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Diversity and distribution pattern of riparian plant species in the Wami River system, Tanzania

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Abstract

Aims

The Wami River system is among the most important rivers for riparian plant biodiversity conservation but it is potentially threatened by anthropogenic activities. This study was aimed to determine riparian plant species diversity and distribution patterns in relation to the anthropogenic disturbances.

Methods

The transect method was used to collect vegetation data. Transects were established perpendicular to the river at intervals of 50 m downstream and five plots were systematically established, separated by 5-m distance along each transect.

Results

A total of 261 plant species in 68 families were recorded in the Wami River system with a Shannon diversity index in the range of 1.63 to 2.94 and a significantly decreasing trend downstream. Using the Two Way Indicator Species Analysis (TWINSPAN), three plant communities (A, B and C) emerged based on variations in riparian plant species composition among sites. Canonical correspondence analysis (CCA) indicated that the spatial pattern of riparian plant species was significantly influenced by environmental variables. This implies that the plant species composition gradients and spatial assemblages of vegetation communities are a result of human disturbances. Because of the fragile nature of the riparian system, some species are more vulnerable than others and hence there is an urgent need for better land use planning to conserve riparian plant biodiversity in the sub-Basin of Wami River.

***Key words*:** communities, CCA, disturbances, diversity, riparian vegetation, Wami River

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Introduction

Riparian vegetation includes plant communities in streams, on river banks and in floodplains and is an integral part of riverine ecosystems. Riparian vegetation may grow in habitats exposed to lateral water flow, which may be the main force regulating the functions of riparian ecosystems and their biogeochemical cycles (Jahnson and McCormick 1978, Graf 1985, Maingi and Marsh 2006). Riparian vegetation along streams and rivers is diverse in species, structure, and regeneration processes (Maingi and Marsh 2006), represents a unique biological community (Ledec 1987) and has important ecological functions in maintaining landscapes and biodiversity (Hitoshi and Toshikazu 2008). Riparian habitats contain a diverse collection of valuable species and are regarded as biodiversity corridors (Corbacho *et al.* 2003). The riparian habitat harbors a wide range of vegetation communities (Leibowitz 2003) that function as a link between terrestrial and aquatic zones (Malason 1993) and may be considered as an ecotone between these two ecosystems. Riparian vegetation requires a perennial supply of water and sediments to perform ecological functions (Mligo 2007), such as stabilizing stream banks, storing nutrients, providing shade to stream banks and migratory fish, maintaining moisture in riparian soils and improving water quality (Gillilan and Brown 1997, Johnson *et al*. 2000, Castelli *et al*. 2000). Riparian habitats also provide diverse foraging and breeding sites that support the coexistence of many wildlife species (Tucker and Wayne 1990).

Regardless of the function of riparian vegetation and the biodiversity contained in riparian zones, riparian degradation occurs in a range of disturbances at different levels, frequencies and intensities resulting from human activities that reduce species diversity (Hughes 1984, Vallari *et al.*2009) and affect composition as well as the plant community structure. Livestock grazing, cultivation, hydrological modification and landscape fragmentation are several of the

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disturbances affecting riparian vegetation communities (Hughes 1990, Rahel 2002, Lougheed 2008). Cultivation may degrade riparian habitat and floodplains through siltation that modify the fluvial geomorphology of the channel and reducing the complexity and diversity of the plant species. Unregulated livestock grazing in riparian areas also increases erosion and reduces plant vigor and forage production, altering the plant age structure and species diversity (Knopf and Cannon 1982).

Moist-habitat-dependent plant species have been used as indicators of habitat conditions in riparian systems. This is based on the assumption that plant species diversity among vegetation communities is closely associated with the quality of habitat conditions. Because of the significant pervasive impacts of clearance of vegetation for cultivation and livestock grazing intensity on riparian ecosystems, the composition of plant communities along riverine systems changes (Dudgeon 2006, Lorion *et al*. 2009). Irrational anthropogenic activities may affect riparian vegetation, degrade riparian habitats (Wantzen 2006), change water temperatures, and alter the abundance and diversity of basal food resources (Benstead and Pringle 2004). The effects of land-use change on riparian vegetation vary considerably along riverine systems (Roy *et al*. 2003), and their influence differs in these systems compared with terrestrial habitats because they are propagated downstream from the affected area (Death 2009). The differences in riparian species richness and composition in response to disturbance have been reported as a possible explanation for the differences along and between rivers (Medley 1993).

This study on the riparian plants of the Wami River system joins the ongoing studies conducted in riparian forests of East African Rivers. Building a history of riparian vegetation dynamics in this river system in relation to anthropogenic disturbances has been difficult

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because limited information has hampered the determination of the riparian plant ecology. The Wami River system is situated in a matrix of various land-use systems, including protected areas such as the forests of the Eastern Arc Mountains (EAM), Wami-Mbiki Wildlife Management Area, Zaraninge Forest Reserve, and Saadani National Park (SANAPA) (Tobey and Robadue 2008), cultivated areas (farmlands) and settlements. However, many ecological studies in the Wami River basin have been focused on terrestrial, swamp or wetland habitats and the protected forests in the catchments that are part of the wet forests of the Eastern Arc Mountains and coastal forests.

Throughout the river system, downstream of the mountain catchments, the river is characterized by poor watershed management accompanied by a lack of a well established land use plan. The increased negative impacts of livestock overgrazing in the Wami River sub Basin date backs to 1984 when the livestock population amounts to 332,682 cattle (i.e at stocking density of 5cattle per square kilometer) which dropped to 237,857 cattle (at stocking density of 3 cattle per square kilometer) by 1995 (URT 1995). However with the recent climate change impacts associated with shortage of water for livestock, pastoralists particularly the maasai have been migrating from the northern part of Tanzania with unknown sizes of livestock populations and settled in the Wami basin where they are assured of water and fresh forage. The apparent documented land use by 1995 in the Wami River sub-Basin was irrigated farming (URT 1995). The total land area used for irrigated farming in the year 1995 was 4460 ha of which 1220 ha were utilized under traditional schemes and the rest were parastatal estates (URT 1995). Most of the irrigated farming took place in the Wami plains downstream of Kilosa area particularly in Dakawa, Mkata and Mtibwa areas that included the small holders and estate farms. The current total area of irrigated agricultural land use has expanded both to the upstream and downstream of the Wami River sub-Basin. In particular in Mtibwa the area has increased to

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2500 ha of which 1740 ha is for Mtibwa sugar estate only, in Mkata site the area is 4800 ha, in Kilosa 7650 ha (Ngana *et al*. 2010) and in Matipwili 1150 ha (URT 2015) respectively, with an increasing trend. These farms have been established at the expense of clearance of riparian and wetland vegetation in addition to establishment of settlements and harvesting of riverbank trees for various uses. A combination of these anthropogenic disturbances affects the plant species composition and degrades the Wami River riparian ecosystem. To date, less attention has been paid to riparian ecology, particularly the impacts of the aforementioned disturbances on riparian vegetation communities and the plant species distribution pattern downstream in the Wami River system. This paper aims to provide insight into the effects of anthropogenic disturbances on riparian vegetation in the Wami River ecosystem. The objective of the study was to determine plants biodiversity along a riparian corridor as well as the plant species distribution patterns to land use regime.

Material and Methods

Location and ecological characteristics of the study area

The Wami River is located in the eastern region of Tanzania and is found between 5°00' - 7°25'S of longitude and 35° 25' - 39°00'E of longitude (Fig. 1). It is one of the major rivers draining the Eastern Arc Mountains (Lovett 1998). As shown in Figure 1, the areas without a large network of tributaries are located on the plains and in riparian zones that are connected to a large floodplain. The study area was selected as a stretch of the river section at an altitudinal gradient from 100 m above sea level after the point where the Wami delta in the coast merged with the cost plain at Matipwili to 350 m above sea level at Dakawa plains and Kilosa , which are the transition zones between the coastal plains and the foothill of the Eastern Arc Mountains. The preliminary observation showed that an altitudinal range of 200-250 meters

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above sea level did not result in natural variations in habitat conditions and riparian species composition. However, the geomorphologic landscape shows that in the upstream of Mkata, there are steep up slopes similar to those found at the Kilosa site. The Kilosa site was located in the upstream of the river section (Fig.1) with an average width of 70 m and a clayey soil supporting a few native trees including *Acacia polyacantha, Ficus sur* and grass family members. With a gradual decrease in slopes downstream of Mkata causes the landscape to receive a number of tributaries in a floodplain. Mkata is a wide floodplain with black cotton soils that supports *Typha capensis* and *Syzygium guineense, Syzygium cordata* and *Salix subserrata* and the existing homogeneous habitat is maintained by soil water saturation conditions. The banks in the two sites are shallow and the catchments are characterized by annual flooding. The flattened landscape continues downstream to Mtibwa and the Wami River is joined by a number of tributaries from the Nguu Mountains to the north. Although the landscape at Mtibwa is characterized by recurrent annual floods, its riparian margin is still defined by native trees such as *Syzygium guineense, Garcinia livingstonei* and *Ficus sur* but the adjacent floodplain has been heavily cultivated for rice and sugarcane crops, which has left less than a 30 m width of riparian forest (Fig. 2). Black cotton soil is the major soil type, and it provides high water retention for the rice and sugar cane plantations. The Madela site has stable banks because of rocky outcrops in a V-shaped landscape with a 50m wide riparian margin; this site is at the minimum level of disturbance from livestock grazing pressure (Fig. 2). The landscape was characterized by a wider flood plain at Matiwpili with unstable banks and therefore eroded (Fig. 2) and has resulted into changes in the channel geomorphology. It has narrow riparian margin measuring 10 m width covered with grasses and a few scattered *Ficus sur* of small diameter sizes because of extensive clearance for cultivation such that approximately 80-100% of many plots had bare soils with no riparian vegetation cover.

