

**AN ECOLOGICAL ANALYSIS OF THE VEGETATION  
ALONG THE EASTERN ESCARPMENT OF WELLO,  
ETHIOPIA**

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## DEDICATION

This piece of work is dedicated to my parents particularly my father, Tadesse Eshete and my mother, Yeshi Kassaw for their relentless support, priceless love and the perseverance they have for the insight of their children and those around their locality.

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## ACRONYMS

AAU	Addis Ababa University
ANOVA	Analysis of Variance
BWDA	Bati Wereda Department of Agriculture
CSA	Central Statistical Agency
EARO	Ethiopian Agricultural Research Organization
EMA	Ethiopian Mapping Authority
EPA	Environmental Protection Authority
EWNHS	Ethiopian Wildlife and Natural History Society
FAO	Food and Agricultural Organization of the United Nations
GIS	Geographic Information Systems
GPS	Geographical Positioning Systems
IUCN	International Union for the Conservation of Nature
MoA	Ministry of Agriculture
NMSA	National Meteorological Services Agency
PET	Potential Evapotranspiration
RPSUD	Research Program for Sustainable Use of Dryland Biodiversity
SAREC	Swedish Agency for Research and Cooperation with Developing Countries
SIDA	Swedish International Development Agency
SPSS	Statistical Package for Social Sciences
TWINSpan	Two-way Indicator Species Analysis
UNEP	United Nations Environmental Program
WCMC	World Conservation Monitoring Center
WWF	World Wildlife Fund

## ABSTRACT

Woody vegetation analysis was made along eastern Rift Valley escarpment in Wello. The study was carried out based on preferential sampling of the vegetation by establishing seventy 20 X 20 m relevés. A total of 216 species belonging to 62 families were identified and described. Out of these, 104 woody species and succulents were used for vegetation classification. Two-way Indicator Species Analysis (TWINSpan) classified the vegetation into seven woody vegetation types. These are: *Dodonaea angustifolia* Type (I), *Euclea schimperi* ssp. *racemosa*-*Acacia lahai-Dichrostachys cinerea* Type (II), *Cordia purpurea*-*Euclea schimperi* ssp. *racemosa*-*Euphorbia candelabrum* Type (III), *Acacia asak*-*Grewia bicolor*-*Sansevieria ehrenbergii* Type (IV), *Ximelia americana*-*Acacia asak* Type (V), *Acacia mellifera*-*A. oerfota* Type (VI), and *Prosopis juliflora* Type (VII). Woody species were counted and later the relative density and importance value index of the dominant woody species was calculated. Endemic and invasive species were identified. The diversity and evenness of each community was compared using Shannon-Weiner diversity and evenness index. Correlation of different environmental factors with the community types was made using Pearson's coefficient and Tukey's HSD family error test. The interrelationships among environmental variables were analyzed. The results of species diversity showed that communities at the high altitudes are species rich while richness decreases down elevation gradient. Altitude and slope were found to be the most important environmental factors in determining the distribution and composition of species along communities. Most of the vegetation was found highly disturbed except along inaccessible steep slopes, few protected and privately owned areas indicating some implications of conservation and management.

**Keywords:** Environmental variables, Plant communities, Relevés, TWINSpan

# 1. INTRODUCTION

Ethiopia is a land of enormous natural diversity with varied biophysical environment. Altitude varies from the tops of the Simien Mountains (4620 m) to one of the lowest dryland points on earth, the Danakil Depression at 115 m below sea level. The enormous variations in elevation are directly reflected by the diversity of the flora. Ethiopian flora is estimated to be between 6000 and 6500 species. Ethiopia has the fifth largest flora in tropical Africa. Ethiopia is well known for endemism of wild plant and animal species and 12% of the flora is considered to be endemic. Endemism is apparently high on the plateaus, mountains, in the drylands particularly the Ogaden region and in Borana lowlands in Sidamo. Wide-ranging climatic and edaphic conditions with variable topographic features like altitude, aspect and slope are attributed for diverse flora of Ethiopia (Stuart *et al.*, 1990; Tewolde Berhane Gebre Egziabher, 1986, 1990; WCMC, 1992; EWNHS, 1996).

The climate varies mainly according to elevation. Temperature variation is unexpectedly high, which ranges between above 30<sup>0</sup>C and below 10<sup>0</sup>C (Daniel Gamachu, 1977). Rainfall distribution in the country is between 300 mm and 2800 mm. Average annual rainfall of areas above 1500 m exceeds 900 mm while rainfall is erratic and less than 600 mm in the lowlands below 1500 m. The principal rainy season in central and northern parts of the country occurs between June and September, followed by a dry season that may be interrupted by a short rainy season in February or March (Daniel Gamachu, 1977; EWNHS, 1996; Leipzig, 1996; MoA, 1998).

Altitudinal gradient influences the composition and floristic diversity of communities for changes in elevation are accompanied by changes in climatic variables mainly temperature and precipitation (Whittaker, 1967; Whittaker, 1975; Begon, *et al.*, 1996). Rainfall distribution generally decreases with descent in altitude, although it depends on local topography, while temperature increases with a decrease in elevation. Altitudinal limits of the distribution of the different vegetation types vary from one part of the country to the other. Rainfall patterns and temperature variation influence types, diversity and distribution of the vegetation over the country. Diverse topographic and climatic factors, parent material and land use have resulted in extreme variability of soils (Tewolde Berhane Gebre Egziabher, 1990; MoA, 1998).

Topographic diversity associated with climatic and edaphic variations influences micro-environmental conditions like availability of water, nutrients, and light along landscape. These in turn affect the distribution pattern, structure, composition and diversity of plant communities (Whittaker, 1975). Environmental gradients influence the nature and the pattern of variation in vegetation structure and composition (Whittaker, 1975; Begon, *et al.*, 1996). On top of these, the interaction of factors along environmental gradients is so complex that no single factor is attributed to the change in community structure and composition (Begon, *et al.*, 1996). Species diversity and richness along environmental gradients is rather the result of a complex interaction of factors including temperature, precipitation, natural disturbances, soil conditions and biotic factors. Direct gradients like soil moisture, temperature, pH, light, N, P, salinity and indirect gradients such as elevation, latitude, precipitation, slope and aspect influence the distribution, abundance and diversity of species in a community at local and landscape levels (Whittaker, 1975; Begon *et al.*, 1996).

Hence, environmental gradient analysis provides the underlying causes for the pattern and distribution of plant communities on landscapes (Begon *et al.*, 1996). The evaluation of the spatial variation of environmental variables is essential to understand the factors governing the distribution and abundance of species. However, environmental gradients and spatial heterogeneity are not only limited to topography, soil moisture availability but related to intraspecific and interspecific interactions within the community too (Whittaker, 1975; Begon *et al.*, 1996).

Beals (1969) analyzed vegetation changes along altitudinal gradients in Southern Wello and Shashemene areas where vegetation along steep and gentle gradients showed respective continuous and discontinuous vegetation changes. He has pointed out that the discontinuity of communities in the study areas is due to changes in the depth and stability of the soil, moisture and competition.

Previous studies of plant community description and identification with ecological approach in Ethiopia have been very few (Tesfaye Awas *et al.*, 2001). Physiognomic features were the basis of vegetation description and classification and only few studies were relying on floristic composition (Tesfaye Bekele, 2000).

The vegetation of South Wello was studied by Mesfin Tadesse (1990), EWNHS (1996), Eyayu Molla (1996), Kebrom Tekle (1998), Mengistou Gonsamo (1998), Sebsebe Demissew (1998), Tesfaye Bekele (2000) and Abate Ayalew (2003). However, vegetation studies in the lowlands including the surrounding Afar region are scanty. On the other hand, the vegetation is increasingly degraded due to human perturbation for long period of time.

Vegetation analysis based on the ecological relationship between plant communities and environmental and anthropogenic factors is indispensable for conservation and management of the vegetation and other environmental resources. Hence, vegetation studies in Ethiopia particularly in the study area are very important for many reasons like management, conservation and sustainable utilization of the plant resources. The objective of this study is to examine the diversity and composition of plant communities and to understand the pattern of distribution along few environmental gradients of the escarpment in the region. In general, this study contributes to the understanding of the degrading vegetation in the region in relation to certain environmental variables.

## 2. OBJECTIVES

This study was carried out based on the following general and specific objectives:

Description of woody plant communities, correlation of the plant communities with some environmental variables, and compilation of floristic list.

### 2.2 Specific Objectives

1. To compile a floristic list of the study area;
2. To identify and describe woody plant communities in the study area;
3. To analyze distribution of woody plant species along altitudinal gradients;
4. To examine the ecological relationships between plant communities and their physical environment;
5. To investigate the diversity and composition plant species in the study area, and
6. To identify the status of the vegetation and recommend proper management and conservation measures.

### 2.3 Research Questions

1. What will be the diversity and composition of woody plant species in the study area?
2. What are the main factors determining woody species richness and diversity in the study area?
3. What are the basic environmental factors determining the occurrence and distribution of the communities?
4. Is there a clear pattern in woody plant species distribution along altitudinal gradients in the study area?

## 3. LITERATURE REVIEW

### 3.1 Drylands

Drylands are extremely diverse in terms of their landforms, soils, flora, fauna, water balances and human activities (UNEP, 1992). They cover a variety of terrestrial biomes that are extremely heterogeneous with wide variations in topographic, climatic, geological, biological and socioeconomic conditions. Due to this diversity, no pragmatic definition of dryland environments can be derived. Despite differences between various dryland ecosystem-types caused by variations in the aforementioned conditions, these ecosystems have a common unifying characteristic: precipitation is low and extremely variable. Therefore, drylands are areas where rainfall is low, variable, often unreliable, and generally unevenly distributed throughout the year (UNEP, 1992; IUCN, 1999).

Drylands cover hyper-arid, arid, semi-arid and dry sub-humid ecosystems having low P/PET ratio (where P is mean annual precipitation and PET is the mean potential evapotranspiration of the area) (Menault and Cesar, 1985; IUCN, 1999). These ecosystems cover areas with unpredictable precipitation in time and space with low total amounts. On top of these, the more arid areas have high diurnal temperature variability. Drylands have highly seasonal rainfall regimes with significant inter-annual variability and mean annual precipitation values which vary from about 800 mm in summer rainfall areas to 250 mm in winter regimes (IUCN, 1999).

### 3.2 Drylands in Ethiopia

The African land mass is 55% arid and semi-arid (White, 1983; IUCN, 1999). About 70% of Eastern Africa land area is covered by drylands that support 75% of the human population and 50% of the livestock population (Kigomo and Chikamai, 2003; White, 1983). According to White (1983), the climate of drylands in East African is characterized by high temperatures and low precipitation. Arid and semi-arid climates are found in Ethiopia, Kenya, Tanzania, Somalia, Djibouti and Eritrea, with annual rainfall ranging between 400 and 750 mm (Kigomo and Chikamai, 2003; White, 1983). Drylands cover 60% of the Ethiopian land surface where 12% of human and 20% of livestock population is living (CSA, 1995; Leipzig, 1996).

White (1983) describes the driest area of Eastern Africa as the "Somalia-Masai Regional Center of Endemism", the predominant physiognomic region in East Africa. This phytochorion includes eastern and southeastern Ethiopia with the exception of mountainous areas, most of Kenya between the highlands and the coastal belt, the dry lowlands of north and central Tanzania, most regions of Somalia and Eritrea, South East Sudan and North East Uganda (White, 1983). Average temperature is between 25 and 30°C and mean annual precipitation is less than 500 mm with a very high PET loss exceeding about 2500 mm/year (White, 1983). There are about 2500 plant species, of which half are endemic, and there are about 50 endemic genera. *Acacia-Commiphora* vegetation type is the dominant type in Somalia-Masai Regional Center of Endemism. Endemic species typical of the dryland tropics, including *Acacia* (30 spp.), *Commiphora* (60 spp.), *Boscia* (7 spp.), *Boswellia* (6 spp.), and *Maerua* (10 spp.) are found (White, 1983). Endemic animals including grazing herbivores and other wild animals are also found (White, 1983).

In Ethiopia, "Kolla" or warm to hot semi-arid and "Berha" or hot arid climates are found at altitudes between 500 and 1800 m; and under 500 m respectively. In arid zones, mean annual rainfall distribution is from 100 to 600 mm (EPA, 1997; MoA, 1998). The semiarid zone has a respective mean annual rainfall distribution and PET ranging from 300 to 800 mm and 1900 to 2100 mm with a growing period of 46-60 days. Monthly PET exceeds rainfall in most parts of arid and semi-arid areas of the country (MoA, 1998; Bourne, 2002).

Drier conditions prevail throughout the Rift Valley region. The Ethiopian rift runs from northeast to southwest of the country and separates the northwestern and southeastern highlands. The rift separates two great plateaus mostly with over 2000 m land surfaces and with high volcanic mountains and deep river valleys. The highlands on each side of the Rift Valley give way to extensive semi-arid lowlands to the east and west of the country. The Ethiopian rift system is a zone of intensive agricultural activity where increasing and progressive settlement has replaced grazing lands by small to medium farms (Bourne, 2002).

### **3.3 Dryland Vegetation in Ethiopia**

Drylands in Ethiopia include rangelands, wooded grasslands, shrublands and bushlands. Bushlands and shrublands contribute 21.4% while grasslands are 30.5% of the total landmass in Ethiopia (CSA, 1995). Shrub communities result from the degradation of forest or grassland ecosystems as a result of overgrazing or deforestation. Shrublands that are important for livestock and wildlife forage are being overgrazed, misused as farmland, and deforested for firewood, allowing deserts to encroach on them (Leipzig, 1996).

The earliest vegetation classification was that of Pichi-Sermolii (1957) which recognized 23 vegetation types in Ethiopia. Recent vegetation classification studies have divided Ethiopian vegetation into nine major types (Zerihun Woldu, 1999). EPA (1997), Sebsebe Demissew (1998) and Zerihun Woldu (1999) indicated that dry evergreen forest; evergreen scrub, *Acacia-Commiphora* deciduous bushland and marshy vegetation types are found in Southern Wello. The main Ethiopian dryland vegetation types worth mentioning in this paper are described as follows.

### 3.3.1 *Acacia -Commiphora* Deciduous Bushland and Thicket

*Acacia-Commiphora* deciduous bushland and thicket occur mainly in the north, east, south and central parts of the country at altitudes between 900 and 1900 m (EWNHS, 1996; Zerihun Woldu, 1999). Average annual precipitation in this region is generally less than 500 mm in most places and may be reduced to 20 mm in some places. This vegetation zone is established with mean annual temperature ranging from 18<sup>o</sup> to 27<sup>o</sup>C and mean annual rainfall between 410 mm and 820 mm. The soil in the region is extremely diverse in type (IUCN, 1999; WWF, 2001).

Shrubs, bushes and thicket generally occur under a wide range of climatic and edaphic conditions and grasses are present in most types of bushlands (White, 1983). Small-leaved deciduous vegetation is dominant in this region. The common species include *Acacia*, *Commiphora*, *Ziziphus*, *Maerua*, *Cadaba*, *Boscia*, *Euphorbia*, *Aloe* and *Sansevieria* (White, 1983; EWNHS, 1996; Zerihun Woldu, 1999).

This vegetation type has been grazing areas although it is highly sensitive to overgrazing due to prolonged dry season that stays up to 10 months. Moreover, this vegetation is becoming more vulnerable and increasingly depleted owing to the supply of fuel wood and charcoal to population centers (Ensermu Kelbessa *et al.*, 1992; Zerihun Woldu 1999). Since the soil is fine, it is more susceptible to wind and water erosion (EWNHS, 1996; EPA, 1997; Zerihun Woldu, 1999).

### 3.3.2 Semi-desert and Desert Vegetation

The most arid vegetation type is found in the drier regions of southern and eastern Ethiopia below altitude of 900 m (EWNHS, 1996; Zerihun Woldu, 1999). There is basically very small proportion of true desert vegetation in Ethiopia, particularly in the Afar depression, the Ogaden, Lake Chew Bahir and the Omo Delta (Beals, 1969). Rainfall is typically low and erratic with unimodal distribution (EWNHS, 1996). It is predominantly composed of drought tolerant and deciduous species with scattered and less frequent evergreen shrubs and succulents. These include small trees and shrubs species of *Acacia*, *Commiphora*, *Boscia*, *Cadaba*, *Maerua* and *Ziziphus*; succulent species of *Euphorbia*, *Cissus*, *Sansevieria* and *Aloe* and grass species of *Dactyloctenium* and *Panicum*. Grass species are more or less absent from rocky areas and are occurring on flat areas where water may lie during the rainy season (EWNHS, 1996; White, 1983). The soils in this vegetation type are alluvial and thus are vulnerable to erosion. Water is very scarce and evapotranspiration is very high consequently vegetation is very scanty (EWNHS, 1996; Leipzig, 1996). According to Zerihun Woldu (1999), soil salinity is a potential environmental problem in the area and this zone is liable to be converted into a desert if the current human activities continue uncontrolled and the drought conditions persist.

### 3.3.3 Dry Evergreen Montane Forest and Grassland Complex

This vegetation type is not found within the altitudinal range characterizing drylands and is found between 1900 and 3400 m (Leipzig, 1996; EWNHS, 1996; EPA, 1997; Zerihun Woldu, 1999). Dry evergreen montane forests occur in much of the highlands in the northern, central and southeastern parts of Ethiopia. However, it is discussed in this paper due to the proximity of this vegetation type to the vegetation under study. It is found in the highlands of South Wello (Sebsebe Demissew, 1998; Tesfaye Bekele, 2000).

Small to large-sized trees and grasslands rich in legumes characterize this vegetation type. The common tree species include *Olea europaea* ssp. *cuspidata*, *Celtis africana*, *Euphorbia ampliphylla*, *Mimusops kummel* and *Ekebergia capensis*. *Carissa spinarum* and *Rosa abyssinica* comprise the shrubs. The common grass genera include species of *Hyparrhenia*, *Eragrostis*, *Panicum*, *Sporobolus*, *Eleusine* and *Pennisetum*. The ecotone between the forest and grasslands is occupied by *Acacia* woodland with *Acacia abyssinica*, *A. negrii* and *A. pilispina* as the most common trees. This vegetation type is particularly important as it is home to a large number of endemic plants (EWNHS, 1996; EPA, 1997; Zerihun Woldu, 1999).

