phenology (leafing), which inturn slowed down ecosystem restoration because such plant species do not recover quickly from their damages. Several authors (e.g., Willard and McKell, 1973; Huston, 1994; Donaghy and Fulkerson, 1997) also reported that defoliation resulting from biotic pressures such as grazing reduces plant growth and photosynthetic capacity associated with the loss of leaf area.

In the study area the dried fuelwood resource is gradually diminished and no charcoal production probably due to strict control, however, people turn to cut the living trees and shrubs, dried at home and sell, while users use the extra energy by wetting as charcoal. Accordingly, the vegetation of the area is mainly affected by anthropogenic activities probably resulted in a small tree and shrub dominated ecosystems. According to IBC (2012) elimination of anthropogenic impacts is imposible unless vegetation management is improved. The process of reversing is very costy if changes are once established (Rosser and Manika, 2002).

Figure 26: Defoliated *Grewia tembensis*

Since the study area experiences severe drought, it is very difficult for the defoliated plants to recover. It has been suggested that plants respond to browsers and climate influences by morphological modifications such as developing small leaves and stunted growth forms to avoid the risks associated with early life phases (Roundy and Ruyle, 1989; Beniston, 2000). Accordingly, the vegetation of the study area is dominated by shrubs and small trees in order to copwith the adverse environmental conditions. Grazing is shown to reduce the accumulation of litter in the soil which often leads to an increase in the amount of bare ground and thus inturn reduces the amount of infiltration, hence, increase erosion and surface run-off (Figure 27).

According to Grime (1977), both stresses and disturbances are factors which reduce the diversity and density of plant species. Stresses are conditions that restrict growth for example, lack of moisture, nutrients and optimal temperatures. Disturbances on the other hand, are associated with the partial or total destruction of plants through the action of browsers, tree cutting, severe drought and erosion. In this study, the depeletion of vegetation was due to both stress and the disturbances.

Figure 27: Grazing leads to increase soil erosion and surface run-off

6.6. Vegetation Community Analysis

From the result of the hierarchical clustering, five plant community types were identified to represent the plant communities of the study area (Figure 13).

The *Cadia purpurea - Acacia tortilis* community is mainly composed of *Cadia purpurea* and *Acacia tortilis*. *Cadia purpurea* does not compete with other trees nor does exist under high canopy trees. It occurs where light hits in relatively empty spaces (gaps). Therefore, this species seems to avoid shade and it grows on rocky areas and where there is sunshine. It has the ability to grow bushy at the base which ecologically good in the control of soil erosion. *Cadia purpurea* is vulnerable to anthropogenic disturbances. However, it is amazingly resilient (returning to its original shape in a rapid recovery) after disturbances by sprouting vegetatively at the base. The *Cadia purpurea* is unarmed shrubby 1 to 3 m tall in height, the branches diverging from near the base and curving slightly outwards. This species is found to some extent at higher elevation of bare rock area and low water table landscapes mainly assocated with *Aloe camperi*. *Acacia tortilis* is a tree 3 to 10 m in height which is found in lower elevation scrubland topography and extends itself to the lower plain areas. Both species donot overlap, this probably due to the *Cadia purpurea* avoides itself from the shading effect of the canopy of *Acacia tortilis*. Wherever *Cadia purpurea* is present, anthropogenic interfrence is detected because it provides bright flame as firewood and as house construction material due to its resistance of decaying in the soil for several years.

The *Acacia asak - Aloe camperi* community*:* the dominant species in this community type is *Acacia asak*. The specific ecological characteristic of this typical species has very little competition capability with other tree species. Its survival environment is isolated mainly on rocky hillsides and stones away from other plants. On the other hand, the *Aloe camperi* is found in disturbed areas with species such as *Cadia purpurea, Carissa spinarum, Cordia sinensis, Euphorbia candelabrum, Maytenus senegalensis, Ziziphus mucronata* and *Acokanthera schimperi*. The climbers *Commicarpus plumbaginus* and *Sarcostemma viminale* were common in this community type. The herb layers including the species *Alternanthera punges, Xanthium spinosum, Argemone mexicana, Datura stramonium, Kleinia odora, Amaranthus caudatus, Setaria verticillata, Pennisetum pedicellatum, Chenopodium ambrosioides, Cyperus bulbosus* and *Cyperus rotundus* were recorded.

The *Acacia tortilis – Acacia etbiaca* community is characterized by the dominant trees *Acacia tortilis* and *Acacia etbaica*. *Acacia tortilis* is observed in all the three sites but dominantly occurred in *Kara* site. The ecological characteristics of this species include a greater environmental adaptability as compared with other species and its competition capability with other species is considered high. The other species associated with this community are *Acacia oerfota, Balanites aegyptiaca, Cadaba farinosa, Capparis tomentosa, Carissa spinarum, Cordia sinensis, Dichrostachys cinerea, Ziziphus mucronata, Withania somnifera, Opuntia ficus-indica, Ziziphus spina-christi*. The climbers *Cissus quadrangularis* and *Senecio hadiensis* were common in this community. The herb layers were represented by *Cyperus bulbosus, Tribulus torrestris, Cynodon* *dactylon, Parthenium hysterophorus, Pennisetum mezianum* and *Pennisetum villosum*.

The *Barleria eranthemoides* - *Aloe camperi* community: in this community type, *Barleria eranthemoides* is the dominant ground layer herb while *Aloe camperi* is the dominant succulent shrub. When the *Aloe camperi* in this woodland is observed in detail, it is often seen at places such as roadsides and degraded areas. The ecological characteristics therefore appear to be in large environmental adaptability, as well as in a place with many disturbances. It does not exist under high tree canopies but it exists where light hits in relatively empty spaces. *Aloe camperi* is comparatively resilient vegetetively (able to resprout better quickly) after disturbance. This community is associated with species such as *Acacia etbaica, Cadia purpurea, Euclea racemosa subsp. schimperi, Acacia tortilis, Acacia mellifera, Ximenia americana, Ziziphus mucronata, Ormocarpum muricatum, Cordia sinensis, Commiphora schimperi* and *Balanites aegyptiaca*. The herb layers were represented by *Tribulus torrestris; Eragrostis papposa, Setaria verticillata, Cyperus bulbosus, Huernia macrocarpa* and *Pennisetum pedicellatum*. The climbers *Jasminum grandiflorum* and *Cissus quadrangularis* were common in this community type.

The *Acacia hockii* – *Acacia etbaica* community is characterized by the abundant tree *Acacia hockii* and well represented by *Acacia etbaica*. *Acacia hockii* is a small tree which grows mostly in *Atsmi-harmaz* at altitudes between 1653-1745 m. The tree stems are generally attaining a height of 3 to 5m. *Acacia hockii* grows in low water table and in rocky topography. As noted by Wickens *et al. (*1995), *Acacia hockii* is too thorny branches to cattle browsing, as a result it considered as abundant species. In addition, Burkill (1995) reported that *Acacia hockii* can tolerate very high temperatures, a poor soil environment and drier sites. This community type is mainly found in degraded and eroded areas because of the unbushy nature of the *Acacia etbaica* and *Acacia hockii*.

6.6.1. Species Diversity in the Communities

A community is said to have high species diversity when in many species nearly equal abundance are present while low species diversity suggests that relatively few successful species are abundant in a community (Zerihun Woldu *et al.,* 1999). Hamilton (2005) noted that high species diversity ensures ecosystem sustainability, no matter how small a species is, each has an important role to play either economically or ecologically. He further noted that measuring the diversity of a plant community is important because a diverse community benefits from a mixture of plants, for instance, some plants provide food for a variety of species, some can survive drought, some protect soil erosion and some can fix nitrogen to improve soil fertility. Because of this, a diverse community contains genetically diverse species which may be useful in long-term survival and stability of the community. In this regard, among the five communities, the diversity index (Table 21) shows that community IV has the highest species diversity followed by community II. Species evenness shows the relative proportional abundance of species in plots. Low evenness value implies the dominance of the environment by few species. Based on this, community II followed by community IV had the highest evenness values whereas community V had the least. Hence, communities with the highest evenness values, imply the species are more diverse whereas communities with the least evenness values, the species imply less diverse.

6.7. Ordination and Environmental Variables

The angles between two vector lines are not directly interpretable in terms of the environmental variable relationships but it can still infer approximately by observing on the vector lines. This means that vector lines pointing in the same direction have a high correlation. As many authors (ter Braak, 1987; ter Braak and Prentice, 1988) explained that variable arrows and ordination axes in the same direction are positively correlated, Variables with an angle of 90 degrees (perpendicular vectors) have a small correlation or not correlated and those pointing in opposing directions are negatively correlated. So, this is a slightly more descriptive interpretation compared with the interpretation based on angles in the correlation biplot. For instance, the vector arrows of the environmental variables pointing to the same direction are highly correlated with each other e.g., OM and TN are highly correlated with each other than with TN and P, and pH and Mg are highly correlated with each other than Mg and CEC.

6.8. Soil Analysis

6.8.1. Soil Physical Analysis

The particle size distribution results are shown in Figure 16. The results show that the sand conten has the highest proportion in the soil texture followed by silt and clay fractions. The dominance of the soil with sand content was probably due to the degraded and eroded soil of the area. Decrease in precipitations associated with high temperatures resulted in severe levels of moisture stresses. As a result, the dominance of sandy soils together with the rainfall fluctuations put extreme stresses not only on natural regenerations but also on artificial plantings every year. Most of the soils show high erodibility due to low organic matter content which implies high proportion of sand followed by silt. The organic carbon content of all the soil samples fell below 3%, which is considered erodible and high surface run-off is also more pronounced as noted by Thiagalingam (2008). In addition he gave the range of soil organic contents 0 – 3%, 4-10% and 10-20% which shows lower, medium and high contents respectively.

6.8.2. Soil Chemical Analysis

As indicated in the chemical properties of soils among communities, the average pH of soils in the 5 communities ranged between 7.6 and 7.8 (Table 23). Hence, all the communities had slightly to strongly alkaline soil pH. The percent organic matter and the total nitrogen content in the soil also vary among the communities (Table 23). High species diversity in community type 2 and 4 (Table 21) could partly be due to the low available phosphorous and total nitrogen contents of the soils. This agrees with the general belief that high nutrient rich soils would tend to support low species diversity (Huston, 1994). Rajaniemi (2002) observed that when nutrient levels are high, a few specialist species can competitively exclude the others, and therefore, the highest number of species is found in areas with low soil fertility. Hall and Swaine (1976) also reported that there was a negative relationship between species richness and soil nutrients.

6.8.2.1. Analysis of Variance (ANOVA) of the Soil Factors

The analysis of variance (ANOVA) for pH indicated that there is a significant difference (P = 0.015) at p = 0.05 level (Table 24). The pH of soil could be affected to some extent by vegetation mainly herbaceous species such as grasses since they produce new growth each year. They may consume and deposit more exchangeable bases on the soil surface keeping the pH high (Troeh and Thompson, 1993). According to Barnes *et al.* (1998), the effect of soil pH on the solubility of nutrients is great but the ranges of 6 to 7 promote the most readily availabe of plant nutrients. The pH of dryland soils could be affected by the accumulation of unleached exchangeable bases on the soil surface. Based on the Tukey post hoc test, pairwise comparisons (Table 25), *Kara* and *Rakata (p = 0.032), Rakata* and *Atsmi-harmaz (p = 0.030)* are significantly different while *Atsmi-harmaz* and *Kara* are not significantly different.

Among the three closed areas, ANOVA for soil organic matter (Table 26) was observed significant difference F (2, 87) = 9.395, p = 0.000 in mean value at 0.05 level. Based on the analysis using Tukey HSD (Table 27) revealed that there is a significant difference between *kara* and *Atsmi-harmaz* area closures at p = 0.001 and between *Rakata* and *Atsmi-harmaz* area closures at p = 0.002 at the 0.05 level. As observed from the multiple comparison (Tukey HSD) tests, area closures have significantly moderate %SOM compared to each other, eventhough, the difference between *Kara* and *Rakata* area closures are not significant at p = 0.947. The study by Descheemaeker *et al.* (2006) indicated that younger closed areas (less than 10 years) had less SOM concentration (1-3%) compared to soils under natural forest (1-6%). Similarly, according to Fernandez *et al.* (2008) semi-arid ecosystems have shown less plant cover, less soil organic carbon and less nitrogen contents.