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The Wami River riparian zones and floodplains together cover an area of 40,000 km^2 (URT 2009), and the discharge in the river system ranges from 5 m^3/s at the Kilosa site to 81.8 m^3/s at the Mandela site (Valimba 2007). Approximately 60 to 70 percent of the flow at Mandela originates from the Nguru, Ukaguru and Rubeho catchments, where the rainfall is high. The Mkata River tributary drains through the Mikumi National Park and spreads over an extensive swamp (Mkata wetlands) on a floodplain which is covered with *Cyperus denudatus*, *Miscanthidiurn violaceum, Phragmites mauritianus* and *Typha capensis, Phoenix reclinata, Hyphaene compressa, Ficus spp.* and *Pennisetum purpureum.* The wetland is significant for water quality preservation because it is a purification reservoir of the water supply for inhabitants downstream. The annual rainfall among catchments varies considerably with elevation, with the upstream receiving between 1200 and 2000 mm (Lovett and Pocs 1993) and the downstream through the floodplains (where sampling was carried out) decreasing to between 500 and 600 mm in the coastal zones and estuary. The persistence of an extreme variation of rainfall within the basin results in marked variations in vegetation cover, soil properties and surface runoff. The rainfall pattern is monsoonal and associated with the Inter-tropical Convergence Zone (ITCZ) (Newmark 2002). The downstream reaches of the Wami River (reaches in the coastal zones) experience a bimodal rainfall pattern where the long rain events occur from approximately March-May and short rains events occur in October-November. Although these short rain events occur for only a few days in the coastal zones of Tanzania, the runoff from these short rains may be heavy and rapid because of the clayey soils and nature of the existing vegetation types predominating in many parts of the coastal ecosystem, except in few areas with sand soils. Most of the downstream areas have extended dry conditions that only support dry woodlands, scrub, thickets and fragmented forests types,

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except along the riparian margin wherein green vegetation presents a striking contrast to the dry season grey terrestrial vegetation communities. The downstream river sections have narrow riparian vegetation cover connected to terrestrial thorny woodland communities. Soil properties of the catchments in the Eastern Arc Mountains are influenced by topography and the pattern of rainfall (Milne 1944). Because the mountains receive high rainfall, the soil is leached and generally poor in nutrients, with the exception of the organic layer formed through litter deposition on the forest floors (Iversen 1991). The escarpment's soil is gray and overlaid with dark brown-sandy loam, and is younger and less leached than the plateau soils (Milne 1944). Soils in the riparian zones and riverbanks are deep and fertile with loam, blackish-brown clay, rich in alluvium and often inadequately drained (Milne 1944). The upstream of the Wami River mountain catchments are pristine from an ecological perspective with high diversity of endemic plant species to include *Impatiens ukagurensis, Allanblackia stuhlmannii, Pavetta lynesii, Streptocarpus schliebenii, Cussonia lukwangulensis, Arisaema uluguruense, Impatiens massumbaensis, Impatiens nguruensis, Saintpaulia nitida, Streptocarpum bambuseti, Aloe schliebenii, Encephalartos kanga, Memecylon verruculosum, Saintpaulia brevipilosa, Lobelia morogoroensis, Neobenthamia gracilis, Urogentias ulugurica, Uvariodendron usambarense* and *Psychotria tanganyicensis.* The downstream of the Wami River (at Zaraninge forest) is also rich in endemic plant species (Burgess and Clarke 2000).

Sampling procedure of the riparian vegetation

A reconnaissance survey was first conducted to identify the various plant communities at various levels of disturbance in the Wami River system. Five sampling sites namely Kilosa, Mkata, Mtibwa, Mandela and Mtipwili were selected for the purpose of this study. These sites represented an anthropogenic disturbance gradient that ranges from a fairly natural plant

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community with minor disturbances to heavily disturbed sites (Fig. 1 and Fig. 2). At each site, five 70-m long transects were established perpendicular to the river at intervals of 50 m downstream. Transects were positioned from the banks to the north and south directions because the river flows from west to east of the basin. Five plots were systematically established, separated by 5-m distance along each transect. Fewer sampling points were set in cases where sections of transects were cultivated for crops or occupied as settlements. A 10 m x 10 m plot was used for the sampling of trees and plot of size 5 m x 2 m were used for sampling of shrubs and saplings, which were nested in the 10 m x 10 m plot. The grasses and herbs were sampled in smaller plots measuring 2 m x 0.5 m, which were randomly nested in the 10 m x 10 m plot. All plant life forms assessed in the subplots were combined to form a composite sample in the 10 m x10 m plot. The smaller plots nested in the larger plots were established to simplify the sampling of herbs and grasses. The size of these plots was the standardized maximum for data collection in riparian vegetation communities considering that the riparian vegetation exists as a thin plant community margin along a river system that can intermittently expand through floodplains and associated river wetlands. The position of the first plot above the water level or nearest to the bank was determined using a metric graduated wooded lath; different positions existed because of the variation in geomorphology of the river channel. Aquatic macrophytes were included in this sampling because the riparian and floodplains are the refugial zone for these plants when flow changes. In this study, plant specimens were identified to the species level in the field, for species that were not easily identifiable, voucher specimens were taken to the herbarium of the University of Dar es Salaam where they were identified by matching with preserved herbarium specimens.

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Assessment of levels of anthropogenic disturbance on riparian vegetation

The level of disturbance resulting from cultivation, erosion, harvesting of plant materials and grazing intensity were estimated based on a six point scale (0 – 5). A scale of 0 represented an undisturbed plot whereas a scale of 5 represented a severely disturbed plot (Mligo 2011). Thus, 0 = (no disturbance), 1= (0-20% of the plot disturbed), 2 = (21- 40% of the plot disturbed), 3 = (41 - 60% of the plot disturbed), 4 = (61 - 80% of the plot disturbed), 5 = (81 - 100% of the plot disturbed). This was a semi-qualitative assessment, and the scaling of levels of disturbance was performed based on the percentage cover of riparian vegetation remaining in a disturbed plot of 10 m x 10 m, and each form of disturbance was assessed independently from the others. The point scale values followed a combination of modified approaches established by Anderson and Currier (1973), Liu and Watabane (2013) and Barry *et al*. (2006) to accommodate the various forms of anthropogenic disturbance as supported by the USDA (1993), and the percent disturbance (i.e. 1= 0-20%) was a measure that referenced the bare ground without riparian vegetation cover in each particular sampling plot.

Data analysis

Riparian plant species diversity

Riparian plant species diversity was determined by using the Shannon diversity index (Shannon and Weaver 1948) according to the following formula (*eq.1*);

$$Diversity\ Index\ (H') = -\sum^{\infty} pi \ln pi \quad .....(eq.1)$$

where *pi* = ni/N and is the proportion of the total number of all species in a plot and ln = natural logarithm to base ***e.***

Evenness (E) was calculated using the formula by Alatalo (1981) (*eq.2*):

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$$Evennes(E) = \frac{(H')}{\ln S} \text{ ....} (eq.2)$$

where H' is the Shannon-Weaver diversity index and S is the total number of species at a site. An analysis of variance (ANOVA) was used to test whether there were significant differences in the species diversity and evenness among sites and Tukey's test was used to identify the data sets that were significantly different (GraphpadInstat 2003).

Classification of vegetation communities using TWINSPAN

Two-way indicator species analysis (TWINSPAN) is a technique in the Community Analysis Package (CAP) software program (Henerson and Seaby 1999) that identifies riparian plant communities based on species composition and indicator species (Hill *et al*. 1979). Using TWINSPAN, the riparian vegetation samples were separated into two groups at the center of gravity of the ordination to produce a dichotomy and an indicator species that defined the two emerging groups of samples. Each of the groups required a division of levels to represent homogeneity among the inclusive vegetation samples of the riparian plant community. The indicator species identified associated communities and the major differences in plant species composition among them based on levels of disturbance. This analysis provided an indicator value (ranging from 0-100%) for all the species, and a species was considered an indicator of a given site if its indicator value was > 25%, which follows the method of Dufrene and Legendre (1997). During the analysis, however, the rare plant species (species that had less than a 5% frequency in all the sampling sites) were excluded to minimize noise in the data set.

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Ordination of riparian vegetation data

The influence of anthropogenic activities on riparian plant species distribution was assessed by the software package CANOCO (ter-Braak 2005). A CANOCO analysis involves two data files (data sheets): the first is a primary data file containing riparian plant species as a vegetation data matrix and the second (secondary data file) contains the anthropogenic disturbance scale values for cultivation, grazing, exploitation and erosion which were considered factors determining the assemblages of plant species in each sampling point as the environmental variable data matrix. A canonical correspondence analysis (CCA) technique that uses inter-sample distances and logarithmically transformed data was selected for the analyses. The distribution gradient lengths were first checked with Detrended correspondence analysis (DCA) of the community analysis package (CAP) and then followed by CCA to include the environmental variables. The first CCA axis identified a linear combination of environmental variables that maximized the dispersion of species scores at the best weights for each environmental variable. The second CCA axis was subject to constraints and restrictions so that site scores became restricted to a linear combination of environmental variables. The Monte Carlo Permutation Procedure (of the full model) was performed to identify the most significant variables of the first axis (at the 5% critical level) that influenced the riparian plant species distribution patterns. The species scores were displayed using CanoDraw for species and variables only because the pattern of plant species responded to gradients of environmental variables.

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Results

The riparian diversity and evenness among sampling locations in the Wami River.

A total of 261 plant species were recorded from all sites in the Wami River system which belong to 68 families/ subfamilies (Appendix 1). The most dominant families with high diversity of plant species were Gramineae (39 species), Papilionaceae (32), Asteraceae (16) and Euphorbiaceae (12). The species diversity ranged between 1.63 and 2.94, whereas the species evenness ranged between 0.314 and 0.488 and displayed an apparent decreasing pattern downstream in the river system from Kilosa (upstream) to Mtibwa (downstream) for the first three sites from the upstream (Fig. 3). This downstream trend did not continue at the Mandela and Matipwili sites, where a higher diversity and evenness were recorded than at the Mtibwa site because of intensive disturbances in the latter site resulting from cultivation in the floodplains and areas close to the riverbanks. The differences in riparian plant species diversity and evenness among sampling sites were statistically significant based on the One-Way Analysis of Variance ($F = 16.98$, $P < 0.05$) and also by Tukey's test, wherein Mtibwa recorded significantly lower diversity and evenness than Kilosa (LSD = 0.1743, $q = 6.443$, and $P<0.001$), Mkata (LSD = 0.1396, $q = 5.161$, and $P<0.01$) and Mandela (LSD = 0.1633, $q = 5.904$, and $P<0.01$) in the Wami River system.