Sedentary, cereal based agriculture has gone for thousands of years in this zone (FAO, 1996). Consequently, the area under natural vegetation is increasingly diminishing as a result of anthropogenic activities. In many places, the forests have been replaced by woodland and grassland on gentle slopes with deep soils, and by evergreen bushland on steeper slopes with thin soils (Leipzig, 1996).

### 3.3.4 Riparian Vegetation

This vegetation type is characterized by different tree and shrubby species associated with herbs and grasses. *Tamarindus indica*, *Tamarix aphylla*, *Ficus sycomorus*, *Maytenus senegalensis*, *Celtis africana*, *Dobera glabra*, and different *Acacia* species like *Acacia mellifera*, *A. senegal* are found (EWNHS, 1996; EPA, 1997). Swamps are dominated by sedges like species of *Cyperus*, *Eleocharis* and *Scirpus* and grasses like species of *Echinochloa* (EWNHS, 1996).

This vegetation is found along dry riverbeds, catchments and tributaries of the Awash River and is also found in the riverine vegetation of the study area. Mitiku Tiksa (2001) has identified one community type along the vegetation of the lower Awash being dominated by *Acacia mellifera*, *A. oerfota*, *A. senegal* and *Dobera glabra* at altitudes between 740 and 920 m.

### 3.5 Vegetation Data Analysis

Community classification approaches include physiognomic approach, dominance types, Braun-Blanquet association approach and numerical approach (Oksanen, 2003). Out of these, floristic approach of Braun-Blanquet was used for this study (Braun-Blanquet, 1983). Only exclusive, selective and preferential species (character species) are used in community analysis. Rare species are not used for community description (Williams and Lambert, 1966; Kershaw, 1973; Mueller-Dombois and Ellenberg, 1974; Werger, 1974; Chapman, 1976; Braun-Blanquet, 1983).

Vegetation data is often voluminous and seemingly disorganized. Thus, the complete data set cannot be easily interpreted unless summarized retaining the information. Application of precise numerical techniques to a data matrix having vegetation and other environmental data is required for vegetation analysis (Allen, 1987; Austin, 1987; Digby and Kempton, 1987). These techniques are classification and ordination (Muller-Dombois and Ellenberg, 1974; Whittaker, 1975; Greig-Smith, 1983; Pielou, 1984; Austin, 1987; Digby and Kempton, 1987; Kent and Coker, 1992). The choice among techniques depends on the objective of the research, size and complexity of the data (Gauch and Whittaker, 1981; Gauch, 1982).

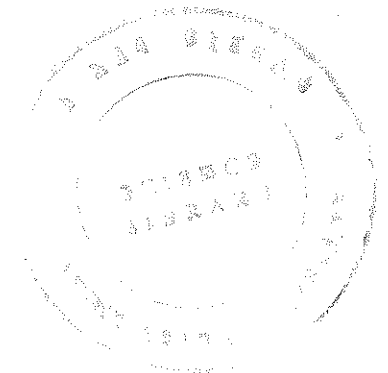
Hierarchical, polythetic and divisive technique was employed to analyze the data of the present study using the computer program TWINSpan (Kent and Coker, 1992; Hill, 1994).

## 4. MATERIALS AND METHODS

### 4.1 The Study Area

#### 4.1.1 Location

The study was carried out in northeast Ethiopia along the eastern escarpment of the Rift Valley in South Wello Administrative Zone ( $11^{\circ} 00' - 11^{\circ} 30' N$  and  $39^{\circ} 30' - 40^{\circ} 00' E$ ) and Oromia Zone in Amhara region and Afar Region. The study plots covered a total of 80 km starting from 10 km below Kombolcha town to a small village called Eliwoaha, which is about 92 km far from Kombolcha along the Kombolcha–Mille road. Kombolcha and Bati are found at about  $11^{\circ} 05' N$  and  $39^{\circ} 45' E$  and  $11^{\circ} 09' N$  and  $40^{\circ} 42' E$  latitudes and longitudes and at an altitude of 1900 m and 1660 m a. s. l. respectively (EMA, 1988). There is a small town called Gerba between Kombolcha and Bati at  $11^{\circ} 09' N$  and  $39^{\circ} 55' E$  with an altitude of 1560 m and about 30 km from Kombolcha. Garsa Gita is a small town in Afar region, Mille Wereda, is found at  $11^{\circ} 14.8' N$  and  $40^{\circ} 12' E$  at a distance of 72 km from Kombolcha. Eliwoaha, a small village in Afar region, is found between  $11^{\circ} 15' N$  and  $40^{\circ} 22' E$  latitudes and longitudes respectively and at a distance of 92 km from Kombolcha and with the lowest altitude (750 m) among the study sites. The map of the study area is shown in Figure 1.



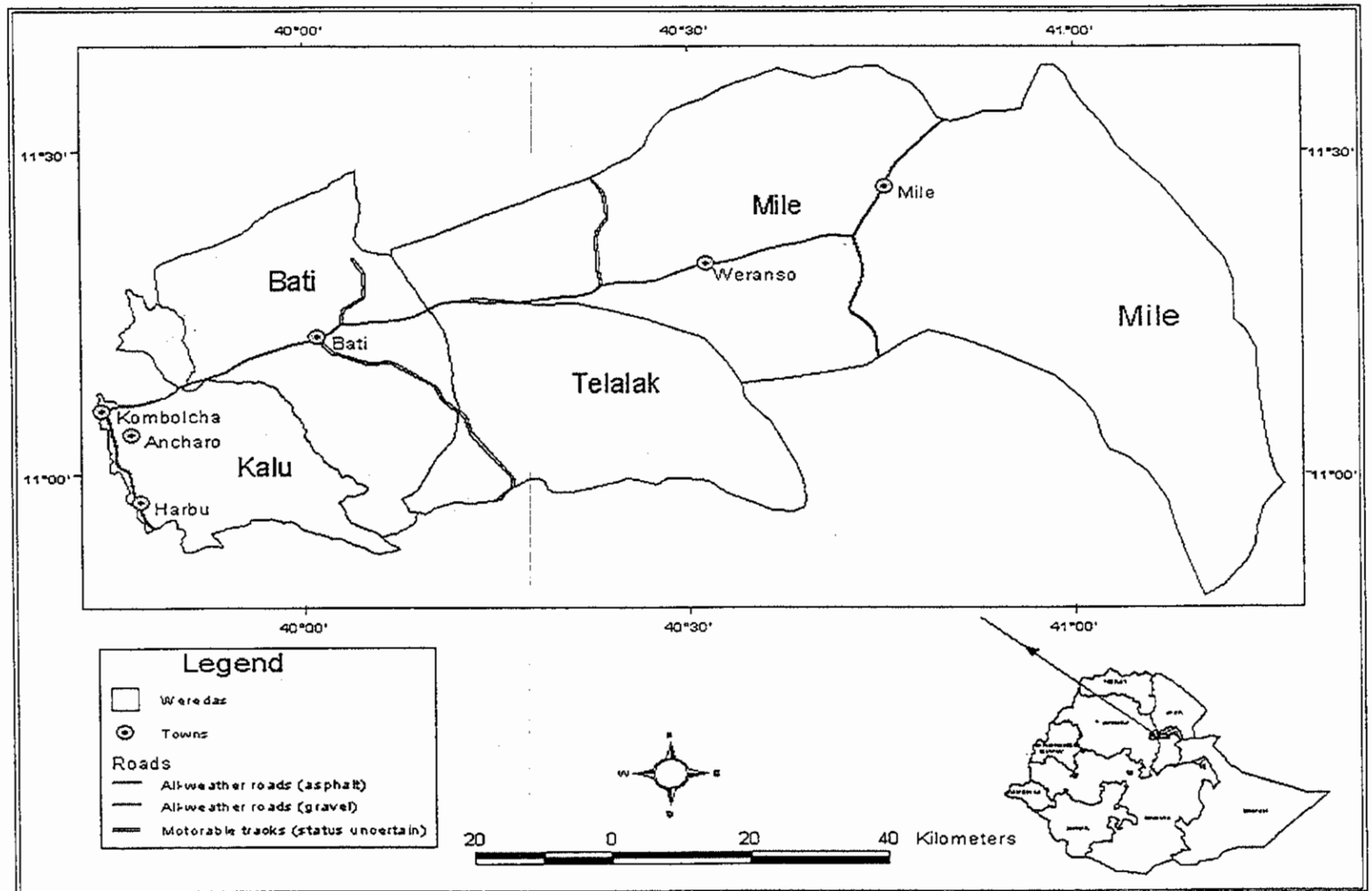


Figure 1. Map of the study area.

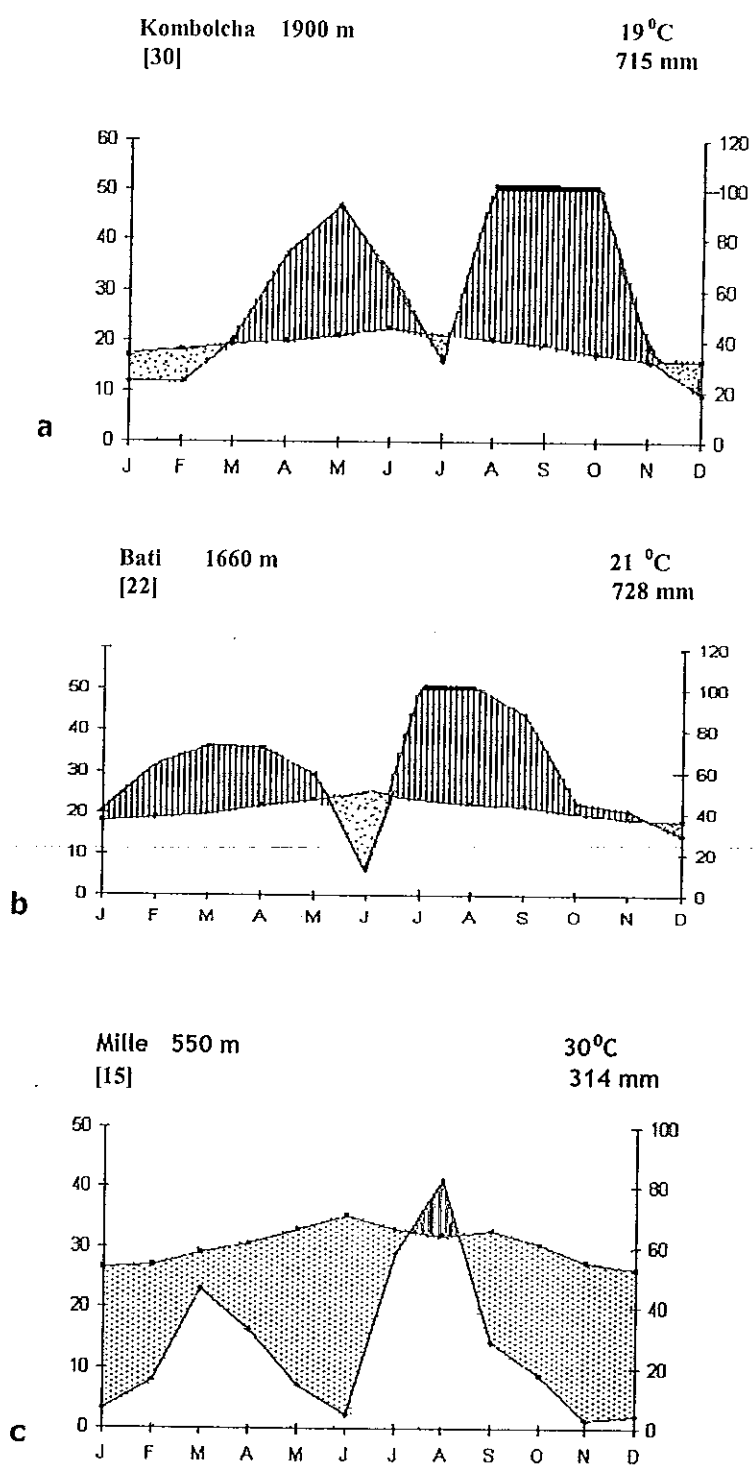
Source: EARO GIS Lab

### 4.1.2 Climate

Although variable in climatic and other environmental conditions, the study area is generally characterized by arid and semi-arid climatic conditions. There is diverse agroecology in the region and is mostly characterized by traditionally classified types: “Berha” and “Kola” climates that are comparable to hot arid and warm to hot semi-arid climatic types respectively (MoA, 1998). The agroecology of Bati Wereda is “Weina Dega”(warm to cool semi-humid) and “Kola” with 19% and 81% respectively in the upper part of the region while arid and semiarid climate predominant in Afar region (BWDA, 2001).

Rainfall distribution varies from place to place within the study area ranging between 200-700 mm annually. It is bimodal with long rains of high intensity between June and September and short rains occurring between mid-March and mid-April. The Afar region often receives some rain during the two small rainy seasons, “Daada” in December and “Sugum” in March and April and a long rainy season, “Karama” in July and August. Most of the Afar region receives only erratic and insufficient precipitation to regenerate grass (Piguet, 2002). Mean annual evapotranspiration is high in Afar Region, which can be as high as 3000 mm in the Afar Depression (EWNHS, 1996).

The mean monthly temperature of Kombolcha station is 19<sup>0</sup>C while that of Bati and Mille towns is about 21<sup>0</sup>C and 30<sup>0</sup>C respectively. Based on the available data from the National Meteorological Services Agency for the study stations Kombolcha, Bati and Mille, the climatic diagram following Walter (1975) were constructed based on mean monthly rainfall and mean monthly temperature for 25 years (Figure 2 a-c).



**Figure 2 a-c. Climatic diagram for Kombolcha (a), Bati (b), and Mille (c) \***  
 (Walter, 1975). Data source: National Meteorological Services Agency, Addis Ababa  
 \*Mean monthly rainfall values above 100 mm was log transformed following Walter, 1975

### 4.1.3 Topography

The altitude in study region ranges from 750 m to 1900 m. Land feature in the study area particularly in the highland regions of Kalu and Bati Weredas is mostly rugged with up and down terrains (42%), and 28% gorgy features. Mountains and plateaus compose 20% and 10% of the total area of Bati Wereda respectively (BWDA, 2001). Most of the study area at high altitudes is sloppy. The lowlands, about 12 km below Bati and the study sites found in the Afar region are plateaus which form plains at the foot of the escarpment around Eliwoaha. According BWDA (2001), 70% of the land in Bati Wereda is between 25<sup>0</sup> and 50<sup>0</sup> slopes.

### 4.1.4 Geology and Soils

The geology of most of the study area is mainly composed of tertiary volcanic rocks of the trap series, with quaternary sediments, which overlay Mesozoic and Precambrian rocks (Paris, 1985; MoPED, 1993). The rift escarpment with an altitude of 1700-2000 m is mainly composed of lacustrine sediments and the highlands above 2000 m mainly consist of basalt, trachyte and ignimbrite (Dagnachew Legesse, 2002). Most of the area has volcanic soils except in the Rift, where alluvial soils occur. The soil type around Bati is predominantly brown (54%). Red, black and gray soils compose 12%, 23% and 11% respectively (BWDA, 2001). The soil in much of the study area is shallow, rocky and poorly developed and soil depth is low in steep slopes of the study area. The soils developed on sloppy areas are more vulnerable to soil erosion which is aggravated by deforestation. About 80% of south Wello has a soil depth less than 20 cm due to excessive soil erosion (Baber, 1984).

#### 4.1.5 Hydrology

There are several catchments in the study areas like the River Chachatu, River Cheleka, River Gelana, River Burka, River Tatesa, River Kiltu, River Beshelo and River Busidima that tend to drain on dry seasons. Perennial rivers in the region include Borkana River, Mille River, Logia River and their catchments. Lake Ardibo and Lake Hayk are also found in the region.

#### 4.1.6 Land Use

Land use in the highlands is mainly mixed agriculture while the main occupation of the people in the lowlands is pastoralism. On top of these, charcoal making is a means of livelihood of many rural people particularly in the areas between Bati and Garsa Gita towns and about 10 kms below Kombolcha town (pers. obs.). Kalu district is one of the highly populated regions in Ethiopia (250 persons/km<sup>2</sup>) with very high growth rate. This implies that there is increasing pressure on vegetation and other environmental resources and the resulting land degradation in the region (Kebrom Tekle *et al.*, 1997).

Crop cultivation involves a primary and a secondary production of sorghum and maize respectively. "Teff", millet, lentils, sesame, pea and chickpea are also cultivated in the highlands. Onion, tomato, green paper, cauliflower, orange, guava, carrot, sugar beet, papaya, citrus, lemon, mango, avocados, banana and sugar cane are also grown in highlands of the region. According to the data from BWDA (2001), land to people ratio in the highlands is generally 0.65 ha/head for crop and 0.5 ha/head for grazing.

Shrublands compose the main proportion of Bati Wereda. The distribution of land use in Bati Wereda is summarized in Table 1. Most of the study area is drought prone and more populated nomadic region. Agricultural productivity is increasingly low due to drought, pest, soil erosion, deforestation, epidemicity of animal diseases, primitive animal husbandry and farming systems, reduced soil fertility, feed deficit, and low animal productivity (BWDA, 2001). In conditions where there is a fair rain, lack of sufficient pasture occurs due to overgrazing, conflicts and tensions among pastoralists where local pastoralists are blocking access to some reserved grazing areas (BWDA, 2001).

**Table 1. Land use and land cover in Bati Wereda**

Land use	Cover in ha	Percentage
Cultivated land	11169	9.8
Grazing land	17099	14.9
Forest	613	0.5
Shrubland	61631	53.8
Others	23940	20.9
Total	114452	100

Source: BWDA, 2001

## 4.2 Vegetation Sampling

Vegetation was sampled along one major transect on the western escarpment of the Rift Valley in Wello. Following preferential sampling, relevés (20 m x 20 m) were established based on homogeneity and representativeness. A total of 70 quadrats were analyzed. Quadrats were laid few hundred meters to several kilometers to the left and right of the main road to avoid the effects of disturbance.

The herbaceous layer, particularly grasses, was not included during the data collection since sampling was done in the dry season. However, to obtain complete floristic list, herbs and other plant species that were not collected and identified during the dry season sampling and data collection period were sampled on the second field data collection that was undertaken during wet season in August 2003.

Even though herbs particularly grasses were not used in community classification; grasses and other herbs were collected and identified to compile the floristic composition of the area. Moreover, herbaceous species that were collected in and around the previously established plots were identified and later roughly described as associated species so as to describe the communities more. The inclusion of associated herbaceous species was made relying on the data collected about altitude and locality of each species sampled and identified and only where there are permanent marks that indicate the location of the previous relevés. This data was then compared with the description on the locality and altitude of the different community types. Based on this, herbaceous species found around localities of each plant community type were later included as associated species and species found around the corresponding communities.