Vegetation cover is higher in closed areas (2.6%) than in grazed areas (2.1%) due to the accumulation of leaf debris which consequently increases the SOM under the closed area. Soil organic matter under the grazed lands declined due to the long-term degradation and frequent drought in the area. Pandey and Singh (1991) the amount of soil organic matter is highest in closed areas but decreases with increasing grazing intensity.

The output of ANOVA indicated that there was a significant difference in means of the total nitrogen (TN) status among the three area closures (Table 28). Further analysis with the Tukey post hoc test revealed that there was a significant difference between *Kara* and *Rakata,* and *Kara* and *Atsmi-harmaz* (Table 29).Consistence with the higher SOM content observed in the soil under the *Kara* and *Rakata, Kara* and *Atsmi-harmaz*, the increase in vegetation cover could also be associated with the increase in TN. In fact, nitrogen is added in the soil not only by decomposition of organic matter but also by nitrogen fixation through micro-organisms from the atmosphere into the soil (Kumelachew Yeshitela and Tamrat Bekele, 2002).

The analysis of variance for cation exchange capacity computed at 0.05 level revealed that there is a significant difference in the mean CEC values among the three areas (Table 30). Cation exchange sites are found primarily on clay minerals and organic matter surfaces which are negatively charged and have the ability to attract positively charged ions (Curtis and Courson, 1981; Foth, 1990; Jordan, 1993; Kimmins, 1997; Saikh *et al.,* 1998; Brady and Weil, 2002). CEC also tends to rise particularly in the semi-arid areas where rainfall is insufficient to leach soluble salts away from the soil and evaporation exceeds the amount of precipitation which leads to the accumulation of basic cations on the soil surface.

6.9. Pearson's Correlation among the Environmental Factors

The relationships among the environmental factors are shown using the Pearson's correlation coefficient (Table 35). According to Donahue *et al.* (1983), soil texture is one of the investigated soil physical properties and an important soil characteristic because it determines water intake rates, water storage capacity, amount of aeration and soil fertility.

From the Pearson's correlation coefficient (r) results, there is a strong positive relationship between CEC and pH (r = 0.777, p = 0.000) since the pH of the soil ranges from neutral to strongly alkaline, as the pH increases, exchangeable bases (Ca^{2+}, Mg^{2+}, and K^{+}) increase, which inturn increase in CEC. Exchangeable base measurements were commonly made as part of the overall assessment of the potential fertility of a soil. Most of the soil's CEC occurs on clays (Donahue *et al.*, 1983) but in semi-arid areas where rainfall is insufficient to leach soluble salts away and evapotranspiration exceeds the amount of precipitation the exchangeable cations are concentraded on the surface of soils. Similarly, Pearson's correlation coefficient (r) between OM and TN (r = 0.706, p = 0.000) is a strong positive relationship implying that as the OM increases the TN increases.

On the contrary, sand particle is strongly negatively correlated with clay particles (r = - 0.720, p = 0.000) suggesting that as the sand increases the clay decreases. The soil textural class in the study area is sand content dominated. There is also a strong negative relationship between CEC and Na (r = - 0.783, p = 0.000), as one increases the other decreases because high Na occurs in soils where drainage system is poor which creates problems of low water flow in soils and availability for plants. Exchangeable sodium changes soil physical and chemical properties mainly by causing swelling and dispersion of clay and organic particles, resulting in limiting water permeability, air movement and mineral uptake by decreasing solubility and availability of calcium and magnesium ions (Sposito, 1989). Research works conducted on Ethiopian soils indicated that exchangeable Ca and Mg cations dominate the exchange sites of most soils and contributed higher to the total percent base saturation particularly in Vertisols (Mesfin Abebe, 1998; Eylachew Zewdie, 2001).

The soil in the study area is generally characterized by alkalinity (high pH), which might resulted in the distribution pattern of plant species in different sites. According to Ramakrishnan and Kumar (1976), alkaline soils are inhospitable media for most plants because high alkalinity influences different activities such as solubility of minerals; nitrogen fixation and nitrification, which in turn influence the distribution patterns of plants. That is the reason why drylands are with few vegetation patterns.

In addition, Landon (1991) described that alkaline soils have lower macronutrient availability such as phosphorus. According to Russell (1973) the great difficulties experienced by plants growing in alkaline soils are absorbing enough phosphate, because the nutrients are insoluble form that the roots can not bring enough of them into solution for their requirements. As indicated in the above, soil pH may affect different activities in the soil like the activity of beneficial microorganisms such as bacterial activities in the decomposition of organic matter and nitrogen fixation into nitrates (NO_3) in root nodules of legumes because most common microorganisms grow best at pH 6 to 8, but are severely inhibited above 8.5.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

The dominant families might have well developed adaptations in exploiting limited resources, highly tolerances in frequent droughts and grazing pressures. These differences in tolerances helped them to have highly competitive ability over others to survive successfully in the area. Most woody species have a high population density in the lower DBH and lower height classes. The densities of species decreased with increasing DBH and height classe sizes. The regeneration status was studied by taking 36 representative sample woody species. In this study, the overall regeneration status showed that the area is in a fair state of regeneration (55.56%) because the floristic composition is very much affected by anthropogenic related activities, grazing and rainfall fluctuations. The overall population structure of the plant species revealed that contribution of seedlings to the total population is highest followed by saplings. The fair status of the future woodlands may be sustained unless there are no major environmental stresses or interferences by anthropogenic activities. Five plant communities were identified and described with varying degree of species richness, evenness and diversity. Variability in population structure or vegetation change can be recognized from the analysis of tree species DBH. In addition, density class distribution of the woodland indicated that the high proportion of small sized individuals in the lower diameter classes confirming the characteristic of fair regeneration potential of the woodland area and rare occurrence of large individuals. This implies that the area is in a stage of secondary development due to the past disturbance of the original vegetation. Analysis of soil sample indicated that the soil texture distribution of the study area is mainly sand content dominated which is concentrated in the five textural classes such as the sandy loam followed by loamy sand, sandy clay loam, clay loam and loam which are associated with high erodibility. Thus, it needs attention through terraces and check-dams because of its highest erodible property due to low contents of organic matter. Grazing, selective cuttings, land degradation and erosion are the major threats to the area. Therefore, there is a need to develop and implement effective conservation systems in the area to facilitate optimal regeneration that assures the sustainable use of the vegetation in the future.

7.2. Recommendations

Conducting an ecological assessment of regeneration status and species composition is important for the sustainable utilization, appropriate controlling of the drivers of an ecosystem and appropriate conservation efforts on the remnant vegetations. Based on this study, the following recommendations would be forwarded.

1. To increase the woodland cover, diversity and richness of the study area and lands with remnant vegetation should be added to the closed area, thereby enhancing the level of natural regeneration and conservation activities.
2. The woodland of the study area is reduced through anthropogenic related activities such as construction materials, fuelwood collection and fencing which affect both regeneration and species composition. Therefore, by increasing awareness of the local communities living around the area closures concerning the value of the low-cost method of natural regeneration and the unmanaged anthropogenic activities should be minimized.
3. The growth, survival, and reproduction potential of some species showing ‘poor’ regeneration (e.g. *Osyris quadripartita, Olea europaea subsp. cuspidata, Cordia monoica* and *Cordia sinensis*) and ‘no’ regeneration (e.g. *Ximenia americana* and *Commiphora schimperi)* may be at risk in future. Therefore, continous assessment of species regeneration is required for their conservation and sustainable utilization.
4. The loss of ecosystem goods and services from the study area should be reversed by properly conserving the remnant species through natural regeneration by further practicing area closures.
5. Natural regeneration alone may not be enough for the recovery of vegetation in the degraded lands of the study area; instead it should be combined with planted seedlings to accelerate the recovery processes. In

such a way, restoration and environmental sustainability can be fulfilled in this area.

6. To promote the remnant vegetation recovery in the study area, plant species with colonizing abilities such as *Cadia purpurea, Acacia species, Euclea racemosa, Carissa spinarum* and others which have bushy growth should be encouraged in rehabilitation purposes to prevent serious soil erosion and surface run-off.
7. The soil textural type of the study area is sand dominated which is highly vulnerable to erosion. Hence, facilitating vegetation regeneration and sustainable practices of terraces and check-dams should be enhanced as a protection measure of the soil erosion.

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APPENDICES

Appendix 1: List of species recorded in the study sites with family, vernacular names and habit

S.no	Scientific names	Family	Vernacular names	Habit
1	*Abutilon hirtum* (Lam.) Sweet	*Malvaceae*	Awusho	Herb
2	*Acacia asak* (Forssk.) Willd.	*Fabaceae*	Tsada sabansa	Tree
3	*Acacia etbaica* Schweinf.	*Fabaceae*	Seraw/dodotae	Tree
4	*Acacia hockii* De Wild.	*Fabaceae*	Keyih sabansa	Tree
5	*Acacia mellifera* (Vahl) Benth.	*Fabaceae*	Tselem sabansa	Tree
6	*Acacia oerfota* (Forssk.) Schweinf.	*Fabaceae*	Ajo	Shrub
7	*Acacia seyal* Del.	*Fabaceae*	Keyh chea	Tree
8	*Acacia tortilis* (Forssk.) Hayne	*Fabaceae*	Kariwora	Tree
9	*Achyranthes aspera* L.	*Amaranthaceae*	Gurbe	Herb
10	*Acokanthera schimperi (*A.DC.) Schweinf.	*Apocynaceae*	Meroz	Tree
11	*Aerva javanica* (Burm.f.) Schultes	*Amaranthaceae*	Yefrash abeba	Shrub
12	*Agave sisalana* Perrine ex Engel.	*Agavaceae*	Gorengoria	Herb
13	*Aloe camperi* Schweinf.	*Aloaceae*	Ere	Herb
14	*Alternanthera pungens* Kunth	*Amaranthaceae*	Tseguram qaqumo	Herb
15	*Amaranthus caudatus* L.	*Amaranthaceae*	Hamlitlian	Herb
16	*Andropogon commutatus*	*Poaceae*		Herb
17	*Antopetitia* abyssinica A. Rich.	*Fabaceae*	Tataeta	Herb
18	*Argemone mexicana* L.	*Papaveraceae*	Medafe tilian	Herb
19	*Balanites aegyptiaca* (L.) Del.	*Balanitaceae*	Bedeno	Tree
20	*Barleria eranthemoides* R. Br.	*Acanthaceae*	Korohurusa	Herb
21	*Bidens pilosa* L.	*Asteraceae*	Tseneg	Herb
22	*Boscia salicifolia* Oliv.	*Capparidaceae*		tree
23	*Bothriochloa insculpta* (Hochst. ex A. Rich.) A. Camus	*Poaceae*		Herb
24	*Brachiaria eruciformis* (J. E. Smith) Griseb.	*Poaceae*	Long alternate flower	Herb
25	*Brassica rapa* L.	*Brassicaceae*		herb