Riparian plant community classification using TWINSPAN

Based on the TWINSPAN classification, three riparian plant communities from the primary data were identified (A, B and C; Fig. 4). Plant communities A and B were separated from the community C based on the presence of *Acacia mellifera, Abutilon mauritianum, Acacia brevispica, Achyranthes aspera* and *Solanum incanum,* which are indicator species that differentiated disturbed and undisturbed habitats. Plant community C differs in species

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composition from A and B by 69.19%, occurring at the Kilosa site (favorable upstream location and less disturbed habitat) with a greater number of wetland dependent plant species, including *Cyperus denudatus, Pennisetum purpureum, Phragmites mauritianus, Ficus exasperata* and *Polygonum senegalense* and *Tectaria gummifera.* The transitional communities between riparian and terrestrial communities were represented by *Acacia nigrescens, Acacia mellifera, Acacia tortilis, Terminalia spinosa, Terminalia sambesiaca, Terminalia brevipes* and *Albizia amara*. Plant community A was separated from community B based on the presence of *Disa ochrostachya, Cyperus denudatus* and *Penissetum purpureum,* which are indicator species of moist habitats. Plant community B was identified in disturbed areas resulting from the clearance for cultivation at the Matipwili site and in some parts at the Mandela and Mkata sites because of a combination of activities such as cultivation and livestock grazing that resulted in a species composition difference from the main plant community A (from Matipwili and certain parts of the Mkata site) of 66.94%. The riparian plant species distribution in community B was such that *Pennisetum purpureum* co-existed with *Cyperus denudatus, Tridax procumbens*, and *Polygonum senegalense,* whereas *Ficus sycomorus* appeared as a monodominant tree on the riverbanks and floodplains and in the alluvial soils. Plant community B was also dominated by *Ipomoea aquatica, Phragmites mauritianus* and *Cyperus articulatus* in all permanently wet habitats during the low flow seasons. Therefore, disturbances in these habitats affected the riparian plant species composition and distribution patterns wherein weeds and invasive species such as *Typha capensis*, *Xanthium strumarium*, *Lantana camara* and *Mimosa pigra* dominated in disturbed riparian habitats. The habitats in which these species were found were greatly affected by siltation resulting from cultivation and erosion. Plant community A was identified at Mtibwa site and in certain samples at the Mkata and Mandela sites. The vegetation community at the Mtibwa site was dominated by *Syzygium guineense, Ficus sur, Garcinia livingstonei* and

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Combretum apiculata, whereas the Mkata wetlands were composed of *Ipomoaea aqautica, Oryza longistaminata, Cyperus denudatus, Cyperus exaltatus, Ceratophyllum demersum, Cyperus mundtii, Cyperus articulatus, Leersia hexandra, Ficus sur,* and *Acacia polyacantha.* The Mkata and Mtibwa sites represented the middle section of the Wami River and were characterized by wide floodplains and wetlands where high plant species diversity was expected. However, the Mtibwa site was more affected by clearance for wetland (rice and sugarcane) cultivation, with only a narrow riparian margin left behind on the river banks.

CCA ordination of plant species pattern among sites from the Wami River system

The CCA ordination showed that riparian plant species were constrained by environmental variables with important gradients as shown in fig. 5, whereas table 1 shows the weighted correlation matrix for the influence of environmental variables on the species pattern in the first four CCA axes. The eigenvalues for the first four CCA axes were 0.65, 0.452, 0.175 and 0.155, respectively, with axes 1 and 2 explaining majority of the variations. The cumulative variances in species data were 7.9, 14.5, 20.2 and 24.5. The cumulative variance accounted for species-environmental relations for the first four axes, i.e., 32, 59.2, 82.5 and 100, respectively. The total ordination constraint in the CCA analysis was 5.382, which is the sum of all eigenvalues in the first four axes, although 1.432 was the only constraint and 3.95 remains unconstrained. The CCA ordinations indicated that the environmental variables assessed were apparently sufficient to explain variations in the Wami River riparian communities regardless of the considerable amount of noise that remained unexplained. This indicated that the scores on the CCA ordination axes did not have the undesirable effects of being merely an approximate quadratic function of scores of one axis for the rest of the axes. The Monte Carlo Permutation Procedure on the first canonical axis indicated that the spatial pattern of riparian plant species was

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significantly influenced by environmental variables (eigenvalues = 0.65, F= 1.704, and P=0.0020). Grazing intensity (F = 1.81 and P< 0.05), erosion (F = 1.77 and P< 0.05) and cultivation (F= 1.46 and P < 0.05) each significantly influenced the patterns of plant species distribution in the Wami River basin. *Lantana camara, Indigofera volkensii, Commelina benghalensis,* and *Cyperus rotundus* are riparian species that were favored by cultivation and correlated with species axes 1 and 2 (r = 0.53 and r =0.72, respectively), (Table 1 and Fig.5). The less eroded areas had well-established riparian trees, such as *Ficus sycomorus, Diospyros cornii, Syzygium guineense,* and *Garcinia livingstonei*. However, erosion significantly affected the distribution of bank and water edge colonizers in the downstream areas, including *Ceratophyllum demersum, Mimosa pigra, Azolla filliculoides, Azolla nilotica, Leersia hexandra* and *Ipomoea aquatica*. Grazing negatively affected the grass and seedling populations on the riverbanks and floodplains, whereas the abundance of wood species was less affected in the overgrazed areas. CCA-species axes 1 and 2 indicated the influence of grazing intensity on distribution of plant species spatial pattern in the riparian habitat (r = -0.72 and r = -0.66, respectively) (Table 1). Palatable riparian plant species (*Pennisetum purpureum* and *Leersia hexandra*) were negatively affected by grazing pressure and they were negative correlated at the CCA-axis 2. The strong positive correlation of exploitation of building materials with the CCA-axis 1 portrays it as a plant species exploitation gradient (Fig. 5).

Discussion

The effect of anthropogenic disturbance on species diversity and evenness

Variations in land use types in Wami-River system may have contributed to the variations in riparian plant species diversity. Disturbance arising from various land use practices was shown by Makkay *et al*. (2008) to affect macrophyte diversity in riparian ecosystems. The potential

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anthropogenic disturbances in the Wami River system to include gazing, cultivation, exploitation of riparian plant species and erosion may be interpreted under Huston's model (1979) as the key factors that controlled local patterns of diversity. While grazing, cultivation and exploitation were primary predictors of a change in diversity and evenness, erosion was regarded an outcome of a combination of the effects of the three variables.

The riparian plant species diversity and evenness decreased downstream for the first three upstream sites (Kilosa, Mkata and Mtibwa), but the downstream sites (Mandela and Matipwili) showed exceptionally high values. This is not the normal trend of uniform downstream decrease of diversity as described by Naiman *et al*. (2000), Hill and Keddy (1992) and Houlahan *et al*. (2006). While the natural disturbance patterns in many rivers at global scale are related to landscape position, watershed area and rate of flow discharge (Hill and Keddy 1992), the impacts of anthropogenic disturbance is not uniform among zones in the watershed area and may happen with unpredictable timing and intensity and often manifested in dramatic change in plant species composition over time (US-EPA 2002). Because of moderate disturbance in the upstream parts of Wami River, only the dominance by a few plant species has been suppressed to give room for underrepresented species to perform and contribute to high riparian plant species diversity in the upstream sites. The differences in riparian plant species diversity among study sites in the Wami River system can be explained based on the intermediate disturbance hypothesis (IDH). The hypothesis describes that, biotic diversity is high in communities subjected to intermediate levels of disturbance (Connel 1978). The upstream sites (Mkata, Kilosa including Mandela) that recorded high species diversity can be interpreted based on this hypothesis because they have been affected by anthropogenic disturbance at an intermediate level than other sites. However, the extent of the original species diversity is not known for the

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disturbed site, so it is difficult to assign IDH as a definitive explanation because the high threshold for IDH is not known. The comparison among sites based on the gathered data from areas affected by anthropogenic disturbance at different levels, including the Kilosa, Mkata and Mandela sites, fall in the framework of the IDH hypothesis. Because ecosystems are complex in terms of their interacting variables (Fox 2013), it was held constant for variables other than those associated with anthropogenic disturbances, and the data from this study can be used as empirical evidence for the comparison among sampling sites within the Wami River system.

The plant species have a decreased ability to naturally regenerate under anthropogenically constrained conditions, which results in low species diversity in highly disturbed sites. This may however exclude poor colonist or long-lived plant species. Because of intensive wetland cultivation, Mtibwa was more disturbed, showing that cultivation was the best predictor of change in species diversity and evenness than the other variables because it entails vegetation clearance and siltation, which drastically degrades habitats and consequently decreases the plant species diversity. The plant species diversity in Wami River system 1.63 and 2.94 had a wider range compared to what was recorded in the Great Ruaha River system (2.32 ± 0.192) (Mligo 2009). This implies that suitable habitat conditions and moderate anthropogenic disturbances exist in certain portions of a river system and extreme conditions exist in other portions. The significance of seed dispersal by water has long been recognized (Ridley 1930), and the wide distribution of *Ficus sur, Ceratophyllum demersum, Ipomoea aquatica, Phragmites mauritianus, Pennissetum purpureum* and *Mimosa pigra* along the river system from the upstream near the estuary means that these plants have a water current assisted dispersal mechanism and are capable of regenerating in riparian areas. According to Morton and Hogg (1989) and Barrat-Segretain (1996), riparian plant species often have special adaptations to

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prolong the flotation of their seeds. However, variations exist among species such that certain seeds float for only a few hours and others for several months before germination (Barrat-Segretain 1996). Disturbances resulting from anthropogenic activities taking place alongside the river suppress the regeneration of riparian plant species, and species such as *Syzygium guineense*, whose propagules float for only a few hours, are more affected by disturbances than *Ficus sur, Phragmites mauritianus* and *Cyperus articulatus.*