Plant specimens in each relevé were collected and pressed for identification at the National Herbarium (ETH), Department of Biology, AAU. Vernacular names of the plant species were also recorded in the field.

### **4.3 Canopy Cover**

Percent canopy cover of woody plant species in each relevé was estimated visually and later converted into a modified 1-9 Braun-Blanquet scale (Van der Maarel, 1979) as follows:

- 1= Rare, generally one individual
- 2= Occasional or sporadic with less than 5% cover of the total area
- 3= Abundant with less than 5% cover of the total area
- 4= Very abundant, with less than 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
- 9= >75% cover of the total area

### **4.4 Woody species density**

The number of individuals of each tree and shrub species was counted in each relevé with 20 m X 20 m. Dominant tree and shrubs were included in the count. The number of individuals of a species in a sample (abundance) and the proportion of samples within which a species (frequency) if found was calculated for dominant trees and shrubs. Individuals having their canopy within the plot and that were rooted outside were not included in the count. Then, the average number of individuals of each tree and shrub species was converted into individuals per hectares for each community as indicated in Kent and Coker (1992).

### **4.5 Life-forms and Growth forms**

The growth forms of plant species for relevés was drawn in the field and used in the description of the vegetation. Plant species were identified and classified based on embryonic or meristematic tissues in to Raunkiaer's life-form types (Raunkiaer, 1934). The following plant life-forms were identified with five recognized types as follows:

Phanerophytes:	Trees and shrubs with perennial buds well up in the air
Chamaephytes:	Perennial shoots or buds on the surface of the ground to about 25 cm above surface
Hemicryptophytes:	Perennial buds at the surface of the ground
Cryptophytes:	Perennial buds buried on the ground on a bulb or rhizome
Therophytes:	Annuals with complete life cycle from seed to seed in one season

The growth structure of the vegetation in each relevé was drawn in the field so that the vegetation growth would be described as either of the following types: bushland, shrubland, scrubland, or thicket.

#### **4.6 Environmental Data**

The environmental variables measured include altitude, slope, soil depth, soil color, conductivity, and salinity. Altitude and slope for each relevé were measured using Everest altimeter and Suunto clinometer respectively. Soil depth was estimated using a locally prepared iron stick whose length is labeled in centimeters. GPS records were taken and the data was used in the generation of topographic map for the study area (Appendix 4).

In each relevé, soil samples were collected from each corner and center of the relevé. Soil samples were taken from the depth of 0-30 cm in the five spots and were mixed to obtain a composite sample for analysis. Soil samples collected from each relevé was air dried, crushed and sieved through a 2 mm sieve. Electrical conductivity and salinity were analyzed following EARO (2000) using conductivity meter and soil color was identified based on the Munsell's color charts as described by Anon. (1975). These soil parameters were analyzed at the soil laboratory of Biology Department, Addis Ababa University.

## 4.7 Data Analysis

TWINSPAN is recommended as the best way to identify plant community types (Hill, 1979; Kent and Coker, 1992). The cover-abundance data was entered into a spreadsheet and was converted into Tablefit format (TABLEFIT) and then to Cornell condensed (CCF) format using the utility programs in TWINSPAN. This program was used to analyze the vegetation data based on the following options: 70 relevés and 104 species, 5 pseudospecies cut levels (0 5 15 30 50), 5 maximum group size for division, maximum number of indicators per division 7, maximum division level 6, and maximum number of species in final tabulation was 60. The weights for levels of pseudospecies established to 5 as 1 2 2 2 2 indicating that pseudospecies corresponding to four higher cut levels were given twice the weight of pseudospecies at the lowest level. Indicator potentials for cut levels were arranged as 0 1 1 1 1, which represents all pseudospecies cut levels, except level one, are used as indicators. Pseudospecies refers to the percentage of a species at different predetermined levels of abundance used for making a dichotomy in classification (Kent and Coker, 1992).

Synoptic cover-abundance value was calculated as mean cover-abundance values for each species (Kent and Coker, 1992). This was calculated by adding all the cover values of the species occurring in relevés belonging to that community and dividing the figure with the number of relevés the species is found in. The naming of communities was given after two or three dominant characteristic species with higher synoptic values. The environmental data of the communities were obtained by calculating the average value of the clusters. One-way analysis of variance (ANOVA) and Tukey's HSD test using the SPSS 10.0 for Windows program was used to analyze the community-environment relationships and Pearson's product moment was applied to examine correlation among the environmental variables.

Importance value index was calculated to find out the relative importance of species in the communities as follows:

**Importance value Index = Relative Density + Relative Dominance + Relative Frequency**

$$\text{Relative density} = \frac{\text{Total no. of individuals, species A} \times 100}{\text{Total no. of individuals of all species}}$$

$$\text{Relative Dominance} = \frac{\text{Dominance of species A} \times 100}{\text{Dominance of all species}}$$

\*Dominance is expressed in terms of canopy cover values (Kent and Coker, 1992).

$$\text{Relative frequency} = \frac{\text{Frequency of species A} \times 100}{\text{Frequency of all species}}$$

The Shannon-Weiner diversity index was used to estimate the species richness and relative abundance (species diversity). Simpson index was not used since it weights the most abundant species more heavily than rare species. Shannon index is better because species abundance is standardized to proportions and since it is based on both species richness and evenness (Shannon & Weiner, 1949; Magurran, 1988; Kent and Coker, 1992).

The Shannon index was calculated using Microsoft Excel for Windows as follows:

$$H' = - \sum_{i=1}^S p_i \ln p_i, \text{ where}$$

$H'$  = Diversity of species

$S$  = number of species

$\ln$  = log base<sub>e</sub>

$p_i$  = proportion of individuals of the total sample belonging to the  $i^{\text{th}}$  species

Equitability or species evenness was calculated using the Shannon Evenness index following the equation:

$$E = H'/H_{\max} \text{ where,}$$

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

$H'$  = Shannon diversity index

$\ln S$  = the natural logarithm of the total number of species in each community

$S$  = Number of species in each community (Shannon-Weiner, 1949).

Floristic comparison was made using similarity analysis index. The similarity index used was Sørensen's similarity coefficients:  $S' = 2c/(a+b)$ , where "c" is the number of species shared by the vegetation types compared, "a" and "b" are the number of species confined to each vegetation. It is preferred to Jaccard's coefficient since common species are given more weight than those confined to one vegetation type (Kent and Coker, 1992).

## 5. RESULTS AND DISCUSSION

### 5.1 Floristic Composition

A total of 216 species, belonging to 62 families were collected and identified during the study. The complete floristic composition is provided in Appendix 1. Poaceae and Fabaceae are the two most dominant families having 12.96% and 11.11% abundance respectively (Appendix 2). The dominance of these two families indicates that the area is more characterized by rangeland or grassland conditions. The family Fabaceae comprises drought tolerant, deciduous and spiny species that are well established to the prevailing drought conditions of the study area. Acanthaceae, Asteraceae, Boraginaceae and Euphorbiaceae are the next dominant families. Thirty-four families were represented by more than one species while the remaining 28 families were represented by a single species.

There are two frequent climber species with photosynthetic stems belonging to the family Vitaceae, and other climber species belonging to families Convolvulaceae, Fabaceae, Oleaceae and Cucurbitaceae. Succulents such as *Aloe* spp., *Sansevieria ehrenbergii* and *Euphorbia* spp. were also commonly found.

Figure 3 shows the relative distribution of growth forms of the vegetation in the study area. Shrubs primarily dominated the growth form composition comprising 43% of the flora. Herbs apart from grasses are the next dominant groups (28%). There are 29 grass species identified, comprising 13.4% of the total composition.

Relatively few tree species (10.6%) are found, and climbers are the least represented growth forms (4.6%). Woody plant species compose 53.6% of the total identified species while herbaceous species comprise 46.4%.

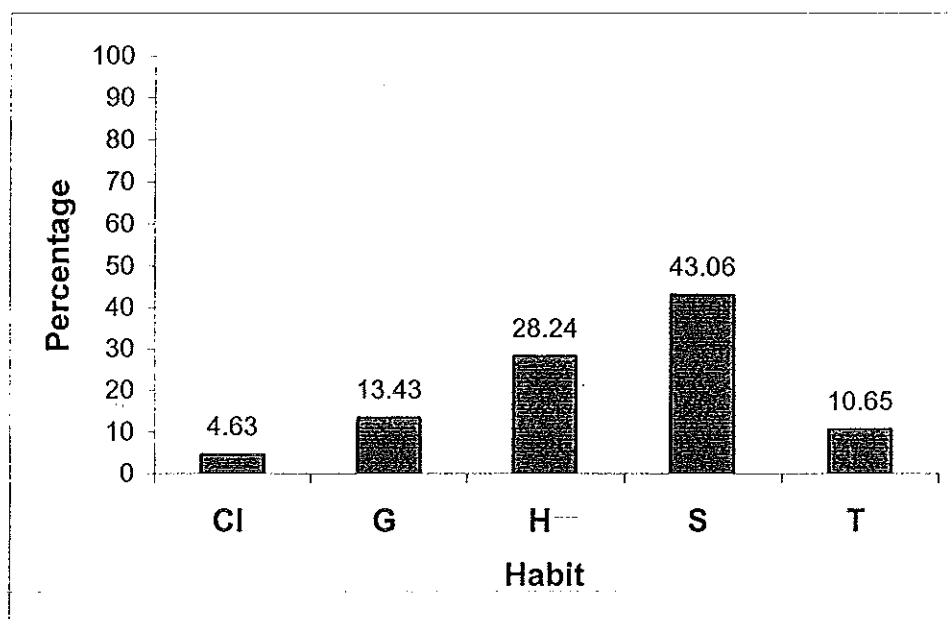


Figure 3. Growth forms by habit types

CI=Climbers, G=Grasses, H= Herbs other than grasses, S=Shrubs, T=Trees

## 5.2 Life-form Dominance

Life-form spectrum describes community composition and indicates adaptations of individuals in the community, and pattern of distribution along environmental gradients. Life-form reveals vegetation distribution along temperature and moisture gradients. For instance, phanerophytes dominate in rainforests, hemicryptophytes are dominant in the Northern hemisphere, while chamaephytes and therophytes are dominant in cold desert and hot desert environments respectively (Raunkiaer, 1934).

Distributions of life-forms in the study area show a higher value for phanerophytes (59.3%) and therophytes (29.19%) and a lower value for hemicryptophytes (2%) and chamaephytes (3.35%) compared with the normal spectrum (Figure 4). The higher value of therophytes compared with hemicryptophytes and chamaephytes indicates low precipitation found in the study area that is unfavorable for perennial growth. Moreover, it indicates that the more arid conditions of the study area to be dominated by ephemerals and annual grasses adapted to high temperature and low precipitation. The low distribution of hemicryptophytes might be attributed to the widespread effect of overgrazing on the vegetation of the region (Zerihun Woldu, 1985).

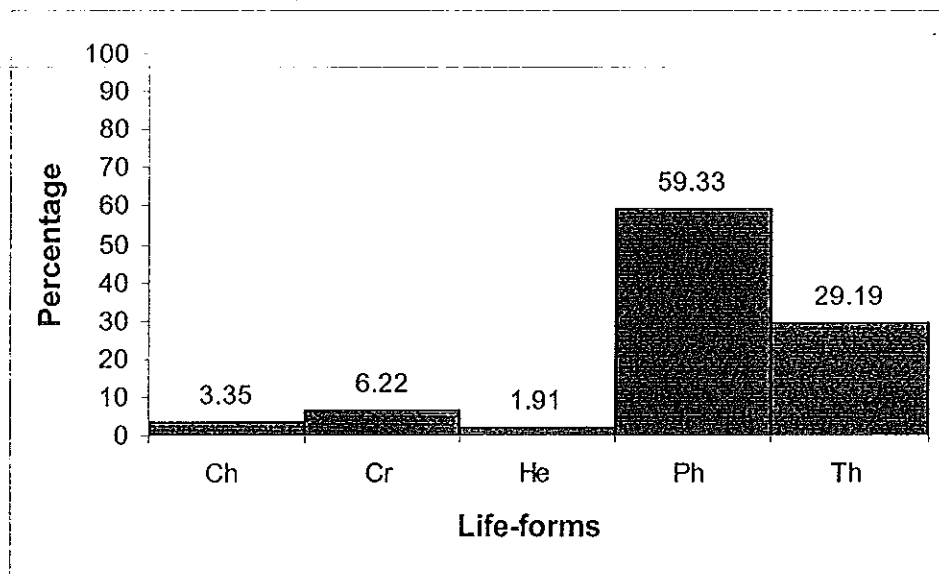


Figure 4. Relative distribution of life-forms in the study area

Ch=Chamaephytes, Cr=Cryptophytes, He=Hemicryptophytes, Ph=Phanerophytes, and Th= Therophytes

## 5.3 Vegetation Analysis

### 5.3.1 Vegetation Community Types

Out of the 216 species collected and identified, 104 woody species were used in vegetation classification. Seven plant community types were identified based on TWINSpan (Hill, 1979, 1994). The result of the vegetation classification shows that there are seven different clusters with two relevés found to be outliers (Appendix 7). Outliers are disparate from the other relevés in having species occurring in the outlying relevés only (Kent and Coker, 1992). The outlier relevés might be caused by the presence of rare species. The seven different types of communities classified are described based on the synoptic cover values (Table 2) as follows.

#### Community I. *Dodonaea angustifolia* type:

This community is found in the highest altitude (1710 m) of the study area. *Dodonaea angustifolia* is the characteristic and dominant species while *Rhus retinorrhoea* and *Calpurnia aurea* are characteristic species with low cover value. Other shrubs and trees in this community include *Rhus natalensis*, *Grewia tembensis*, *Carissa spinarum*, *Euclea racemosa* ssp. *schimperii*, *Cordia purpurea* and *Olea europaea* ssp. *cuspidata*. *Cissus rotundifolia*, *C. quadrangularis* and *Jasminum grandiflorum* ssp. *floribundum* are the common climbers found. *Aloe camperi*, *Plectranthus* sp., *Ocimum forskalei*, *O. lamiifolium*, *Kalanchoe citrina* and *Tagetes minuta* are the herbs associated in this community. The associated grasses were *Heteropogon contortus*, *Enteropogon macrostachyus* and *Festuca abyssinica*.

**Community II. *Euclea racemosa*-*Acacia lahai*-*Dichrostachys cinerea* type:**

This vegetation type covers an extensive area located at an average elevation of 1645 m. This community is dominated by *Euclea racemosa* ssp. *schimperi*, *Acacia lahai* and *Dichrostachys cinerea*. *Steganotaenia araliacea* and *Dichrostachys cinerea* are the characteristic species for this community. Various trees and shrubs including *Cordia purpurea*, *Rhus natalensis*, *Pterolobium stellatum*, *Ziziphus spina-christi*, *Euphorbia candelabrum*, *Olea europaea* ssp. *cuspidata*, *Combretum aculeatum*, *Sageretia thea*, *Carissa spinarum*, *Diospyros abyssinica*, *Rhus glutinosa*, *Grewia tembensis*, *Capparis tomentosa* and *Ziziphus mucronata* make up this community.

Succulents like *Aloe camperi*, *Euphorbia abyssinica*, and *Kalanchoe* spp. commonly occur in this community. Evergreen shrubs like *Rhus* spp., *Carissa spinarum*, *Diospyros abyssinica* and herbaceous and woody climbers or lianas including *Cissus quadrangularis*, *C. rotundifolia*, *Jasminum grandiflorum* and *Ipomea* spp. are also associated. Grasses associated with this vegetation type include *Heteropogon controtus*, *Enteropogon macrostachyus*, *Hyparrhenia* spp. and *Digitaria* spp.

**Community III. *Euclea racemosa* -*Cordia purpurea*- *Euphorbia candelabrum* type:**

This is an association with a mean altitude of 1690 m. The tree and shrub layer is dominated by *E. abyssinica*, *Acacia asak*, *Cordia purpurea* and *Euclea racemosa* ssp. *schimperi*. Other trees and shrubs with low cover value include *Acacia seyal*, *A. tortilis*, *Opuntia ficus-indica*, *Maytenus senegalensis*, *Diospyros abyssinica*, *Carissa spinarum*, *Grewia bicolor*, *Grewia tembensis*, *Grewia velutina*, *Grewia villosa*, *Rhus glutinosa* and *Capparis tomentosa*.

Different forbs, climbers and succulents comprise *Tagetes minuta*, *Aloe camperi*, *Kalanchoe citrina*, *K. lanceolata*, *Cissus quadrangularis*, *C. rotundifolia* and *Jasminum grandiflorum*.

**Community IV. *Acacia asak* - *Grewia bicolor*- *Sansevieria ehrenbergii* type:**

The vegetation in the mid-altitudes (mean of 1260 m) of the study area is dominated by *A. asak* that is a non-differential species. Both *A. asak* and *Sansevieria ehrenbergii* were found to have a higher cover value. Most of the shrubs in this community are deciduous among which *A. senegal*, *Grewia bicolor*, *G. villosa*, *G. velutina* and *Commiphora africana* are common. *Kleinia* sp., *Solanum* spp., *Aerva javanica*, *Barleria eranthemoides*, and *B. parviflora* are the associated woody herbs. Climbers including *Jasminum grandiflorum*, *Cissus quadrangularis*, *C. rotundifolia* are common having a significant cover especially during dry periods. *Balanites aegyptiaca* and *Ziziphus spina-christi* are rarely associated in this vegetation except in drier riverbeds.

**Community V. *Ximenia americana*-*Acacia asak* type:**

This type has a relatively dominant *Ximenia americana* species with still dominant *Acacia asak*. *Ximenia americana* is the characteristic species for this community. *Cissus quadrangularis*, *Cissus rotundifolia*., *Kleinia* sp. and *Sansevieria ehrenbergii* occur abundantly. *Rhus natalensis*, *Grewia bicolor*, *Acacia senegal*, *Barleria eranthemoides*, and *Commiphora africana* were also found. This community occurs at an average altitude of 1340 m around steep slopes.