26	*Cadaba farinosa* Forssk.	*Capparidaceae*	Qalqesha	Shrub
27	*Cadia purpurea* (Picc.) Ait.	*Fabaceae*	Shilaen	Shrub
28	*Calotropis procera* (Ait.) Ait. f.	*Asclepiadaceae*	Gelaeto	Shrub
29	*Calpurnia aurea* (Ait.) Benth.	*Fabaceae*	Hisawuts	Shrub
30	*Cappris tomentosa* Lam.	*Capparidaceae*	Harengama	Shrub
31	*Carissa spinarum* L.	*Apocynaceae*	Egam	Shrub
32	*Celosia antbelmintbica* Asch. In Schweinf.	*Amaranthaceae*		herb
33	*Chenopodium album* L.	*Chenopodiaceae*	Qibio	Herb
34	*Chenopodium ambrosioides* L.	*Chenopodiaceae*	Sinihinihi	Herb
35	*Cissus quadrangularis* L.	*Vitaceae*	Chewe	Climber
36	*Cleome gynandra* L.	*Capparidaceae*	Hamli abetiye	Herb
37	*Clerodendrum myricoides* (Hochst.) Vatke	*Lamiaceae*	Shewha	Shrub
38	*Commelina africana* L.	*Commelinaceae*	Gamale	Herb
39	*Commicarpus plumbagineus* (Cav.) Standley	*Nyctaginaceae*	Eziniechewa	Climber
40	*Commiphora schimperi* (Berg) Engl.	*Burseraceae*	Anqa	Tree
41	*Conyza hypoleuca* A.Rich.	*Asteraceae*	Tsaeda-kotsilo	shrub
42	*Conyza pyrrhopappa* Sch. Bip. ex A. Rich.	*Asteraceae*	Momotsi derasa	Shrub
43	*Cordia monoica* Roxb.	*Boraginaceae*	Sokoke	Shrub
44	*Cordia sinensis* Lam.	*Boraginaceae*	Matiyaro	Tree
45	*Cucumis dipsaceus* Ehrenb. ex Spach	*Cucurbitaceae*	Chegar baringo	Herb
46	*Andropogon commutatus* (Steud.) Stapf	*Poaceae*	Alejega (sunbelt)	Herb
47	*Cynodon dactylon* (L.) Pers.	*Poaceae*	Tehag	Herb
48	*Cynoglossum lanceolatum* Forssk.	*Boraginaceae*	Chaba	Herb
49	*Cyperus bulbosus* Vahl	*Cyperaceae*	Kuenti	Herb
50	*Cyperus dubius* Rottb.	*Cyperaceae*		Herb
51	*Cyperus rotundus* L.	*Cyperaceae*	Hishis	Herb
52	*Datura stramonium* L.	*Solanaceae*	Mestenagr	Herb
53	*Delphinium wellbyi* Hemsl.	*Ranunculaceae*		herb
54	*Dichrostachys cinerea* (L.) Wight & Arn.	*Fabaceae*	Harshamersha	Shrub

55	*Digitaria pennata* (Hochst.) T. Cooke	*Poaceae*		Herb
56	*Diplocyclos palmatus* (L.) C. jeffrey	*Cucurbitaceae*	Keyh baringo	Climber
57	*Dodonea angustifolia* L.f.	*Sapindaceae*	Tahises	Shrub
58	*Ehretia cymosa* Thonn.	*Boraginaceae*	Ulaga	Shrub
59	*Eragrostis papposa (Roem. & Schult.) Steud.*	*Poaceae*	Taftafo	Herb
60	*Euclea racemosa* subsp. *schimperi* (A. DC.) White	*Ebenaceae*	Kuliow	shrub
61	*Euphorbia candelabrum* Kotschy	*Euphorbiaceae*	Kulkual	Tree
62	*Euphorbia hirta* L.	*Euphorbiaceae*		Herb
63	*Euphorbia nubica* N. E. Br.	*Euphorbiaceae*	Tutubo	Shrub
64	*Euphorbia petitiana* A. Rich.	*Euphorbiaceae*	Hindukduk	Herb
65	*Euphorbia tirucalli* L.	*Euphorbiaceae*	Kinchb	Tree
66	*Ficus mucuso* Ficalho	*Moraceae*	Shegla (shanfa)	Tree
67	*Flueggea virosa* (Willd.) Voigt.	*Euphorbiaceae*	Achabti	Shrub
68	*Gomphocarpus fruticosus* (L.) Ait. f.	*Asclepiadaceae*	Tsebadimu	Herb
69	*Grewia tembensis Fresen.*	*Tiliaceae*	Chaka	Shrub
70	*Grewia mollis* A. Juss.	*Tiliaceae*	Reway	Shrub
71	*Grewia villosa* Willd.	*Tiliaceae*	Agobide (hable)	Shrub
72	*Harrisonia abyssinica* Oliv.	*Simaroubaceae*	Kilchm agam	Shrub
73	*Heliotropium cinerascens* DC. & A. DC.	*Boraginaceae*	Am-am-gimel (tsaeda)	Herb
74	*Heliotropium europaeum L.*	*Boraginaceae*	Am-am-gimel (tselim)	Herb
75	*Heliotropium indicum* L.	*Boraginaceae*	Chaba	Herb
76	*Hibiscus micranthus* L. f.	*Malvaceae*	Chenger amirakut	Shrub
77	*Huernia macrocarpa* (A.Rich.) Sprenger	*Asclepiadaceae*	Hamashiro	Herb
78	*Indigofera coerulea* Roxb.	*Fabaceae*		Herb
79	*Indigofera schimperi* Jaub. & Spach	*Fabaceae*		Shrub
80	*Indigofera spicata* Forssk.	*Fabaceae*	Yeayt misir	Herb
81	*Indigofera spinosa* Forssk.	*Fabaceae*		Shrub
82	*Jasminum grandiflorum* L.	*Oleaceae*	Tselim-habi	Climber

83	*Jatropha curcas* L.	*Euphorbiaceae*	Jatropha	shrub
84	*Justicia flava* (Vahl) Vahl	*Acanthaceae*		Herb
85	*Justicia odora* (Forssk.) Lam.	*Acanthaceae*	Kuniye agew	Shrub
86	*Justicia shimperiana* (Hochst. ex Nees) T. Anders.	*Acanthaceae*	Shimeja	Shrub
87	*Kalanchoe petitiana* var *petitiana* A. Rich.	*Crassulaceae*	Awoawo	Herb
88	*Kleinia odora* (Forssk.) DC.	*Asteraceae*	Birir	Shrub
89	*Lantana camara* L.	*Verbenaceae*		Shrub
90	*Leucas abyssinica (Benth.)* Briq.	*Lamiaceae*	Shewakarini	Shrub
91	*Maerua angolensis* DC.	*Capparidaceae*	Timbzaf	Tree
92	*Maerua sessiliflora* Gilg	*Capparidaceae*	Qabjale	Shrub
93	*Maytenus arbutifolia* (A. Rich.) Wilczek	*Celastraceae*	Atsi-atsi	Shrub
94	*Maytenus senegalensis* (Lam.) Exell	*Celastraceae*	Kebkeb	Shrub
95	*Ocimum gratissimum* L.	*Lamiaceae*	Seseg argi	Herb
96	*Olea europaea* subsp. *cuspidata* (Wall. ex G. Don) Cif.	*Oleaceae*	Awlie	Tree
97	*Opuntia ficus-indica* (L.) Miller	*Cactaceae*	Beles-kolkola	Shrub
98	*Ormocarpum muricatum* Chiov.	*Fabaceae*	Gurbo	Shurb
99	*Osyris quadripartita* Decn.	*Santalaceae*	Kerets	Shrub
100	Oxalis corniculata *L.*	*Oxalidaceae*		Herb
101	*Oxygonum sinuatum* (Meisn.) Dammer	*Polygonaceae*	Chewchewa	Herb
102	*Panicum maximum* Jacq.	*Poaceae*		Herb
103	*Parthenium hysterophorus L.*	*Asteraceae*	Kniche	Herb
104	*Pennisetum mezianum* Leeke	*Poaceae*	Sairi damoto	Herb
105	*Pennisetum pedicellatum* Trin.	*Poaceae*	Sairi areda	Herb
106	*Pennisetum setaceum* (Forssk.) Chiov.	*Poaceae*		Herb
107	*Pennisetum villosum* Fresen.	*Poaceae*	Sari labesha (big head)	Herb
108	*Portulaca foliosa* Ker.-Gawl.	*Portulacaceae*	Hamli qanto	Herb
109	*Portulaca oleracea* L.	*Portulacaceae*	Mehitsebi laga	Herb
110	*Prosopis juliflora* (Sw.) DC.	*Fabaceae*	Ajo woyane	Shrub
111	*Psiadia punctulata* (DC.) Vatke.	*Asteraceae*	Achabti	Shrub

112	*Pterolobium stellatum* (Forssk.) Brenan	*Fabaceae*	Konteftefe	Shrub
113	*Rhus natalensis* Krauss	*Anacardiaceae*	Atam	Tree
114	*Ricinus communis* L.	*Euphorbiaceae*	Gulie	Tree
115	*Rumex nervosus* Vahl	*Polygonaceae*	Hohot	Shrub
116	*Sarcostemma viminale* (L.) R. Br.	*Apocynaceae*	Elibey	Climber
117	*Senecio hadiensis* Forssk.	*Asteraceae*	Suhumatali	Shrub
118	*Setaria megaphylla* (Steud.) Th. Dur. & Schinz	*Poaceae*		Herb
119	*Setaria verticillata* (L.) P.Beauv.	*Poaceae*	Sairi argi	Herb
120	*Solanum dennekense* Dammer	*Solanaceae*	Engule	Shrub
121	*Solanum incanum* L.	*Solanaceae*	Hintit	Shrub
122	*Solanum schimperianum* Hochst. ex A. Rich.	*Solanaceae*	Berbereawald	Shrub
123	*Tagetes minuta* L.	*Asteraceae*	Chena baria	Herb
124	*Teclea simplicifolia* (Engl.) Verdoom	*Rutaceae*	Selahi	Shrub
125	*Tribulus terrestris*L.	*Zygophyllaceae*	Kakumo	Herb
126	*Verbena officinalis* L.	*Verbenaceae*		Herb
127	*Verbesina encelioides* (Cav.) A. Gray	*Asteraceae*	Embaba hanis	Herb
128	*Vernonia cinerascens* Sch. Bip. In Schweinf. & Asch.	*Asteraceae*	Ergum om	Shrub
129	*Withania somnifera* (L.) Dunal	Solanaceae	Guluho	Shrub
130	*Xanthium spinosum* L.	*Asteraceae*	Eshokbiru	Herb
131	*Ximenia americana* L.	*Olacaceae*	Mendea	Tree
132	*Ziziphus mucronata* Willd.	*Rhamnaceae*	Kunkura-hido	Shrub
133	*Ziziphus spina-christi* (L.) Desf.	*Rhamnaceae*	Kunkura Geba	Shrub

Appendix 2: List of species recorded in each of the study sites (x = present)

S.no	Scientific names	Family	Species recorded in		
			Kara	Rakata	Atsmi-hamaz
1	*Abutilon hirtum*	*Malvaceae*	x	-	-
2	*Acacia asak*	*Fabaceae*	-	x	x
3	*Acacia etbaica*	*Fabaceae*	x	x	x
4	*Acacia hockii*	*Fabaceae*	x	x	x
5	*Acacia mellifera*	*Fabaceae*	x	x	x
6	*Acacia oerfota*	*Fabaceae*	x	-	x
7	*Acacia seyal*	*Fabaceae*	x	-	-
8	*Acacia tortilis*	*Fabaceae*	x	x	x
9	*Achyranthes aspera*	*Amaranthaceae*	x	x	x
10	*Acokanthera schimperi*	*Apocynaceae*	-	x	-
11	*Aerva javanica*	*Amaranthaceae*	-	-	x
12	*Agave sisalana*	*Agavaceae*	-	x	-
13	*Aloe camperi*	*Aloaceae*	x	x	x
14	*Alternanthera pungens*	*Amaranthaceae*	-	x	-
15	*Amaranthus caudatus*	*Amaranthaceae*	-	x	-
16	*Andropogon commutatus*	*Poaceae*	x	x	x
17	*Antopetitia* abyssinica	*Fabaceae*	-	-	x
18	*Argemone mexicana*	*Papaveraceae*	-	x	-
19	*Balanites aegyptiaca*	*Balanitaceae*	x	x	x
20	*Barleria eranthemoides*	*Acanthaceae*	x	x	x
21	*Bidens pilosa*	*Asteraceae*	x	-	-
22	*Boscia salicifolia*	*Capparidaceae*	x	-	-
23	*Bothriochloa insculpta*	*Poaceae*	x	-	x
24	*Brachiaria eruciformis*	*Poaceae*	x	-	-
25	*Brassica rapa*	*Brassicaceae*	x	x	-
26	*Cadaba farinosa*	*Capparidaceae*	x	-	x
27	*Cadia purpurea*	*Fabaceae*	x	x	-
28	*Calotropis procera*	*Asclepiadaceae*	-	x	-
29	*Calpurnia aurea*	*Fabaceae*	x	-	-
30	*Cappris tomentosa*	*Capparidaceae*	x	-	x
31	*Carissa spinarum*	*Apocynaceae*	x	x	x
32	*Celosia antbelmintbica*	*Amaranthaceae*	-	x	-
33	*Chenopodium album*	*Chenopodiaceae*	-	x	-
34	*Chenopodium ambrosioides*	*Chenopodiaceae*	-	x	-
35	*Cissus quadrangularis*	*Vitaceae*	x	x	x
36	*Cleome gynandra*	*Capparidaceae*	-	x	-

