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Ecosystem services assessment of the urban forests of Addis Ababa, Ethiopia

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Abstract Addis Ababa is a highland city with varied topography and landscape features. The mountains that surround the city are covered with urban forest of different types. These forests are providing various ecosystem services for the urban and peri-urban population of the city. Apart from surface temperature regulating function of the green spaces of Addis Ababa, no quantitative assessment of the carbon sequestration and soil protection ecosystem services provided by the urban forest has been conducted to date. The aim of this study was to assess selected ecosystem services such as carbon storage potential, habitat support and soil erosion protection provided by different categories of urban forest of Addis Ababa. The result showed that carbon density in the study area varied with forest categories viz. 293tons/ha, 142tons/ha and 132tons/ha in the dense, medium and open forest types respectively. The Shannon-Wiener diversity index is3.24 for *Junipers* dominated forest, 2.98 for mixed forest and 2.76 for *Eucalyptus* dominated forest. The formation of soil erosion features is significantly different among the *Eucalyptus* forest, *Juniperus* forest and Mixed forest where high incidence of soil erosion was recorded in the *Eucalyptus* forest. Therefore, irrespective of the environmental factors such as slope, aspect and elevation differences, there is an association between *Eucalyptus* forest cover and high soil erosion features. To ensure sustainable supply of ecosystem services and maintain a balanced urban environment, all green spaces in the city should be ecologically networked and diversified. Therefore, assessment of ecosystem services provided essential information for effective planning of the green space in terms of species composition and interconnectivity.

Keywords Carbon storage · Ecosystem service · Green space · Species composition · Soil erosion

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Introduction

Plants are major regulators of global and local climate and urban green spaces reduce the impact of temperature by cooling, shading and shielding buildings and street surfaces. For example, Gill et al. (2007) found that for Manchester city the addition of 10% evapotranspiring surfaces in high-density residential areas has the potential to moderate surface temperatures enough to offset expectedincreases in temperatures due to climate change until the 2050s. Conversely, 10% reduction in green cover increases surface temperatures by 3 to 4 °C under the 2080s high emissions scenario. Furthermore, green spaces also protect water quality, support species diversity and habitat and contribute to the overall life quality of citizens (Stiftel and Vanessa 2004).

With more than half of the world's population becoming urban dwellers (UN 2011), urban green spaces have to be recognized as a key element in urban redevelopment to ensure recreational, social and ecological uses (Van de Voorde et al. 2011). Besides, urban green space is an essential tool for conservation of ecosystem values and functions (Giugni et al. 2015).

In response to increasing atmospheric CO_2 concentrations, (IPCC 2007; Tolla 2011), urban forests are increasingly important due to their role in sequestrating and storing carbon and thus helping to meet climate mitigation goals (McPherson et al. 1999; McHale et al. 2007; Strohbach et al. 2012). Various studies (e.g. Malhi and Grace 2000; Fearnside and Laurance 2004) reported that forest sequesters and stores more carbon than any other terrestrial ecosystem. Similar studies also highlighted that significant reductions in the global flux of CO_2 can be achieved through forest management (Hynynen et al. 2005; Gustavsson and Sathre 2006; Neilson et al. 2006; Fahey et al. 2010). Urban trees offer benefits in terms of atmospheric carbon reduction (Nowak 1993; Jim and Chen 2008), transform CO_2 into above and belowground biomass and store carbon in the form of stems, branches, and roots (McPherson 1998; Jo 2002; Nowak and Crane 2002). It is thus critical to assess the actual and potential role of urban forest in reducing atmospheric CO_2 (Nowak and Crane 2002; Liu and Li 2012). Recently, there has been an increasing interest in estimating the amount of C sequestration and storage by urban forest but contributions are still poorly understood (Brack 2002; Jo 2002; Yang et al. 2005; Myeong et al. 2006; Stoffberg et al. 2010; Zhao et al. 2010).

Urban forests are also important due to their role in preventing soil erosion and associated C losses. Evaluation of soil erosion risk by rainwater using micro-topographic soil erosion features, developed as an alternative to the conventional models (Bergsma 1997; Kunwar 1995; de Bie 2000), do not quantify soil loss per unit area but actually indicate distribution and extent of soil erosion intensity on the field (Kunwar et al. 2003). Observing and recording different types of micro-topographic erosion features allows determining the intensity of soil erosion (Bergsma 1997; de Bie 2000), as the type and amount of vegetation cover determines the way rainfall splash is intercepted (Xiao et al. 1998; USDA 2008).

A little over 5000 ha of land is covered by urban forest in Addis Ababa (Woldegerima et al. 2016). The forests are mostly dominated by species of *Eucalyptus* and found on the mountains in the northern part of the city. *Eucalyptus* species have been introduced to the city in 1985 for satisfying the growing demand of wood as source of fuel and construction material and to reduce the pressure on the remaining natural vegetation (Horst 2006).

The urban forests of Addis Ababa which are considered as “the lungs of the city” by the city residents have been affected by anthropogenic activities, mostly by tree cutting for construction and fuel wood and settlement, resulting in a reduced species composition and diversity (Fetene and Worku 2013). Soil erosion by rainwater is a crucial problem in the Ethiopian highlands (FAO 1986). Addis Ababa, part of the Ethiopian highlands with rugged steep topographic conditions, has suffered by erosion hazards. This has been exacerbated by the degradation of the urban forests on the mountains of the city, possibly affecting the various ecosystem services provision potential of the forests.

Quantification of ecosystem services provision by urban forests can be used to assess the actual and potential role of urban forests in providing environmental, social and economic benefits. Assessment of ecosystem services provided by the green spaces of Addis Ababa is quiet scanty. The EU FP7 CLimate change and Urban Vulnerability in Africa (CLUVA) project (www.cluva.eu) provided a foundation for the assessment of ecosystem services by the green spaces of the city. Cavan et al. (2014) demonstrated the impact of urban morphology types of Addis Ababa on surface temperature regulation. Apart from the above study, quantitative assessment of individual ecosystem services provided by urban forests of Addis Ababa is generally lacking. As a result, information on ecosystem services from urban forests and green spaces are not available for use in the urban planning activities of the city.

The objectives of this study are (i) to quantify the carbon storage potential, (ii) to assess the plant diversity and (iii) to assess the soil erosion mitigation potential of the urban forest of Addis Ababa.

In this paper, we address three research questions:

1. What is the carbon storage potential of the urban forest of Addis Ababa?
2. What is the contribution of the urban forest of Addis Ababa in supporting floristic diversity?
3. What is the contribution of the urban forest of Addis Ababa in mitigating soil erosion?

Data collection and analysis

Description of the study area

This study was conducted in Addis Ababa, the capital of Ethiopia, which is located between 8°45’ and 9°49′ North latitudes and 38°39′ and 38°54′ East longitudes, in the central part of Ethiopia (Fig. 1). Urban forest is found on Mount Entoto on the northern part of the city at altitudes from 2700 m to around 3100 m above sea level. The mountain forms the watershed boundary of the Blue Nile and the Awash Rivers, and the upper catchment area for Akaki and Kebena Rivers, two of the major rivers passing through the city. The topographic feature of Mt. Entoto is composed of rolling terrain, steep slopes on the southern and northern parts and flat-topped plateau.

Floristic composition and diversity and soil erosion mitigation studies were conducted in the forests found in the Gullele Botanic Garden, which is part of the upper Akaki River catchment, covering about 900 ha. This site was selected because of its relatively strong conservation activities, which means that the area exhibits a clear distinction of forest types and associated species diversity from indigenous to more modified plant communities. Development of the Gullele Botanic Garden at

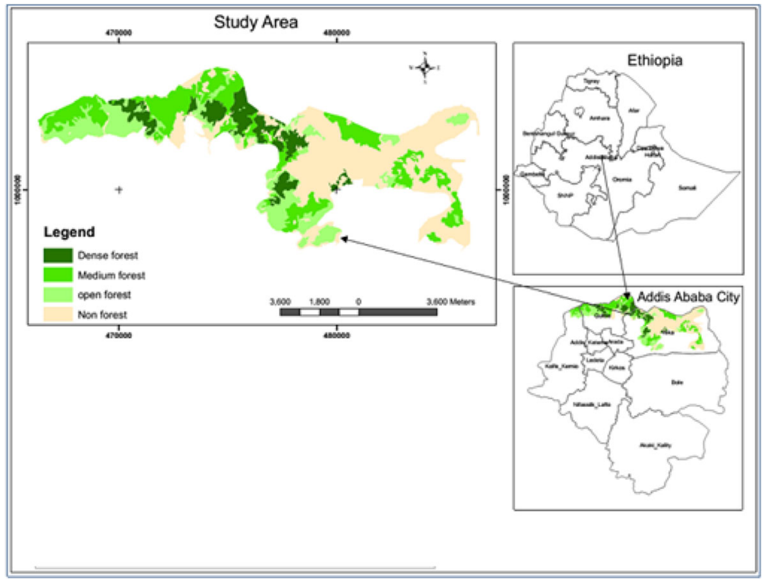


Fig. 1 Location of the urban forest area of Addis Ababa

the northern outskirt of Addis Ababa was initiated some 7 years ago in order to conserve the flora of Ethiopia.