Variation in species composition among vegetation communities based on TWINSPAN

Based on the TWINSPAN, analyses the three communities (A, B and C) that emerged among the samples were a result of variation in plant species composition caused by anthropogenic disturbances (Fig. 4). Disturbance is considered an important agent that contributes to the structure of plant communities (Death 1996), and riparian plants in this study were observed to vary in composition among communities in certain parts of the study sites because of the impacts of anthropogenic disturbances. This can be verified by the indicator species, such as *Achyranthes aspera, Solanum incanum* and *Abutilon mauritianum* of the disturbed natural communities A and B based on TWINSPAN analysis (Fig. 4). Disturbances are factors that determine the plant community composition in wetland environments (Keddy 2000). Human-induced disturbances observed, particularly at the Mtibwa and Matipwili sites as a result of various land-use types, left behind little cover of riparian plant patches, but dominated by invasive species, such as *Lantana camara, Typha capensis, Dichrostachys cinerea, Flueggea virosa*, *Mimosa pigra, Indigofera volkensii* and *Cyperus exaltatus*. Osborne and Kovacic (1993) noted that riparian vegetation buffers sediments and nutrients from agricultural runoff, stabilizes stream banks and provides shade that minimizes evaporation and moderates stream temperatures. This held true for the less disturbed riparian zones at Kilosa, Mandela and Mkata

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sites, where the banks are stable and favorable moist habitats that support diverse plant species were found. Sweeney (1993) highlights the importance of riparian plant communities in contributing particulate organic matter as a source of food and habitat for macro-invertebrates. Because the organic material serves as a source of energy for wetland ecosystems (Hall *et al*. 2001), the ongoing anthropogenic disturbances deplete the plant species and decrease the potential energy in the river system. Pastoralists have introduced their livestock to riparian areas and associated wetlands in recent decades because of an insufficient amount of seasonal rains and long-term droughts that have created a shortage of foraging habitat elsewhere. The Wami River is a perennial water flow system and provides sufficient moisture for the performance of riparian vegetation on the banks when the rainy season ends. This attracts more grazing during the dry season when the quality of the pasture in terrestrial habitats declines. Therefore, the riparian plant communities become the main source of forage for livestock in the river system in seasons without rain. Because the green zone covers a small area, it becomes overgrazed. This leaves the banks with less riparian plant cover, and they easily erode during surface runoff and flow recession. The trampling of soils in the river bank and nearby hill slopes by livestock causes siltation and sedimentation to descend to the low plains in the channel, leaving behind a degraded habitat unsuitable for the establishment of riparian plants and aquatic macrophytes (*Ceratophyllum demersum, Ipomoea aquatica* and *Equisetum ramosissimum)*.

The influence of disturbances on the distribution pattern of riparian plant species

Grazing pressure, cultivation, exploitation and erosion were the factors assessed in this study that have influenced the distribution of plants species in the Wami River riparian ecosystem. Maingi and Marsh (2006) reported a correlation between the ordination axes and the environmental variables, including the soil organic carbon, in the Tana River. In the Wami

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River system, there was a negative correlation between erosion, grazing and land clearance for cultivation and the CCA axes. However, a positive correlation for exploitation of plant material with the CCA species axis 1 implies that this axis represents a plant exploitation gradient whereby the number of species increases as a result of the exploitation of larger trees. This result also indicates that the dominant plant species that have been removed have allowed underrepresented species to perform in the area, resulting in the present composition of plant species. The negative correlation of grazing with the CCA species axes 1 and 2 (Table 1) implies that many palatable and unpalatable species in the riparian zones are affected by intensive grazing and trampling. The abundance of pioneer species is indicative of the unstable condition of riparian vegetation (Fernandez-Alaez *et al*. 2005). The positive correlation of *Lantana camara, Indigofera volkensii, Typha capensis* and *Commelina benghalensis* with cultivation at the second axis indicates that the increased abundance of these species was associated with cultivation gradients because they are often early colonizers in disturbed habitats. Flow dependent plant species, including those in the wetlands and floodplains (*Ceratophyllum demersum, Azolla filliculoides, Azolla nilotica, Pistia stratiotes, Cyperus articulatus, Typha capensis* and *Mimosa pigra*), were negatively correlated with erosion gradients in the CCA axis 2. This suggests that the eroded soil clods from banks and hill slopes affected the existing natural vegetation communities. Composition gradients and spatial assemblages of vegetation in an ordination space may be characterized by several types of manmade disturbances (Laitinen *et al.* 2008). The intensity of disturbances on riparian vegetation through cultivation was reflected in the formation of large vegetation gaps with low plant species diversity. The Matipwili and Mtibwa riparian zones had the lowest species diversity, which was most likely the result of degradation caused by clearing of riparian vegetation for cultivation. This is because of the increased land use for wetland irrigated

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farming from 200 to 1150 ha at Matipwili and 1765 to 2500 ha at Mtibwa (URT 1995, Ngana *et al*. 2010) and the riparian vegetation is at the lowest rate of recovery through natural regeneration than it was at Kilosa Mkata and Mandela sites that were less degraded.

Conclusion

The assessment of the effect of anthropogenic disturbance on riparian plant diversity in the Wami-River system forms part of few studies conducted in the tropical east African rivers to highlight the importance of conserving the riparian ecosystem. The observed variation in plant species diversity and distribution among sites is primarily because of differences in habitat qualities caused by anthropogenic disturbances in the Wami River system. The correlation of environmental variables with riparian plant species based on CCA ordination implies a major shift that has taken place in the riparian plant biodiversity patterns and ecological function of the Wami River ecosystem. Based on the above observation, a change in land use planning for the conservation of riparian ecosystems and improved water shed management is required to ease the pressure on riparian ecosystems by minimizing anthropogenic disturbance. Agreements must be reached among various sectors and institutions so that the efforts to conserve the Wami River ecosystem are shared and the local community should not be left out since they are the beneficiary of the ecosystem at a local scale. Such efforts will tremendously reduce the ongoing disturbances and degradation of riparian habitat in the Wami-River ecosystem.

Acknowledgements

I would like to thank the University of Dar es Salaam for financial support through the Sida SAREC research fund, which covered most of the fieldwork. Many thanks to the Environmental Flow Assessment coordinators from the Florida International University, who helped me

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become familiarized in the field, locate possible study sites and recognize that botanical information in riparian ecosystems is communicable. I extend my gratitude to Mr. Hadji Suleiman (botanical field assistant) and K. Kibwigiri (driver) for their assistance in the field.

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Figure captions

Figure 1. The Map of Wami River basin in Tanzania showing the location of the five sampling sites (Kilosa, Mkata, Mtibwa, Mandela and Matipwili)

Figure 2. The depleted riparian vegetation cover because of farming, livestock grazing and exploitation of trees and other plant material for various uses *(**At Mkata site** = exploitation of riparian trees and clearance of vegetation for banana and sugarcane growing; **Kilosa site**= Grown bananas and sugarcane at the expense of clearance of riparian vegetation; **Mtibwa** = cleared vegetation for rice and sugarcane plantations; **Mandela site** = showing grazing impacts, **Matipwili sites** = Wetland cultivation and eroded banks)*

Figure 3. Riparian plant species diversity and evenness among sample sites in Wami River, Tanzania

Figure 4. The plant communities in various parts in Wami River System based on TWINSPAN (*K =Kilosa, M = Mkata, Mat = Matipwili, Mn = Mandela* and *Mt = Mtibwa; P1- P5 =*

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Sampling transects); Community A: Cleared for wetland cultivation, B: Disturbed though cultivation and grazing, C: Characterized with less disturbed conditions.

Figure 5. The influence of environmental factors on spatial patterns of riparian species using CCA ordination. The environmental variables are written in full whereas plant species are represented by the first three or four letters of the genus and one to three letters of the species and the short forms are translated as shown.(*Trid pro = Tridax procumbens*, *Ech pyr= Echnocloa pyramidalis, Hyp com = Hyphaene compressa, Polg sen = Polygonum senegalensis, Syzig gu = Syzygium guineense, Phra mau= Phragmites mauritianus, Comb api= Combretum apiculata*, *Hapl fol = Haplocoelum foliosum* , *Diosp ve = Diospyros verucosa, Garc liv = Garcina livingstonei, Heli steud = Heliotropium steudineri*, *Ficu cyc = Ficus cycomorus, Digi = Digitaria macroblephara*, *Cype ron = Cyperus rotundus, Comm sub = Commelina subulata, Abut mau = Abutilon mauritianum, Typha cap = Typha capensis, Acac tang = Acacia tanganyikensis, Acac pol = Acacia polyacanhta, Cyathul = Cyanthula sp, Adandig = Adansonia digitata, Hypo for = Hypoestes forskalii, Sola inc = Solanum incanum, plect kil= Plectranthus kilimandjarica, Acac xan = Acacia xanthophloea, Grew b = Grewia bicolor, Acaly or = Acalypha ornata, Scler bi = Sclerocarya birrea, Cham hil = Chamaecrista hilbrenditii, Acac sey = Acacia seyal, Acaci mel =Acacia mellifera, Sola afr, Solanum africana, Albiz gu =Albizia gumifera, Diospyros co = Diospyros cornii, Hype fil = Hyperrhenia filipendula, Cerat de = Ceratophylum demersum*, *Ipom sp. = Impomoea sp*, *Mimo pyg = Mimosa pygra*, *Azol nil =Azola nilotica*, *Pist stra = Pistia stratiotes*, *Poly sen = Polygonum senegalense*, *Achy asp = Achyranthes aspera*, *Azol fili = Azola filiculoides*, *Leers he =Leersia hexandra*, *comm ben= Commelina benghalensis, Them tri = Themeda triandra, Hete con = Heteropogon contortus, Bide pil = Bidens pilosa, Lanta cam = Lantana camara, Cype gig = Cyperus giganteus, Penn pur = Pennisetum purpureum,Cocc acu = Coccinia acuata, Acac bre = Acacia brevispica, Indig sp= Indigofera sp.*).

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Table 1. CCA weighted correlation matrix of riparian species and environmental variables in the Wami River ecosystem as observed in May 2008**.**

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Appendix 1. The plant species composition and their growth forms recorded from different sampling sites in the Wami River ecosystem (T= Tree, S= Shrub, H = Herb, Cl = Climber, Sg = sedge).