37	*Clerodendrum myricoides*	*Lamiaceae*	-	-	x
38	*Commelina africana*	*Commelinaceae*	x	x	x
39	*Commicarpus plumbagineus*	*Nyctaginaceae*	-	x	-
40	*Commiphora schimperi*	*Burseraceae*	-	x	x
41	*Conyza hypoleuca*	*Asteraceae*	-	x	x
42	*Conyza pyrrhopappa*	*Asteraceae*	-	x	x
43	*Cordia monoica*	*Boraginaceae*	-	x	x
44	*Cordia sinensis*	*Boraginaceae*	-	x	x
45	*Cucumis dipsaceus*	*Cucurbitaceae*	x	-	-
46	*Andropogon commutatus*	*Poaceae*	x	x	x
47	*Cynodon dactylon*	*Poaceae*	x	x	x
48	*Cynoglossum lanceolatum*	*Boraginaceae*	-	x	-
49	*Cyperus bulbosus*	*Cyperaceae*	-	x	x
50	*Cyperus dubius*	*Cyperaceae*	-	x	-
51	*Cyperus rotundus*	*Cyperaceae*		x	x
52	*Datura stramonium*	*Solanaceae*	-	x	-
53	*Delphinium wellbyi*	*Ranunculaceae*	-	x	-
54	*Dichrostachys cinerea*	*Fabaceae*	x	x	x
55	*Digitaria pennata*	*Poaceae*	x	-	-
56	*Diplocyclos palmatus*	*Cucurbitaceae*	x	-	-
57	*Dodonea angustifolia*	*Sapindaceae*	x	-	-
58	*Ehretia cymosa*	*Boraginaceae*	x	x	-
59	*Eragrostis papposa*	*Poaceae*	-	x	x
60	*Euclea racemosa* subsp. *schimperi*	*Ebenaceae*	x	x	x
61	*Euphorbia candelabrum*	*Euphorbiaceae*	-	x	-
62	*Euphorbia hirta*	*Euphorbiaceae*	-	-	x
63	*Euphorbia nubica*	*Euphorbiaceae*	x	x	-
64	*Euphorbia petitiana*	*Euphorbiaceae*	x	x	-
65	*Euphorbia tirucalli*	*Euphorbiaceae*	x	-	-
66	*Ficus mucuso*	*Moraceae*	-	x	-
67	*Flueggea virosa*	*Euphorbiaceae*	-	x	-
68	*Gomphocarpus fruticosus*	*Asclepiadaceae*	-	x	-
69	*Grewia tembensis*	*Tiliaceae*	x	x	x
70	*Grewia mollis*	*Tiliaceae*	x	x	x
71	*Grewia villosa*	*Tiliaceae*	x	x	x
72	*Harrisonia abyssinica*	*Simaroubaceae*	x	-	-
73	*Heliotropium cinerascens*	*Boraginaceae*	x	x	x
74	*Heliotropium europaeum*	*Boraginaceae*	-	x	-

75	*Heliotropium indicum*	*Boraginaceae*	-	x	-
76	*Hibiscus micranthus*	*Malvaceae*	x	-	x
77	*Huernia macrocarpa*	*Asclepiadaceae*	-	x	-
78	*Indigofera coerulea*	*Fabaceae*	x	-	-
79	*Indigofera schimperi*	*Fabaceae*	x	-	-
80	*Indigofera spicata*	*Fabaceae*	x	-	-
81	*Indigofera spinosa*	*Fabaceae*	x	-	-
82	*Jasminum grandiflorum*	*Oleaceae*	-	x	-
83	*Jatropha curcas*	*Euphorbiaceae*		x	x
84	*Justicia flava*	*Acanthaceae*	x	-	-
85	*Justicia odora*	*Acanthaceae*	x	x	x
86	*Justicia shimperiana*	*Acanthaceae*	-	x	-
87	*Kalanchoe petitiana* var *petitiana*	*Crassulaceae*	x	x	-
88	*Kleinia odora*	*Asteraceae*	-	x	-
89	*Lantana camara*	*Verbenaceae*	-	x	-
90	*Leucas abyssinica*	*Lamiaceae*	x	x	x
91	*Maerua angolensis*	*Capparidaceae*	-	-	x
92	*Maerua sessiliflora*	*Capparidaceae*	x	x	x
93	*Maytenus arbutifolia*	*Celastraceae*	-	x	x
94	*Maytenus senegalensis*	*Celastraceae*	-	x	-
95	*Ocimum gratissimum*	*Lamiaceae*	-	x	x
96	*Olea europaea* subsp. *cuspidata*	*Oleaceae*	-	x	x
97	*Opuntia ficus-indica*	*Cactaceae*	x	-	x
98	*Ormocarpum muricatum*	*Fabaceae*	-	-	x
99	*Osyris quadripartita*	*Santalaceae*	x	-	-
100	Oxalis corniculata	*Oxalidaceae*	x	-	-
101	*Oxygonum sinuatum*	*Polygonaceae*	-	x	-
102	*Panicum maximum*	*Poaceae*	-	-	x
103	*Parthenium hysterophorus*	*Asteraceae*	x	x	-
104	*Pennisetum mezianum*	*Poaceae*	x	-	-
105	*Pennisetum pedicellatum*	*Poaceae*	x	x	x
106	*Pennisetum setaceum*	*Poaceae*	-	-	x
107	*Pennisetum villosum*	*Poaceae*	x	-	x
108	*Portulaca foliosa*	*Portulacaceae*	-	x	-
109	*Portulaca oleracea*	*Portulacaceae*	-	x	-
110	*Prosopis juliflora*	*Fabaceae*	-	-	x
111	*Psiadia punctulata*	*Asteraceae*	x	-	-
112	*Pterolobium stellatum*	*Fabaceae*	x	x	-

113	*Rhus natalensis*	*Anacardiaceae*	x	x	x
114	*Ricinus communis*	*Euphorbiaceae*	-	x	-
115	*Rumex nervosus*	*Polygonaceae*	-	x	-
116	*Sarcostemma viminale*	*Apocynaceae*	-	x	-
117	*Senecio hadiensis*	*Asteraceae*	x	x	-
118	*Setaria megaphylla*	*Poaceae*	x	-	-
119	*Setaria verticillata*	*Poaceae*	-	x	x
120	*Solanum dennekense*	*Solanaceae*	x	x	x
121	*Solanum incanum*	*Solanaceae*	x	x	x
122	*Solanum schimperianum*	*Solanaceae*	-	-	x
123	*Tagetes minuta*	*Asteraceae*	-	-	x
124	*Teclea simplicifolia*	*Rutaceae*	-	x	-
125	*Tribulus terrestris.*	*Zygophyllaceae*	x	x	x
126	*Verbena officinalis*	*Verbenaceae*	-	-	x
127	*Verbesina encelioides*	*Asteraceae*	x	-	-
128	*Vernonia cinerascens*	*Asteraceae*	-	-	x
129	*Withania somnifera*	Solanaceae	x	-	-
130	*Xanthium spinosum*	*Asteraceae*	-	x	-
131	*Ximenia americana*	*Olacaceae*	-	x	-
132	*Ziziphus mucronata*	*Rhamnaceae*	x	x	-
133	*Ziziphus spina-christi*	*Rhamnaceae*	x	-	x

Appendix 3: List of representative woody species used in the analysis of natural regeneration with their number of seedlings, saplings and adults recorded for each.

Species selected for regeneration analysis	*Family*	Seedlings	Saplings	Adults	Total stems
Acacia asak	*Fabaceae*	173	94	72	339
Acacia etbaica	*Fabaceae*	136	81	194	411
Acacia hockii	*Fabaceae*	378	76	256	710
Acacia mellifera	*Fabaceae*	59	22	54	135
Acacia oerfota	*Fabaceae*	37	28	36	101
Acacia seyal	*Fabaceae*	0	0	3	3
Acacia tortilis	*Fabaceae*	86	48	218	352
Acokanthera schimperi	*Apocynaceae*	0	1	13	14
Balanitesa egyptiaca	*Balanitaceae*	16	12	28	56
Boscia salicifolia	*Cappariadaceae*	0	2	3	5
Cadaba farinosa	*Cappariadaceae*	5	3	6	14
Cadia purpurea	*Fabaceae*	280	217	385	882
Capparis tomentosa	*Cappariadaceae*	11	8	12	31
Carissa spinarum	*Apocynaceae*	15	9	22	46
Commiphora schimperi	*Burseraceae*	0	0	11	11
Cordia monoica	*Boraginaceae*	0	2	4	6
Cordia sinensis	*Boraginaceae*	0	5	4	9
Dichrostachys cinerea	*Fabaceae*	50	24	79	153
Dodonea angustifolia	*Sapindaceae*	5	3	5	13
Ehretia cymosa	*Boraginaceae*	6	4	9	19
Euclea racemosa subsp. schimperi	*Ebenaceae*	0	6	6	12
Euphorbia candelabrum	*Euphorbiaceae*	0	0	16	16
Ficus mucuso	*Moraceae*	0	0	1	1
Grewia mollis	*Tiliaceae*	9	7	6	22
Grewia tembensis	*Tiliaceae*	150	58	34	242
Grewia villosa	*Tiliaceae*	30	15	20	65
Maerua angolensis	*Cappariadaceae*	0	4	2	6
Maytenus senegalensis	*Celastraceae*	7	3	3	13

Olea europaea subsp. cuspidata	*Oleaceae*	0	14	7	21
Osyris quadripartita	*Santalaceae*	0	2	1	3
Prosopis juliflora	*Fabaceae*	2	1	2	5
Rhus natalensis	*Anacardiaceae*	5	6	5	16
Teclea simplicifolia	*Rutaceae*	0	0	2	2
Ximenia americana	*Olacaceae*	0	0	1	1
Ziziphus mucronata	*Rhamnaceae*	4	3	4	11
Ziziphus spina-christi	*Rhamnaceae*	12	8	13	33
Total		1476	766	1537	3779
Density/ha		410.00	212.78	426.94	1049.72

Appendix 4: The natural regeneration status of the representative woody species and their distribution in the three sites (G = Good regeneration, F = Fair regeneration, P = Poor regeneration, N = No regeneration, √ = present)

	Regenearation status				Species distribution in		
Species name	Good regen.	Fair regen.	Poor regen.	No regen.	*Kara*	*Rakata*	*Atsmi-harmaz*
Acacia asak	**G**	-	-	-	-	√	√
Acacia etbaica	**-**	F	-	-	√	√	√
Acacia hockii	**-**	F	-	-	√	√	√
Acacia mellifera	**-**	F	-	-	√	√	√
Acacia oerfota	**-**	F	-	-	√	-	√
Acacia seyal	**-**	-	-	N	√	-	-
Acacia tortilis	**-**	F	-	-	√	√	√
Acokanthera schimperi	**-**		P	-	-	√	-
Balanites aegyptiaca	**-**	F	-	-	√	√	√
Boscia salicifolia	**-**	-	P	-	√	-	-
Cadaba farinosa	**-**	F	-	-	√	-	√
Cadia purpurea	**-**	F	-	-	√	√	-
Capparis tomentosa	**-**	F	-	-	√	-	√
Carissa spinarum	**-**	F	-	-	√	√	√
Commiphora schimperi	**-**	-	-	N	-	√	√