**Community VI. *Acacia mellifera* - *A. oerfota* Type:**

It is found between 800 m and 1300 m (mean 950 m) altitudes and is described by *Acacia mellifera* and *A. oerfota* dominated vegetation. *Dobera glabra*, *Acalypha fruticosa*, *Acacia oerfota*, *Boscia coriacea* and *Phyllanthus sepialis* are the characteristic species in this community. The most dominant species forming thickets in areas where flood deposits and riverbanks is *A. oerfota*. *Balanites aegyptiaca*, *Acacia tortilis*, *Dobera glabra*, *A. asak*, *Phyllanthus sepialis*, *Boscia coriacea* and *Cadaba farinosa* are trees and shrubs in this thicket formation. There are various associated shrubs and trees such as *Salvadora persica*, *Ziziphus spina-christi*, *Berchemia discolor*. *Solanum* spp., *Acalypha fruticosa* and *Phyllanthus* spp. are found under canopy. Climbers commonly associated with this community include *Cocculus pendulus*, *Jasminum grandiflorum* ssp. *floribundum*, *Cissus quadrangularis*, *C. rotundifolia*, *Boerhavia coccinea* and *Achyranthes aspera*. Herbs associated with in this community include *Commicarpus* spp., *Gomphocarpus fruticosus*, *Tribulus terrestris* and *Plectranthus* sp.

**Community VII. *Prosopis juliflora* Type:**

This is a community found at the foot of the escarpment with an altitude of about 750 m a.s.l. It is dominated by the invasive species *Prosopis juliflora* that is established on flood deposits. Other species with low cover values include *A. tortilis*, *A. asak*, *A. mellifera* and *Balanites aegyptiaca*. Annual herbs particularly *Tribulus terrestris* was found to flourish after the rainy season. This community is the poorest in species diversity and richness. This vegetation type is appearing green during the dry season and is established around a village called Eliwoaha.

**Table 2. Synoptic cover-abundance values for species having a value of >1.0 in at least one community type.**

Values in bold refer to occurrences with higher synoptic values or species with high degree of fidelity (the degree to which species are confined to particular group of quadrats)

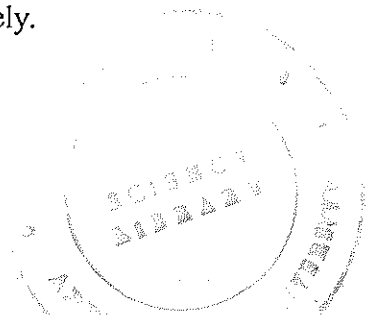
Species	Type	I	II	III	IV	V	VI	VII
	Cluster Size	8	13	13	16	4	10	4
<i>Dodonaea angustifolia</i>		<b>8.7</b>	0.0	0.0	0.0	0.0	0.0	0.0
<i>Calpurnia aurea</i>		2.7	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rhus retinorrhoea</i>		1.4	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rhus natalensis</i>		5.3	4.2	2.8	1.6	0.0	0.0	0.0
<i>Euclea racemosa</i> ssp. <i>schimperi</i>		5.1	<b>7.0</b>	<b>7.1</b>	0.0	0.0	0.0	0.0
<i>Cadia purpurea</i>		5.0	4.4	<b>4.3</b>	0.0	0.0	0.0	0.0
<i>Grewia tembensis</i>		1.8	4.0	1.3	0.0	0.0	0.0	0.0
<i>Euphorbia candelabrum</i>		0.0	3.3	<b>5.0</b>	0.0	0.0	0.0	0.0
<i>Dichrostachys cinerea</i>		0.0	<b>4.5</b>	1.0	0.0	0.0	0.0	0.0
<i>Acacia lahai</i>		0.0	<b>5.7</b>	2.7	0.0	0.0	0.0	0.0
<i>Capparis tomentosa</i>		0.0	1.8	2.0	0.0	0.0	0.0	0.0
<i>Diospyros abyssinica</i>		0.0	1.5	1.0	2.0	0.0	0.0	0.0
<i>Rhus glutinosa</i>		0.0	1.0	1.0	1.0	0.0	0.0	0.0
<i>Cissus quadrangularis</i>		0.0	0.0	1.0	1.7	3.0	0.0	0.0
<i>Acacia asak</i>		0.0	0.0	4.1	<b>6.4</b>	<b>6.8</b>	2.0	1.0
<i>Grewia bicolor</i>		0.0	0.0	2.8	<b>3.9</b>	3.0	1.8	0.0
<i>Sansevieria ehrenbergii</i>		0.0	0.0	0.0	<b>3.2</b>	3.1	1.0	0.0
<i>Acacia senegal</i>		0.0	0.0	0.0	2.0	1.0	0.0	0.0
<i>Kleinia</i> sp.		0.0	0.0	0.0	1.0	1.0	1.0	0.0
<i>Ximenia americana</i>		0.0	0.0	0.0	0.0	<b>4.0</b>	0.0	0.0
<i>Acacia mellifera</i>		0.0	0.0	0.0	0.0	0.0	<b>6.9</b>	1.0
<i>Dobera glabra</i>		0.0	0.0	0.0	0.0	0.0	2.7	0.0
<i>Acalypha fruticosa</i>		0.0	0.0	0.0	0.0	0.0	5.8	0.0
<i>Acacia oerfota</i>		0.0	0.0	0.0	0.0	0.0	<b>6.5</b>	0.0
<i>Balanites aegyptiaca</i>		0.0	0.0	0.0	0.0	0.0	5.4	1.0
<i>Boscia coriacea</i>		0.0	0.0	0.0	0.0	0.0	2.5	0.0
<i>Phyllanthus sepialis</i>		0.0	0.0	0.0	0.0	0.0	3.0	0.0
<i>Salvadora persica</i>		0.0	0.0	0.0	0.0	0.0	4.3	0.0
<i>Prosopis juliflora</i>		0.0	0.0	0.0	0.0	0.0	0.0	<b>8.5</b>

### 5.3.2 General Community Description

Drought tolerant trees and shrubs, with either small deciduous leaves or leathery persistent ones characterize most of the communities in the study area. Some of the most common deciduous trees and shrubs include *A. asak*, *A. mellifera*, *A. oerfota*, *A. senegal*, *A. seyal*, *Acacia tortilis*, and *Balanites aegyptiaca*. Most of the vegetation in the study area is deciduous. This vegetation is composed of woody plants that seasonally lose their leaves and become bare-stemmed during drought season. According to White (1983), deciduous vegetation includes associations with more than 75% of the total plant cover.

Community type I is within hillside closure although there is grazing (Kebrom Tekle, 1998). *Dodonaea angustifolia* and *Euclea racemosa* ssp. *schimperi* are species regenerating in and within the vicinity of this community. According to Tesfaye Bekele (2000) and Kebrom Tekle (1998), areas a few km from Kombolcha along Kombolcha-Bati road are shrublands dominated by regenerating shrubs of *Dodonaea angustifolia* and *Euclea racemosa* ssp. *schimperi*. *Opuntia ficus-indica* is the succulent found on the rocky slopes in patches where shallow surface soil and steep slopes occur.

*Acacia asak*, which is dominant in the mid and low altitudes of the study area, begins to replace *Euclea racemosa* ssp. *schimperi* and other evergreen shrubs dominating between communities III and V. The *Acacia* shrubs in community IV have shorter stature (< 3 m) except in riverbeds where relatively taller individuals are found. Community types II, III, IV, V and VI are mainly composed of deciduous shrubs. Communities I and VII are dominated by evergreen shrubs *Dodonaea angustifolia* and *Prosopis juliflora* respectively.



In community V, *Acacia mellifera* is the most dominant shrub in the drier soils and relevés far from riverbeds and bank of rivers. The riverine associations found along riverbeds that tend to dry during dry season have a distinct physiognomy with taller *Acacia* tree species and *Balanites aegyptiaca*. The riparian vegetation that occurs along bank of rivers and riverbeds acts as refuge for some species like *Salvadora persica*, *Phyllanthus sepialis*, *Cocculus pendulus*, *Solanum somalense*, *S. nigrum*, *S. coagulans*, *Physalis micrantha* and *Acalypha indica*.

Community type VII is low in species richness and diversity owing to the invasive nature of *Prosopis juliflora*. It is established on the foot of the escarpment where the area is flooded during wet season. The herbaceous cover of this community is very low in most periods of the year and the dominant herbaceous species flourishing after rains is *Tribulus terrestris*.

There are various associated herbs and shrubs such as species of *Aerva*, *Barleria*, *Justicia*, *Hypoestes*, *Commelina*, *Euphorbia* and *Xanthium* where there is available soil moisture at the surface particularly along the riverbeds. The wet season sampling and observation shows that the herbaceous layer is mainly composed of shrubby herbs such as *Barleria eranthemoides*, *Aerva javanica*, *Solanum incanum*, *S. nigrum*, *Commicarpus grandiflorus*, *Gomphocarpus fruticosus*, *Tribulus terrestris*, *Plectranthus* sp., *Acalypha fruticosa* and *A. indica* that are common in most communities at low and mid-altitudes.

## 5.4 Species Diversity

The description of plant community involves the analysis of species richness and diversity (Whittaker, 1975). Species richness, or the number of species, is the most direct measure of biological diversity. It is less problematic than diversity indices but more ambiguous and is sensitive to the capture of rare species (Oksanen, 2003). Diversity and equitability of species in plant communities is used to interpret the relative variation of the community indices and explain the underlying reasons for the differences among communities.

The diversity and evenness of species in the seven different communities was calculated using Shannon-Weiner index (Table 3). The Shannon-Wiener index varies from 0, for a community with one species only, to values of 7 or more in rich forests-(Kent and Coker, 1992). The results of the Shannon-Weiner Index showed that communities I, II, III, IV and VI have high species diversity and richness while community V and VII have low diversity and richness. The low species diversity in community V might be the high overgrazing and land degradation in the area.

**Table 3. Comparison of plant species diversity, evenness and richness among the seven community types following Shannon-Weiner index**

	Community Types						
	I	II	III	IV	V	VI	VII
<b>Species Diversity (H')</b>	3.14	3.46	3.52	3.24	2.65	3.30	1.34
<b>Species Evenness (E)</b>	0.93	0.94	0.97	0.90	0.94	0.94	0.69
<b>Species Richness (N)</b>	29	40	38	30	17	33	7

Community type III has the highest species diversity and evenness probably due to man-made and natural protection of the vegetation. In terms of species richness, community types II and III are the most species rich followed by type IV and VI. Community type I is also species rich having 29 species as it is more protected by humans and the inaccessible hillslopes. Community type VII has the least evenness, diversity and richness as it is a community dominated by the invasive species *Prosopis juliflora* that displaces most of the local plant species. *Prosopis juliflora* is alien species, and according to the information from local communities, it has excluded different indigenous species like *Acacia asak*, *A. mellifera* and *A. oerfota* from their natural habitats. Moreover, the area occupied by *Prosopis juliflora* is characterized by high temperature and low precipitation than areas in the other community types.

Even though community type VI is found at low altitudes, it is the third species rich community type probably due to its riverine component with different shrub and tree species that are particularly found in the rivers.

The results of species diversity in the study area indicate a high figure at altitudes below 1700 m and species diversity is relatively high between 1350-1650 m altitudes. Species richness in Borana lowlands is positively correlated with altitude (Gemedo Dalle, 2004) that is also the case in the vegetation of the study area.

According to the intermediate disturbance hypothesis, both high and low levels of disturbance reduce diversity while intermediate levels promote higher diversity (Rosenzweig, 1995). Frequency of disturbances has also considerable implications for determining species diversity (Whittaker, 1975). Accordingly, communities with high disturbance such as IV, V and VII are having low species diversity while the high species diversity in communities II and III might be due to the intermediate disturbance maintained by protection of the shrublands.

The diversity-stability hypothesis predicts that ecosystem productivity and recovery increases as the number of species increases (Begon *et al.*, 1996). Although there is no automatic relationship between species diversity and community stability, many communities with high diversity and richness indicate more stability and low disturbance (Whittaker, 1975). Species diversity is related to drought resistance since more diverse communities are more resistant than less diverse ones. High species diversity can also reduce the probability of large changes in ecosystem processes in response to invasions of other species (Jörn, 2003). Therefore, communities with relatively high species diversity (II, III and IV) may be more stable and drought resistance than the communities with low species diversity (types IV, V and VII).

Communities with low diversity and richness suffer the tragedy of the commons where the land is communal grazing field and thus battleground for resource conflicts. In contrast, communities with high diversity are found in lands owned privately by local farmers or protected by the government. The differences in the diversity of species among communities may generally be correlated to different environmental parameters such as soil depth, slope, soil moisture, altitude, grazing and disturbance (Section 5.9).

## 5.5 Woody Species Density

Density was calculated for woody plant species, by calculating the average individual shrub and tree count, in terms of number of individuals per hectare in each community (Figure 5). The density of woody plant species having higher abundance of individuals is shown in Appendix 5.

Density calculations are significant for objective analysis of vegetation and comparison of individuals of non-differential species among communities (Kent and Coker, 1992). Density is affected by quadrat size and the pattern of species growth. For instance, more individuals of the small sized species can grow within the same area compared to larger species (Kent and Coker, 1992) which was also observed in the study vegetation. The average number of tree and shrub individuals as calculated from the data taken from all relevés is 3146 per hectare. The mean density of woody species of the study vegetation was more or less similar to that of Borana lowlands (3149 individuals per ha) (Gemedo Dalle, 2004).

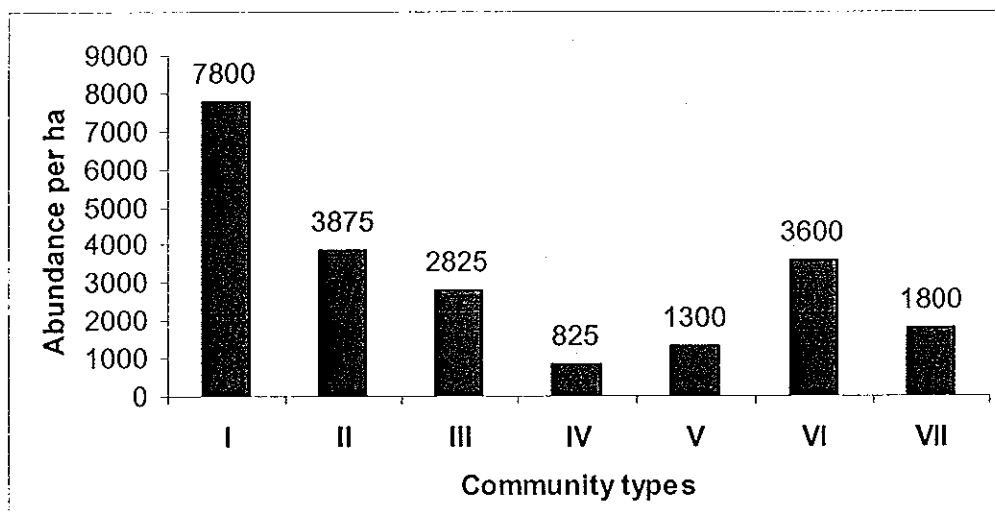


Figure 5. Average number of individual trees and shrubs per hectare

Community type I is the highest in terms of total count of shrub and trees (7800 individuals per ha). This is due to the fact that most of the sites in this community are either protected or are found in inaccessible sites and very steep slopes. On top of this, the shrubs in this community are composed of species having small sized individuals, like *Dodonaea angustifolia*, *Cordia purpurea*, *Dichrostachys cinerea* and *Euclea racemosa* ssp. *schimperi* that contribute to higher total count within a given quadrat size. Community types II and VI are having the next highest woody species density being 3785 and 3600 individuals per ha respectively. Community type II lies in areas that are either protected or found in inaccessible sites and very steep slopes too.

In contrast, community types IV and V were found to have low average counts of 825 and 1300 individuals per ha respectively. This may be attributed to the high disturbance, and grazing and browsing pressure. Cutting of shrubs for firewood and charcoal production could probably have reduced the tree and shrub density. Community type VI has relatively higher density owing to the fact that most of it is riparian vegetation and the presence of dense thickets in drier riverbeds and flooding sites. Besides, cutting of shrubs for charcoal production was not observed to be very intense like those found in community types II, III, IV and V.

According to Gemedo D alle (2004), density of woody plant species is negatively correlated with altitude in Borana lowlands. However, the results of density of the woody vegetation in this study have shown a relatively higher figure at higher altitudes. This might be attributed to the minimum disturbance level found at higher altitudes owing to conservation activities and natural protection of the vegetation by the inaccessible hillslopes.

## 5.6 Importance Value Index

Importance value index (IVI) of woody species were calculated and the results is shown in Appendix 5. The results of importance value index showed that *Euclea racemosa* ssp. *schimperi* (27.71), *Dodonaea angustifolia* (22.76), *Acacia asak* (21.93) and *Grewia bicolor* (14.38) are plant species with highest importance values resulted from high relative density, relative frequency and relative dominance. Species with low IVI values include *Calpurnia aurea* (1.37), *Berchemia discolor* (1.92), *Ziziphus spina-christi* (1.66) and *Boscia coriacea* (.59), mainly found at lower altitudes.

*Dodonaea angustifolia* and *Euclea racemosa* ssp. *schimperi* have the highest relative density, 21 and 20 respectively. *Acacia asak* has the highest relative dominance value (9.5) followed by *Grewia bicolor* with a relative dominance value of 5.9. In terms of relative frequency, *Grewia bicolor* is the most frequent species (5.45) followed by *A. asak* (5.36) and *Euclea racemosa* ssp. *schimperi* (4.21).

Gemedo Dalle (2004) explained the most frequent woody species in Borana lowlands as *Commiphora africana*, *Acacia nilotica*, *Acacia mellifera* and *Grewia bicolor*. In contrast, *Commiphora africana* has the least frequency in the eastern escarpment of the vegetation of Wello. *Lannea rivae* is one of the most frequent species in Borana lowlands, whereas this species was not recorded in the vegetation under study. Although *Acacia mellifera* is more frequent in the lowlands of the study area, it is not as frequent as it is in Borana lowlands.

## 5.7 Woody Species Richness along Altitudinal Gradients

Richness of woody species was compared along altitudinal gradients starting from 750 m to 1760 m. The comparison was made based on woody species counts in each relevé. Regression analysis between altitude and species richness shows that as altitude increases, the woody species composition generally increases as shown by the curve fitting regression (Figure 6).

Higher woody species richness between altitudes 1000 and 1200 m might be due to bush encroachment as a result of disturbance and overgrazing while deforestation of shrublands between altitudes 1200 and 1600 m relatively may have attributed for low richness in woody species.

In the present study, species richness generally increases with increase in altitude since the places at higher altitudes are not extremely high elevations that can bring island effect. On the whole, species richness of the vegetation in the study area is positively correlated with altitude as in the vegetation of Borana lowlands described by Gemedo Dalle (2004).