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Table 1

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4	Cultivation	Grazing	Erosion	Harvesting
SPEC AX1	1.00											
SPEC AX2	0.01	1.00										
SPEC AX3	0.00	0.01	1.00									
SPEC AX4	-0.01	-0.03	-0.02	1.00								
ENVI AX1	0.98	0.00	0.00	0.00	1.00							
ENVI AX2	0.00	0.98	0.00	0.00	0.00	1.00						
ENVI AX3	0.00	0.00	0.97	0.00	0.00	0.00	1.00					
ENVI AX4	0.00	0.00	0.00	0.92	0.00	0.00	0.00	1.00				
Cultivation	0.53	0.72	0.31	-0.22	0.54	0.74	0.32	-0.24	1.00			
Grazing	-0.72	-0.66	0.08	0.01	-0.74	-0.67	0.08	0.01	-0.87	1.00		
Erosion	0.53	-0.68	0.45	0.09	0.54	-0.69	0.46	0.09	-0.09	0.11	1.00	
Harvesting	0.82	0.13	0.11	-0.48	0.83	0.13	0.12	-0.52	0.71	-0.70	0.37	1.00

SPEC= Species, ENVI = Environmental, Ax1- Ax4 = Axes 1 to 4

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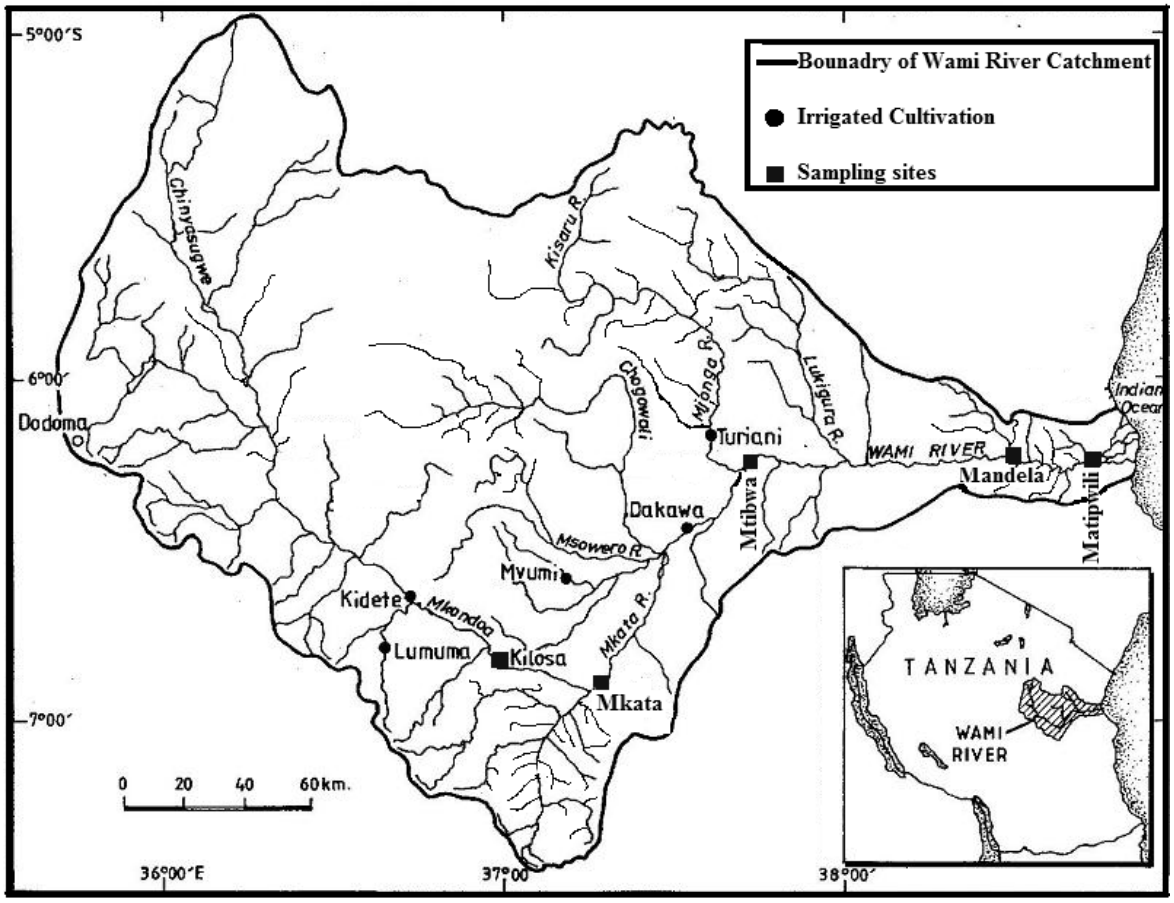


Figure 1.

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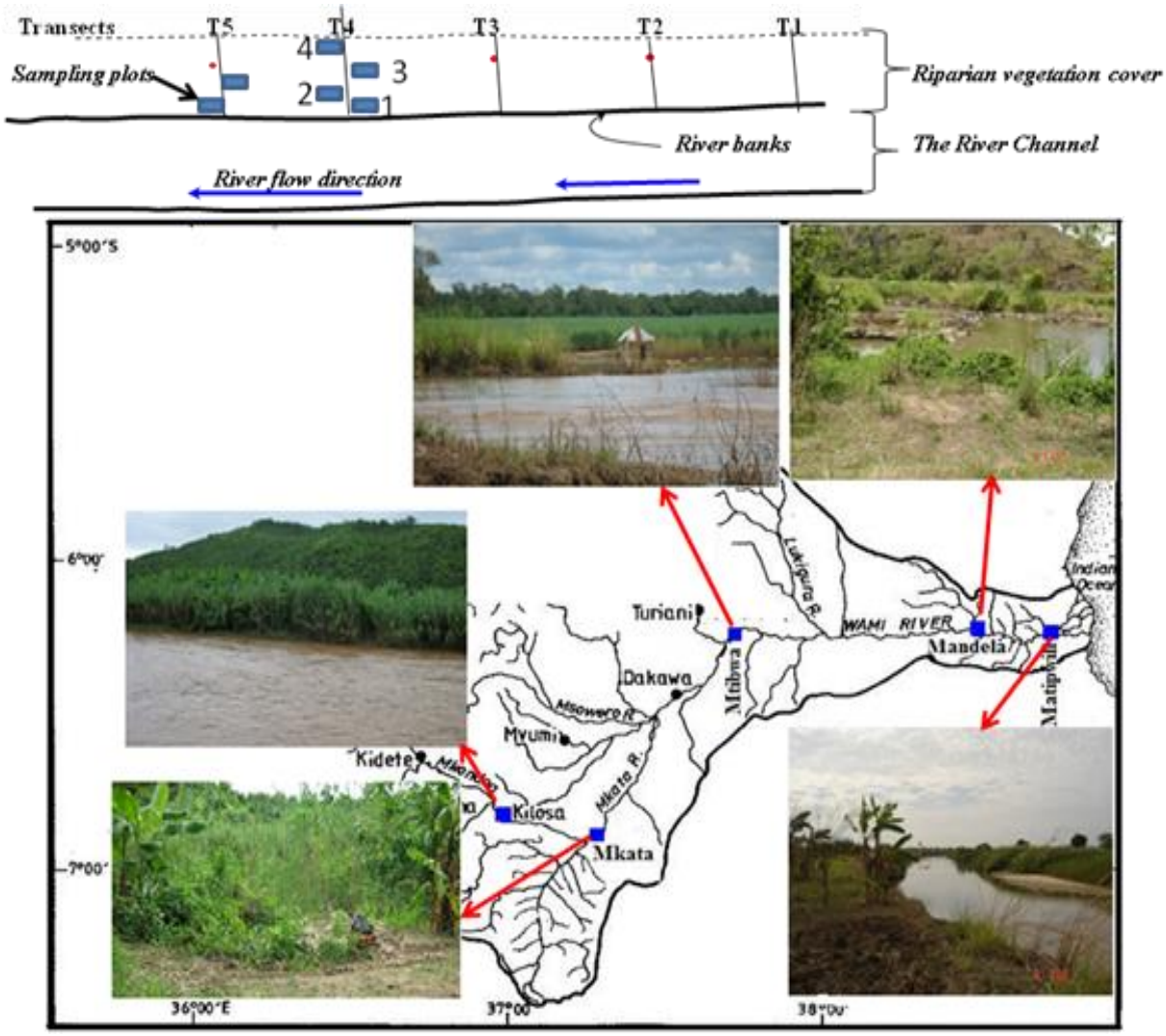


Figure 2.

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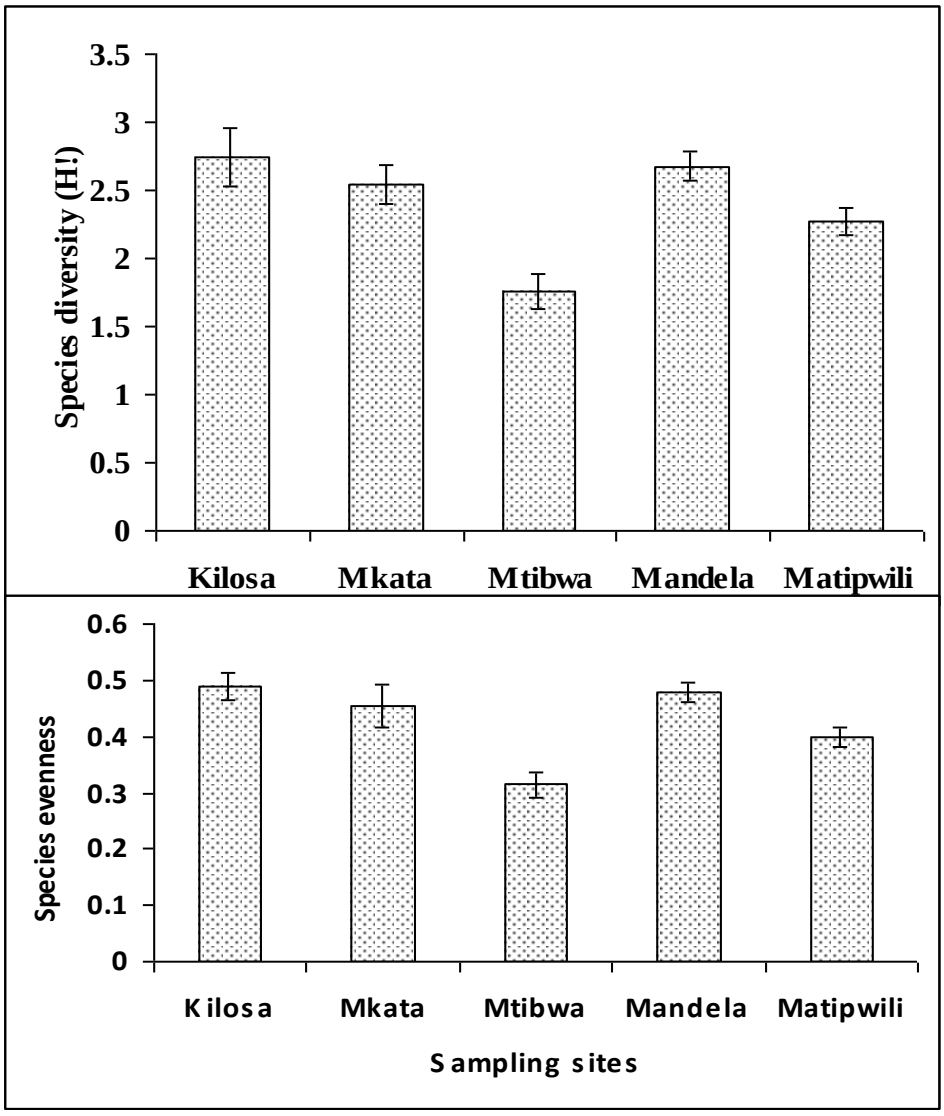


Figure 3.