Cordia monoica	-	-	P	-	-	√	√
Cordia sinensis	-	-	P	-	-	√	√
Dichrostachys cinerea	-	F	-	-	√	√	√
Dodonea angustifolia	-	F	-	-	√	-	-
Ehretia cymosa		F			√	√	
Euclea racemosa subsp. Schimperi	-	-	P	-	√	√	√
Euphorbia candelabrum	-	-	-	N	-	√	-
Ficus mucuso	-	-	-	N	-	√	-
Grewia mollis	-	F	-	-	√	√	√
Grewia tembensis	**G**	-	-	-	√	√	√
Grewia villosa	-	F	-	-	√	√	√
Maerua angolensis	-	-	P	-	-	-	√
Maytenus senegalensis	-	F	-	-	-	√	-
Olea europaea subsp. cuspidata	-	-	P	-	-	√	√
Osyris quadripartita	-	-	P	-	√	-	-
Prosopis juliflora	-	F	-	-	-	-	√
Rhus natalensis	-	F	-		√	√	√
Teclea simplicifolia	-	-	-	N	-	√	-
Ximenia americana	-	-	-	N	-	√	-
Ziziphus mucronata	-	F	-	-	√	√	-
Ziziphus spina-christi	-	F	-	-	√	-	√
Total	2	20	8	6			

Appendix 5: Summary of the DBH classes in the study area
I) in all closed and grazing areas

DBH classes	Total stems	Density/ha	percent
1	1732	481	49.69
2	1116	310	32.02
3	314	87	8.99
4	99	28	2.89
5	59	16	1.65
6	166	46	4.75
Total	3486	968	100.00

Appendix 6: Summary of the height classes in the study area
I) in all closed and grazing area

Height classes	Total stems	Density/ha	percent
1	2388	663	66.10
2	955	265	26.42
3	140	39	3.89
4	88	24	2.39
5	43	12	1.20
Total	3614	1003	100.00

Appendix 7: The basal area of woody species in the study area (BA=basal area, RDO= relative dominance, ha= hectare)

species name	Basal area (BA)	Dominance	BA/ha
Acacia hockii	0.0013	0.8879	0.0004
Cadia purpurea	0.0006	0.5238	0.0002
Grewia tembensis	0.0006	0.1374	0.0002
Acacia tortilis	0.0069	2.4081	0.0019
Rhus natalensis	0.0002	0.0026	0.0001
Ziziphus spina-christi	0.0002	0.0060	0.0001
Grewia mollis	0.0004	0.0072	0.0001
Balanites aegyptiaca	0.0038	0.2090	0.0011

Dichrostachys cinerea	0.0005	0.0780	0.0001
Euphorbia nubica	0.0001	0.0170	0.0000
Acacia etbaica	0.0034	1.3396	0.0009
Carissa spinarum	0.0007	0.0273	0.0002
Acacia oerfota	0.0004	0.0416	0.0001
Opuntia ficus-indica	0.0002	0.0036	0.0001
Ehretia cymosa	0.0005	0.0090	0.0001
Achyranthes aspera	0.0001	0.0061	0.0000
Capparis tomentosa	0.0001	0.0027	0.0000
Acacia seyal	0.0129	0.0387	0.0036
Grewia villosa	0.0004	0.0196	0.0001
Pterolobium stellatum	0.0006	0.0018	0.0002
Dodonea angustifolia	0.0013	0.0065	0.0004
Ziziphus mucronata	0.0002	0.0014	0.0001
Euclea racemosa subsp. *schimperi*	0.0009	0.0054	0.0003
Osyris quadripartita	0.0000	0.0000	0.0000
Acacia mellifera	0.0022	0.3036	0.0006
Solanum schimperianum	0.0000	0.0000	0.0000
Olea europaea subsp. *cuspidata*	0.0006	0.0108	0.0002
Cordia sinensis	0.0003	0.0033	0.0001
Acacia asak	0.0029	0.4582	0.0008
Acokanthera schimperi	0.0112	0.1344	0.0031
Maytenus senegalensis	0.0003	0.0039	0.0001
Teclea simplicifolia	0.0018	0.0036	0.0005
Justicia shimperiana	0.0003	0.0009	0.0001
Euphorbia candelabrum	0.0258	0.4128	0.0072
Ricinus communis	0.0032	0.0032	0.0009
Clerodendrum myricoides	0.0008	0.0008	0.0002
			0.0238

Appendix 8: Frequency distribution of woody species in the study area (FR = frequency, %FR = % frequency, RFR = relative frequency).

Species name	FR	% FR	RFR
Grewia tembensis	70	77.78	7.76
Acacia tortilis	60	66.67	6.65
Barleria eranthemoides	54	60.00	5.99
Acacia etbaica	50	55.56	5.54
Cadia purpurea	46	51.11	5.10
Aloe camperi	43	47.78	4.77
Leucas abyssinica	40	44.44	4.43
Cissus quadrangularis	34	37.78	3.77
Acacia hockii	30	33.33	3.33
Acacia asak	26	28.89	2.88
Carissa spinarum	22	24.44	2.44
Dichrostachys cinerea	22	24.44	2.44
Euphorbia nubica	21	23.33	2.33
Balanites aegyptiaca	20	22.22	2.22
Eragrostis papposa	17	18.89	1.88
Achyranthes aspera	15	16.67	1.66
Ehretia cymosa	15	16.67	1.66
Acacia mellifera	14	15.56	1.55
Acacia oerfota	14	15.56	1.55
Capparis tomentosa	14	15.56	1.55
Grewia villosa	14	15.56	1.55
Grewia mollis	12	13.33	1.33
Eragrostis papposa	12	13.33	1.33
Pennisetum pedicellatum	12	13.33	1.33
Commelina africana	11	12.22	1.22
Cynodon dactylon	11	12.22	1.22
Cyperus rotundus	11	12.22	1.22
Olea europaea subsp. *Cuspidata*	10	11.11	1.11
Rhus natalensis	10	11.11	1.11
Tribulus terrestris.	10	11.11	1.11
Cyperus bulbosus	9	10.00	1.00
Setaria verticillata	9	10.00	1.00
Andropogon commutatus	8	8.89	0.89
Antopetitia abyssinica	8	8.89	0.89
Euclea racemosa subsp. *Schimperi*	8	8.89	0.89
Senecio hadiensis	8	8.89	0.89

Ziziphus mucronata	7	7.78	0.78
Ziziphus spina-christi	7	7.78	0.78
Jatropha curcas	6	6.67	0.67
Commiphora schimperi	5	5.56	0.55
Cordia sinensis	5	5.56	0.55
Euphorbia petitiana	5	5.56	0.55
Pennisetum villosum	5	5.56	0.55
Acokanthera schimperi	4	4.44	0.44
Cadaba farinosa	4	4.44	0.44
Hibiscus micranthus	4	4.44	0.44
Opuntia ficus-indica	4	4.44	0.44
Parthenium hysterophorus	4	4.44	0.44
Acacia seyal	3	3.33	0.33
Chenopodium ambrosioides	3	3.33	0.33
Dodonea angustifolia	3	3.33	0.33
Euphorbia candelabrum	3	3.33	0.33
Maytenus senegalensis	3	3.33	0.33
Pterolobium stellatum	3	3.33	0.33
Sansevieria trifasciata	3	3.33	0.33
Alternanthera pungens	2	2.22	0.22
Jasminum grandiflorum	2	2.22	0.22
Ormocarpum muricatum	2	2.22	0.22
Xanthium spinosum	2	2.22	0.22
Aerva javanica	1	1.11	0.11
Amaranthus caudatus	1	1.11	0.11
Argemone mexicana	1	1.11	0.11
Clerodendrum myricoides	1	1.11	0.11
Commicarpus plumbagineus	1	1.11	0.11
Datura stramonium	1	1.11	0.11
Heliotropium europaeum	1	1.11	0.11
Huernia macrocarpa	1	1.11	0.11
Justica shimperiana	1	1.11	0.11
Kleinia odora	1	1.11	0.11
Osyris quadripartita	1	1.11	0.11
Panicum maximum	1	1.11	0.11
Portulaca foliosa	1	1.11	0.11
Prosopis juliflora	1	1.11	0.11
Portulaca grandiflora	1	1.11	0.11
Ricinus communis	1	1.11	0.11

Rumex nervosus	1	1.11	0.11
Sarcostemma viminale	1	1.11	0.11
Solanum schimperianum	1	1.11	0.11
Tagetes minuta	1	1.11	0.11
Teclea simplicifolia	1	1.11	0.11
Withania somnifera	1	1.11	0.11
Ximenia americana	1	1.11	0.11

Appendix 9: Importance value index of woody species (RF= relative frequency, RD= relative density, RDO= relative dominance, IVI=important value index)

Species name	RF	RD	RDO	IVI	IVI %
Acacia hockii	6.0241	18.4995	1.5169	26.0405	8.6802
Cadia purpurea	9.2369	23.6457	0.7001	33.5828	11.1943
Grewia tembensis	9.2369	6.2026	0.7001	16.1397	5.3799
Acacia tortilis	12.0482	9.4529	8.0513	29.5524	9.8508
Rhus natalensis	1.6064	0.3521	0.2334	2.1919	0.7306
Ziziphus spina-christi	1.4056	0.8126	0.2334	2.4516	0.8172
Grewia mollis	2.2088	0.4875	0.4667	3.1631	1.0544
Balanites aegyptiaca	3.8153	1.4897	4.4341	9.7390	3.2463
Dichrostachys cinerea	4.4177	4.2254	0.5834	9.2265	3.0755
Euphorbia nubica	3.8153	4.6046	0.1167	8.5365	2.8455
Acacia etbaica	9.8394	10.6717	3.9673	24.4784	8.1595
Carissa spinarum	4.4177	1.0563	0.8168	6.2908	2.0969
Acacia oerfota	2.6104	2.8169	0.4667	5.8941	1.9647
Opuntia ficus-indica	0.6024	0.4875	0.2334	1.3233	0.4411
Ehretiacymosa	2.8112	0.4875	0.5834	3.8822	1.2941
Achyranthes aspera	2.6104	1.6522	0.1167	4.3793	1.4598
Capparis tomentosa	2.6104	0.7313	0.1167	3.4584	1.1528
Acacia seyal	0.6024	0.0813	15.0525	15.7362	5.2454
Grewia villosa	2.6104	1.3272	0.4667	4.4044	1.4681
Pterolobium stellatum	0.4016	0.0813	0.7001	1.1830	0.3943
Dodonea angustifolia	0.6024	0.1354	1.5169	2.2548	0.7516
Ziziphus mucronata	1.4056	0.1896	0.2334	1.8286	0.6095
Euclea racemosa subsp.	1.2048	0.1625	1.0502	2.4175	0.8058

schimperi					
Osyris quadripartita	0.4016	0.0813	0.0000	0.4829	0.1610
Acacia mellifera	2.6104	3.7378	2.5671	8.9153	2.9718
Solanum schimperianum	0.4016	0.1625	0.0000	0.5641	0.1880
Olea europaea subsp. cuspidata	2.0080	0.4875	0.7001	3.1957	1.0652
Cordia sinensis	1.2048	0.2979	0.3501	1.8528	0.6176
Acacia asak	4.4177	4.2795	3.3839	12.0811	4.0270
Acokanthera schimperi	0.8032	0.3250	13.0688	14.1971	4.7324
Maytenus senegalensis	0.6024	0.3521	0.3501	1.3046	0.4349
Teclea simplicifolia	0.2008	0.0542	2.1004	2.3553	0.7851
Justica shimperiana	0.2008	0.0813	0.3501	0.6321	0.2107
Euphorbia candelabrum	0.6024	0.4334	30.1050	31.1408	10.3803
Ricinus communis	0.2008	0.0271	3.7340	3.9618	1.3206
Clerodendrum myricoides	0.2008	0.0271	0.9335	1.1614	0.3871
	100	100	100	300	**100.00**

Appendix 10: Percentage of different soil particles (sand, silt and clay) from the sample plots and their soil classification

Sample plots	Sand %	Silt %	Clay %	soil classification
1	70	24	6	sandy loam
2	74	22	4	loamy sand
3	68	26	6	sandy loam
4	84	12	4	loamy sand
5	68	26	6	loamy sand
6	86	10	4	sandy loam
7	72	22	6	sandy loam
8	66	24	10	sandy loam
9	66	16	18	sandy loam
10	72	18	10	sandy loam
11	58	24	18	sandy loam
12	76	16	8	sandy loam
13	66	20	14	sandy loam