Estimation of biomass and carbon storage

The biomass and carbon storage study was conducted on the urban forest on Mount Entoto encompassing a total area of 5868 ha, which comprises 28% of the total designated green space area of the city. However, in this study only 3227 ha were found under forest cover while the remaining 2641 ha were used for crop cultivation, grazing and settlement. The forest selected for this study is relatively strongly protected, and is thus good for carbon storage analysis within the urban boundary.

Even though the study area is within a relatively uniform ecosystem in the overall climate, topographic and soil conditions, the vegetation cover shows some spatial variability in the form of patches and varying tree stock density, which has a direct relationship with carbon stock potential. Thus, the study area was stratified into more homogeneous forest types such as dense forest, medium dense forest and open forest based on the tree stock density (WBISPP 2000). This reduced the variation within the forest types and increased the precision of population estimate (Husch et al. 1982).

The forest categorization into dense, medium and open forest strata began by studyingthe method applied by the woody biomass inventory project of Ethiopia (WBISPP 2000). This was supplemented by a reconnaissance survey and careful examination of the image characteristics of the forest cover using the ortho-rectified aerial photography of the city. On-screen inspection of aerial photography was done to identify the different strata based on forest stock of the sites, which was later confirmed by collecting ground verification points using GPS. Total and stratum areas was calculated and transect lines were laid along an elevation gradient ranging from 2500 to 2900. The number of plots was identified using an optimal allocation approach. This was applied through taking the total study area as a compilation unit and in proportion to (i) the standard deviation of the weighted mean of the woody biomass stock (air dried in ton/ha) and (ii) the weighted area of a given forest stratum to the total study area or

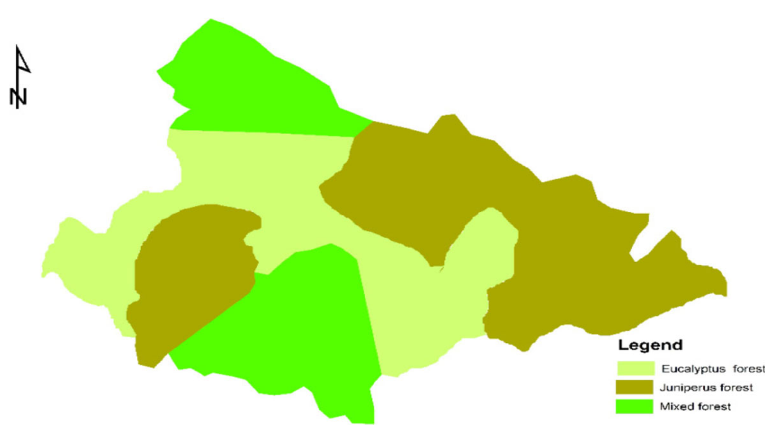


Fig. 2 Forest category of the Gullele Botanic Garden

Table 1 List of woody species at the urban forest of Addis Ababa

No.	Family	Species	Habit
1	Fabaceae	*Acacia abyssinica* Hochst. ex Benth	Tree
2	Fabaceae	*Acacia decurrens* (Wendl.f.)Willd.	Tree
3	Fabaceae	*Acacia saligna* Labill. (Wendl.)	Tree
4	Sapindaceae	*Allophylus abyssinica* (Hochst.) Radlk.	Shrub
5	Melianthaceae	*Bersama abyssinica* Fresen.	Shrub
6	Logonaceae	*Buddleja polystachya* Fresen.	Shrub
7	Apocynaceae	*Carissa spinarum* L.	Shrub
8	Rutaceae	*Clausena anisata (Willd.) Benth.*	Shrub
9	Euphorbiaceae	*Croton macrostachyus* Hochst. Ex A. Rich	Tree
10	Cupresaceae	*Cuprssus lusitanica* Mill.	Tree
11	Solonacaea	*Discopodium penninervium* Hochst.	Shrub
12	Sterculiaceae	*Dombya torrida* (J.F Gmel.) P. Bamps	Shrub
13	Flacortiaceae	*Dovyalis abyssinca* (A.Rich.)Warb	Shrub
14	Meliaceae	*Ekebergia capensis* Sparrm.	Tree
15	Myrtaceae	*Eucalyptus camaldulensis* Dehnh.	Tree
16	Myrtaceae	*Eucalyptus globulus* Labill	Tree
17	Myrtaceae	*Eucalyptus grandis* Maiden.	Tree
18	Hypericaceae	*Hypericum revolutum* Vahl	Shrub
19	Cupresaceae	*Juniperus procera* Hochst ex Endl	Tree
20	Myrsinacea	*Maesa lanceolata* Forssk.	Shrub
21	Celastraceae	*Maytenus andata* (Loes.) Sebsebe	Shrub
22	Celastraceae	*Maytenus arbutifolia* (A.Rich.)Wilezek	Shrub
23	Celastraceae	*Maytenus senegalensis* (Lam.) Exell	Shrub
24	Myrsinacea	*Myrsine africana* L.	Shrub
25	Myrsinacea	*Myrsine melanophloes* (L.) R.Br.	Shrub
26	Oleaceae	*Olea europaea* subsp. *cuspidita* (Wall. ex G. Don) Cif.	Tree
27	Loganiaceae	*Nuxia congesta* R. Br. Ex Fresen.	shrub
28	Oliniaceae	*Olinia rochetiana* A.juss	Tree
29	Santalaceae	*Osyris quadripartita* Decn.	Shrub
30	Rubiaceae	*Pentas schimperi* (Hochst) Weiringa	shrub
31	Pittosporaceae	*Pittosporum viridiflorum* Sims	Shrub
32	Anacardiaceae	*Rhus glutinosa* A.rich.	Shrub
33	Rosaceae	*Rosa abyssinica* Lindley.	Shrub
34	Rosaceae	*Rubus apetales* Poir.	Shrub
35	Rosaceae	*Rubus steudneri* Schwcinf.	Shrub
36	Araliaceae	*Schefflera abyssinica (A.Rich.)Harms.*	Tree
37	Asteraceae	*Vernonia amygdalina* Del.	Shrub

compilation unit. The number of plots for the compilation unit was determined using the formula below (Husch et al. 1982).

$$N = t^2 \left\{ \sum (W\delta) \right\}^2 / EV^2 \qquad (1)$$

Where:

- t — t value; usually a level of probability of 95% confidence is targeted in forest inventories.
- w — Proportion of a forest stratum, i.e. area occupied by a given forest stratum in the compilation unit.
- δ — the standard deviation or the coefficient of variation (%) of the air dried wood biomass of the forest stratum calculated from the woody biomass inventory and strategic planning project (WBISPP 2000).
- EV — Sampling error, the sampling error of the estimated woody biomass stock at the specified level of probability, in this case 95%, the stock being air dried in ton/ha.