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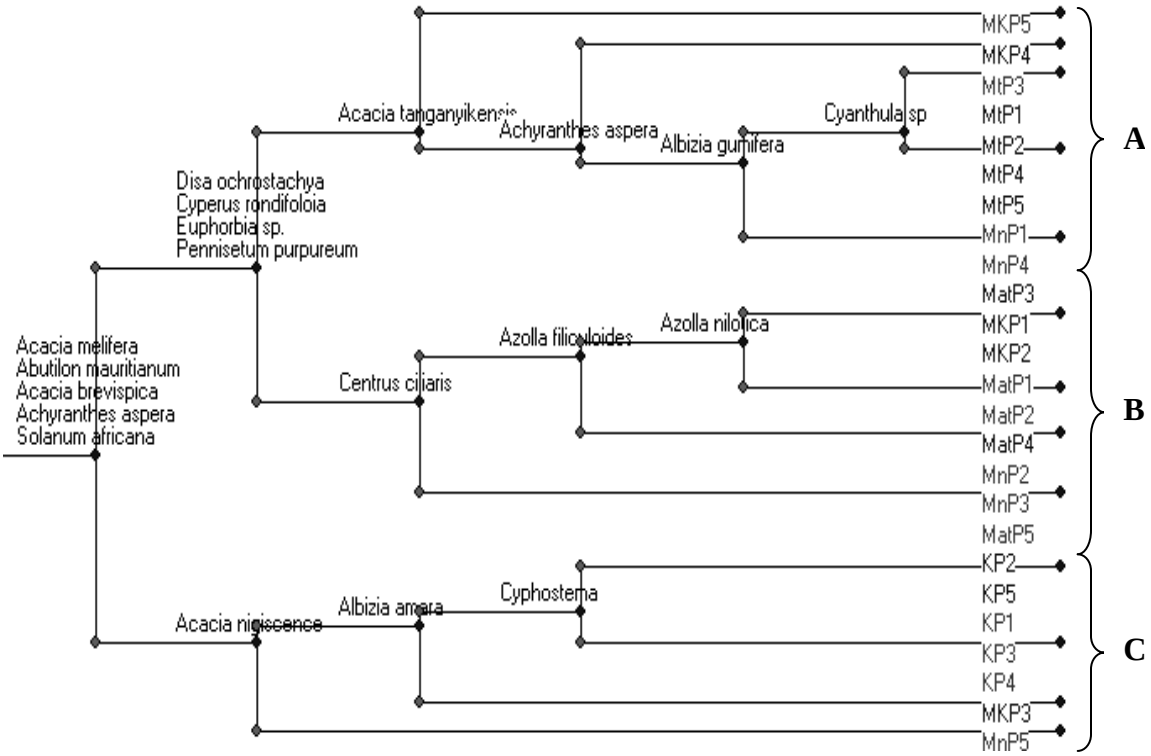


Figure 4.

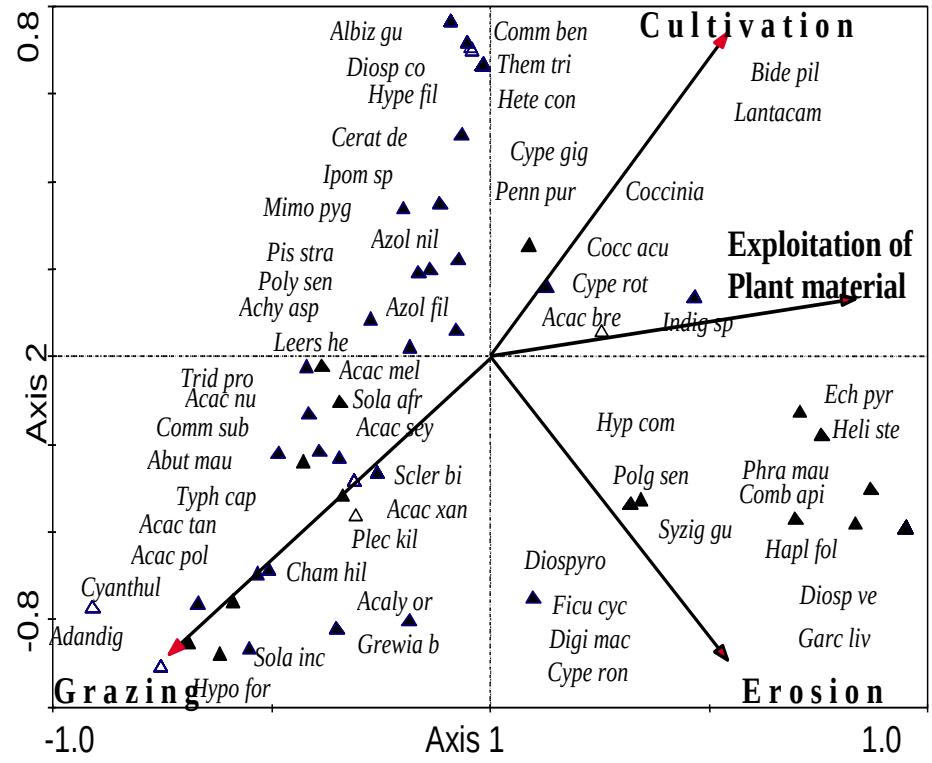


Figure 5.

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Appendix 1. The plant species composition and their growth forms recorded from different sampling sites in the Wami River ecosystem (T= Tree, S= Shrub, H = Herb, Cl = Climber, Sg = sedge)

Composition	Growth Form	Family/Subfamily	Kilosa	Mkata	Mtibwa	Mandela	Matipwili
Abrus precatorius L.	CL	Papilionaceae	+	+	-	+	-
Abutilon mauritianum (Jacq) medic	S	Malvaceae	+	+	-	+	-
Acacia nigrescens Oliv.	T	Mimosoidea	-	-	-	+	-
Acacia nilotica (L.) Willd. ex Delile	T	Mimosoidea	-	+	-	-	-
Acacia polyacantha (A.Rich) Brenan	T	Mimosoidea	+	+	-	-	-
Acacia robusta Burch.	T	Mimosoidea	-	+	-	+	-
Acalypha neptunica Müll.Arg.	S	Euphorbiaceae	-	+	+	+	-
Acalypha ornata A.Rich.	H	Euphorbiaceae	-	+	-	+	-
Achyranthes aspera L.	H	Amaranthaceae	+	+	+	+	-
Achyrothalamus marginatus O.Hoffm	H	Asteraceae	+	+	-	-	-
Adansonia digitata L.	T	Bombacaceae	-	+	-	+	-
Aeschynomene schimperi A.Rich	S	Papilionaceae	-	+	-	-	-
Ageratum conyzoides L.	H	Asteraceae	+	-	+	-	-
Albizia anthelmintica Brongn.	T	Mimosoidea	-	+	-	+	-
Albizia glaberrima (Schum&Thonn)	T	Mimosoidea	+	+	-	+	-
Alysicarpus glumaceus (Vahl) DC.	CL	Papilionaceae	+	-	-	+	-
Amaranthus hybridus L.	H	Amaranthaceae	+	+	-	-	+
Annona senegalensis Pers.	S	Annonaceae	+	-	-	+	-
Antidesma venosum Engl	T	Euphorbiaceae	+	-	-	-	-
Argemone mexicana L.	H	Papaveraceae	-	-	+	+	-
Aristida adoensis Hochst.	G	Gramineae	-	-	+	-	+
Aspilia mossambicensis (Oliv) willd	H	Compositae	+	-	-	-	-
Azolla africana R.Br.	H	Azollaceae	+	+	+	+	+
Azolla nilotica Mett.	H	Azollaceae	-	-	-	-	+
Balanites aegyptiaca L. Delile	T	Balanitaceae	-	+	-	-	-
Baringtonia racemosa (L.) Spreng	T	Baringtoniaceae	+	-	+	-	-
Barleria spinulosa Kloyzsch	H	Acanthaceae	-	+	-	-	-
Basella alba L.	CL	Basellaceae	+	-	-	-	+
Bersama abyssinica Fresen.	T	Melianthaceae	-	-	-	+	-
Bidens pilosa L	H	Compositae	+	-	+	-	-
Bidens schimperi Sch.Bip. ex Walp.	H	Compositae	+	+	-	+	-
Boerhervia diffusa L.	H	Nyctaginaceae	-	+	-	+	-
Bridelia cathartica G. Bertol.	S	Euphorbiaceae	-	+	-	+	-
Bridelia micrantha (Hochst) Bail	T	Euphorbiaceae	-	-	-	+	-
Cajanus cajan (L) Millsp.	S	Papilionaceae	+	-	+	-	+
Carissa spinarum (Forssk.) Vahl	S	Apocynaceae	-	+	-	+	-
Cassia abbreviata Oliv.	T	Caesalpinioideae	+	-	+	+	+
Cassia obtusifolia L.	S	Caesalpinioideae	-	-	-	+	-
Cassia occidentalis L.	S	Caesalpinioideae	+	-	-	+	-
Catunaregam spinosa (Thunb.) Tirveng	S	Rubiaceae	-	-	-	+	-
Ceiba petandra (L.) Gaertn.	T	Bombacaceae	-	-	-	+	-
Ceratophyllum demersum L.	H	Ceratophyllaceae	-	+	+	-	-