14	64	32	4	sandy loam
15	62	24	14	sandy loam
16	72	24	4	sandy loam
17	66	16	18	sandy loam
18	68	28	4	sandy loam
19	62	22	16	sandy loam
20	72	22	4	sandy loam
21	68	18	14	sandy loam
22	76	20	4	loamy sand
23	72	10	18	sandy loam
24	68	30	4	sandy loam
25	66	16	18	sandy loam
26	66	28	6	sandy loam
27	68	20	12	sandy loam
28	66	26	8	sandy loam
29	52	26	22	sandy loam
30	68	28	4	sandy loam
31	46	26	28	sandy clay loam
32	66	30	4	sandy loam
33	76	10	14	sandy loam
34	66	26	8	sandy loam
35	64	22	14	sandy loam
36	66	30	4	sandy loam
37	72	14	14	sandy loam
38	64	26	10	sandy loam
39	54	26	20	sandy loam
40	66	24	10	sandy loam
41	54	26	20	sandy loam
42	66	25	8	sandy loam
43	64	18	18	sandy loam
44	70	22	8	sandy loam
45	72	16	12	sandy loam
46	70	22	8	sandy loam

47	78	12	10	sandy loam
48	72	18	10	sandy loam
49	74	18	8	sandy loam
50	70	18	12	sandy loam
51	62	20	18	sandy loam
52	70	18	12	sandy loam
53	72	18	10	sandy loam
54	72	18	10	sandy loam
55	78	14	8	loamy sand
56	86	2	12	loamy sand
57	50	22	28	sandy clay loam
58	72	20	8	sandy loam
59	52	30	18	sandy loam
60	70	18	12	sandy loam
61	70	12	18	sandy loam
62	64	32	4	sandy loam
63	64	22	14	sandy loam
64	66	30	4	sandy loam
65	58	24	18	sandy loam
66	62	28	10	sandy loam
67	58	24	18	sandy loam
68	64	26	10	sandy loam
69	78	14	8	loamy sand
70	70	24	6	sandy loam
71	60	16	24	sandy clay loam
72	68	28	4	sandy loam
73	62	20	18	sandy loam
74	82	12	6	loamy sand
75	60	22	18	sandy loam
76	72	22	6	sandy loam
77	62	16	22	sandy clay loam
78	64	32	4	sandy loam
79	62	26	12	sandy loam

80	74	22	4	loamy sand
81	72	14	14	sandy loam
82	72	20	8	sandy loam
83	38	24	38	clay loam
84	74	22	4	loamy sand
85	42	32	26	loam
86	60	30	10	sandy loam
87	62	20	18	sandy loam
88	62	26	14	sandy loam
89	52	22	26	sandy clay loam
90	62	28	10	sandy loam

Appendix 11: Soil laboratory results analysis of pH, EC (ds/m), TN (%), OM (%), P (PPm), CEC and exchangeable bases (cmol(+)/kg)

sample	pH	EC	Na	K	Ca	Mg	CEC	TN	OM	av.P
1	7.5	0.382	0.13	0.22	20.82	5.15	29.92	0.260	3.12	3.66
2	7.2	0.152	2.31	2.12	13.80	10.60	22	0.154	2.47	4.12
3	7.5	0.232	0.11	0.22	18.42	5.02	29.30	0.220	3.25	2.07
4	7.1	0.242	1.88	1.95	11.40	10.40	21.2	0.129	1.53	1.9
5	7.7	0.299	0.16	0.67	22.47	5.02	35.36	0.196	2.78	2.58
6	7.3	0.192	2.44	1.91	14.20	8.40	17.2	0.123	1.98	3.94
7	7.7	0.385	0.17	0.25	20.85	5.18	29.92	0.263	3.13	3.69
8	7.3	0.204	2.53	2.30	11.60	12.40	17.2	0.308	3.25	4.62
9	7.9	0.229	0.09	0.19	18.39	4.99	29.30	0.217	3.24	2.04
10	7.3	0.147	2.53	2.31	11.68	12.41	18.2	0.305	3.24	4.61
11	7.9	0.302	0.19	0.71	22.51	5.05	35.36	0.199	2.79	2.61
12	7.0	0.147	2.40	0.75	9.80	13.20	9.6	0.09	2.51	2.16
13	8.0	0.280	0.21	0.67	19.85	3.84	31.38	0.205	2.49	2.64
14	7.1	0.141	2.49	0.75	9.80	13.20	21.2	0.14	1.60	0.84

15	8.1	0.325	0.15	0.45	29.16	6.30	43.24	0.329	3.75	2.87
16	7.2	0.117	2.34	0.74	14.40	10.80	38.8	0.134	1.90	0.96
17	8.0	0.328	0.18	0.48	29.19	6.33	43.27	0.332	3.76	2.67
18	7.2	0.178	2.42	0.57	12.80	10.20	13.6	0.259	5.94	3.68
19	7.8	0.322	0.12	0.42	29.13	6.27	43.21	0.326	3.75	2.84
20	7.3	0.195	2.42	0.57	12.88	10.21	14.6	0.255	5.94	3.61
21	7.8	0.524	0.15	1.37	26.07	7.57	41.46	0.252	4.32	7.57
22	7.2	0.124	2.70	0.64	14.00	8.00	23.8	0.088	0.75	1.3
23	8.1	0.521	0.11	1.34	26.04	7.54	41.43	0.249	4.32	6.54
24	7.2	0.219	2.77	0.65	12.80	5.60	23	0.038	1.57	3.18
25	8.3	0.527	0.19	1.41	26.11	7.61	41.49	0.255	4.33	7.61
26	7.2	0.187	2.50	0.59	13.40	5.00	23.6	0.118	1.05	3.18
27	7.9	0.473	0.17	0.78	31.00	6.10	46.14	0.236	3.00	6.27
28	7.3	0.295	2.99	0.71	16.60	5.60	23.4	0.153	2.24	5.4
29	8.1	0.476	0.21	0.81	30.03	6.13	46.14	0.239	3.01	6.07
30	7.3	0.168	3.55	0.84	18.60	10.60	22	0.154	2.17	6.42
31	8.5	0.587	0.28	2.38	27.28	5.39	45.42	0.156	1.97	4.85
32	7.1	0.176	3.11	0.73	16.00	11.60	20.8	0.169	3.19	7.26
33	8.5	0.220	0.20	0.43	31.55	7.28	48.12	0.123	2.15	0.71
34	7.2	0.139	2.53	0.60	12.60	17.40	28	0.148	2.63	4.2
35	8.5	0.255	0.17	0.31	33.47	6.53	50.47	0.146	1.71	2.02
36	7.2	0.134	2.68	0.63	19.00	5.40	31.68	0.106	1.85	0.88
37	8.5	0.591	0.31	2.41	27.31	5.42	45.42	0.159	1.97	4.81
38	7.2	0.121	2.83	0.67	14.80	16.00	23.6	0.052	2.42	0.96
39	8.1	0.217	0.17	0.40	31.52	7.25	48.12	0.121	2.15	0.74
40	7.3	0.114	2.83	0.67	14.89	16.01	24.6	0.052	2.41	0.91

41	8.1	0.252	0.21	0.34	33.51	6.56	50.47	0.149	1.72	2.04
42	7.3	0.165	3.05	0.72	19.40	4.80	20.2	0.073	1.90	0.96
43	8.4	0.317	0.76	0.18	37.48	7.68	53.92	0.142	2.16	1.45
44	7.3	0.171	2.60	0.72	19.40	4.80	21.8	0.067	2.32	0.7
45	8.4	0.314	0.73	0.15	36.45	7.65	53.92	0.139	2.16	1.41
46	7.4	0.115	2.73	0.64	11.80	13.20	25.96	0.064	1.59	1.22
47	8.1	0.255	0.35	0.19	35.01	6.53	51.66	0.202	3.05	1.79
48	7.5	0.101	2.67	0.63	10.20	8.40	21	0.069	2.95	0.7
49	8.1	0.258	0.38	0.22	34.04	6.58	51.66	0.205	3.06	1.82
50	7.4	0.145	2.67	0.65	10.29	8.41	22	0.071	2.94	0.8
51	8.4	0.220	0.13	0.33	35.31	6.61	51.86	0.070	1.32	2.47
52	7.5	0.107	2.87	0.68	10.40	17.20	25	0.174	2.83	1.9
53	8.2	0.217	0.09	0.29	33.28	6.58	51.83	0.067	1.32	2.04
54	7.4	0.121	2.75	0.65	10.40	13.40	37.6	0.127	1.92	0.88
55	8.3	0.223	0.16	0.36	35.37	6.64	51.89	0.073	1.33	2.39
56	7.4	0.101	2.28	0.54	16.00	10.80	28.4	0.059	2.69	0.76
57	8.1	0.445	0.54	1.87	33.08	7.31	49.02	0.192	2.27	3.04
58	7.3	0.101	2.67	0.63	9.40	9.00	40.6	0.129	1.58	0.78
59	8.1	0.442	0.49	1.84	33.04	7.28	49.02	0.189	2.26	2.88
60	7.2	0.11	3.12	0.74	16.20	11.00	25.6	0.06	1.93	0.54
61	7.7	0.297	0.20	0.31	36.90	6.95	54.76	0.178	2.65	1.51
62	7.6	0.101	2.69	0.63	13.20	3.20	33.2	0.057	2.53	0.62
63	7.7	0.301	0.23	0.34	36.03	6.98	54.76	0.181	2.65	3.25
64	7.4	0.106	2.58	0.61	16.40	2.40	27	0.125	2.82	0.6
65	7.9	0.307	0.20	0.52	34.38	7.03	52.12	0.186	2.18	5.25
66	7.2	0.101	2.73	0.64	15.00	3.40	23.8	0.059	2.08	0.58

67	7.9	0.304	0.17	0.49	34.25	6.99	52.09	0.183	2.18	5.05
68	7.1	0.129	2.62	0.62	10.00	8.60	29.8	0.108	1.45	14.42
69	8.2	0.299	0.14	0.44	33.32	7.01	52.15	0.179	2.17	3.78
70	7.2	0.126	2.62	0.65	10.31	8.61	30.8	0.107	1.45	14.41
71	7.8	0.251	0.11	0.43	34.25	6.93	52.10	0.176	2.16	2.55
72	7.3	0.121	2.81	0.66	17.00	10.40	24	0.105	2.03	2.32
73	8.1	0.220	0.26	0.35	32.14	6.54	49.36	0.178	2.89	1.96
74	7.1	0.108	2.78	0.66	10.60	7.80	23.8	0.137	2.70	2.84
75	7.7	0.223	0.29	0.38	32.17	6.57	49.36	0.181	2.89	2.41
76	7.2	0.194	3.06	0.72	13.40	9.60	29.8	0.06	0.84	3.6
77	7.9	0.467	0.24	0.29	31.43	6.04	46.16	0.167	2.82	2.87
78	7.1	0.134	2.67	0.63	14.00	8.60	28.4	0.143	2.89	3.94
79	7.8	0.464	0.21	0.26	31.39	6.01	46.16	0.164	2.81	2.22
80	7.1	0.127	2.90	0.68	11.00	7.40	25.8	0.19	2.61	1.56
81	8.1	0.195	0.17	0.17	30.74	5.62	44.96	0.094	1.58	1.56
82	7.2	0.105	2.84	0.67	13.40	5.00	21.6	0.108	1.53	1.72
83	7.9	0.191	0.14	0.14	30.11	5.59	44.93	0.091	1.58	2.21
84	7.1	0.111	2.91	0.69	17.20	7.80	34.4	0.125	2.02	7.36
85	7.9	0.189	0.11	0.21	31.04	5.46	44.90	0.089	1.58	3.25
86	7.1	0.129	2.82	0.66	26.40	10.00	35.6	0.119	1.52	5.22
87	7.8	0.944	0.37	1.02	36.02	7.18	58.22	0.115	2.05	4.28
88	7.1	0.134	3.20	0.75	14.40	8.80	32.8	0.113	1.45	3.44
89	8.1	0.841	0.31	1.11	38.12	7.03	58.20	0.105	2.01	3.16
90	7.1	0.12	2.88	0.68	16.20	6.20	38.4	0.115	1.58	6.92

Appendix 12: List of palatable and unpalatable species of the study area *(clo-pala = palatable spp in closed area; clo-unpala = unpalatable spp in closed area; gra-pala = palatable spp in grazed area; gra—unpala = unpalatable spp in grazed area; x = shows absence)*