The required level of accuracy (%) targeted for forest inventories was calculated by taking the sampling accuracy or precision of 100% minus the level of sampling error (%). The common level of precision in forest inventories is thus a maximum precision of 100% minus an acceptable level of standard error of 15%. To convert the sampling error in Percent (**EV %**) into a real value of ton/ha the following equations was used,

$$EV = E(\%)MCU(Y) \quad (2)$$

Where MCU (Y) is the weighted mean value of the compilation unit obtained by summing the average stock values (M(Y)) of each forest stratum and multiplied by the proportion (**W**) of a given forest stratum in the total area or compilation unit.

$$MCU(Y) = \sum\{W*M(Y)\} \quad (3)$$

To allocate the required number of plots per forest stratum the following formula was used,

$$\boldsymbol{n} = \frac{\{(\boldsymbol{w}*\boldsymbol{\delta})\}}{*\left[\sum\left\{(\boldsymbol{w}*\boldsymbol{\delta})\right]\right\}\boldsymbol{N}} \quad (4)$$

Where**:**

n number of plots required per forest stratum
W proportion of area covered by a specific forest stratum
δ Standard deviation of the mean weight of the biomass stock of a stratum
N total number of sample plots required for whole compilation unit (study area).

The total number of sample plots for the compilation unit was estimated by substituting the values into Eq. 1as below:

$$N = \frac{(1.96)^2*(84.75)^2}{(16.95)^2} \approx 100 \text{ plots.}$$

Similarly, the required number of plots to each forest stratum (n) was performed by substituting values into Eq. 4 and after approximating to nearest values, the results were 40, 35 and 25 plots for medium, open and dense forest categories respectively. The start points of each transect lines were located randomly; however, this was balanced against ease of access with cost considerations and location of the forest in relation to its proximity to road access. A main sample plot of 20 m × 20 m was employed to collect data of woody plants of diameter at breast height (DBH) ≥ 20 cm. A sub plot of 7 m × 7 m for woody plants with DBH between 10 cm and 20 cm as well as sub plot of 2mx2m for woody plants having DBH above 5 cm and less than 10 cm were laid within the main sample plot (Brown et al. 1989). Plots were located at every 100 m along the transect line. In all the 100 plots sampled, species, DBH, plant height, GPS coordinate points; altitude and slope data were recorded and transferred to a spreadsheet for subsequent analysis.

To quantify above and belowground biomass an allometric equation that expresses aboveground tree biomass as a function of its DBH (Brown et al. 1989; Brown 1997; Wang 2006) was selected and used. Individual tree biomass was converted into a hectare basis using corresponding plot sizes and carbon content calculated as half of the biomass (Brown 1997; FAO 1997). For the aboveground biomass estimation, different mathematical equations have been developed and used by many researchers (Negi et al. 1988; Brown et al. 1989; Clark et al. 2001; Phillips et al. 2002; Chave et al. 2005). These biomass estimation methods are non-destructive and are most suitable for carbon stock estimation (Brown 1997; FAO 1997). The equation employed for the present study is

$$Y = 34.4703 - 8.0671(\text{DBH}) + 0.6589\left(\text{DBH}^2\right)$$

Where,

Y is aboveground biomass
DBH is diameter at breast height;

This allometric equation was selected due to the fact that it has been developed and tested to estimate aboveground biomass of woody vegetation in regions where the climate is dry with an annual rainfall of <1500 mm and the woody vegetation is with a dbh of ≥5 cm (Brown et al. 1989). Biomass for each woody individual was calculated and summed up to find

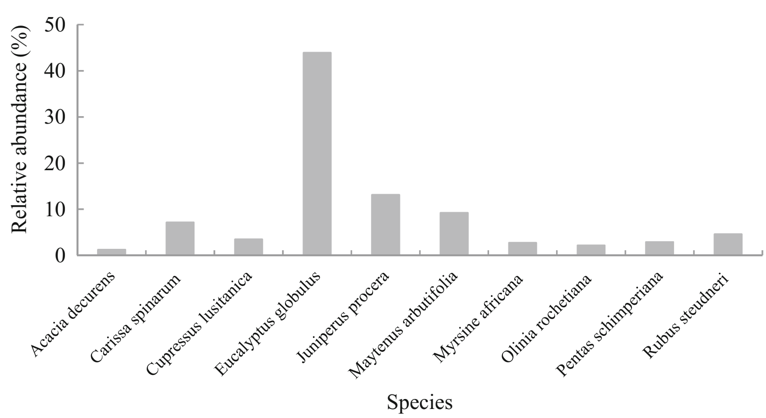


Fig. 3 Ten most abundant species of the study area

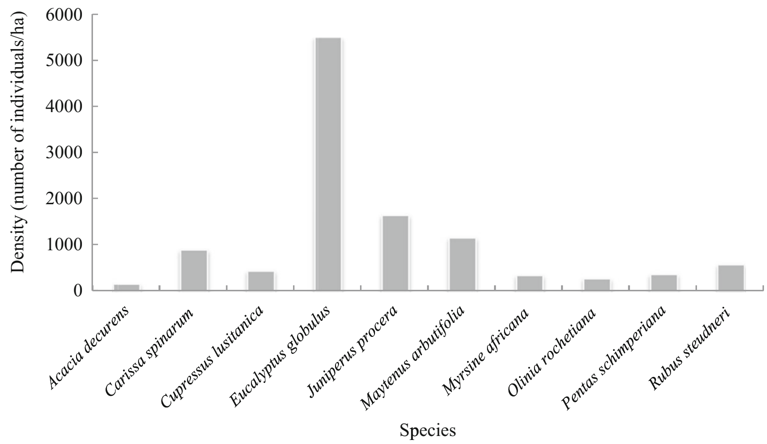


Fig. 4 Ten most dense woody species of the study area

the total biomass stock in each plot and which was then converted to a per hectare basis. Belowground biomass was calculated based on the relationship between root (belowground) and shoot (aboveground) or the root to shoot ratio (Cairns et al. 1997; Brown 2002). Thus for estimating belowground biomass, root to shoot ratio of 1:5 was used (MacDicken 1997) because 20% of the aboveground biomass is equal to the total amount of belowground biomass. In this regard, belowground biomass was estimated by multiplying the aboveground biomass by a factor of 0.2 (belowground biomass = aboveground biomass × 0.2). The total carbon stock was calculated by summing the carbon stock densities of the individual carbon pools using the Pearson et al. (2005) formula as below:

$$\text{C density} = \text{CAGB} + \text{CBGB}$$

Where,

C density Carbon stock density for all pools [t C/ha]
C AGB Carbon stock in aboveground [t C/ha]
C BGB Carbon stock in belowground [tC/ha]

Floristic composition and species diversity

Initial biophysical assessment was conducted on the forests of the Gulelle Botanic Garden and the forest was categorized into *Eucalyptus* dominated (EF), *Juniperus* dominated (JF) and mixed forest types (MF) based on the relative dominance of tree species (Fig. 2).

In each stratum, a systematic sampling scheme was followed using transect lines laid along an elevation gradient and at horizontal distance of 300 m. Along each transect, sample plots 20 m X 20 m were placed at 100 m altitudinal interval. In each sample plot, each individual woody plant was recorded and dbh and height were measured. Five sample plots of 1mx1m size were also established within the 20 m X 20 m sample plot to record herbaceous and graminoid species. Plant species identification was conducted using the Floras of Ethiopia and Eritrea (Hedberg and Edwards 1989); Edwards et al. (1995), 1997); Hedberg and Edwards (1995); Edwards et al. (2000), Hedberg et al. (2003a, b, 2004). For those species, which were difficult to identify on field, plant specimens were collected and pressed for identification at the National Herbarium of Addis Ababa University.

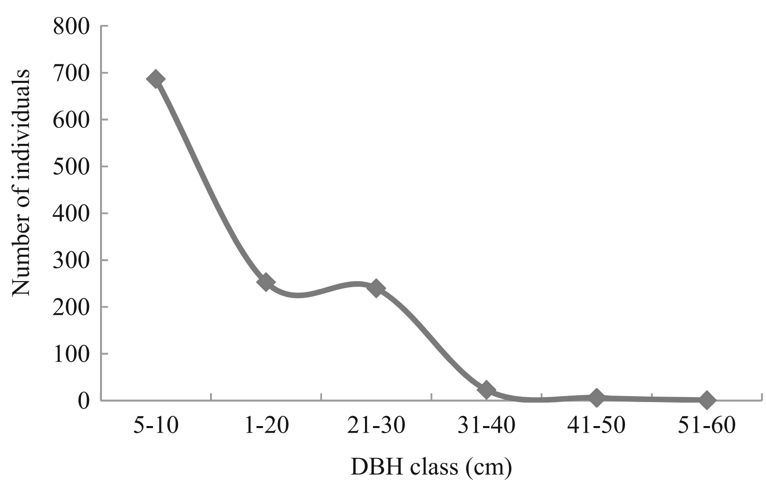


Fig. 5 DBH class distribution of woody species

Table 2 Above and belowground biomass (tons) distribution among the three forest strata

Forest strata	Area (ha)	Aboveground biomass	Belowground biomass	Total biomass
Dense forest	704	337,667	74,287	411,953
Medium forest	1,408	327,984	72,157	400,141
Open forest	1,115	239,964	52,792	292,756
Total	3,227	905,615	199,235	1,104,850

Species density was computed for each forest stratum. Species diversity was analyzed using Shannon-Winer diversity index (Shannon and Wiener 1963), a widely used diversity index in ecologycalculated from the proportional abundances of each species as depicted in the following equation.

$$H' = -\sum_{i=1}^{S} p_i \log(p_i)$$

Where: H' is the standard symbol for Shannon index,
S is number of species and.
p_i,is the proportion of species i.