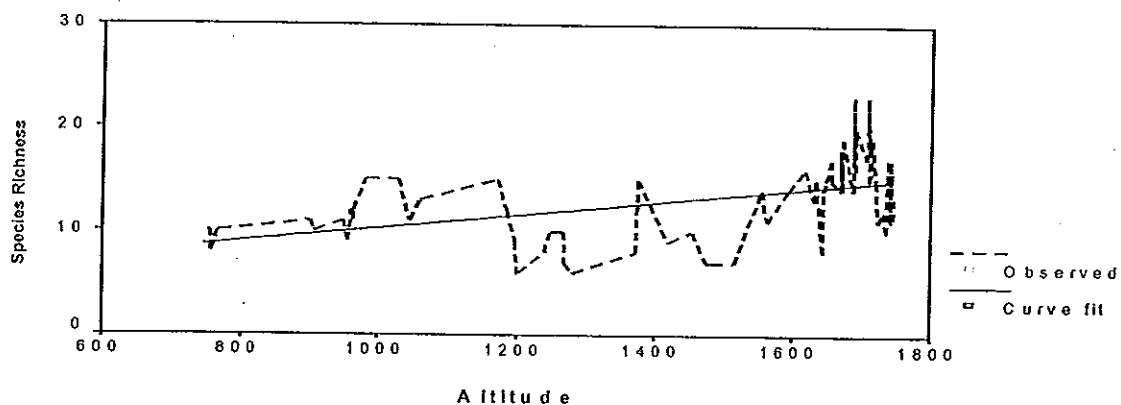


Figure 6. Regression analysis of woody species richness and altitudinal gradient

## 5.8 Vegetation Growth forms

The growth form of the vegetation in each relevé was drawn in the field. Plates 1 a-c and 2 a and b show some of the different growth forms of the vegetation in the study area. The various growth forms include scrubs, thickets, bushes and shrubs following White (1983), which indicate the type of plant communities and the underlying environmental factors. The vegetation in the study area consists of short-stemmed and multi-branched shrubs of about 3 m tall sometimes forming thickets and scattered umbrella shaped trees reaching 8 m heights, like *Acacia tortilis* and *Balanites aegyptiaca*. At higher altitudes (above 1650 m), the vegetation is dominated by evergreen shrubs and sometimes scrubs in steep slopes and protected areas. Deciduous shrubland is dominant at the mid-altitudes with an average height of 2.5 m.

*Acacia* bushes of 8 m average heights dominate the riverine vegetation. Trees and shrubs along the rivers have umbrella-like flat crowns with large canopy openings filled with short shrubs, grasses, herbs and bare spots. Ephemerals cover the bare spots after rains. *Acacia oerfota* scrub with an average height of 2.5 m is common in flood sites and sometimes around banks of rivers.

At lower altitudes (below 1200 m), the height of the shrubs decreases to 1.5 m except in the riverbeds and riverbanks. Thickets were also found around riverbanks at low altitudes and protected sites in the mid-altitudes. The vegetation in the lowlands is generally stunted deciduous bushland with less than 3 m height where trees are absent and vegetation is intermediate between bushland and shrubland, except in riverbeds where the height of the shrubs is greater than 5 m. Trees are mainly dominant in the riverine vegetation of the study area.

Shrubs are the most dominant growth forms of the vegetation in the study area. White (1983) indicates that the climax vegetation in arid and semi-arid regions is generally shrubby vegetation. This is attributed to competitive dominance of woody species particularly shrubs over grasses and herbs for moisture, light, nutrients, overgrazing, soil and other forms of disturbance and land degradation. Since shrubs do not have high root-to-shoot ratio and because of their perennial nature, they do not draw high nutrient input into the aboveground biomass. Therefore, nutrient-recycling process is very limited in such ecosystems that consequently favor invasion of alien species. Therefore, the vegetation is continually changed to woodland with associated reduction of grass cover through bush encroachment and invasion of other shrubs due to environmental and anthropogenic factors.



Plates 1 a-c. *Acacia mellifera*-*A. senegal*-*A. asak* shrubland (a), *Prosopis juliflora* thicket (b), and *Tribulus terrestris* dominated plain at the foot of the escarpment (c)



**Plate 2 a & b. Disturbed deciduous vegetation in the lowlands of the study area**

## 5.9 Environmental Correlation Analysis

The environmental variables considered for correlation analysis were salinity, electrical conductivity, altitude, slope and soil depth (Table 4). The results of correlation analysis show that there is significant positive correlation between soil salinity and electrical conductivity and negative significant correlation between soil salinity and altitude and soil salinity and slope. Electrical conductivity is negatively correlated with altitude and slope. Altitude is positively correlated to slope and negatively correlated to soil depth. The higher the altitude, the higher the steepness of the slope of the area. Soil depth is negatively correlated to altitude and slope because the soil at hillslopes is more susceptible to erosion and the surface soil is not stable in steep slopes.

Table 4. Pearson's product moment showing correlation among environmental variables

	Salinity	Electrical Conductivity	Altitude	Soil Depth	Slope
Salinity	1.00				
Electrical Conductivity	.524**	1.00			
Altitude	-.496**	-.412**	1.00		
Soil Depth	.145 ns	.234 ns	-.296**	1.00	
Slope	-.335**	-.293*	.744**	-.103 ns	1.00

\*\* Correlation is significant at the 0.01 level (2-tailed)

\* Correlation is significant at the 0.05 level (2-tailed)

ns =not significant

The nature, distribution patterns, composition and abundance of plant communities are strongly correlated with the environmental conditions. Even though the area might be floristically species-rich, it will be degraded as a result of overuse and harsh environmental conditions.

The complex interaction of environmental variables along spatial gradients will form a complex environmental gradient that characterizes the nature and distribution of communities along a landscape (Begon *et al.*, 1996). The different communities are therefore more or less correlated with different interaction of environmental factors (Table 5).

According to Palmer and Staden (1992), the potential distribution of a community can be predicted based on annual rainfall and elevation data. The climate diagram in Figure 2 a-c indicates that significant variations in temperature and rainfall distribution occur in the study area. Mean monthly temperature varies between 18<sup>0</sup>C and 30<sup>0</sup>C and mean monthly rainfall distribution varies between 315 mm and 715 mm. These variations are reflected in the variations of the species composition and structure of communities.

At relatively low temperatures and high rainfall distribution, evergreen shrubs, herbs and grasses are relatively dominant while deciduous and spiny shrubs are dominant and grasses are less abundant at low temperatures and rainfall distribution. Altitude, soil depth and slope show essential variation while there is no significant variation with respect to electrical conductivity.

Altitude affects temperature, moisture, radiation and atmospheric pressure and thereby influences the growth and development of plants and the distribution of vegetation. Altitude is one of the most important environmental factors that determine the type of plant communities in the region. Altitudinal factors determining the nature of soil and the prevailing moisture and temperature conditions have a very significant effect on vegetation. Altitude is found to be a major factor affecting species distributions based on the inference from the data.

According to Zerihun Woldu *et al* (1989), the most important factor that orders the tree-shrub layer into respective vegetation types is altitude for it is positively correlated with other environmental factors like organic matter and negatively correlated with pH, clay and calcium. Figure 7 shows the mean values of altitude for each community that clearly indicates that there is considerable relationship between altitudinal distribution and the community types.

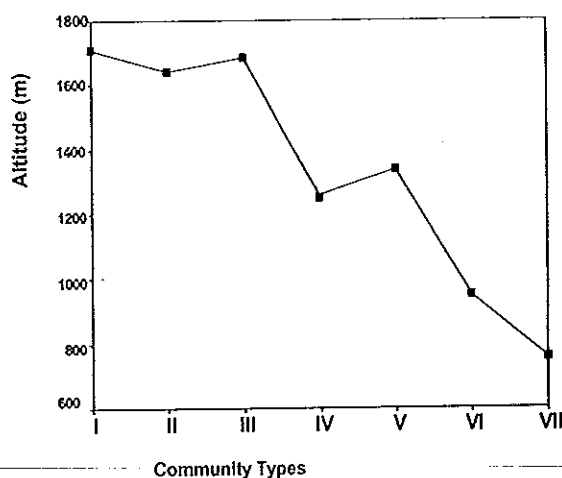


Figure 7. The relative distribution of communities with respect to altitude

*Acacia* species particularly *A. mellifera* and *A. oerfota* are dominant at lower altitudes where as *A. senegal* prevails between the relatively higher altitude species *A. asak* and the lower altitude species *A. mellifera*. *A. lahai*, *A. seyal*, *Diospyros abyssinica*, *Acokanthera schimperi* and *Terminalia brownii* were found at higher altitudes. Then, there is *Euphorbia* dominated zone that is just found above the tall *A. asak* scrub. *Euclea racemosa* ssp. *schimperi*, *Dodonaea angustifolia*, and *Calpurnia aurea* dominate the high altitudes while *A. asak*, *A. oerfota*, *A. senegal*, *A. tortilis*, *Dobera glabra*, *Balanites aegyptiaca*, *Delonix elata* and *Berchemia discolor* are occurring at low altitudes of the study area. The common grasses at higher altitude of the study area are *Enteropogon macrostachyus* and *Pennisetum setaceum*.

Table 5. Tukey HSD test to compare the seven community types using some environmental variables\*

Environmental variables	Plant community types						
	I	II	III	IV	V	VI	VII
Salinity	.11 a	.12 a	.09 a	.17 a	.13 a	.16 a	.34 b
Conductivity	.15 ns	.15 ns	.12 ns	.22 ns	.18 ns	.43 ns	.46 ns
Altitude	1708 d	1642 d	1686 d	1258 c	1338 c	950 b	750 a
Soil depth	20.4 ab	19.7 ab	18.9 ab	15 a	15.6 a	23.9 b	23.6 b
Slope	31.1 c	27.3 c	28.8 c	12.75 ab	23.75 bc	5.2 a	3.4 a

\*Significance differences at  $p < 0.05$  are indicated by different letter notations at each row, ns= no significance

Dominant trees and shrubs in the lowland communities include: *Prosopis juliflora*, *Tamarix aphylla*, *Calotropis procera*, *Parkinsonia aculeata*, *Balanites aegyptiaca*, *Acacia mellifera*, *A. oerfota* and *A. senegal*. Succulents such as species of *Euphorbia* are scattered in most of the higher altitude sites (1650-1750 m) having high rainfall distribution. Climbers with photosynthetic stems and succulents like *Cissus* and *Jasminum* are commonly found at lower altitude below 1500 m.

Slope determines light intensity, moisture differences, runoff, intensity of erosion and vegetation distribution. Slope is also related to altitude and soil depth. Slope classifies all communities into three clusters. Community I, II and III do not have significant variation in slope. There is significant variation between communities IV and V with the other communities with respect to slope.

Moreover, soil salinity determines the nature of plant communities. Community VII is found to exist in a relatively saline soil and is different from the rest. This community is established in highly saline soil because *Prosopis juliflora* resists saline soils and is used to reclaim saline soils of cultivated fields abandoned because of salinization (Hailu Shiferaw, 2002). This is because the area is a flood plain that concentrates different salts. All community types do not show significant difference in soil conductivity.

On the other hand, plant communities affect soil type altering moisture retention, infiltration capacity, structure and chemistry upon the decomposition of organic material into the soil. Moisture holding characteristic of soils is affected by texture, structure and soil depth. Soil moisture, though not directly measured, was found to influence the structure and distribution of plant species.

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For instance, species growing along riverbeds and riverbanks were observed to have taller individuals compared to individuals of the same species growing on drier soils. In contrast, low soil moisture and competitive dominance of shrubs diminishes the grass cover resulting in bush encroachment. Herbs are relatively dominant at higher altitudes where moisture is available for their growth. The increasing shrub dominance and the concomitant reduction of grass cover down elevation gradients in the communities under study substantiates this fact.

Soil depth classifies the communities into three clusters too: I, II and III; IV and V; and VI and VII. Soil depth governs the amount of soil moisture and nature of root disposition of trees. Soil depth and soil moisture availability is not conducive for tree growth in most places of the study area. Therefore, shrubs are well adapted to the prevailing environmental conditions, and trees are not dominant in the study sites.

Soils in steep slopes are shallow while those of gentle slopes and valleys are deep. According to White (1983), grasses are dominant in deep sandy soils and protected areas while woody plants are dominant in stony and rocky places.

The physiognomy of the vegetation is variable depending on seasons indicating that annuals and deciduous species are dominant. Succulents and climbers become more conspicuous during the dry season while deciduous woody species will have a higher cover value during the wet season. It was observed that the amount of rainfall and disturbance influences more the herbaceous species. Annuals and ephemerals flourish after rains as evidenced by the most pervasive weed *Tribulus terrestris* in the low altitudes and around the foot of the escarpment in flood sites. Grasses are not dominant particularly in the dry season and ephemerals and annual herbs commonly flourish after rain.

Certain species like the thicket forming *Acacia oerfota* and the riverine evergreen shrub *Salvadora persica* were observed to be restricted to limited microclimatic conditions. The former species is limited to flooding sites while the latter one is confined to riverbanks and riverbeds. *Acacia oerfota* prevails in areas that may be waterlogged during rainy seasons like that of *Acacia drepanolobium* in Borana lowlands (Gemedo Dalle, 2004).

## 5.10 Endemic and Invasive Plant Species

The following endemic taxa have been recorded from the study area: *Aloe camperi*, *Aloe trichosantha* and *Rhus glutinosa* ssp. *glutinosa*. Environmental degradation and depletion of natural vegetation is resulting in the extinction of different species, and there are about 120 threatened plant species listed from Ethiopia (Ensermu *et al.*, 1992). Diversity of endemic plant species in the horn of Africa increases as altitude increases between 0 and 304 m a.s.l. and mid altitudes (1220-1524 m a.s.l.) while it declines between 304 and 1220 m a.s.l. and at high altitudes above 1524 m a.s.l. (Bürger *et al.*, 2003).

There are various indicator species for disturbance, some of which with invasive nature, in the study area along the roads, flooding sites and in highly disturbed places (Table 6). Fire, flood, disturbance and overgrazing provide open space, creating areas of open soil or reducing competition from other plants (Anon., 2003). This is favorable for colonization by invasive plants. Floods or good rainfall years may recruit some invasive species like *Prosopis juliflora*. According to Hailu Shiferaw (2002), *Prosopis juliflora* is dispersed due to rain floods, livestock mobility routes, following all types of roads in Afar region. The distribution of this species in drylands with less than 300 mm rainfall per year is limited to major river systems and alluvial plains (Anon., 2003).

Since the species requires access to ground water, it is not invading the upland areas in arid ecosystems which is consistent with the observation in the vegetation under study. Here the species is not currently expanding to the high altitudes and is limited to the foot of the escarpment. Another economically important invasive species is *Opuntia ficus-indica* found in areas where the vegetation is degraded and rocky hillslopes (Dessaegn Desissa, 2003) as is the case in the study region.

Table 6. Invasive plant species and/or indicators of disturbance from the study area

No	Species Name	Family	Habit	Indicators of Disturbance	Invasive nature
1.	<i>Achyranthes aspera</i>	Amaranthaceae	Herb	++	-
2.	<i>Althernanthera pungens</i>	Amaranthaceae	Herb	+	-
3.	<i>Argemone mexicana</i>	Papaveraceae	Herb	++	+
4.	<i>Calotropis procera</i>	Asclepiadaceae	Shrub	++	-
5.	<i>Cleome gynandra</i>	Capparidaceae	Shrub	+	-
6.	<i>Commelina benghalensis</i>	Commelinaceae	Herb	++	+
7.	<i>Dichrostachys cinerea</i>	Fabaceae	Shrub	+	-
8.	<i>Heliotropium ovalifolium</i>	Boraginaceae	Herb	++	+
9.	<i>Opuntia ficus-indica</i>	Cactaceae	Shrub	+	+
10	<i>Parthenium hysterophorus</i>	Asteraceae	Herb	++	+
11	<i>Prosopis juliflora</i>	Fabaceae	Shrub/Tree	+	+
12	<i>Sansevieria ehrenbergii</i>	Dracenaceae	Herb	+	-
13	<i>Solanum nigrum</i>	Boraginaceae	Shrub	+	+
14	<i>Tagetes minuta</i>	Asteraceae	Herb	+	+
15	<i>Tribulus terrestris</i>	Zygophyllaceae	Herb	++	+
16	<i>Xanthium spinosum</i>	Asteraceae	Herb	++	-
17	<i>Xanthium strumarium</i>	Asteraceae	Herb	++	+

Source: Anon., 2003; Dessalegn Desissa, 2003

+ Establishes in less disturbed habitats

++ Establishes in more disturbed areas: along main roads, cultivated fields and overgrazed areas

Invasive nature: + = yes and - = No

## 5.11 Floristic Comparison and Phytogeographical Description

The dryland vegetation of the eastern escarpment of Wello was compared to seven different vegetation types based on similarities in species composition and distribution (Table 7). About 210 species were considered in the comparison of the vegetation types. The presence or absence of plant species was evaluated to carry out similarity analysis and determine the relationship between the different vegetation types. Both woody and herbaceous species were used for similarity analysis. Although there is no complete floristic list and the sizes of the different vegetation types may not be equal, phytogeographical comparison will give some indications of relationships (Tamrat Bekele, 1993).

The results of Sørensen's coefficient of similarity shows that the vegetation of the eastern escarpment of Wello is more closer to the vegetation of eastern slopes of South Wello highlands and that of Shoa Robit area (Mengistou Gonsamo, 1998; Hussien Adal, 2004) that have many species in common. The similarity in floristic associations may be due to geographical proximity accompanied by more or less similar climatic and edaphic conditions. Although there is no geographical proximity, similar association of species is observed between the vegetation of the study area and that of the eastern escarpment of Eritrea, shrubland vegetation of Adwa and Borana lowlands owing to similar climatic conditions.