Species names	Family names	closed	grazed
Abutilon hirtum	*Malvaceae*	clo--unpala	x
Acacia asak	*Fabaceae*	clo--pala	gra--pala
Acacia etbaica	*Fabaceae*	clo--pala	gra--pala
Acacia hockii	*Fabaceae*	clo--pala	gra--pala
Acacia mellifera	*Fabaceae*	clo--pala	gra--pala
Acacia oerfota	*Fabaceae*	clo--unpala	gra--unpala
Acacia seyal	*Fabaceae*	clo--pala	x
Acacia tortilis	*Fabaceae*	clo--pala	gra--pala
Achyranthes aspera	*Acanthaceae*	clo--pala	gra--pala
Acokanthera schimperi	*Apocynaceae*	clo--unpala	gra--unpala
Aerva javanica	*Amaranthaceae*	clo--unpala	x
Agave sisalana	*Agavaceae*	clo--unpala	x
Aloe camperi	*Aloaceae*	clo--unpala	gra--unpala
Alternanthera pungens	*Amaranthaceae*	clo--unpala	gra--unpala
Amaranthus caudatus	*Amaranthaceae*	clo--pala	x
Andropogon commutatus	*Poaceae*	clo--pala	gra--pala
Antopetitia abyssinica	*Fabaceae*	clo--unpala	gra--unpala
Argemone mexicana	*Papaveraceae*	x	gra--unpala
Balanites aegyptiaca	*Balanitaceae*	x	gra--pala
Barleria eranthemoides	*Acanthaceae*	clo--unpala	gra--unpala
Bidens pilosa	*Asteraceae*	clo--unpala	x
Boscia salicifolia	*Capparidaceae*	clo--pala	gra--pala
Bothriochloa insculpta	*Poaceae*	clo--pala	x
Brachiaria eruciformis	*Poaceae*	clo--pala	x
Brassica rapa	*Brassicaceae*	clo--pala	x
Cadaba farinosa	*Cappriadaceae*	clo--unpala	gra--unpala
Cadia purpurea	*Fabaceae*	clo--unpala	gra--unpala
Calotropis procera	*Asclepiadaceae*	x	gra--unpala
Calpurnia aurea	*Fabaceae*	clo--unpala	x
Capparis tomentosa	*Capparidaceae*	clo--unpala	gra--unpala
carissa spinarum	*Apocynaceae*	clo--pala	gra--pala
Celosia antbelmintbica	*Amaranthaceae*	x	gra--unpala

Chenopodium album	*Chenopodaceae*	clo--unpala	gra--unpala
Chenopodium ambrosioides	*Chenopodaceae*	clo--unpala	gra--unpala
Cissus quadrangularis	*Vitaceae*	clo--unpala	gra--unpala
Cleome gynandra	*Capparidaceae*	x	gra--unpala
Clerodendron myricoides	*Lamiaceae*	clo--unpala	x
Commelina africanus	*Commelinaceae*	clo--pala	gra--pala
Commicarpus plumbaginus	*Nyctagginaceae*	clo--unpala	x
Commiphora schimperi	*Burseraceae*	clo--pala	gra--pala
Conyza hypoleuca	*Asteraceae*	clo--unpala	x
Conyza pyrrhopappa	*Asteraceae*	clo--unpala	x
Cordia monoica	*Boraginaceae*	clo--pala	gra--pala
Cordia sinensis	*Boraginaceae*	clo--pala	gra--pala
Cucumis dipsaceus	*Cucurbitaceae*	clo--unpala	x
Andropogon commutatus	*Poaceae*	clo--pala	x
Cynodon dactylon	*Poaceae*	clo--pala	gra--pala
Cynoglossum lanceolatum	*Boraginaceae*	clo--unpala	x
Cyperus bulbosus	*Cypraceae*	clo--pala	gra--pala
Cyperus dubius	*Cyperaceae*	x	gra--pala
Cyperus rotundus	*Cypraceae*	clo--pala	gra--pala
Datura stramonium	*Solanaceae*	x	gra--unpala
Delphinium wellbyi	*Ranunculaceae*	clo--unpala	x
Digitaria pennata	*Poaceae*	clo--pala	x
Dichrostachys cinerea	*Fabaceae*	clo--unpala	gra--unpala
Diplocyclos palmatus	*Cucurbitaceae*	clo--unpala	x
Dodonea angustifolia	*Sapindaceae*	clo--unpala	x
Ehretia cymosa	*Boraginaceae*	clo--pala	gra--pala
Eragrostis papposa	*Poaceae*	clo--pala	gra--pala
Euclea racemosa subsp. schimperi	*Ebenaceae*	clo--unpala	x
Euphorbia candelabrum	*Euphorbiaceae*	x	gra--unpala
Euphorbia hirta	*Euphrobiaceae*	x	gra--unpala
Euphorbia nubica	*Euphorbiaceae*	clo--unpala	gra--unpala
Euphorbia petitiana	*Euphorbiaceae*	clo--unpala	gra--unpala
Euphorbia tirucalli L.	*Euphorbiaceae*	x	gra--unpala

Ficus mucoso	*Moraceae*	clo--unpala	x
Flueggea virosa	*Euphorbiaceae*	clo--unpala	x
Gomphocarpus fruticosus	*Asclepiadaceae*	clo--unpala	x
Grewia tembensis	*Tiliaceae*	clo--pala	gra--pala
Grewia mollis	*Tiliaceae*	clo--pala	gra--pala
Grewia villosa	*Tiliaceae*	clo--pala	gra--pala
Harrisonia abyssinica	*Simaroubaceae*	x	gra--unpala
Heliotropium cinerascens	*Boraginaceae*	clo--pala	gra--pala
Heliotropium europaeium	*Boraginaceae*	x	gra--unpala
Heliotropium indicum	*Boraginaceae*	x	gra--unpala
Hibiscus micranthus	*Malvaceae*	clo--pala	x
Huernia macrocarpa	*Asclepiadaceae*	clo--unpala	x
Indigofera coerulea	*Fabaceae*	clo--pala	x
Indigofera schimperi	*Fabaceae*	clo--pala	x
Indigofera spicata	*Fabaceae*	clo--pala	x
Indigofera spinosa	*Fabaceae*	clo--unpala	x
Jasminum grandiflorum	*Oleaceae*	clo--unpala	x
Jatropha curcas	*Euphorbiaceae*	clo--unpala	gra--unpala
Justicia flava	*Acanthaceae*	clo--unpala	x
Justicia odora	*Acanthaceae*	clo--unpala	gra--unpala
Justicia shimperiana	*Rubiaceae*	clo--unpala	x
Kalanchoe petitiana	*Crassulaceae*	clo--unpala	gra--unpala
Kleinia odora	*Asteraceae*	clo--unpala	x
Lantana camara	*Lamiaceae*	x	gra--unpala
Leucas abyssinica	*Lamiaceae*	clo--unpala	gra--unpala
Maerua angolensis	*Capparidaceae*	clo--unpala	x
Maerua sessiliflora	*Capparidaceae*	clo--unpala	gra--unpala
Maytenus senegalensis	*Celastraceae*	clo--unpala	x
Ocimum gratissimum	*Lamiaceae*	clo--unpala	gra--unpala
Olea europaea subsp cuspidata	*Oleaceae*	clo--pala	gra--pala
Opuntia ficus-indica	*Cactaceae*	clo--pala	gra--pala
Ormocarpum muricatum	*Fabaceae*	clo--pala	gra--pala
Osyris quadripartite	*Santalaceae*	clo--pala	x
Oxalis corniculata	*Oxalidaceae*	clo--pala	x

Oxygonum sinuatum	*Polygonaceae*	clo--pala	gra--pala
Panicum maximum	*Poaceae*	clo--pala	x
Parthenium hysterophorus	*Asteraceae*	clo--unpala	gra--unpala
Pennisetum mezianum	*Poaceae*	clo--pala	x
Pennisetum pedicellatum	*Poaceae*	clo--pala	x
Pennisetum setaceum	*Poaceae*	clo--pala	x
Pennisetum villosum	*Poaceae*	clo--pala	x
Portulaca foliosa	*Portulacaceae*	clo--pala	x
Portulaca oleracea	*Portulacaceae*	clo--unpala	x
Prosopis juliflora	*Fabaceae*	clo--unpala	x
Psiadia punctulata	*Asteraceae*	clo--unpala	x
Pterolobium stellatum	*Fabaceae*	clo--unpala	gra--unpala
Rhus natalensis	*Anacadiaceae*	clo--pala	gra--pala
Ricinus communis	*Euphorbiaceae*	x	gra--unpala
Rumex nervosus	*Polygonaceae*	x	gra--unpala
Sansevieria trifasciata	*Agavaceae*	clo--unpala	gra--unpala
Sarcostemma viminale	*Apocynaceae*	clo--pala	x
Senecio hadiensis	*Asteraceae*	clo--pala	gra--pala
Setaria megaphylla	*Poaceae*	clo--pala	x
Setaria verticillata	*Poaceae*	clo--pala	gra--pala
Solanum schimperianum	*Solanaceae*	x	gra--unpala
Solanum dennekense	*solanaceae*	clo--unpala	gra--unpala
Solanum incanum	*Solanacea*	clo--unpala	gra--unpala
Tagetes minuta	*Asteraceae*	clo--unpala	x
Teclea simplicifolia	*Rutaceae*	clo--unpala	x
Tribulus torrestris	*Zygophyllaceae*	clo--pala	gra--pala
Verbena officinalis	*Verbenaceae*	clo--unpala	x
Verbesina encelioides	*Asteraceae*	clo--unpala	x
Vernonia cinerascens	*Asteraceae*	clo--unpala	x
Withania somnifera	*Solanaceae*	clo--unpala	x
Xanthium spinosum	*Asteraceae*	x	gra--unpala
Ximenia americana	*Olacaceae*	clo--pala	x
Ziziphus mucronata	*Rhamnaceae*	clo--pala	gra--pala
Ziziphus spina-christi	*Rhamnaceae*	clo--pala	x
		clo-pala=54=47%	gra-pala=33=44%
		clo-unpala=61=53%	gra-unpala=42=56%

Appendix 13: pH analysis results and its description

sample plots	depth	soil pH	pH description	C-1	C-2	C-3	C-4	C-5
1	0-15 cm	7.5	slightly alkaline	√	-	-	-	-
2	0-15 cm	7.2	neutral	√	-	-	-	-
3	0-15 cm	7.5	slightly alkaline	√	-	-	-	-
4	0-15 cm	7.1	neutral	√	-	-	-	-
5	0-15 cm	7.7	slightly alkaline	√	-	-	-	-
6	0-15 cm	7.3	neutral	-	-	√	-	-
7	0-15 cm	7.7	slightly alkaline	-	-	√	-	-
8	0-15 cm	7.3	neutral	√	-		-	-
9	0-15 cm	7.9	moderately alkaline	-	-	√	-	-
10	0-15 cm	7.3	neutral	-	-	√	-	-
11	0-15 cm	7.9	moderately alkaline	√	-	-	-	-
12	0-15 cm	7.0	neutral	√	-	-	-	-
13	0-15 cm	8.0	moderately alkaline	√	-	-	-	-
14	0-15 cm	7.1	neutral	-	-	√	-	-
15	0-15 cm	8.1	moderately alkaline	-	-	√	-	-
16	0-15 cm	7.2	neutral	√	-	-	-	-
17	0-15 cm	8.0	moderately alkaline	√	-	-	-	-
18	0-15 cm	7.2	neutral	-	-	√	-	-
19	0-15 cm	7.8	slightly alkaline	√	-	-	-	-
20	0-15 cm	7.3	neutral	√	-	-	-	-
21	0-15 cm	7.8	slightly alkaline	√	-	-	-	-
22	0-15 cm	7.2	neutral	√	-	-	-	-
23	0-15 cm	8.1	moderately alkaline	√	-	-	-	-
24	0-15 cm	7.2	neutral	√	-	-	-	-
25	0-15 cm	8.3	moderately alkaline	-	-	√	-	-
26	0-15 cm	7.2	neutral	-	-	√	-	-
27	0-15 cm	7.9	moderately alkaline	√	-	-	-	-