Species richness was determined as the number of species per unit area. Shannon's equitability (E) was calculated using the following formula.

$$E = \frac{H'}{H_{\max}} = \frac{-\sum p_i \times \log(p_i)}{\log(S)}$$

Where, E is equitability (Evenness). This index is reflects the evenness of species distribution within the sample.

Soil erosion features

Three soil erosion features that are most appropriate to forest land use were selected for this study (Bergsma 1997; de Bie 2000). These are:

Flow surfaces: Initially emerging erosion features of shallow unconcentrated flows, developed on deposits that have smoothed the micro relief with frequent presence of parallel linear flow patterns.
Prerills:refer to areas of very shallow concentrated flows with low storage for water and sediments showing micro channels pattern incisions of 3-5 cm and usually concave in cross section.
Rills: erosion features of shallow linear channels formed by incisions into the soil usually forming part of the drainage system of an area with an upper depth of 30 cm.

Soil erosion features, frequency of incidence, area distribution and percent of area cover was estimated using four (5 m X 5 m) sub plots located within the 20 m X 20msample plots laid for floristic richness and diversity data collection. Within each subplot, bare soil ground cover was estimated and the percentage area coverage of each soil erosion feature viz. flow surfaces, prerills and rills (Kunwar 1995; Bergsma 1997; Woldegerima 1998) within the bare soil ground was carefully estimated. Whole plot level soil erosion features was computed from the sub plot data so that analyses and results will be on uniform area basis instead of bare soil part which vary from one plot to another. The relationship between forest category and soil erosion features incidence was then statistically analyzed to establish the role of forest categories in providing erosion protection ecosystem services.

Results

Estimation of biomass and carbon storage

A total of 37 woody species (13 trees and 24 shrubs) were recorded from the urban forest selected for this study (Table 1).

The highest relative abundance was recorded for *Eucalyptus globulus* (43.94%) followed by *Juniperus procera* (13.15%) while the lowest relative abundance was for *Buddleja polystachya* (0.17%). Figure 3 shows the ten most abundant species of the study area.

The density of woody species in the study area ranges from 21individuals/ha for *Olea europea* subsp. *cuspidata* to 5513 individual trees/ha for *Eucalyptus*

Table 3 Carbon storage distribution among the three forest strata

Forest strata	Area (ha)	Above -ground carbon (tons)	Below-ground carbon (tons)	Total Carbon (tons)	Carbon density (tons/ha)
Dense forest	704	168,833	37,143	205,976	293
Medium forest	1,408	163,990	36,079	200,069	142
Open forest	1,115	119,974	26,396	146,370	131
Total	3,227	452,797	99,618	552,415	171

globulus. *Eucalyptus globulus* and *Juniperus procera* form the first and the second densest species in the urban forest of Addis Ababa with density of 5513 individual trees /ha and 1650 individual trees/ha respectively (Fig. 4).

The result also showed that DBH varies from species to species and the average DBH of tree species ranged from 5.3 cm for *Olinia rochetiana* to 52 cm for *Eucalyptus globulus*. Out of the recorded 1210 individuals with DBH > 5 cm, 687 individuals had DBH between 5 cm and 10 cm and 523 individuals had DBH >10 cm (Fig.5).

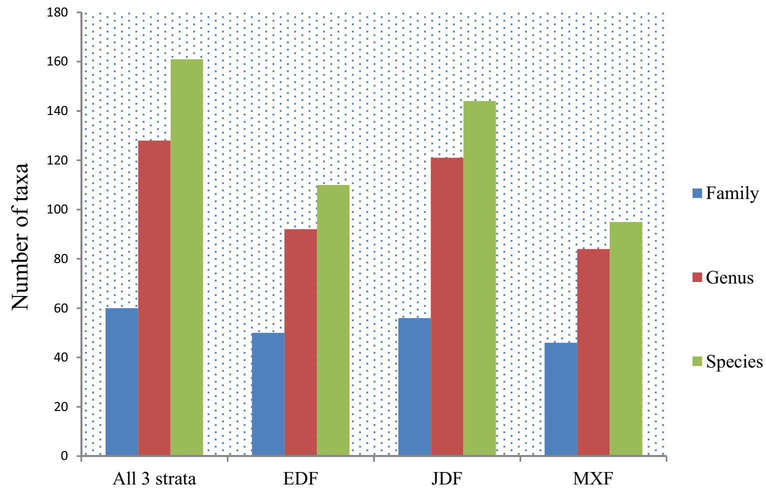
Above and belowground biomass

The total biomass of the urban forest of Addis Ababa was estimated at 1,104,850 tons of dry matter (Table 2). Total biomass was higher for the dense forest followed by medium

Table 4 Average C stock density of different species among the three forest strata

No	Species	C density (tons/ha)			Total
		Dense forest	Medium forest	Open forest	
1	*Acacia abyssinica*	0.60	0.76	0.52	1.88
2	*Acacia decurens*	-	-	3.66	3.66
3	*Acacia saligna*	-	-	0.04	0.04
4	*Allophylus abyssinica*	3.39	-	-	3.39
5	*Bersema abyssinica*	-	-	2.22	2.22
6	*Buddleja polystachya*	-	1.06	-	1.06
7	*Carissa spinarum*	30.35	9.54	-	39.89
8	*Clausena anisate*	-	0.04	-	0.04
9	*Croton macrostachyus*	1.87	2.33	-	4.20
10	*Cupressus lusitanica*	-	5.04	0.14	5.18
11	*Discopodium penninervium*	-	1.88	1.18	3.06
12	*Dombya torrida*	-	-	1.12	1.12
13	*Dovyalis abyssinica*	5.17	0.09	-	5.26
14	*Ekebergia capensis*	-	-	1.36	1.36
15	*Eucalyptus camaldulensis*	-	-	0.29	0.29
16	*Eucalyptus globulus*	104.93	77.16	74.95	257.04
17	*Eucalyptus grandis*	-	-	0.60	0.60
18	*Hypericum revolutum*	-	-	2.39	2.39
19	*Juniperus procera*	56.02	14.94	25.85	96.81
20	*Maesa lanceolata*	0.66	0.32	-	0.98
21	*Maytenus andata*	-	0.82	-	0.82
22	*Maytenus arbutifolia*	36.60	12.68	3.19	52.47
23	*Maytenus senegalensis*	-	-	0.04	0.04
24	*Myrsine africana*	11.07	7.17	6.23	24.47
25	*Myrsine melanophloes*	-	0.06	1.18	1.24
26	*Nuxia congista*	4.95	-	-	4.95
27	*Olea europaea subsp. Cuspidata*	-	-	0.43	0.43
28	*Olinia rochetiana*	10.53	1.97	0.09	12.59
29	*Osyris quadripartite*	-	-	0.46	0.46
30	*Pentas schimperiana*	18.05	-	-	18.05
31	*Pittosporum viridiflorum*	-	0.83	1.12	1.95
32	*Rhus glutinosa*	-	-	1.12	1.12
33	*Rosa abyssinica*	10.98	1.94	1.54	14.46
34	*Rubus apetales*	-	-	1.12	1.12
35	*Rubus steudneri*	-	2.02	-	2.02
36	*Schefflera abyssinica*	-	-	2.06	2.06
37	*Vernonia amygdalina*	-	-	0.97	0.97
	Total	295.20	140.60	133.36	569.65

Fig. 6 Number of families, genera and species recorded in the whole forest and in the forest strata (EF = Eucalyptus forest, JF = *Juniperus*, MF = Mixed forest)



and open forest categories, which is related with the nature of the forest category irrespective of the area coverage. While the medium forest had the largest area (1408 ha) its biomass is less than that of the dense forest which had area of 704 ha. The mean aboveground biomass and belowground biomass of the three strata was estimated at 281tons/ha and 62tons/ha respectively, the average biomass density being 343 tons/ha.