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Chamaecrista mimosoides L.	S	Caesalpinioideae	-	-	-	+	-
Chassalia umbraticola Benth	S	Rubiaceae	-	-	-	-	-
Chloris virgata Sw.	G	Gramineae	+	+	-	-	-
Cissampelos pareira L.	CL	Menispermaceae	-	-	+	-	+
Cissus intergrifolia (Baker) Planch	CL	Vitaceae	+	+	-	+	+
Cissus rotundifolia (Forssk.) Vahl	CL	Vitaceae	+	-	-	+	-
Cissus welwistchii (Baker) Planch	CL	Vitaceae	-	+	-	+	-
Clausena anisata (Willd.) Benth	S	Rutaceae	-	-	+	+	-
Coccinia adoensis (A.Rich.) Cogn	CL	Cucurbitaceae	+	+	-	+	+
Coccinia grandiflora Cogn.	CL	Cucurbitaceae	-	-	+	+	-
Coccinia grandis Wight & Arn.	CL	Cucurbitaceae	+	+	-	+	+
Cocos nucifera L.	T	Arecaceae	+	-	-	-	+
Cola microcarpa Brenan	S	Sterculiacaea	-	-	-	+	+
Combretum apiculatum Sond.	S	Combretaceae	-	+	+	+	+
Combretum molle G.Don	T	Combretaceae	-	-	-	+	-
Combretum pentagonum M.A. Lawson	T	Combretaceae	-	+	-	-	-
Combretum zeyheri Sond.	T	Combretaceae	+	-	-	+	-
Combretun constrictum (Benth.) M. A. Lawson	S	Combretaceae	-	+	-	+	+
Commelina benghalensis Wall.	H	Commelinaceae	+	+	+	+	+
Commiphora africana (A.Rich.) Engl.	T	Burseraceae	-	-	-	+	-
Cordia monoica Roxb.	S	Boraginaceae	-	+	-	+	-
Crotalaria incana L.	H	Papilionaceae	-	-	-	+	-
Crotalaria retusa L.	H	Papilionaceae	+	-	-	-	+
Crotalaria spinosa Benth.	H	Papilionaceae	+	-	-	-	-
Crotalaria verrucosa L.	H	Papilionaceae	+	-	-	-	+
Croton macrostachyus Delile	S	Euphorbiaceae	-	+	-	+	-
Cucumis aculeatus Cogn	CL	Cucurbitaceae	-	-	-	+	+
Cucumis metuliferus Naudin	L	Cucurbitaceae	+	+	-	-	-
Cyperus alternifolia L.	SG	Cyperaceae	-	+	+	-	-
Cyperus denudatus L.f.	SG	Cyperaceae	+	-	-	-	-
Cyperus exaltatus Retz	SG	Cyperaceae	+	+	-	-	-
Cyperus grandis C.B.Cl.	SG	Cyperaceae	-	+	-	-	-
Cyperus obtusiflorus Vahl	SG	Cyperaceae	-	-	+	-	-
Cyperus rotundus L.	SG	Cyperaceae	+	+	+	+	+
Cyphostemma adenocaule (A.Rich.) Wild & R.B.Drumm.	L	Vitaceae	-	-	-	+	+
Cyphostemma cyphopetalum (Fresen.) Wild & R.B.Drumm.	L	Vitaceae	+	-	-	-	-
Cyphostemma gigantophyllum (Gilg & Brandt) Wild & R.B.Drumm.	L	Vitaceae	+	+	-	-	-
Cyphostemma kilimandscharicum(Gilg) Wild & R.B.Drumm.	L	Vitaceae	+	-	-	-	-
Dactyloctenium aegyptium (L.) Willd.	G	Gramineae	-	-	-	+	+
Dactyloctenium geminatum Hack.	G	Gramineae	+	+	-	+	-
Dalbergia melanoxylon Guill&Perr.	T	Papilionaceae	-	-	-	+	+
Dalbergia nitidula Baker	T	Papilionaceae	-	-	-	+	-
Dalbergia obovata Beth	S	Papilionaceae	-	+	-	+	-
Deinbolia borbonica Scheffler	T	Sapindaceae	-	-	-	-	+

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Desmodium barbatum Benth	H	Papilionaceae	+	+	-	+	-
Desmodium repandum (L.) Benth.	H	Papilionaceae	+	-	-	-	+
Desmodium velutinum (Willd.) DC.	H	Papilionaceae	+	+	-	-	-
Dichanthium annulatum (Forssk.) Stapf	G	Gramineae	-	+	-	-	-
Dichrostachys cinerea (L.) Wight & Arm	S	Mimosoidea	-	-	+	-	+
Dictyophleba lucida (K.Schum.) Pierre	CL	Apocynaceae	+	-	-	+	-
Digitaria gayana (Kunth) A.Chev.	G	Gramineae	-	+	-	-	+
Digitaria macroblephara (Hack.) Stapf	G	Gramineae	-	-	+	-	+
Digitaria milanjiana (Rendle) Stapf	G	Gramineae	+	-	-	-	+
Diospyros fischeri Gürke	S	Ebenaceae	-	+	+	-	-
Diospyros verrucosa Hiern	T	Ebenaceae	+	-	+	-	-
Disa ochrostachya Rchb.f.	H	Orchidaceae	-	-	-	+	-
Dombeya shupangae K.Schum.	T	Sterculiacaea	-	-	-	+	-
Dorstenia hildebrandtii Engl.	S	Moraceae	+	-	-	+	-
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	G	Gramineae	+	-	+	+	+
Echinocloa haploclada (Stapf) Stapf	G	Gramineae	-	+	-	-	+
Echnocloa scabra Lam.) Roem. & Schult.	G	Gramineae	+	+	-	-	-
Ehretia amoena Kloyzsch	S	Boraginaceae	-	-	-	+	-
Eleusine africana Kenn.-O'Byrne	G	Gramineae	+	+	-	-	+
Eleusine indica (L.) Gaertn.	G	Gramineae	+	-	-	-	-
Enicostema axillare (Lam.) A.Raynal	H	Gentianaceae	+	-	-	-	-
Entada abyssinica Steud.	T	Mimosoidea	-	+	-	+	+
Equisetum ramossismum Desf	T	Equisetaceae	+	-	-	-	-
Eragrostis aspera (Jacq.) Nees	G	Gramineae	+	-	+	-	-
Eragrostis superba Peyr.	G	Gramineae	+	+	-	+	-
Ethulia conyzoides L.f.	H	Asteraceae	+	-	-	-	-
Euclea divinorum Hiern	S	Ebenaceae	-	+	+	-	+
Euphorbia hirta L.	H	Euphorbiaceae	+	-	-	+	+
Ficus exaperata Vahl.	S	Moraceae	-	+	+	+	-
Ficus sur Forssk.	T	Moraceae	+	+	-	+	+
Ficus sycomorus L.	T	Moraceae	+	-	+	+	-
Fimbristylis cymosa R.Br.	SG	Cyperaceae	-	-	+	+	-
Flacourtia indica Arg.	S	Flacourtiaceae	+	+	-	+	-
Flueggea virosa (wild) voigt	S	Euphorbiaceae	-	-	+	+	+
Garcinia livingstonei T.Anderson	T	Guttiferae	-	-	+	+	-
Gomphorcarpus fruticosus (L.) W.T.Aiton	S	Asclepidiaceae	-	-	+	-	-
Grewia conocarpa K.Schum.	S	Tiliaceae	-	+	-	+	-
Grewia forbesii Mast.	S	Tiliaceae	-	+	+	-	-
Grewia microcarpa K.Schum.	S	Tiliaceae	-	+	-	+	-
Grewia platyclada K.Schum.	S	Tiliaceae	-	+	-	-	-
Gynandropsis gynandra (L.) Briq.	H	Capparaceae	-	-	-	+	-
Haplocoelium foliosum (Hiern) Bullock	T	Sapindaceae	-	-	+	-	-
Harisonia abyssinica Oliv.	S	Simaroubaceae	-	-	-	-	+
Helichrysum forskahlii (J.F.Gmel) Hillent	H	Asteraceae	+	-	-	-	-
Heliotropium steudineri Vatke	H	Boraginaceae	+	-	+	-	-
Heteropogon contortus (L.) Roen &Schult	G	Gramineae	-	-	-	+	+