Table 7. Floristic similarities between vegetation of the eastern escarpment of Wello and seven other vegetation types

No	Vegetation	Altitudes (m)	Total No. of species	Common species	Similarity Index
1	Vegetation of hillslopes of South Wello <sup>1</sup>	1350-2700	53	23	0.17
2	Vegetation of eastern slopes of south Wello highlands <sup>2</sup>	1200-2800	144	60	0.34
3	Vegetation of Borana lowlands <sup>3</sup>	1250-1780	109	35	0.21
4	Eastern escarpment of Eritrea <sup>4</sup>	190-2075	284	51	0.20
5	Denkoro forest <sup>5</sup>	2330-3415	174	17	0.08
6	Vegetation in Shoa Robit area <sup>6</sup>	1050-1290	152	56	0.31
7	Shrubland vegetation of Adwa <sup>7</sup>	1500-2030	203	53	0.23

Source: <sup>1</sup>Kebrom Tekle *et al.*, 1997; <sup>2</sup>Mengistou Gonsamo, 1998; <sup>3</sup>Gemedo Dalle, 2004; <sup>4</sup>Sahle Gebre Kirstos, 1984; <sup>5</sup>Abate Ayalew, 2002; <sup>6</sup>Hussien Adal, 2004; <sup>7</sup>Zerihun Woldu and Feoli, 2001

There is very little similarity between Denkoro afro-montane forest and the study vegetation due to differences in altitudinal, climatic and edaphic conditions regardless of geographical proximity. This indicates that altitude and climatic factors like rainfall distribution and temperature are much more significant than geographical proximity for species distributions.

*Juniperus procera*, *Acacia abyssinica*, *Cordia africana* and *Dovyalis abyssinica* cover most of the higher altitude hills and mountain slopes between Dessie and Kombolcha (Kebrom Tekle, 1998; Tesfaye Bekele, 2000). However, the hillslopes of the lowlands between Kombolcha and Bati are covered by different species such as *Euclea racemosa* ssp. *schimperi*, *Dichrostachys cinerea*, *Diospyros abyssinica* and *Calpurnia aurea* owing to differences in altitudinal and other environmental settings. *Acacia etbaica* is prevalent in most of the vegetation types of the shrubland vegetation of Adwa (Zerihun Woldu and Feoli, 2001) while *A. asak* is common in most community types of the eastern escarpment of Wello.

According to Wilson (1977; cited in Sahle Gebre Kirstos 1984), the distribution of *Euclea racemosa* ssp. *schimperi* and *Dodonaea angustifolia* in Eritrea shows that the former species survives better at lower altitudes and the latter is better adapted to limestone soils and relatively higher altitudes. Similarly, *Dodonaea angustifolia* is found at higher altitudes with restricted range while *Euclea racemosa* ssp. *schimperi* is relatively distributed in a wide range and was found at lower altitudes of the study area. *Adenia* and *Caralluma* spp. found between 500 and 1200 m of the sub-desert succulent scrubs in eastern escarpments of Eritrea (Sahle Gebre Kirstos, 1984) are not found in similar altitudes of the study area.

The sub-desert scrub on the eastern escarpment of Eritrea has more or less similar species composition to the lowland vegetation of the eastern escarpment of Wello. The common species include associations of the species of *Acacia*, *Ziziphus*, *Maerua*, *Cadaba* and *Boscia* with different succulent species (Sahle Gebre Kirstos, 1984). *Opuntia ficus-indica* is found above 1800 m through the eastern Eritrea escarpment and was observed to hold soils well (Sahle Gebre Kirstos, 1984). Similar conditions occur on eastern escarpment of Wello though it is mainly limited to rocky hills, shallow soils and highly disturbed sites.

The vegetation of the study area belongs to Somali-Masai regional center of endemism with predominant *Acacia-Commiphora* deciduous bushland and thicket. In Ethiopia, the vegetation of the study area lies in two major vegetation types: semi-desert and desert vegetation and *Acacia- Commiphora* deciduous bushland and thicket. The vegetation is mainly *Acacia* woodland in the lowlands and semi-evergreen shrubland in the highlands. The vegetation has an altitudinal range between 750 m and 1750 m, which is within the altitudinal range of *Acacia-Commiphora* deciduous bushland and thicket in the country. The species are distributed in various habitats like dry *Acacia* woodland, bushland, rocky outcrops, dry mountain and rocky slopes, disturbed habitats, vicinity of habitations, dry river beds, river banks, open dry scrub, semi-desert flood plains, and semi-desert scrublands. Even though the vegetation mainly belongs to *Acacia- Commiphora* deciduous bushland and thicket, *Commiphora* woodlands are absent unlike the vegetation of Borana lowlands (Gemedo Dalle, 2004) and individuals of *Commiphora africana* are sparsely distributed in the study area.

The vegetation at higher altitudes (1700-1750 m) has some elements of dry evergreen Afromontane forest characterized by *Olea europaea* ssp. *cuspidata*. The dry evergreen Afromontane forests in the highlands of Ethiopia have been degraded and were replaced by montane scrubs of *Carissa edulis*, *Dodonaea angustifolia* and *Euclea racemosa* ssp. *schimperi* (Pichi-Sermolli, 1957) as observed at higher altitudes in the study sites. As indicated by Friis (1992), the altitudinal limit between a montane forest and lowland is placed between 1300 and 2000 m, which holds true in the study area. Deciduous species in the study area increase with decrease in altitudinal gradients and the percentage is becoming very high at lower altitudes below 1500 m. The lowland vegetation around Mille is predominantly semi-desert with thorny shrubs and patches of evergreen scrubs while the middle Awash valley is dominated by woodland vegetation (EPA, 1997).

## 5.12 Anthropogenic Influences on the Vegetation

Environmental factors are not the only variables affecting the nature of plant communities but anthropogenic influences too. Plant species diversity and richness is low in the communities owing to high level of disturbance by humans and livestock. The diversity of species is also correlated to disturbance and diversity peaks with intermediate disturbance levels (Rosenzweig, 1995). Disturbance in most of the communities is significant and the vegetation does not have much ground cover but most of the species dominating the communities are thorny *Acacia* shrubs. In areas where the vegetation of the degraded slopes is regenerating, the unpalatable species *Dodonaea angustifolia* and *Euclea racemosa* ssp. *schimperi* are dominant.

The absence of tree-dominated vegetation is attributed to the presence of high disturbance and intervention in the study area. However, areas with rocky outcrops and very shallow soils will remain covered by open vegetation even if such areas become protected and human intervention is controlled (Kebrom Tekle *et al.*, 1997). Anthropogenic and climatic factors are increasingly contributing to the deterioration of shrublands in the study area. According to Kebrom Tekle (1998), most of the shrublands in Kalu district were degraded to open areas, as there was an increase of 14.3 km<sup>2</sup> of the open areas and a matching decrease of 15.5 km<sup>2</sup> of the shrublands between the years 1958-1986.

Afar pastoralists have increased firewood and charcoal production as a survival mechanism and sell them along main roads to counteract income losses emanating from declining terms of trade for livestock against grain. And thus, by cutting down indigenous trees they are further damaging an already fragile biophysical environment, increasing the depletion of shrublands and other natural resources (Piguet, 2002).

Since the area is continuously dry for as long as 10 months, it is sensitive to overgrazing and environmental degradation. As a result, it is highly affected by human and livestock and there are only a few sites where human disturbance is not significantly high. Some plants having significant adaptation to disturbance conditions were observed to be dominant in disturbed areas along roads, degraded hillslopes and overgrazed areas (See Section 5.10). These species are mostly non-palatable or spiny and those that can resist overgrazing.

The distribution of herbs along different communities is variable owing to anthropogenic and climatic conditions. For instance, overgrazing influences the distribution of community types and results in the replacement of perennials by annuals or invasive species. Moreover, it was observed that in areas where human intervention and grazing is low, grasses are having a higher cover value. On the other hand, at lower altitudes and high disturbance sites with frequent and high overgrazing, the abundance and diversity of grasses is low. As indicated by Zerihun Woldu and Feoli (2001), recovery starts with increment in richness and cover of grass species and there is direct correlation between length of protection time and species richness and vegetation structure.

## 6. CONCLUSIONS AND RECOMMENDATION

Phytogeographical comparison of the vegetation in the study area shows that the vegetation belongs to the *Acacia-Commiphora* small-leaved deciduous bushland and thicket type in Ethiopia. The area was found to be rich in diversity and abundance of plant species and is home for at least three endemic plant species. The results of this study showed that there is still high species diversity regardless of the effect of climatic and anthropogenic factors.

The results of this study have indicated that the measured environmental variables particularly altitude, soil depth and slope have a strong correlation with the types and diversity of plant communities. There is wide variation in plant species composition and diversity within the study area since there is diverse microclimatic and edaphic conditions. Physical attributes such as steepness of slope and altitude influence the nature of the plant communities since they influence soil and climatic factors. These features contribute to natural protection of the vegetation cover too.

The vegetation in the study area generally reflects the level of degradation and anthropogenic factors apart from effects of climatic and edaphic conditions. Shrubs were found to be more dominant than trees and the herbaceous cover is also low due to overgrazing and bush encroachment. The low altitude sites are typically dominated by rangelands, where invasion of grasslands by bush species is a typical manifestation, and is perceived to be a serious environmental and economic problem.

According to the information from local communities, there may be a change in species composition in some areas particularly those invaded by *Prosopis juliflora*. These changes may have pros and cons to livestock grazing and rangeland productivity. It was observed that infestation with *Prosopis juliflora* has a strong negative impact on the availability of grazing land.

Human and livestock density is very high in most places of the study region. At higher altitudes, there is significant grazing and browsing pressure that resulted in severe land degradation. Grazing is pushed to steep slopes and marginal lands to compensate the diminishing soil fertility in fulfilling an ever-increasing food demand in these areas. The settlement of the military is also leading to deforestation and land degradation due to tree cutting for fuelwood and construction of military camps. The vegetation along the road and even several kilometers away from the road is highly disturbed owing to the fact that the area is heavily populated with humans and livestock.

Crop cultivation is widespread in the high altitudes, and on steep slopes, leading to deforestation. Hillsides in most areas are terraced leaving very small patches of vegetation. Plateaus are cultivated to margins causing erosion and loss of arable land. Deforestation is resulting in an exposure of the hillslopes to serious water and wind erosion. Charcoal production is also common over the entire range of the study area but is very intense in the mid-altitude sites. This has led to severe deforestation and degradation of the shrublands in the area.

Invasion and diminishing biodiversity occurs due to the combined effects of population pressure, charcoal production and overgrazing aggravated by climatic fluctuations. Bush encroachment is threatening the potential of grasslands to support livestock productivity on a sustainable basis. Overgrazing and bush encroachment combined with recurrent drought causes scarcity of water and pastureland that is forcing lowland inhabitants to become environmental refugees.

Political instability, more than a decade ago, has been the cause of deforestation in government-protected sites in the study area. There is conflict in land-use between the pastoralists and the crop cultivators. Crop cultivators displace the traditional pastoralists to the marginal areas that are the sources of conflict and problems in land tenure system.

In general, scarcity of fuelwood, expansion of farmland, population growth, poverty led charcoal production and lack of biodiversity use policy are threatening the vegetation. The above problems are more aggravated by the lack of application of indigenous conservation practices, absence of land use system and property ownership rights.

Since drylands in general and the vegetation in this study in particular are refuges for unique plant associations and various plant and animal lives, such ecosystems should be managed and utilized on a sustainable basis. To maintain the resilience of these ecosystems, the degraded hillslopes and overgrazed areas should be allowed to regenerate or rehabilitate using proper management and conservation activities.

Study on the relationships among patchiness, resources, production and diversity will give implications for rehabilitation of degraded environments. These should involve the participation of local communities in soil and biodiversity conservation programs. It is the collective effort of village elders and various governmental and non-governmental organizations that can make a real difference.

Most places in the study area are communal grazing lands and there is no property ownership of land. As a result, the land is vulnerable to degradation due to lack of responsibility and the effect of conflict for land resources.

The areas protected by the local people and the government may be rich in plant species as compared to unprotected sites. This indicates that the communities in these areas might have high potential for regeneration. While open access resources are inevitably degraded as individuals maximize exploitation for immediate gains, community resources tend to be well managed. Proper land use policy together with reliable land tenure system and grazing management should therefore be emphasized. Converting communal grazing lands into private ownership with appropriate measures might also contribute to sustainable biological and environmental resources in these areas.

There is high potential for regeneration for plant communities found as protected or privately owned sites have low human and livestock pressure and were observed to be floristically rich. As protected areas were observed to show a high potential for regeneration in some areas between Kombolcha and Bati towns, conservation of the vegetation is an effective measure to be used in restoring the natural vegetation of the area.

Plant species having high drought tolerance and economic importance like *Dobera glabra*, and *Ziziphus* spp. should be conserved and well managed. Introducing drought tolerant and environmentally friendly species of multipurpose nature and those that can be established on shallow soils can also alleviate environmental and socioeconomic problems. *Jatropha glauca* and *Prosopis juliflora* are drought tolerant multipurpose species of such kind. The former is introduced and used to maintain soil and water around cultivated fields and used as a boundary hedge. The latter is an invasive species that is used as a feed for livestock, shade, windbreak, live fence, charcoal and firewood. The above mentioned species may not only be the best choices for agroforestry purposes but *Acacia tortilis*, *A. saligna*, *A. seyal*, *Tamarix aphylla*, *Azadirachta indica*, *Commiphora africana* and *Eucalyptus camaldulensis* can also be used.

Care should be taken since species that can easily be grown in degraded environments and selected for land rehabilitation and agroforestry projects can be invasive. Therefore, local communities should be aware of the importance of introducing multipurpose species through weighting the pros and cons of such species. Moreover, ecological and socioeconomic surveys and research should be made based on cost-benefit analysis of introducing drought tolerant multipurpose plant species vis-à-vis the indigenous biodiversity and socioeconomic conditions of the local communities.

Further in-depth studies on the ecology of the region including the aspects of degradation and potentials of regeneration in the context of the prevailing climatic and socioeconomic environment will be beneficial in the planning and implementation of conservation activities and biodiversity use in the study area. Moreover, since the local communities were observed to have a great deal of knowledge about the nature and uses of the plant species growing in these areas, ethnobotanical studies are highly recommended.

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## APPENDICES

### Appendix 1. Species list from the study area

No	Scientific name	Vernacular name	Habit	Family
1	<i>Abutilon hirtum</i> (Lam.) Sweet	Hamukuto (Af)	S	Malvaceae
2	<i>Acacia asak</i> (Forssk.) Willd.	Sebansa (Or), Tikibilita (Af)	S	Fabaceae
3	<i>Acacia lahai</i> Steud. & Hochst. ex Benth.	Dodotie (Or)	T	Fabaceae
4	<i>Acacia mellifera</i> (Vahl) Benth.	Merkaatoo (Af)	T	Fabaceae
5	<i>Acacia nilotica</i> (L.) Willd. ex Del. *	Keseltoo (Af)	T	Fabaceae
6	<i>Acacia oerfota</i> (Forssk.) Schweinf.	Gerento (Af) /Ajo (Or)	S	Fabaceae
7	<i>Acacia senegal</i> (L.) Willd.	Ajo (Or)	S	Fabaceae
8	<i>Acacia seyal</i> Del.	Wacho (Or)	T	Fabaceae
9	<i>Acacia tortilis</i> (Forssk.) Hayne	Keraro (Am)	T	Fabaceae
10	<i>Acalypha indica</i> L.	Subahi (Af)	S	Euphorbiaceae
11	<i>Acalypha fruticosa</i> Forssk.	Subahi/Subahita (Af)	S	Euphorbiaceae

Appendix 1 Continued

12	<i>Achyranthes aspera</i> L.		H	Amaranthaceae
13	<i>Acokanthera schimperi</i> (A. DC.) Schweinf.	Keror (Am)	H	Apocynaceae
14	<i>Actinopteris radiata</i> (SW.) Link *		H	Actinopteridiaceae
15	<i>Aerva javanica</i> (Burm. f.) Juss. ex. Schult.	Ollaitoo (Af)	H	Amaranthaceae
16	<i>Aloe camperi</i> Schweinf.	Ret (Am)	H	Aloaceae
17	<i>Aloe trichosantha</i> Berger*	Ret (Am)	H	Aloaceae
18	<i>Alternanthera pungens</i> Kunth*		S	Amaranthaceae
19	<i>Argemone mexicana</i> L.	Nechilo (Am)	H	Papaveraceae
20	<i>Aristolochia bracteolata</i> Lam. *	Sue sue (Af)	H	Aristolochiaceae
21	<i>Aristida</i> sp.		G	Poaceae
22	<i>Arthraxon prionodes</i> (Steud.) Dandy	Yekok sar (Af)	G	Poaceae
23	<i>Asparagus africanus</i> Lam.*		S	Asparagaceae
24	<i>Balanites aegyptiaca</i> (L.) Del.	Bedena (Or)/Uda (Af)	T	Balanitaceae
25	<i>Balanites rotundifolia</i> (van Tieghem) Blatter *	Allaitoo (Af)	S	Balanitaceae

Appendix 1 Continued

26	<i>Barleria eranthemoides</i> C. B. Clarke	Yeset Af (Am)	H	Acanthaceae
27	<i>Barleria parviflora</i> R. Br ex. T. Anders	Gansalto (Af)	H	Acanthaceae
28	<i>Berchemia discolor</i> (Klotzsch) Hemsl.	Jejeba (Am)/Dedibayto (Af)	S	Rhamnaceae
29	<i>Blepharis edulis</i> (Forssk.) Pers.*		S	Acanthaceae
30	<i>Boerhavia coccinea</i> Mill.		Cl	Nyctaginaceae
31	<i>Boerhavia erecta</i> L.	Habunie (Af)	H	Nyctaginaceae
32	<i>Boscia angustifolia</i> A. Rich. *	Ormaytto/Urma (Af)	S	Capparidaceae
33	<i>Boscia coriacea</i> Pax	Ayteneba (Am)	S	Capparidaceae
34	<i>Bothriochloa insculpta</i> (Hochst. ex A. Rich.) A. Camus		G	Poaceae
35	<i>Cadaba farinosa</i> Forssk.	Dinbayto (Af)	S	Capparidaceae
36	<i>Cadaba longifolia</i> (R. Br.) DC. *	Dinbayto (Af)	S	Capparidaceae
37	<i>Cadia purpurea</i> (Picc.) Ait.	Enjiro (Or)	S	Fabaceae
38	<i>Calotropis procera</i> (Ait.) Ait. f. *	Gelehatoo (Af) /Tobiaw (Am)	S	Asclepiadaceae
39	<i>Calpurnia aurea</i> (Ait.) Benth.	Digita (Am)	S	Fabaceae