Carbon storage and density

The total carbon stored by urban forest of Addis Ababa was estimated at 552,415tons, out of which dense forest, medium forest and open forest respectively accounted for 37, 36 and 27% of the total carbon (Table 3). The maximum aboveground carbon stock was recorded for dense forest with total carbon of 205,977 tons, followed by medium forest with 200,069 tons and open forest with 146,370 tons. Belowground carbon stock followed the same trend as the aboveground carbon stock in that the highest carbon stock of 37,143 tons was recorded for dense forest, followed by medium forest with 36,074 tons and the open forest had the lowest carbon stock of 26,396 tons.

The average carbon density of the urban forest of Addis Ababa was estimated at 172tons/ha. The result indicated that carbon storage varied among the different urban forest types (dense, medium and open) with different species composition. The highest carbon density of 293 tons/ha was recorded in the dense forest and among the tree species *Eucalyptus globulus* had the highest carbon density of 257 tons/ha, followed by *Juniperus procera* (96.8 tons/ha) (Table 4). It must be understood however that, the allometric equation employed to calculate the biomass is not species specific, rather it is a general model for dry forest and therefore species-wise comparison of biomass and carbon storage is not straightforward.

Floristic composition and species diversity

A total of 161 plant species belonging to 128 genera and 60 families were recorded from the forest of Gulelle Botanic Garden. Out of these 12 species were endemic to Ethiopia. These are *Erythrina brucei, Impatiens rothii, Hyparrhenia tuberculata, Jasminum stans, Laggera tomentosa, Urtica simensis, Maytenus addat, Rubus erlangeri, Satureja paradoxa, Solanecio gigas, Thymus schimperi* and *Vernonia*

Fig. 7 Number of species by growth habit and forest category (EF = *Eucalyptus* forest, JF = *Juniperus* forest, MF = Mixed forest)

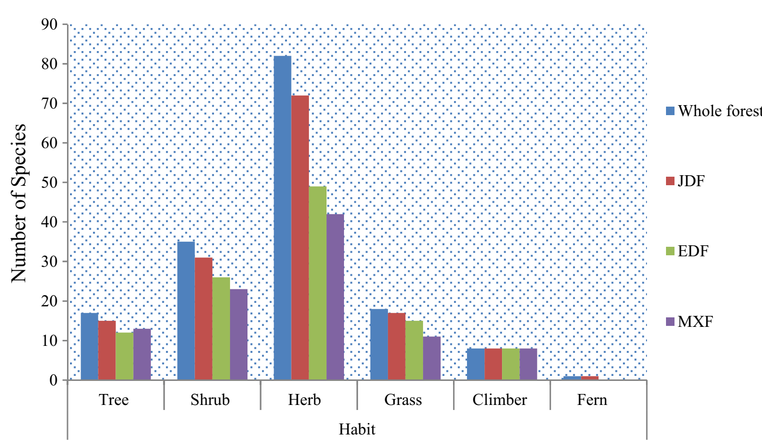


Table 5 Species diversity of the three forest types in Gulelle Botanic Garden

Diversity indices	Forest type		
	Eucalyptus forest	*Juniperus* forest	Mixed forest
Taxa_S	113	143	95
Individuals	2827	5076	2836
Shannon_H'	2.76	3.24	2.98
Evenness_e^H/S	0.14	0.18	0.21
Equitability	0.58	0.65	0.66

leoploldii. From *Juniperus* dominated forest 144 species were recorded, 110 species from *Eucalyptus* dominated forest and 97 species from mixed forest. Most of the families (96%) are represented in the *Juniperus* dominated forest while the *Eucalyptus* and mixed forest categories contained 86 and 77% of the families respectively. Additionally, 95, 72 and 66% of the genera were represented in the *Juniperus*, *Eucalyptus* and mixed forest categories respectively (Fig. 6).

In terms of growth habit, 17 species were trees, 35 shrubs, 81 herbs, 18 grasses, 8 climbers and one species was a fern (Fig. 7). Number of species with tree habit ranged from 12 to 15 in the three forest categories where the highest being in *Juniperus* dominated forest (JF) followed by mixed forest (MF) and *Eucalyptu*s dominated forest (EF) forest categories.

Comparing the three forest types, *Juniperus* dominated forest contained 88% of the trees, 87% of the shrubs, 88% of the herbs and 94% of the grasses while *Eucalyptus* dominated forestcontained71% trees, 74% shrubs, 61% herbs and 83% grasses and mixed forest category consisted 77% trees, 66% shrubs, 52% herbs and 61% grasses. Equal numbers of climbing species were recorded from the three forest categories.

Based on the Shannon-Wiener information function, the floristic diversity in the Gullele Botanic Garden was 2.76 for *Eucalyptus* dominated forest, 3.24 for *Junipers* dominated forest and 2.98 for mixed forest with species richness of 113, 143 and 95 respectively. Species equitability was 0.58 for *Eucalyptus* dominated forest, 0.65 for *Junipers* dominated forest and 0.66 for mixed forest (Table 5).

Forest category and incidence of soil erosion features

The result showed that the formation of soil erosion features are significantly different ($p < 0.001$) between the three forest categories of *Eucalyptus* forest, *Juniperus* forest and Mixed forest (Table 6).

However, other environmental variables such as aspect, elevation and slope did not show significant difference in the formation of soil erosion features (Fig. 8). This could be due to high under growth particularly under *Juniperus* forest and mixed forest.

Discussion

The carbon storage, plant biodiversity support and soil erosion mitigation result showed that the urban forests of Addis Ababa have the potential to provide different ecosystem services.

Carbon storage capacity of the urban forest

The carbon density in the study area varied with forest categories viz. 293 tons/ha, 142 tons/ha and 132 tons/ha in the dense, medium and open forest strata respectively. The average carbon density of 172 tons/ha of the urban forest of Addis Ababa is more than five times higher than the 33.22 tons/ha average carbon density recorded from the urban forest of Shenyang, China (Liu and Li 2012) and 3 to 52 times higher than the carbon density estimated for urban forests of USA (Nowak and Crane 2002). This indicates that the urban forests of Addis Ababa have the potential to remove a substantial amount of greenhouse gas accumulation and contribute towards the development of green economy of the country. The carbon stock recorded in this study, particularly the one within the dense forest category is comparable to similar studies in the afromontane natural forest of Ethiopia. Tesfaye (2007) reported carbon density of 403 tons/ha for a dry afromontane forest in central Ethiopia and Mohammed et al. (2014) reported 588.17 tons/ha for a dry afromontane natural forest in northern Ethiopia.