28	0-15 cm	7.3	neutral	√	-	-	-	-
29	0-15 cm	8.1	moderately alkaline	√	-	-	-	-
30	0-15 cm	7.3	neutral	√	-	-	-	-
31	0-15 cm	8.5	strongly alkaline	-	-	-	√	-
32	0-15 cm	7.1	neutral	-	-	-	√	-
33	0-15 cm	8.5	strongly alkaline	-	-	-	√	-
34	0-15 cm	7.2	neutral	-	-	-	√	-
35	0-15 cm	8.5	strongly alkaline	-	-	-	√	-
36	0-15 cm	7.2	neutral	-	√	-	-	-
37	0-15 cm	8.5	strongly alkaline	-	√	-	-	-
38	0-15 cm	7.2	neutral	-	√	-	-	-
39	0-15 cm	8.1	moderately alkaline	-	√	-	-	-
40	0-15 cm	7.3	neutral	-	√	-	-	-
41	0-15 cm	8.1	moderately alkaline	-	√	-	-	-
42	0-15 cm	7.3	neutral	√	-	-	-	-
43	0-15 cm	8.4	moderately alkaline	√	-	-	-	-
44	0-15 cm	7.3	neutral	-	√	-	-	-
45	0-15 cm	8.4	moderately alkaline	-	√	-	-	-
46	0-15 cm	7.4	slightly alkaline	-	√	-	-	-
47	0-15 cm	8.1	moderately alkaline	-	-	-	√	-
48	0-15 cm	7.5	slightly alkaline	-	-	-	√	-
49	0-15 cm	8.1	moderately alkaline	-	-	-	√	-
50	0-15 cm	7.4	slightly alkaline	√	-	-	-	-
51	0-15 cm	8.4	moderately alkaline	-	√	-	-	-
52	0-15 cm	7.5	slightly alkaline	-	-	-	√	-
53	0-15 cm	8.2	moderately alkaline	-	√	-	-	-
54	0-15 cm	7.4	slightly alkaline	-	-	-	√	-
55	0-15 cm	8.3	moderately alkaline	-	-	-	√	-
56	0-15 cm	7.4	slightly alkaline	-	√	-	-	-

57	0-15 cm	8.1	moderately alkaline	-	√	-	-	-
58	0-15 cm	7.3	neutral	-	√	-	-	-
59	0-15 cm	8.1	moderately alkaline	-	√	-	-	-
60	0-15 cm	7.2	neutral	-	√	-	-	-
61	0-15 cm	7.7	slightly alkaline	-	-	-	-	√
62	0-15 cm	7.6	slightly alkaline	-	-	-	-	√
63	0-15 cm	7.7	slightly alkaline	-	-	-	-	√
64	0-15 cm	7.4	slightly alkaline	-	-	-	-	√
65	0-15 cm	7.9	moderately alkaline	-	-	√	-	-
66	0-15 cm	7.2	neutral	-	-	-	-	√
67	0-15 cm	7.9	moderately alkaline	-	-	-	-	√
68	0-15 cm	7.1	neutral	-	-	-	-	√
69	0-15 cm	8.2	moderately alkaline	-	-	-	-	√
70	0-15 cm	7.2	neutral	-	-	√	-	-
71	0-15 cm	7.8	slightly alkaline	-	-	-	-	√
72	0-15 cm	7.3	neutral	-	-	-	-	√
73	0-15 cm	8.1	moderately alkaline	-	-	-	-	√
74	0-15 cm	7.1	neutral	-	-	-	-	√
75	0-15 cm	7.7	slightly alkaline	-	-	-	-	√
76	0-15 cm	7.2	neutral	-	-	-	-	√
77	0-15 cm	7.9	moderately alkaline	-	-	-	-	√
78	0-15 cm	7.1	neutral	-	-	-	-	√
79	0-15 cm	7.8	slightly alkaline	-	-	-	-	√
80	0-15 cm	7.1	neutral	-	-	-	-	√
81	0-15 cm	8.1	moderately alkaline	-	-	-	-	√
82	0-15 cm	7.2	neutral	-	-	√	-	-
83	0-15 cm	7.9	moderately alkaline	-	-	√	-	-
84	0-15 cm	7.1	neutral	-	-	√	-	-
85	0-15 cm	7.9	moderately alkaline	-	-	√	-	-

86	0-15 cm	7.1	neutral	-	-	-	√	-
87	0-15 cm	7.8	slightly alkaline	-	-	-	√	-
88	0-15 cm	7.1	neutral	-	-	-	√	-
89	0-15 cm	8.1	moderately alkaline	-	-	√	-	-
90	0-15 cm	7.1	neutral	-	-	√	-	-

Appendix 14: Plots and their altitudes, latitudes and longitudes (plots 1-30= site I; plots 31-60= site II; and plots 61-90 = site III)

Plots	Altitude	Latitude	Longitude
1	1790 m	12^{0} 43.631' N	039^{0}38.120' E
2	1780 m	12^{0}43.589' N	039^{0}38.136' E
3	1778 m	12^{0}43.545' N	039^{0}38.142' E
4	1768 m	12^{0}43.504' N	039^{0}38.140' E
5	1765 m	12^{0}43.471' N	039^{0}38.156' E
6	1755 m	12^{0}43.431' N	039^{0}38.158' E
7	1750 m	12^{0}43.398' N	039^{0}38.190' E
8	1750 m	12^{0}43.372' N	039^{0}38.215' E
9	1740 m	12^{0}43.341' N	039^{0}38.245' E
10	1738 m	12^{0}43.321' N	039^{0}38.270' E
11	1762 m	12^{0}43.572' N	039^{0}38.226' E
12	1761 m	12^{0}43.527' N	039^{0}38.224' E
13	1758 m	12^{0}43.483' N	039^{0}38.239' E
14	1751 m	12^{0}43.447' N	039^{0}38.244' E
15	1745 m	12^{0}43.406' N	039^{0}38.240' E
16	1776 m	12^{0}43.563' N	039^{0}38.383' E
17	1777 m	12^{0}43.527' N	039^{0}38.386' E
18	1790 m	12^{0}43.505' N	039^{0}38.417' E
19	1805 m	12^{0}43.489' N	039^{0}38.436' E
20	1800 m	12^{0}43.475' N	039^{0}38.459' E
21	1802 m	12^{0} 43.643' N	039^{0}38.070' E
22	1780 m	12^{0} 43.600' N	039^{0}38.062' E
23	1780 m	12^{0} 43.564' N	039^{0}38. 041' E
24	1775 m	12^{0} 43.528' N	039^{0}38. 015' E

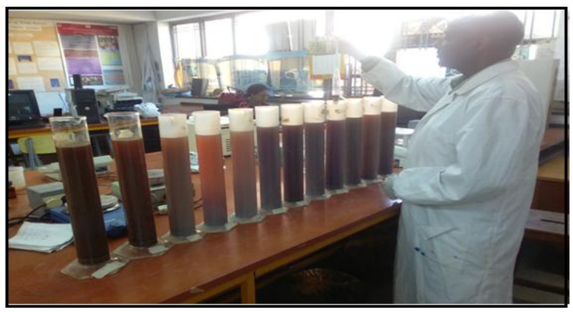
25	1763 m	12^0 43.483' N	$039^0$38. 014' E
26	1760 m	12^0 43.434' N	$039^0$38. 008' E
27	1764 m	12^0 43.395' N	$039^0$38. 986' E
28	1765 m	12^0 43.364' N	$039^0$38. 983' E
29	1764 m	12^0 43.332' N	$039^0$38. 013' E
30	1770 m	12^0 43.297' N	$039^0$38. 018' E
31	1742 m	12^0 52.530' N	$039^0$43. 026' E
32	1733 m	12^0 52.515' N	$039^0$43. 058' E
33	1733 m	12^0 52.505' N	$039^0$43. 079' E
34	1735 m	12^0 52.478' N	$039^0$43. 127' E
35	1718 m	12^0 52.461' N	$039^0$43. 157' E
36	1710 m	12^0 52.435' N	$039^0$43. 221' E
37	1715 m	12^0 52.466' N	$039^0$43. 228' E
38	1738 m	12^0 52.347' N	$039^0$43. 898' E
39	1732 m	12^0 52.334' N	$039^0$43. 928' E
40	1730 m	12^0 52.334' N	$039^0$43. 265' E
41	1728 m	12^0 52.335' N	$039^0$43. 004' E
42	1720 m	12^0 52.233' N	$039^0$43. 043' E
43	1715 m	12^0 52.317' N	$039^0$43. 088' E
44	1716 m	12^0 52.314' N	$039^0$43. 122' E
45	1715 m	12^0 52.302' N	$039^0$43. 166' E
46	1715 m	12^0 52.305' N	$039^0$43. 160' E
47	1721 m	12^0 52.666' N	$039^0$43. 050' E
48	1712 m	12^0 52.292' N	$039^0$43. 073' E
49	1703 m	12^0 52.766' N	$039^0$43. 129' E
50	1688 m	12^0 52.814' N	$039^0$43. 192' E
51	1710 m	12^0 52.809' N	$039^0$43. 967' E
52	1715 m	12^0 52.746' N	$039^0$43. 947' E
53	1714 m	12^0 52.722' N	$039^0$43. 926' E
54	1730 m	12^0 52.677' N	$039^0$43. 890' E
55	1733 m	12^0 52.608' N	$039^0$43. 826' E
56	1741 m	12^0 52.528' N	$039^0$43. 776' E
57	1886 m	12^0 52.787' N	$039^0$43. 712' E

58	1780 m	12^{0} 52.764' N	039^{0}43. 674' E
59	1780 m	12^{0} 52.722' N	039^{0}43. 664' E
60	1784 m	12^{0} 52.710' N	039^{0}43. 645' E
61	1733 m	12^{0} 35.815' N	039^{0}46.225' E
62	1742 m	12^{0} 35.825' N	039^{0}46.188' E
63	1745 m	12^{0} 35.836' N	039^{0}46.158' E
64	1745 m	12^{0} 35.849' N	039^{0}46.122' E
65	1735 m	12^{0} 35.850' N	039^{0}46.088' E
66	1728 m	12^{0} 35.927' N	039^{0}46.296' E
67	1715 m	12^{0} 35.939' N	039^{0}46.328' E
68	1710 m	12^{0} 35.973' N	039^{0}46.345' E
69	1707 m	12^{0} 35.995' N	039^{0}46.386' E
70	1704 m	12^{0} 35.007' N	039^{0}46.423' E
71	1713 m	12^{0} 35.052' N	039^{0}46.287' E
72	1721 m	12^{0} 35.048' N	039^{0}46.253' E
73	1723 m	12^{0} 35.066' N	039^{0}46.215' E
74	1740 m	12^{0} 35.079' N	039^{0}46.186' E
75	1730 m	12^{0} 35.082' N	039^{0}46.171' E
76	1715 m	12^{0} 35.117' N	039^{0}46.292' E
77	1711 m	12^{0} 35.165' N	039^{0}46.294' E
78	1700 m	12^{0} 35.224' N	039^{0}46.298' E
79	1700 m	12^{0} 35.276' N	039^{0}46.308' E
80	1705 m	12^{0} 35.327' N	039^{0}46.296' E
81	1672 m	12^{0} 35.491' N	039^{0}46.322' E
82	1665 m	12^{0} 35.562' N	039^{0}46.338' E
83	1662 m	12^{0} 35.611' N	039^{0}46.331' E
84	1660 m	12^{0} 35.658' N	039^{0}46.352' E
85	1660 m	12^{0} 35.697' N	039^{0}46.352' E
86	1653 m	12^{0} 35.744' N	039^{0}46.393' E
87	1654 m	12^{0} 35.795' N	039^{0}46.336' E
88	1656 m	12^{0} 35.760' N	039^{0}46.308' E
89	1663 m	12^{0} 35.704' N	039^{0}46.277' E
90	1675 m	12^{0} 35.697' N	039^{0}46.233' E

Some Field and Lab Activity Pictures

Appendix 15: Pictures from the soil testing progresses at the AAU laboratory

Measuring soil pH with electrod pH meter



Soil measuring with Bouyoucos hydrometer

Soil weighing

Measuring EC by conductivty meter

Appendix 16: Pictures from the study sites during the field work

Field workers at the field

Workers mixing the soil samples

Soil samples in the plastic bags

Acacia tortilis

Cadia purpurea

Acacia etbaica