Appendix 1 Continued

40	<i>Capparis tomentosa</i> Lam.	Harengama (Or)	S	Capparidaceae
41	<i>Cardiospermum helicacabum</i> L. *		Cl	Sapindaceae
42	<i>Carduus</i> sp. *		S	Asteraceae
43	<i>Carissa spinarum</i> Whal.	Agam (Am)	S	Apocynaceae
44	<i>Celsia pedunculosa</i> Hochst. ex. Steud.		H	Scrophulariaceae
45	<i>Cenchrus pennisetiformis</i> Steud. *		G	Poaceae
46	<i>Chamaecrista mimosoides</i> (L.) Greene*		H	Fabaceae
47	<i>Chascanum laetum</i> Fenzl ex Walp.		S	Verbenaceae
48	<i>Chenopodium ambrosioides</i> L.		H	Chenopodiaceae
49	<i>Chloris roxburghiana</i> Schult.		G	Poaceae
50	<i>Cissus quadrangularis</i> L.	Busruga (Af) /Chobi (Af)	Cl	Vitaceae
51	<i>Cissus rotundifolia</i> (Forssk.) Vahl	Chobi (Or)/Gomiz (Am)	Cl	Vitaceae
52	<i>Cleome gynandra</i> L. Briq. *	Adrekumeli (Af)	S	Capparidaceae
53	<i>Clerodendron myricoides</i> R. Br.	Misirch (Am)	S	Verbenaceae
54	<i>Coccinia grandis</i> (L.) Voight*		H	Cucurbitaceae
55	<i>Cocculus pendulus</i> (J. R. & G. Forst.) Diels*****	Hayukuto (Af)	Cl	Menispermaceae
56	<i>Combretum aculeatum</i> Vent.	Chocho (Or)	S	Combretaceae
57	<i>Combretum collinum</i> Fresen.	Abalo (Am)	T	Combretaceae
58	<i>Commelina benghalensis</i> L.		H	Commelinaceae

Appendix 1 Continued

59	<i>Commicarpus grandiflorus</i> (A. Rich) Standl. ****	Sarroytta (Af) /Habunie (Af)	Cl	Nyctaginaceae
60	<i>Commiphora africana</i> (A. Rich.) Engl.	Dido (Or)/ Curbetta (Af)	S	Burseraceae
61	<i>Conyza pyrohappapa</i> A. Rich. *		S	Asteraceae
62	<i>Cordia gharaf</i> (Forssk) Aschers*		T	Boraginaceae
63	<i>Cordia monoica</i> Roxb.	Mintiro (Or)	T	Boraginaceae
64	<i>Cordia ovalis</i> R. Br.		S	Boraginaceae
65	<i>Cordia sinensis</i> Lam	Mudera (Af)	S	Boraginaceae
66	<i>Croton macrostachyus</i> Del. *	Mekanisa (Or)	T	Euphorbiaceae
68	<i>Cynodon dactylon</i> L. Pers.		G	Poaceae
69	<i>Cyperus</i> sp.		G	Cyperaceae
70	<i>Delonix elata</i> (L.) Gamble *		T	Fabaceae
71	<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	Horssabissa (Or)	S	Fabaceae
72	<i>Digera muricata</i> (L.) Mart.		H	Amaranthaceae
73	<i>Digitaria abyssinica</i> (Hochst. ex A. Rich) Stapf	Sebezie (Am)	G	Poaceae
74	<i>Digitaria</i> sp.	Baldwini (Af)	G	Poaceae
75	<i>Diospyros abyssinica</i> (Hiern) F. White	Selawa (Am)	S	Ebenaceae
76	<i>Dobera glabra</i> (Forssk.) Poir. ****	Garsa (Or)	T	Salvadoraceae

Appendix 1 Continued

77	<i>Dodonaea angustifolia</i> L. f.	Kitikita (Am)	S	Sapindaceae
78	<i>Ehretia cymosa</i> Thonn.	Oulaga (Am)	S	Boraginaceae
79	<i>Eleusine multiflora</i> A. Rich.		G	Poaceae
80	<i>Endostemon tereticaulis</i> (Poir.) Ashby		S	Lamiaceae
81	<i>Enicostema litorale</i> Blume		H	Gentianaceae
82	<i>Enteropogon macrostachyus</i> (Hochst. ex A. Rich.) Benth.	Sekokie (Am)	G	Poaceae
83	<i>Eragrostis</i> sp.*	Anfaro (Or)	G	Poaceae
84	<i>Erichloa</i> sp.*		G	Poaceae
85	<i>Erythroclamys spectabilis</i> Gürke		S	Lamiaceae
86	<i>Eucalyptus saligna</i> Smith ***		T	Myrtaceae
87	<i>Eucalyptus camaldulensis</i> Dehnh. ***		T	Myrtaceae
88	<i>Euclea racemosa</i> ssp. <i>schimperi</i> (A. DC.) White	Dedeho (Am)	S	Ebenaceae
89	<i>Eulophia steroptopetala</i> Lindl. *		H	Orchidaceae
90	<i>Euphorbia abyssinica</i> Gmel.	Kulkual (Am)	T	Euphorbiaceae
91	<i>Euphorbia candelabrum</i> Kotschy	Kulkual (Am)	T	Euphorbiaceae
92	<i>Euphorbia hirta</i> L.*		H	Euphorbiaceae

Appendix 1 Continued

93	<i>Euphorbia lophiosperma</i> S. Carter*		H	Euphorbiaceae
94	<i>Euphorbia polycnemoides</i> Boiss*		H	Euphorbiaceae
95	<i>Festuca abyssinica</i> Hochst. ex A. Rich. ****		G	Poaceae
96	<i>Ficus ovata</i> Vahl.	Gomiz (Am)	S	Boraginaceae
97	<i>Ficus sur</i> Forssk. *	Shola (Am)	T	Boraginaceae
98	<i>Ficus sycomorus</i> L.	Sholla (Am)	S	Boraginaceae
99	<i>Flaveria trinervia</i> (Spreng.) C. Mohr*		H	Asteraceae
100	<i>Gomphocarpus fruticosus</i> (L.) Ait. f. ****		H	Asclepiadaceae
101	<i>Grewia bicolor</i> Juss.	Aroressa (Or)	S	Tiliaceae
102	<i>Grewia erythraea</i> Schweinf.		S	Tiliaceae
103	<i>Grewia ferruginea</i> Hochst. ex A. Rich.	Aroressa (Or)/ Fo (Af)	S	Tiliaceae
104	<i>Grewia flavescens</i> Juss.		S	Tiliaceae
105	<i>Grewia tembensis</i> Fresen.	Libassa (Or)	S	Tiliaceae
106	<i>Grewia trichocarpa</i> Hochst. ex. A. Rich. *	Filameata (Af)	S	Tiliaceae
107	<i>Grewia velutina</i> (Forssk.) Vahl	Shimburo (Or)	S	Tiliaceae
108	<i>Grewia villosa</i> Willd.	Ogobdi (Or)	S	Tiliaceae
109	<i>Hackelochloa granularis</i> (L.) Kuntze*		G	Poaceae

Appendix 1 Continued

110	<i>Helinus integrifolius</i> (Lam.) O. Ktze. *****		S	Rhamnaceae
111	<i>Heliotropium longifolium</i> (DC.) Jaub. & Spach*	Amqadda (Af)	H	Boraginaceae
112	<i>Heliotropium rariflorum</i> Stocks *	Kottomeyu (Af)	H	Boraginaceae
113	<i>Helixanthera thomsonii</i> (Sprague) Danser *		G	Loranthaceae
114	<i>Heteropogon contortus</i> (L.) Roem. & Schult.	Bila (Or)	G	Poaceae
115	<i>Hibiscus micranthus</i> Hochst. ex A. Rich		S	Malvaceae
116	<i>Holothrix</i> sp. *	Yebere chew (Am)	H	Orchidaceae
117	<i>Hyparrhenia antihistrioides</i> (A. Rich) Stapf.	Senbelet (Am)	G	Poaceae
118	<i>Hyparrhenia hirta</i> E. Fourn.	Senbelet (Am)	G	Poaceae
119	<i>Hypoestes forskalii</i> (Vahl) R. Br	Arema (Or)	S	Acanthaceae
120	<i>Indigofera articulata</i> Gouan. *		H	Fabaceae
121	<i>Indigofera secundifolia</i> Poir. *	Yayit Misir (Am)	H	Fabaceae
122	<i>Indigofera</i> sp.	Ayrowagit (Af)	H	Fabaceae
123	<i>Indigofera spicata</i> Forssk. *****	Yayit Misir (Am)	H	Fabaceae

Appendix 1 Continued

124	<i>Ipomea</i> sp.*		Cl	Convolvulaceae
125	<i>Ipomea sinensis</i> (Desr.) Choisy *		Cl	Convolvulaceae
126	<i>Jatropha curcas</i> L. ***	Hagulo (Or)	S	Euphorbiaceae
127	<i>Jatropha glauca</i> Vahl***	Hagulo (Or)	S	Euphorbiaceae
128	<i>Jasminum abyssinicum</i> Hochst. ex DC.	Hamukuto (Af)	Cl	Oleaceae
129	<i>Jasminum grandiflorum</i> L. ssp <i>floribundum</i> R. Br ex Fresen.	Hamukuto (Af)/Xukanxuksussi (Af)	Cl	Oleaceae
130	<i>Justicia flava</i> (Vahl) Vahl		S	Acanthaceae
131	<i>Justicia odora</i> (Forssk.) Vahl		S	Acanthaceae
132	<i>Justicia schimperiana</i> (Hochst. ex Nees) T. Anders. *	Dodobee (Or)/Sensel (Am)	S	Acanthaceae
133	<i>Kalanchoe citrina</i> Schweinf.	Endahula (Am)	H	Crassulaceae
134	<i>Kalanchoe lanceolata</i> (Forssk.) Pers.	Endahula (Am)	H	Crassulaceae
135	<i>Kanahia laniflora</i> (Forssk.) R. Br.*	Leeamo (Af)	H	Asclepiadaceae
136	<i>Kleinia</i> sp.	Lukalukie (Or)	H	Asteraceae
137	<i>Lantana camara</i> L. *		S	Verbanaceae

Appendix 1 Continued

138	<i>Leucas glabrata</i> (Vahl) Smith		H	Lamiaceae
139	<i>Leucas vertifolia</i> (Vahl) Smith		H	Lamiaceae
140	<i>Lycium shawii</i> Roem. & Schult. *	Hedalusaito (Af)/ Hadalu (Af)	H	Solanaceae
141	<i>Maerua angolensis</i> DC.	Alam Solala (Or)	S	Capparidaceae
142	<i>Maytenus arbutifolia</i> (A. Rich.) Wilczek	Atat (Am)/ Kombolcha (Or)	S	Celastraceae
143	<i>Maytenus senegalensis</i> (Lam.) Exell	Atat (Am)/ Kombolcha (Or)	S	Celastraceae
144	<i>Melinis repens</i> (Willd.) Zizika		G	Poaceae
145	<i>Moringa stenopetala</i> (Bak. f.) Cuf. ***		T	Moringaceae
146	<i>Ochna inermis</i> (Forssk.) Schweinf.		S	Ochnaceae
147	<i>Ocimum forskaolei</i> Benth. *	Damakesie (Am)	S	Lamiaceae
148	<i>Ocimum lamiifolium</i> Hochst.	Yezinjero zikakibie (Am)	S	Lamiaceae
149	<i>Olea europaea</i> L. ssp. <i>cuspidata</i> (Wall. ex DC.) Cifferri	Weyra (Am)	T	Oleaceae
150	<i>Opuntia ficus-indica</i> (L.) Miller	Yeareb Kulkual (Am)	S	Cactaceae
151	<i>Osyris quadripartita</i> Decn. *	Keret (Am)	S	Santalaceae

Appendix 1 Continued

152	<i>Otostegia integrifolia</i> Benth.	Tinjut (Am)	S	Acanthaceae
153	<i>Ozora insignis</i> Del. ****		S	Anacardiaceae
154	<i>Panicum maximum</i> Jacq.	Chita (Or)	G	Poaceae
155	<i>Panicum</i> sp.		G	Poaceae
156	<i>Parthenium hysterophorus</i> L. *	Baro beru (Af)	H	Asteraceae
157	<i>Paspalidum</i> sp. *		G	Poaceae
158	<i>Pavetta gardenifolia</i> A. Rich. *		S	Rubiaceae
159	<i>Pelargonium multibracteatum</i> Hohst. ex A. Rich. *		H	Geraniaceae
160	<i>Pennisetum setaceum</i> (Forssk.) Chiov. *		G	Poaceae
161	<i>Phyllanthus sepialis</i> Muell & Arg.		S	Euphorbiaceae
162	<i>Physalis micrantha</i> Link*	Gaidiberara (Af)	H	Solanaceae
163	<i>Plectranthus</i> sp.	Botor (Or)	S	Lamiaceae
164	<i>Polygala abyssinica</i> Fres. *****	Astefie Arem (Am)	H	Polygalaceae
165	<i>Polygala obtusissima</i> Chod. *	Calmala (Af)	H	Polygalaceae

Appendix 1 Continued

166	<i>Premna resinosa</i> (Hochst.) Schauer	Misirch (Am)	S	Verbenaceae
167	<i>Prosopis juliflora</i> (SW.) DC. **	Weyannetta (Af)	S	Fabaceae
168	<i>Pterolobium stellatum</i> (Forssk.) Brenan	Kentefa (Am)	S	Fabaceae
169	<i>Pupalia lappacea</i> (L.) A. Juss. *		H	Amaranthaceae
170	<i>Rhus glutinosa</i> A. Rich.	Tatessa (Or)	S	Anacardiaceae
171	<i>Rhus natalensis</i> Krauss	Debobosha (Or)	S	Anacardiaceae
172	<i>Rhus retinorrhoea</i> Oliv.	Tilem (Am)	S	Anacardiaceae
173	<i>Rosa abyssinica</i> Lind.	Kega (Am)	S	Rosaceae
174	<i>Ruellia patula</i> Jacq.	Doytoo (Am)	S	Acanthaceae
175	<i>Rumex nervosus</i> Vahl	Embwacho (Am)	S	Polygonaceae
176	<i>Sageretia thea</i> (Osbeck.) M. C. Johnston	Kechechilo (Or)/Firtitie (Or)	S	Rhamnaceae
177	<i>Salvadora persica</i> L.	Adayto (Af)	S	Salvadoraceae
178	<i>Sansevieria ehrenbergii</i> (L.) R. Br *	Algae (Or)	H	Dracenaceae
179	<i>Seddera arabica</i> Forssk. *	Adumegeri (Af)	H	Convolvulaceae

Appendix 1. Continued

180	<i>Seddera hirsuta</i> Hall. F. *	Bikiltefra (Af)	H	Convolvulaceae
181	<i>Senna alexandrina</i> Mill. *	Mekisenu (Af)	H	Fabaceae
182	<i>Senna italica</i> Mill. *	Senuu (Af)/Ayrowagit (Af)	H	Fabaceae
183	<i>Senna occidentalis</i> (L.) Link*	Birbira (Am)	H	Fabaceae
184	<i>Sericocomopsis pallida</i> (S. Moore) Schinz	Quadmagarritta (Af)	H	Amaranthaceae
185	<i>Sida ovata</i> Forssk. *		S	Malvaceae
186	<i>Sida rhombifolia</i> L.		S	Malvaceae
187	<i>Siegesbeckia orientalis</i> L. *		H	Asteraceae
188	<i>Solanum coagulans</i> Forssk.	Alulis (Af) / Moretabreh (Af)	S	Solanaceae
189	<i>Solanum incanum</i> L.	Wakrikoqos (Af) / Alulis (Af)	S	Solanaceae
190	<i>Solanum nigrum</i> Vatke	Alulis (Af) / Moretabreh (Af)	S	Solanaceae
191	<i>Solanum somalense</i> Franch. *	Alulis/Moretabreh/Gaideberarae (Af)	S	Solanaceae
192	<i>Spermacoce chaetocephala</i> DC.		S	Rubiaceae
193	<i>Sporobolus festivus</i> Hochst. ex A. Rich.	Chita (Or)	G	Poaceae

Appendix 1 Continued

194	<i>Sporobolus ioclados</i> (Trin.) Nees *		G	Poaceae
195	<i>Sporobolus pellucidus</i> Hochst. *	Chita (Or)	G	Poaceae
196	<i>Steganothaenia araliacea</i> Hochst. ex. A. Rich	Arfetu (Or)	S	Apiaceae
197	<i>Stephania abyssinica</i> (Dillon & A. Rich.) Walp. *		H	Menispermaceae
198	<i>Tagetes minuta</i> L.	Gimie (Am)	S	Asteraceae
199	<i>Talinum portulacifolium</i> (Forssk.) Asch. ex Schweinf.*		H	Portulacaceae
200	<i>Tamarix aphylla</i> (L.) Karst*	Segentoo (Af)	T	Tamaricaceae
201	<i>Teclea nobilis</i> Del. *****		S	Rutaceae
202	<i>Tephrosia villosa</i> (L.) Pers.*****		S	Fabaceae
203	<i>Terminalia brownii</i> Fresen.	Weyba (Am)	T	Combretaceae
205	<i>Tragus berteronianus</i> Schult.		G	Poaceae
204	<i>Tragus</i> sp.		G	Poaceae
206	<i>Tribulus terrestris</i> L. ****	Kumedo (Or)/Bunket (Af)	H	Zygophyllaceae
207	<i>Trifolium</i> sp.	Maget (Am)	H	Fabaceae

Appendix 1 Continued

208	<i>Urochloa</i> sp.		G	Poaceae
209	<i>Verbascum sinaticum</i> Benth.*	Somie (Af)	H	Scrophulariaceae
210	<i>Vernonia abyssinica</i> Sch. Bip. ex Walp *		S	Asteraceae
211	<i>Withania somnifera</i> (L.) Dunal*	Kokerabtoo (Af)	S	Solanaceae
212	<i>Xanthium spinosum</i> L.	Chegogit (Am)	S	Asteraceae
213	<i>Xanthium strumarium</i> L.	Bangi (Am)	H	Asteraceae
214	<i>Ximenia americana</i> L.	Enkoy (Am)/Huda (Or)	S	Olacaceae
216	<i>Ziziphus mucronata</i> Willd.	Hate Kurkura (Am)	T	Rhamnaceae
216	<i>Ziziphys spina-christi</i> (L.) Desf.	Kurkura (Am)/ Gusura(Af)	T	Rhamnaceae

**NB:** Cl = Climbers, G= Grasses, H= Herbs, S = Shrubs, and T = Trees

Am=Amharic, Af= Afarigna, Or= Oromiffa (Wello)

\* Represents species that are found out of relevés

\*\* Introduced and naturalized species

\*\*\* Both found out of relevés and introduced species

\*\*\*\* Not previously reported to be found in WU and Afar region/the study area