The carbon storage by the urban forest of Addis Ababa varies among different forest strata and with the

Table 6 Mean values ±SE of soil erosion features among the different forest types at Gulelle Botanic Garden

Soil erosion features	Forest categories			*p-value*
	Eucalyptus forest	*Juniperus* forest	Mixed forest	
Flow surface erosion	38.78 ± 4.15^{a}	12.81 ± 1.65^{b}	2.71 ± 23.65^{c}	<0.001
Pre-rill erosion	11.56 ± 1.34^{a}	5.66 ± 0.73^{b}	6.82 ± 0.76^{c}	<0.001
Rill erosion	6.94 ± 0.46^{a}	1.88 ± 0.37^{b}	4.53 ± 0.76^{c}	<0.001

Superscript letters across the row indicate significant differences ($p < 0.001$), Tukey's HSD test

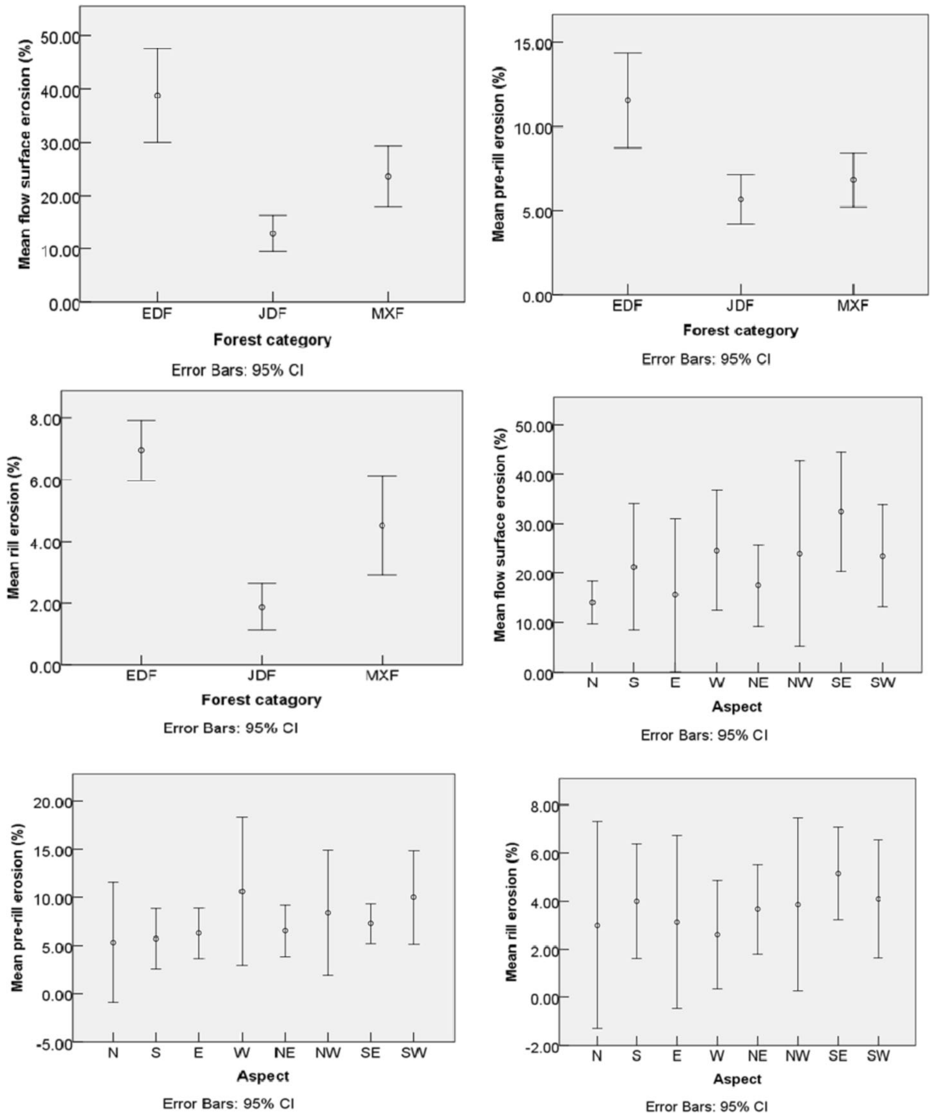


Fig. 8 Soil erosion features (Mean ± SE) by forest type (EDF = Eucalyptus forest, JDF = *Juniperus* forest, MXF = mixed forest) and aspect

species diameter distribution. Tree species have different carbon storage capacities where smaller trees have lower carbon storage levels than larger trees (Nowak 1993). In this study, the differences in biomass and carbon accumulation among the different forest strata could be largely due to differences in soil characteristics and anthropogenic disturbances, which greatly affect the growth rates of plants (Redondo 2007). Generally, the good amount of carbon currently stored by the urban forest of Addis Ababa is a strong argument for at least conserving and developing the present urban forest structure. This implies that high deforestation rate of urban trees without replacement will act as an increment of net CO_2 to the atmosphere, both directly and indirectly. Thus, enhancing further afforestation in combination with selecting the right species with higher canopy for maintaining urban trees can make urban forest a sink for atmospheric carbon, along with producing other urban forest benefits (e.g. temperature reduction and air pollution mitigation) (Cavan et al. 2014).

Floristic composition and species diversity

The numbers of plant species recorded from the three forest categories of Gullele Botanic Garden are comparable with species number recorded from natural forests of Ethiopia. Fetene et al. (2010) recorded 142 species from Menagesha-Suba forest, 40 km south of Addis Ababa and 81 species were recorded from Dindin forest (Shibru and Balcha 2004).Like the forest of the study area, these two forests belong to the dry afromontane forest types of Ethiopia. The difference in species composition among the three forest types of the study area could be attributed to the nature of vegetation type that fosters the growth and regeneration of undergrowth vegetation. The relatively high species richness (144) in the *Juniperus* forest compared to *Eucalyptus* and mixed forest is due to the open canopy of *Juniperus* forest allowing light to penetrate the lower strata of the forest thus allowing undergrowth vegetation to sprawl. The diversity and abundance of regenerating native plants in the understory of planted forest appear to depend more on the intrinsic characteristics of the plantation species such as canopy parameters (Powers et al. 1997; Lemenih et al. 2004). Higher plant diversity in forest would benefit animals through providing alternative habitats, ameliorating local climates and controlling soil erosion.

The floristic diversity (H′ = 2.76 for *Eucalyptus* dominated forest, H′ = 3.24 for *Junipers* dominated forest and H′ = 2.98 for mixed forest) in the present study is essentially comparable with the diversity estimated from natural forests in Ethiopia. Senbeta and Denich (2006) estimated Shannon diversity of 3.17 for Bonga forest, 2.83 for Berhane-Kontir forest, 2.60 for Harenna forest and 2.80 for Yayu forest. Higher diversity value in the present study reflects the good management strategies that enable the promotion of indigenous species in the Botanic Garden. There is a general relationship between biodiversity and ecosystem services (Mace et al. 2012). Therefore, the higher plant species diversity in the study area are expected to support the provision of multiple ecosystem services for the urban and peri-urban residents of Addis Ababa and ensure the survival of plant and animal communities through providing essential habitat and food.

Forest type and soil erosion mitigation

The result suggests that different vegetation types may have different tendencies in controlling rill erosion formation. Aboveground vegetation with intercepting vegetation layer near the soil surface is known to favor water infiltration and to protect soil from erosion. In this study, *Juniperus* forest and mixed forest are found to have more diversified species with rich under growth than *Eucalyptus* forest and have the ability to reduce the formation of rill erosion. Compared to the *Juniperus* and mixed forests, all the three soil erosion features were observed in the *Eucalyptus* forest. The trees in the *Eucalyptus* forest are generally tall, aggravating runoff generation and erosion initiation (Valentin et al. 2005). This has been aggravated by the absence or very sparse understory vegetation in the forest and reduced accumulation of leaf litter on the ground due to its removal by local people for energy source. Increased leaf litter depth under *Eucalyptus* forest was found to intercept rainfall (Thompson et al. 2016). Hence, urban forest management on steep terrain in an urban landscape should enhance the formation of undergrowth vegetation and the accumulation of leaf litter using different silvicultural practices.

Conclusions

The study has demonstrated that the urban forest of Addis Ababa, even at the current low level of conservation and management, has a good level of carbon storage potential. It is anticipated that improved management of the forest would increase the carbon storage potential and the provision of other ecosystem services.

The mountains on the northern part of Addis Ababa are the source of some of the major rivers of the city. However, due to mismanagement of the urban forest and the plantation of Eucalyptus trees on steep terrain, soil erosion and storm water runoff has become a serious problem affecting the mountainous and riverine areas of the city. Consequently, urban dwellers living in riverine corridors can be severely affected (Jaleyer et al. 2014).

Since the *Juniperus* and mixed forests support more species diversity and lower soil erosion features than the *Eucalyptus* forest, undergrowth vegetation development on the rugged mountains of the city could be enhanced through systematic replacement of *Eucalyptus*tree with indigenous trees. The requirement of the booming construction industry of the city for construction poles could be supported with the proper management of the *Eucalyptus* forest on the mountain plateau.