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Hibiscus aponeurus Sprangue & Hutch.	S	Malvaceae	-	+	-	+	+
Hibiscus cannabinus L.	S	Malvaceae	-	+	-	+	-
Hibiscus palmatus Forsk.	S	Malvaceae	+	+	-	-	+
Hyparrhenia variabilis Stapf	G	Gramineae	+	+	-	-	-
Hyptis suaveolens Poit.	H	Labiatae	-	-	-	+	-
Indigofera arrecta Hochst. ex A.Rich.	H	Papilionaceae	-	-	-	+	-
Indigofera cuneata Baker f.	H	Papilionaceae	+	-	-	+	+
Indigofera hirsuta L.	H	Papilionaceae	+	+	-	+	+
Indigofera rhynchocarpa Baker	H	Papilionaceae	-	-	-	+	-
Indigofera spinosa Forsk	H	Papilionaceae	-	-	-	+	+
Indigofera volkensii Taub.	H	Papilionaceae	+	+	+	-	-
Ipomoea aquatica Forssk.	L	Convolvulaceae	+	-	-	+	-
Ipomoea involucrata P.Beauv.	S	Convolvulaceae	+	+	-	-	-
Ipomoea purpurea (L.) Roth	L	Convolvulaceae	-	+	-	-	-
Ipomoea rubens Choisy	L	Convolvulaceae	-	+	-	+	-
Ipomoea sinensis (Desr.) Choisy	L	Convolvulaceae	+	-	-	+	-
Kanahia lanifflora (Forsk)R.Br.	S	Asclepidiaceae	-	-	+	+	-
Kyllinga alata Kunth	G	Cyperaceae	+	-	-	+	-
Lantana camara L.	S	Verbenaceae	-	-	+	+	+
Launaea cornuta (Hochst. ex Oliv. & Hiern) C.Jeffrey	H	Asteraceae	-	+	+	-	+
Leersia hexandra Sw.	G	Gramineae	+	+	+	-	-
Leonotis nepetifolia (L.) R.Br.	S	Lamiaceae	+	+	-	-	-
Leucas deflexa Hook.f.	S	Labiatae	-	+	-	-	-
Ludwigia abyssinica A.Rich	H	Onagraceae	-	+	+	-	+
Ludwigia stolonifera (Guil & Per Raven.)	H	Onagraceae	+	+	-	-	-
Macrotyloma axillare (E.ma) Verdc	CL	Papilionaceae	-	+	-	-	-
Maerua triphylla A.Rich.	S	Capparaceae	-	+	-	-	-
Mangifera indica L.	T	Anacardiaceae	+	+	-	-	+
Manihot glaziovii Mull. Arg.	S	Euphorbiaceae	+	-	-	-	+
Manilkara mochisia (Baker) Dubard	T	Sapotaceae	-	-	-	-	+
Melhania velutina Forssk.	H	Sterculiaceae	-	+	+	+	+
Melinis repens Willd	G	Gramineae	+	+	-	-	-
Milicia excelsa Welw.c. Berg	T	Moraceae	+	+	-	+	-
Mimosa pigra L.	S	Mimosoidea	+	-	+	+	+
Momordica foetida Schumach	CL	Cucurbitaceae	+	-	-	-	+
Musa sapientum Linn.	H	Musaceae	+	-	+	-	+
Mytenus undata (Thunb.) Blakelock	S	Celastraceae	-	+	+	+	-
Ocimum suave Wolld	H	Labiatae	+	-	+	-	-
Orthosiphon hildebrandtii Baker	H	Labiatae	-	-	-	+	-
Orthosiphon schimperi Benth.	H	Labiatae	+	+	+	-	-
Oryza longistaminata A.Chev. & Roehr.	G	Gramineae	+	+	+	-	+
Oryza sativa L.	G	Gramineae	-	+	+	-	+
Panicum coloratum L.	G	Gramineae	-	+	+	+	-
Panicum heterostachyum Hack.	G	Gramineae	+	-	+	+	+
Panicum maximum Jacq.	G	Gramineae	+	-	+	+	+
Panicum phragmitoides Stapf	G	Gramineae	-	+	-	+	-

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Panicum trichocladum K. Schum.	G	Gramineae	+	-	+	-	+
Passiflora foetida L.	CL	Passifloraceae	+	-	-	-	-
Paullinia pinnata L.	CL	Sapindaceae	-	+	-	+	-
Pavetta gardeniifolia A.Rich.	S	Rubiaceae	-	-	-	+	+
Pennisetum purpureum Schumach.	G	Gramineae	+	-	+	-	+
Pennisetum trachyphyllum Pilg.	G	Gramineae	-	-	+	-	-
Phoenix reclinata L.	T	Palmae	-	-	-	+	+
Phragmites mauritianus Kunth	G	Gramineae	+	-	+	+	+
Phyllanthus amarus Schumach	H	Euphorbiaceae	+	-	-	-	+
Physalis peruviana L.	H	Solanaceae	+	-	+	-	-
Pilliostigma thonningii Bueth	T	Caesalpiniaceae	+	-	-	+	-
Plectranthus barbatus DC	H	Labiatae	+	+	-	-	-
Plectranthus forskalii (Willd.) Briq.	H	Labiatae	-	-	+	+	-
Plectranthus kilimandscharica (Gürke) Agnew	H	Labiatae	-	-	+	-	-
Pluchea dioscorides (L.) DC.	S	Asteraceae	+	+	+	-	-
Polgygonum senegalense Meisn	H	Polygonaceae	+	+	+	-	-
Polygonum glomeratum Dammer	H	Polygonaceae	+	+	-	-	-
Portulaca oleraceae L.	H	Portulacaceae	-	+	+	+	-
Psidium guajava L.	S	Myrtaceae	+	-	+	-	+
Psychotria kirkii Hiern	S	Rubiaceae	+	-	-	+	-
Pteleopsis myrtifolia(M.A. Lawson) Engl. & Diels	T	Combretaceae	-	-	-	+	+
Rauvolfia mombasiana Stapf	S	Apocynaceae	+	-	-	+	-
Rhus natalensis Krauss	S	Anacardiaceae	+	+	-	+	-
Rhynchosia hirta (Andr) Meikle & Verdc.	CL	Papilionaceae	+	+	-	-	+
Rhynchosia micrantha Harms	CL	Papilionaceae	-	+	-	-	-
Rhynchosia minima (L.) DC.	CL	Papilionaceae	+	-	-	+	-
Rhynchosia orthobotrya Harms	CL	Papilionaceae	+	+	-	+	-
Ricinus communis L.	S	Euphorbiaceae	+	+	-	-	-
Rinorea elliptica (Oliv.) Kuntze	S	Violaceae	-	-	-	+	-
Ruellia patula Jacq.	H	Acanthaceae	-	-	-	+	-
Saccharum officinarum L.	S	Gramineae	+	+	+	-	-
Salacia madagascariensis (Lam.) DC.	S	Celastraceae	+	-	-	+	-
Salvadora persica L.	T	Salvadoraceae	-	-	-	-	-
Sapium ellipticum (Kruss)Pex	T	Euphorbiaceae	+	-	+	-	-
Schyzozygia coffaeoides Bail.	S	Apocynaceae	+	-	-	-	-
Sclerocarya birrea (A.Rich.) Hochst.	T	Anacardiaceae	-	-	-	+	-
Senecio abyssinicus Sch.Bip	H	Asteraceae	-	-	+	-	-
Sesbania bispinosa (Jacq) WF.Wight	T	Papilionaceae	-	+	-	-	-
Sesbania greenwayi Gillett	T	Papilionaceae	-	+	-	-	-
Sesbania sesban (L) Merril	S	Papilionaceae	+	-	-	-	+
Setaria incrassata (Hochst.) Hack.	G	Gramineae	-	+	-	-	-
Sida acuta Burm. F.	H	Malvaceae	+	-	-	+	-
Solanum arundo Mattei	S	Solanaceae	-	-	-	+	-
Solanum atropurpureum Schrank	S	Solanaceae	-	+	-	-	-
Solanum incanum L.	S	Solanaceae	+	+	-	-	-

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Solanum nigrum L	H	Solanaceae	+	-	-	+	-
Sorghastrum stopoides (Kunth) Nash	G	Gramineae	-	-	-	-	+
Sorghustrum bipennatum (Hack.) Pilg.	G	Gramineae	+	+	-	-	-
Sorindeia madagascariensis DC.	T	Anacardiaceae	-	-	-	+	-
Spermococe senensis (Klotzsch) Hier	H	Rubiaceae	-	-	-	+	-
Sphaeranthus gomphrenoides O.Hoffm.	H	Asteraceae	-	-	+	-	-
Sphaeranthus indicus L.	H	Asteraceae	+	+	-	-	-
Sphaeranthus suaveolens (Forssk) DC.	H	Asteraceae	-	+	-	+	-
Spirostachys africana Sond.	T	Euphorbiaceae	-	-	-	-	+
Sporobolus fimbriatus (Trin.) Nees	G	Gramineae	+	-	-	-	-
Sporobolus pyramidalis P.Beauv	G	Gramineae	+	-	-	-	-
Sporoborus stapfianus Benth	G	Gramineae	+	-	-	-	-
Strychnos cocculoides Baker	S	Loganiaceae	-	-	-	+	-
Synsepalum brevipes (baker) Pennington	T	Sapotaceae	-	+	-	+	+
Syzygium guineense Boutque	T	Myrtaceae	-	-	+	-	-
Talinum caffrum Eckl. & Zeyh.	H	Portulacaceae	+	+	-	-	-
Tarenna pavettoides Schrank	S	Rubiaceae	-	+	-	-	+
Tectaria gemmifera (Fée) Alston	H	Dryopteridaceae	+	-	-	-	-
Tectona grandis L. f.	T	Lamiaceae	+	-	-	-	-
Tephrosia maxima (L.) Pers.	S	Papilionaceae	+	+	-	-	-
Tephrosia pumila (Lam.) Pers.	H	Papilionaceae	+	-	-	-	+
Tephrosia villosa (L.)Pers.	H	Papilionaceae	-	-	-	+	-
Terminalia spinosa Engl.	T	Combretaceae	-	-	-	+	-
Thunbergia alata Bojer ex Sims	H	Acanthaceae	-	-	-	+	-
Toddalia asiatica)L.)Lam.	S	Rutaceae	-	-	-	-	-
Tribulus terrestris L.	H	Zygophyllaceae	+	+	-	-	+
Tridax procumbens L.	H	Asteraceae	+	+	-	+	+
Turraea nilotica Kotschy & Peyr.	S	Meliaceae	+	+	-	-	-
Typha capensis L	H	Typhaceae	+	-	-	-	-
Urochloa panicoides P.Beauv.	G	Gramineae	-	-	+	+	-
Urtica massaica Milld. Br.	H	Urticaceae	+	-	-	-	-
Vangueria infausta Burch.	S	Rubiaceae	+	+	-	+	-
Vernonia perrotetii Sch. Bip. ex Walp.	H	Asteraceae	-	+	-	-	-
Vigna schimperii Baker	H	Papilionaceae	+	+	-	-	-
Waltheria indica L	H	Sterculiaceae	-	+		-	+
Xanthium strumarium L.	H	Solanaceae	+	+	+	-	+
Zea mayze L.	G	Gramineae	-	-	-	-	+
Ziziphus pubescens Oliv.	S	Rhamnaceae	-	-	-	-	+
Plant species richness			130	118	70	126	79
Shannons' diversity index			2.7 ± 0.2	2.5 ± 0.1	1.7 ± 0.1	2.6 ± 0.14	2.26 ± 0.1
Species evenness			0.49 ±0.02	0.45 ±0.04	0.31 ±0.02	0.48 ±0.02	0.4 ± 0.02

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