\*\*\*\*\*Found out of relevés and not previously reported in WU and AF of Flora of Ethiopia

Source: *Flora of Ethiopia*, Vols. 1-4, 6 and 7

Appendix 2. Plant family composition and percentage distribution

	FAMILY	NO. OF SPECIES	PERCENTAGE
1	Poaceae	28	12.96
2	Fabaceae	24	11.11
3	Acanthaceae	10	4.63
4	Asteraceae	9	4.17
5	Boraginaceae	9	4.17
6	Euphorbiaceae	9	4.17
7	Capparidaceae	8	3.70
8	Tiliaceae	8	3.70
9	Amaranthaceae	7	3.24
10	Lamiaceae	7	3.24
11	Solanaceae	7	3.24
12	Convolvulaceae	5	2.31
13	Rhamnaceae	5	2.31
14	Anacardiaceae	4	1.85
15	Malvaceae	4	1.85
16	Asclepiadaceae	3	1.39
17	Combretaceae	3	1.39
18	Nyctaginaceae	3	1.39
19	Oleaceae	3	1.39
20	Rubiaceae	3	1.39
21	Verbenaceae	3	1.39
22	Aloaceae	2	0.93
23	Apocynaceae	2	0.93
24	Balanitaceae	2	0.93
25	Celastraceae	2	0.93
26	Crassulaceae	2	0.93
27	Ebenaceae	2	0.93
28	Menispermaceae	2	0.93
29	Myrtaceae	2	0.93
30	Orchidaceae	2	0.93
31	Polygalaceae	2	0.93
32	Salvadoraceae	2	0.93
33	Sapindaceae	2	0.93
34	Vitaceae	2	0.93
	28 families with one species each	28	12.96

Appendix 3. Relevé characteristics of the study area

Com. type	Relevé. No	Salinity	EC	Soil color	Altitude	Soil Depth	Slope
I	60	0.05	0.11	2	1656	15.8	25
I	63	0.125	0.15	2	1688	22	30
I	64	0.1	0.14	2	1747	22	25
I	65	0.15	0.2	2	1710	21.1	35
I	66	0.11	0.12	2	1724	22.8	25
I	67	0.05	0.1	2	1672	18.6	40
I	68	0.15	0.17	2	1711	19.2	25
I	69	0.15	0.23	2	1731	20.6	40
I	70	0.1	0.13	2	1738	22	35
II	48	0.15	0.17	2	1649	22	20
II	49	0.1	0.11	2	1644	20	18
II	50	0.1	0.15	2	1670	20.2	30
II	51	0.085	0.07	2	1657	21	30
II	52	0	0.07	2	1672	18.3	35
II	53	0.1	0.13	3	1688	18.5	25
II	54	0.1	0.12	3	1690	18	35
II	55	0.1	0.14	3	1562	17	35
II	56	0.12	0.13	3	1634	20	25
II	57	0.105	0.11	4	1632	18.4	25
II	58	0.15	0.2	4	1618	22.4	30
II	59	0.3	0.42	4	1594	21.6	20
III	35	0.045	0.1	2	1554	15.4	25
III	36	0.04	0.08	2	1644	15.8	35
III	37	0.045	0.09	2	1690	18	25
III	38	0	0.07	2	1688	18	25
III	39	0	0.06	2	1672	18.4	30
III	40	0.1	0.12	2	1720	21.2	15
III	41	0.105	0.11	2	1735	22.4	25
III	42	0.1	0.1	2	1742	27.8	35
III	43	0	0.06	2	1708	18.2	35
III	44	0.15	0.15	2	1742	20.2	40
III	45	0	0.08	2	1712	12.4	25
III	46	0.2	0.24	2	1689	15.2	35
III	47	0.15	0.24	2	1631	23.8	25
IV	1	0.15	0.18	1	1480	9.5	30
IV	2	0.15	0.21	1	1454	8.5	25
IV	4	0.17	0.2	1	1373	10	20
IV	5	0.1	0.13	1	1280	7.5	20
IV	6	0.2	0.3	2	1249	18	10
IV	7	0.11	0.1	2	1268	16	5
IV	8	0.15	0.3	2	1270	15.5	10

**Appendix 3 Continued**

IV	9	0.15	0.19	2	1198	13.4	6
IV	10	0.11	0.1	2	1185	13.1	5
IV	11	0.15	0.15	2	1172	17	5
IV	12	0.15	0.18	2	1200	18	5
IV	13	0.15	0.2	2	1029	24	3
IV	24	0.6	0.85	3	1240	12.6	4
IV	30	0.1	0.12	3	1475	25	11
IV	31	0.15	0.16	2	1202	12.6	15
IV	32	0.1	0.12	2	1060	19.4	30
V	3	0.15	0.21	1	1420	9	25
V	23	0.155	0.2	3	1375	15	5
V	33	0.15	0.18	2	1045	21	35
V	34	0.05	0.14	2	1515	17.4	30
VI	14	0.185	0.3	2	981	25	5
VI	15	0.04	0.1	2	956	24.5	5
VI	16	1.2	0.16	2	962	26	3
VI	17	0.15	0.19	3	961	29.5	5
VI	18	0.2	0.29	3	906	21	5
VI	19	0.25	0.35	3	949	24	6
VI	20	0.15	0.19	2	900	12.5	3
VI	27	194.6	0.4	2	964	27.8	7
VI	28	0.2	0.32	2	960	22.5	6
VI	29	1.45	2.01	2	964	26.2	7
VII	21	0.35	0.49	3	750	21.8	3
VII	22	0.55	0.76	3	756	27.5	3
VII	25	0.15	0.2	3	755	18.5	4
VII	26	0.3	0.41	3	765	26.6	7
R	61	0	0.1	4	1715	18.6	25
R	62	0.15	0.19	2	1671	21.2	30

EC=Electrical Conductivity

Soil color: 1= Black, 2= Brown, 3= Gray, 4= Red

R= Residual relevé

**Appendix 4. Some sampling plots and their GPS records**

GPS reading	Distance from Kombolcha
11°05'N 39°45'E	0km (Kombolcha-reference)
11°07'N, 39°49'E	12km
11°07'N, 39°49.63'E	14km
11°07'N, 39°51'E	16km
11°08'N, 39°52'E	18km
11°08.5'N, 39°53.6'E	22km
11°10'N, 39°56'E	30km
11°10.5'N, 39°57.6'E	33km
11°11'N, 39°59'E	37km
11°11.5'N, 40°0.1'E	41km
11°12'N, 40°01.6'E	45km
11°12'N, 40°01.8'E	46km
11°12.5'N, 40°03'E	45km
12°06'N, 40°03'E	51km
11°13'N, 40°05'E	54km
11°13.5'N, 40°05.5'E	56km
11°14'N, 40°09'E	65km
11°14'N, 40°10'E	66km
11°14.7'N, 40°11'E	68km
11°14.8'N, 40°12'E	71km
11°15'N, 40°13'E	73km
11°15'N, 40°14'E	74km
11°15'N, 40°15'E	77km
11°14.8'N, 40°17'E	82km
11°15'N, 40°18'E	83km
11°15'N, 40°21.7'E	91km
11°13'N, 40°13.5'E	77km
11°13'N, 40°13.5'E	77km
11°15'N, 40°22'E	92km

**Appendix 5. Importance values of some dominant shrubs and trees**

No	Species	Relative Density	Relative Frequency	Relative Dominance	Importance value index
1	<i>Euclea racemosa</i> ssp. <i>schimperi</i>	20	4.21	3.3	27.71
2	<i>Dodonaea angustifolia</i>	21	1.15	0.4	22.76
3	<i>Acacia asak</i>	7	5.36	9.5	21.93
4	<i>Grewia bicolor</i>	3	5.45	5.9	14.38
5	<i>Cadia purpurea</i>	5	3.06	4.9	13.01
6	<i>Acacia mellifera</i>	3	3.92	5.8	12.75
7	<i>Grewia tembensis</i>	2	4.09	4.3	11.01
8	<i>Acalypha fruticosa</i>	7	1.05	1.6	9.72
9	<i>Acacia tortilis</i>	1	4.5	4.1	9.61
10	<i>Euphorbia abyssinica</i>	4	2.3	3	9.34
11	<i>Rhus natalensis</i>	4	3.92	1	8.96
12	<i>Acacia senegal</i>	1	4.02	3.7	8.73
13	<i>Acacia lahai</i>	1	4.02	3.6	8.63
14	<i>Carissa spinarum</i>	2	2.78	3.3	8.1
15	<i>Rhus retinorrhoea</i>	0	1.34	6.6	7.94
16	<i>Acacia seyal</i>	1	3.54	2.7	7.25
17	<i>Grewia villosa</i>	1	3.54	2.2	6.75
18	<i>Acacia oerfota</i>	2	2.39	2.2	6.61
19	<i>Euphorbia candelabrum</i>	1	2.49	2.5	6
20	<i>Sageretia thea</i>	1	3.06	1	5.07

Appendix 5 Continued

21	<i>Diospyros abyssinica</i>	1	1.63	1.9	4.54
22	<i>Balanites aegyptiaca</i>	1	2.2	0.9	4.11
23	<i>Dichrostachys cinerea</i>	2	2.01	0	4.03
24	<i>Acokanthera schimperi</i>	0	1.44	2.5	3.94
25	<i>Prosopis juliflora</i>	2	0.57	1.2	3.79
26	<i>Maytenus arbutifolia</i>	0	1.63	1.8	3.43
27	<i>Salvadora persica</i>	0	0.67	2.6	3.27
28	<i>Olea europaea ssp. cuspidata</i>	0	1.53	1.7	3.23
29	<i>Ximenia americana</i>	0	1.05	1.8	2.85
30	<i>Opuntia ficus-indica</i>	0	1.34	1.4	2.74
31	<i>Dobera glabra</i>	0	0.67	1.7	2.37
32	<i>Pterolobium stellatum</i>	0	0.86	1.3	2.16
33	<i>Capparis tomentosa</i>	0	1.34	0.8	2.14
34	<i>Ziziphus mucronata</i>	0	1.34	0.8	2.14
35	<i>Terminalia brownii</i>	0	1.53	0.6	2.13
36	<i>Berchemia discolor</i>	0	1.82	0.1	1.92
37	<i>Ziziphus spina-christi</i>	0	0.96	0.7	1.66
38	<i>Combretum aculeatum</i>	0	0.48	0.9	1.38
39	<i>Calpurnia aurea</i>	0	0.67	0.7	1.37
40	<i>Boscia coriacea</i>	0	0.19	0.4	0.59

**Appendix 6. Altitude and woody species richness**

Relevé No	Altitude (m)	No. of Woody Species
1	1200	6
2	1202	6
3	1280	6
4	1270	7
5	1475	7
6	1480	7
7	1515	7
8	756	8
9	1240	8
10	1373	8
11	1644	8
12	956	9
13	1198	9
14	1420	9
15	750	10
16	755	10
17	765	10
18	906	10
19	1249	10
20	1268	10
21	1454	10
22	1735	10
23	900	11
24	949	11
25	964	11
26	1045	11
27	1562	11
28	1724	11
29	1742	11
30	1747	11
31	960	12
32	961	12
33	962	12
34	964	12
35	1185	12
36	1731	12
37	1060	13
38	1631	13
39	1554	14
40	1594	14

Appendix 6 Continued

41	1644	14
42	1670	14
43	1672	14
44	1688	14
45	981	15
46	1029	15
47	1172	15
48	1375	15
49	1632	15
50	1634	15
51	1649	15
52	1657	15
53	1711	15
54	1712	15
55	1720	15
56	1618	16
57	1672	16
58	1690	16
59	1656	17
60	1688	17
61	1708	17
62	1738	17
63	1742	17
64	1671	18
65	1672	19
66	1715	19
67	1690	20
68	1688	23
69	1689	23
70	1710	23

Appendix 7. Structure vegetation table with species considered important in

classification of the community types, R= Residual relevés

Com.Types	R	I	II	III	IV	V	VI	VII
RELEVES	66	6676666666	445555555555	3344444444333	230000001111 <sup>02</sup>	233	1222111112	2222
	12	690034578	890967581234	8901234567576	24114567890123 <sup>02</sup>	3334	9078456789	1256
Ciss rotu	--	-1--1-111	1--1-111--1	-----1-----	-----1-----	-1-	-----	0000
Rhus nata	22	122222122	11122222-22	11--1-111-11-	--11111-111--	1-1-	-----	0000
Cari edul	--	-2122-222	1111111-----	1-212-11111-1	-----	-----	-----	000100
Calp aure	--	111-----	-----2-----	-----	-----	-----	-----	000101
Dode angu	22	222222222	-----	-----	-----	-----	-----	000101
Olea euro	1-	-11--1111	1--1-----1-	-----1-----	-----	-----	-----	000101
Rhus reti	--	111-----11	-----	-1-----2----	-----	-----	-----	000101
Acok schi	--	--111--	111--111--1-	-----	-----	-----	-----	00011
Dich cine	12	1--11-111	11-22--2-2-	-----	-----	-----	-----	00011
Sage thea	-1	----11111	11-1111-	-----111--	-----	-----	-----	00011
Dios abys	--	--111--11	-1--12-2----	--111--11-2	1--1-----	-----	-----	00100
Grew temb	11	1-11-1-1-	1-1112212112	-11-1-111-1--	11--1-----	-----	-----	00100
Pter stel	--	-----	-1-----	-----2----	-----	1--	-----	00100
Acac seya	-2	-----	-1-2-----1-	1--11-1112-	-----1--	-----	-----	001011
Aloe camp	11	111111111	111111-2-111	2121212112-12	--2-----	-1-1	-----	001011
Cadi purp	22	--2222-1	-1112221-11	1211121212-1-	-----	-----	-----	001011
Eucl schi	22	21-22222	22222222122	222222222222	--1-----	-----	-----	001011
Mayt sene	-1	-----	1-----1--	-----2-1	-----	-----	-----	001100
Euph abys	--	-----	-----11--1--	1-111-1-----	-----	-----	-----	001101
Euph cand	--	-----	11--122111--	-2221222111-	-----1--	-----	-----	001101
Rhus glut	--	-----	--1--1-1--	1-11--221--	-----1--	-----	-----	001101
Tage minu	--	1-----	1--2-----	1121-21111-1-	-----	-----	-----	001101
Acac laha	-1	-----	222-22-1--	-----1--1-	-----	-----	-----	001110
Capp tome	--	-----1-	1-11--11--	-----11--	-----	-----	-----	001110
Cler myri	--	-----	-----1--11	-----	-----	-----	-----	001110
Opun ficu	--	-----	-----122-	-----1-	-----	-----	-----	001110
Zizi mucr	--	-----1--	-2-1--1--1-	-----	-----	-----	-----	001110
Mayt arbu	--	-----	--11--1-1--	-----	-----1--	-----	-----	001111
Barl eran	-1	---1-1-11	--1-1111111	-----	--11-1-11--1	1--	-----	01
Jasm abys	11	---1-1-1	-1-1--1111	--11--1-1--	-1--1--1-1--	-----	-----1--12	--1-01
Acac tort	--	---1-11-	--12--21--1	1-----	-----1--	-----	-----1-12	1111 100
Ciss quad	11	-----	-----11-	111111-1-11--	-22-----1111 <sup>1</sup>	-----	-----	1010
Acac asak	--	-----	---1122222	2222112211212	212222222222 <sup>22</sup>	2222	11-1212-11	-11-1011
Barl parv	--	1-----	-----	-----1--	-----1-1--	-----	-----	1011
Berc disc	--	-----	-1-----	1-1-----	1-----1--	1--	1-----	1011
Grew bico	-1	-----11	1-21-111211-	11-11-12-11--	-211111122-12 <sup>12</sup>	--11	111-1--1-	----1011
Achy aspe	-1	-----	-----1	-----1--	-----1--	-----	-----1--1	----1100
Aerv java	--	-----	-----1-1	-----	-----	-----	1--1--1--	----1100
Jasm gran	--	-----	-----1-1--	-----1--	-----1--1--	-----	-----1-2--	----1100
Acac oerf	--	-----	-----	-----	-----1--	--1-	22--1222-	--11 110100
Acal frui	--	-----	-----	-----	-----	-----	---122222	----110100
Bala aegy	--	-----	-----	-----	-----	-----	2--222-2-	111- 110100
Cada fari	--	-----	-----	-----	-----	-----	-111-----	----110100
Salv pers	--	-----	-----	-----	-----	-----	1--2-2--2	----110100
Xant stru	--	-----	--1-----	-----	-----	-----	--1-11--1-	----110100
Acac meli	--	-----	-----	-----	--1-1-----1	-----	2222221121	1111 110101
Dobe glab	--	-----	-----	-----	-----1--	-----	-----211-	---1 110101
Pros juli	--	-----	-----	-----	-----	-----	-----	2222 110101
Sedd arab	--	-----	-----	-----	-----11-1-1	-----	111-11-1-1	--11 11011
Klen spec	--	-----	---1-----	-----	-----1111111 <sup>1</sup>	-----	1--11--1-	1-- 111001
Sola inca	--	-----	-----	-----1-	-1-1--11-111--1	1--1	11-211111-	----111001
Boer erac	--	-----	-----	-----	---1--1--	-1--	---11-11-	1-- 111001
Grew vill	--	-----1-	-----1-	-----	1-----1111 <sup>1</sup>	-1-	-----1-1-	----11101
Acac sene	--	-----1-	-----	-----	1111-11111111 <sup>1</sup>	--1-	-----1-1	----11101
Sans fors	--	-----1-	-----	-----	121122222222 <sup>2</sup>	1-1--	---1--11-	----111100
Comm afri	--	-----	-----	-----1-	--11-111-1--1 <sup>1</sup>	1211	1111211--1	----111100
Xime amer	--	-----	-----	-----1-	-----1--	1222	-----	--1- 11111
00	000000000	000000000000	000000000000	1111111111111 <sup>1</sup>	1111	1111	1111111111	1111
00	000000000	111111111111	111111111111	000000000000 <sup>00</sup>	0000	0000	1111111111	1111
00	111111111	000000000000	111111111111	000000000000 <sup>00</sup>	1111	0000000000	1111	1111
	0001111110	000001111110	000000000001	0111111111111 <sup>11</sup>	0	000000001		
	0000110	000110011110	00000000011	0011111111111 <sup>11</sup>	0	00011111		

## DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other University and that all sources of materials used for the Thesis have been duly acknowledged.

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Name

Getachew  
Signature

23 February 2005  
Date