In conclusion, the findings of the present study showed the importance of studies on ecosystem services for improving resource management policies and decisions in urban landscape. The quantitative assessment of ecosystem services allows the mapping of their spatial distribution, which could be used by policy and decision makers to visualize the status of resources (e.g. urban forest and green spaces) and thereby allow them to make informed decision for improved resource management. It is expected that the present research could encourage ecosystems service quantification research focusing on urban landscape of the country which otherwise is rare even in the African context (Wangaia et al. 2016).

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Annex I. Plant species recorded from the urban forest of Gulelle Botanic Garden EF = *Eucalyptus* forest, JF = *Juniperus* forest, MF = Mixed forest

No	Species	Family	Habit	Forest Category
1	*Acacia abyssinica* Hochst. ex Benth.	Fabaceae	Tree	EF, JF, MF
2	*Acacia mearnsii* De Wild.	Fabaceae	Tree	MF
3	*Achyranthesaspera* L.	Amaranthaceae	Herb	JF
4	*Achyrocline stenopterum* (DC.) Hilliard & Burtt	Asteraceae	Herb	JF
5	*Achyrospermum schimperi* Hochst. ex Briq	Lamiaceae	Herb	JF
6	*Adiantum thalicatroides* Schltdl.	Adianthaceae	Herb	EF, JF, MF
7	*Agrocharis melanantha* Hochst.	Apiaceae	Herb	JF, MF
8	*Agrostis quinqueseta* (Hochst. ex Setud.) Hochst.	Poaceae	Grass	EF, JF, MF
9	*Aira caryophyllea* L.	Poaceae	Grass	EF, MF
10	*Alchemilla abyssinica* Fresen.	Rosaceae	Herb	EF, JF, MF
11	*Alchemill apedata* A. Rich.	Rosaceae	Herb	EF, JF, MF
12	*Alepidia peduncularis* A. Rich.	Apiaceae	Herb	EF, JF, MF
13	*Andropogon abyssinicus* Fresen	Poaceae	Grass	EF, JF
14	*Apodytes dimidiata* E.Mey. ex Arn.	Icacinaceae	Tree	JF
15	*Argyrolobium ramossissimum* Baker	Fabaceae	Herb	EF, JF, MF
16	*Argyrolobium rupestre* (E. Mey.) Walp.	Fabaceae	Herb	EF, JF, MF
17	*Arisaema enneaphyllum* Hochst. ex. A. Rich.	Araceae	Herb	EF
18	*Asparagus africanus* Lam.	Asparagaceae	Shrub	EF, JF, MF
19	*Asplinium aethiopicum* (Burm.f.) Bech.	Aspliniaceae	Fern	EF, JF, MF
20	*Bersama abyssinica* Fres.	Melianthaceae	Shrub	EF, JF, MF
21	*Bidensma croptera* (Sch. Bip. ex Chiov.) Mesfin	Asteraceae	Herb	JF, MF
22	*Bidens prestinaria (*Sch. Bip.)	Asteraceae	Herb	EF, JF
23	*Brassica carinata* A. Braun	Brassicaceae	Herb	JF
24	*Bromus leptoclados* Nees	Poaceae	Grass	EF, JF, MF
25	*Buddleja polystachya* Fresen.	Loganiaceae	Shrub	EF, JF
26	*Cardamine trichocarpa* Hochst. ex A. Rich.	Brassicaceae	Herb	JF
27	*Carduus leptacanthus* Fresen.	Asteraceae	Herb	EF, MF
28	*Carduus schimperi* Sch. Bip.	Asteraceae	Herb	EF, JF,MF
29	*Carex spicato-paniculata* Böck. ex C.B. Clarke	Cyperaceae	Herb	EF, JF,MF
30	*Carissa spinarum* L.	Apocynaceae	Shrub	EF, JF,MF
31	*Centela asiatica* (L.) Urban	Apiaceae	Herb	EF, JF,MF
32	*Cheilanthes farinosa* (Forssk.) Kaulf.	Sinopteridaceae	Fern	JF
33	*Chenopodium ambrosioides* L.	Chenopodiaceae	Herb	JF
34	*Clematis simensis* Fresen.	Ranunculaceae	Climber	EF, JF,MF
35	*Clutia abyssinica* Jaub. & Spach	Euphorbiaceae	Shrub	EF, JF,MF
36	*Conyza schimperi* Sch.Bip. ex A. Rich.	Asteraceae	Herb	JF
37	*Conyza steudelii* Sch. Bip.	Asteraceae	Herb	JF
38	*Conyza stricta* Willd.	Asteraceae	Herb	JF
39	*Cotula anthemoides* L.	Asteraceae	Herb	EF, JF,MF
40	*Crassula schimperi* Fisch. & Mey.	Crassulaceae	Herb	JF
41	*Crepis foetida* L.	Asteraceae	Herb	JF
42	*Crepis rueppellii* Sch. Bip	Asteraceae	Herb	EF, JF,MF
43	*Cupressus lusitanica* Mill.	Cupressaceae	Tree	EF, JF,MF
44	*Cyanotis barbata* D. Don	Commelinaceae	Herb	EF, JF,MF
45	*Cyathula uncinulata* (Schrad.) Schinz	Amaranthaceae	Herb	JF
46	*Cynodondactylon* (L.) Pers.	Poaceae	Grass	EF, JF, MF
47	*Cynoglossum geometricum* Bak. and Wright	Boraginaceae	Herb	EF, JF, MF

48	*Dicrocephala integrifolia* (L.f.) Kuntze	Asteraceae	Herb	EF, JF, MF
50	*Digitaria abyssinica* (Hochst. ex A. Rich.) Stapf	Poaceae	Grass	JF
51	*Discopodium penninervium* Hochst.	Solanaceae	Shrub	EF, JF, MF
52	*Dovyalis abyssinica (*A. Rich.) Warb.	Flacortiaceae	Shrub	EF, JF, MF
53	*Echinops hispidus* Fresen.	Asteraceae	Herb	EF, MF
54	*Echinops macrochaetus* Fresen.	Asteraceae	Herb	EF
55	*Ehrharta erecta* Lam.	Poaceae	Grass	EF, JF
56	*Ekebergia capensis* Sparrm.	Meliaceae	Tree	EF, JF,MF
57	*Eleusin ecoracana* (L.) Gaertn.	Poaceae	Grass	EF, JF
58	*Erica arborea* L.	Ericaceae	Shrub	EF, JF,MF
59	*Erythrina brucei S*chweinf.	Fabaceae	Tree	EF, JF
60	*Eucalyptus globulus* Labill.	Myrtaceae	Tree	EF, JF, MF
61	*Festuca abyssinica* Hochst. ex A. Rich.	Poaceae	Grass	EF, JF, MF
62	*Festuca simensis* Hochst. ex A. Rich. .	Poaceae	Grass	EF, JF
63	*Galiniera saxifraga* (Hochst.) Bridson	Rubiaceae	Tree	MF
64	*Galium simense* Fresen.	Rubiaceae	Herb	JF
65	*Geranium arabicum* Forssk.	Geraniaceae	Herb	EF, JF, MF
66	*Gerbera piloselloides* (L.) Cass.	Asteraceae	Herb	EF, JF, MF
67	*Gnaphalium rubriflorum* Hilliard.	Asteraceae	Herb	EF, JF, MF
68	*Guizotia scabra* (Vis.) Chiov	Asteraceae	Herb	EF, JF, MF
69	*Hagenia abyssinica* (Bruce) G.F. Gmel.	Rosaceae	Tree	JF
70	*Halleria lucida* L.	Scrophulariaceae	Shrub	JF
71	*Haplocarpha schimperi*(Sch.Bip.) Beauverd	Asteraceae	Herb	JF
72	*Helichrysum foetidum* (L.) Moench.	Asteraceae	Shrub	EF, JF
73	*Helichrysum nudifolium* (L.) Less.	Asteraceae	Shrub	EF, JF
75	*Helichrysum schimperi* (Schultz - Bip.) Moeser	Asteraceae	Shrub	EF, JF
76	*Helichrysum stenopterum* DC. Prodr	Asteraceae	Shrub	JF
77	*Hyparrhenia hirta* (L.) Stapf	Poaceae	Grass	EF, JF, MF
79	*Hypericum peplidifolium* A. Rich.	Clusiaceae	Herb	JF
80	*Hypericum revolutum* Vahl	Clusiaceae	Shrub	EF, JF, MF
81	*Hypoestes forskaolii* (Vahl) R.Br	Commelinaceae	Herb	EF, JF, MF
82	*Hypoestes triflora* (Forssk.) Roem. & Schult.	Commelinaceae	Herb	EF, JF, MF
83	*Hypoxis villosa* (L.) Coville	Hypoxidaceae	Herb	EF
84	*Impatiens tinctoria* A. Rich.	Balsaminaceae	Herb	JF
85	*Jasminum abyssinicum* Hochst. ex A. Rich.	Oleaceae	Climber	EF, JF, MF
86	*Jasminum stans* Pax.	Oleaceae	Shrub	EF, JF, MF
87	*Juniperus procera* Hochst ex.Endl.	Cupressaceae	Tree	EF, JF, MF
88	*Kalanchoe petitiana* A. Rich.	Crassulaceae	Herb	EF, JF, MF
89	*Koeleria capensis* (Steud.) Nees	Poaceae	Grass	EF, JF, MF
90	*Lactuca inermis* Forssk.	Asteraceae	Herb	EF, MF
91	*Laggera crispata* (Vahl) Hepper & J.R.I. Wood	Asteraceae	Herb	EF
92	*Laggera tomentosa* (Sch. Bip. ex A. Rich.) Oliv. & Hiern.	Asteraceae	Shrub	EF, JF, MF
93	*Leonotis ocymifolia* (Burm. f.) Iwarsson	Lamiaceae	Herb	JF
94	*Leucas stachydiformis* (Hochst. ExBenth) Briq	Lamiaceae	Herb	EF, JF, MF
95	*Linum trigynum* L.	Lamiaceae	Herb	JF, MF
96	*Lippia adoensis* Hochst. ex. Walp.	Verbenaceae	Shrub	EF, JF, MF
97	*Lobelia holstii* Engl.	Lobeliaceae	Herb	JF
98	*Maesa lanceolata* Forrsk.	Myrsinaceae	Tree	EF, JF, MF
99	*Malvaparviflora*Höjer	Malvaceae	Herb	JF
100	*Maytenus addat* (Loes.) Sebsebe	Celastraceae	Shrub	EF, JF, MF
101	*Maytenus arbutifolia* (A.Rich.) Wilczek	Celastraceae	Shrub	EF, JF, MF

102	*Myrsine africana* L.	Myrsinaceae	Shrub	EF, JF, MF
103	*Myrsine melanophloeos* (L.) R.Br.	Myrsinaceae	Shrub	EF, JF, MF
104	*Nuxia congesta* R.Br. ex Fresen.	Loganiaceae	Tree	EF, JF, MF
105	*Oenanthe palustris* (Chiov.) Norman	Apiaceae	Herb	EF, JF, MF
106	*Olea europea* L. subsp. C*uspidata* (Wall. ex G.Don) Cif.	Oleaceae	Tree	EF, JF, MF
107	*Olinia rochetiana* A. Juss.	Olineaceae	Tree	EF, JF, MF
108	*Opuntia ficus-indica* (L.) Mill.	Cactaceae	Shrub	EF
109	*Orobanche minor* Smith.	Orbanchaceae	Herb	JF
110	*Osyris quadripartita* Decne	Santalaceae	Shrub	EF, JF, MF
111	*Oxalis radicosa* A. Rich.	Oxalidaceae	Herb	EF, JF, MF
112	*Pennisetum sphacelatum* (Nees) Th.Dur. & Schinz	Poaceae	Grass	EF, JF
113	*Pennisetum thunbergii* Kunth	Poaceae	Grass	JF, MF
114	*Pennisetum villosum* Fresen	Poaceae	Grass	EF, JF, MF
115	*Pentas schimperiana* (A.Rich.) Vatke	Rubiaceae	Shrub	EF, JF, MF
116	*Pittosporum viridiflorum* Sims	Pittosporaceae	Tree	EF, JF, MF
117	*Plantago lanceolata* L.	Plantagnaceae	Herb	EF, JF, MF
118	*Plantago major* L.	Plantagnaceae	Herb	EF, JF, MF
119	*Plectocephalus varians* (A.Rich.) C. Jeffrey ex Cufod.	Lamiaceae	Herb	EF, JF, MF
120	*Poa leptoclada* Hochst .ex A.Rich.	Poaceae	Grass	EF, JF
121	*Prunus africana* (Hook.f.) Kalkm.	Rosaceae	Tree	EF, JF, MF
122	*Rhamnus prinoides* L' Herit	Rhamnaceae	Shrub	EF, MF
123	*Rhamnus staddo* A. Rich.	Rhamnaceae	Shrub	EF, JF, MF
124	*Rhusglutinosa*A.Rich.	Anacardiaceae	Shrub	EF, JF, MF
125	*Rhus vulgaris* Meikle	Anacardiaceae	Shrub	EF, MF
126	*Rosa abyssinica* Lindley	Rosaceae	climber	EF, JF, MF
127	*Rubia cordifolia* L.	Rubiaceae	Climber	EF, JF, MF
128	*Rubus steudneri* Schweinf.	Rosaceae	climber	EF, JF, MF
129	*Rumex nepalensis* Spreng.	Polygonaceae	Herb	EF, JF
130	*Salvia nilotica* Juss. ex Jacq.	Lamiaceae	Herb	EF, JF, MF
131	*Satureja pseudosimensis* Brenan.	Lamiaceae	Herb	EF, JF, MF
132	*Satureja paradoxa* (Vatke) Engl.ex Seybold	Lamiaceae	Herb	EF, MF
133	*Satureja punctata* (Benth.) Briq.	Lamiaceae	Herb	EF, MF
134	*Scabiosa columbaria* L.	Dibsacaceae	Herb	EF, JF, MF
135	*Senecio myriocephalus* Sch. Bip. ex. A. Rich.	Asteraceae	Herb	EF, JF, MF
136	*Senecio schimperi* Sch. Bip ex A.Rich.	Asteraceae	Shrub	JF
137	*Sida schimperiana* Hochst. ex A.Rich.	Malvaceae	Herb	EF, MF
138	*Sideroxylon oxyacanthum* Baill.	Sapotaceae	Shrub	EF, JF, MF
139	*Smilex aspera* L.	Smilacaceae	Climber	EF, JF, MF
140	*Solanecio gigas* (Vatke) C. Jeffrey	Asteraceae	Shrub	JF
141	*Solanum marginatum* L.f.	Solanaceae	Shrub	JF
142	*Solanum nigrum* L.	Solanaceae	Herb	JF
143	*Sonchus bipontnii* Asch.	Asteraceae	Herb	JF
144	*Sporobolus africanus* (Poir.) Robyns & Tournay	Poaceae	Grass	JF, MF
145	*Stellaria media* (L) Vill.	Caryophyllaceae	Herb	JF
146	*Stephania abyssinica* (Dillon &A. Rich.) Walp.	Menispermaceae	Climber	EF, JF, MF
147	*Tagetes minuta* L.	Asteraceae	Herb	JF
148	*Tephrosia* sp.	Fabaceae	Herb	JF
149	*Thalictrum rhynchocarpum* Dill. & A. Rich.	Ranunculaceae	Herb	JF
150	*Thymus schimperi* Ronn.	Lamiaceae	Herb	EF, JF
151	*Trifolium acaule* Steud. ex. A. Rich.	Fabaceae	Herb	EF, JF
152	*Trifolium semiplosum* Fresen.	Fabaceae	Herb	JF

153	*Trifolium simense* Fresen.	Fabaceae	Herb	JF
154	*Urtica simensis* Steudel	Urticaceae	Herb	JF
155	*Verbascum sinaiticum* Benth.	Scrophulariaceae	Herb	JF
156	*Vernonia amygdalina* Del.	Asteraceae	Tree	JF
157	*Vernonia leoploldii* (Sch.Bip. ex Walp.) Vatke	Asteraceae	Shrub	EF, JF, MF
158	*Veronica abyssinica* Fresen.	Scrophulariaceae	Herb	EF, JF
159	*Vicia hirsuta* (L) S.F.Gray	Fabaceae	Herb	JF
160	*Viola abyssinica* Steud. ex Oliv.	Violaceae	Herb	EF
161	*Zehneria scabra* (L.f.) Sond.	Cucurbitaceae	Climber	EF, JF, MF

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