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The composition and distribution of riparian vegetation on the courses of Mulunguzi River in Zomba Mountain, Zomba, Malawi.

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ABSTRACT

Zomba Mountain in Malawi is an aquifer that harbours significant riparian vegetation that plays different roles in stabilizing the surrounding ecosystem. The Mulunguzi River has enormous remnant riparian vegetation which influences the purification of water that is abstracted for household usage in Zomba City. This study explored riparian vegetation along the Mulunguzi River to discover the variation in its composition and distribution on river's courses.

The riparian vegetation was sampled in their environment using the nested quadrat method in 18 sampled plots (6 on each course). Nested quadrats with demarcations 20m x 20m, 5m x 5m and 1m x 1m for trees, shrubs, and herbaceous plants, respectively.

Three riparian communities were discovered that comprised 151 species, belonging to 24 families and were dominated by the Fabaceae family. The riparian vegetation was dominated by Herbaceous plant species (44.4%) followed by trees (32.5%). Analysis by the Shannon-Weiner diversity index showed high diversity of riparian vegetation on all river courses that decreased on moving downstream.

The results suggest that there was a variation in composition, distribution and diversity of riparian vegetation on the river's courses. The study may enhance the understanding of riparian communities that require proper conservational management to have a stable and functional ecosystem.

Keywords: Herbaceous plants, Longitudinal gradient, Nested quadrats, Plant communities, Species diversity, Species richness.

INTRODUCTION

It is fascinating to know that riparian vegetation is one of the most diverse communities, yet few studies to explore their species composition and distribution have been carried out globally unlike studies of animals that inhabit riparian plant communities.

Studies worldwide have revealed that riparian vegetation varies greatly in terms of species composition, distribution and abundance along their habitat (streambanks or riverbanks) due to constant changes that occur in their surrounding environment (Nilsson, 1986). The presence of riparian vegetation in this fragile riparian zone makes them very sensitive and respond differently to biotic and abiotic changes they encounter for their survival. This then leads to diverse flora that is different in structure and function from their adjacent ecosystems (Naiman and Decamps,1997).

It is widely known that riparian vegetation plays vital ecological roles in their ecosystems when they provide essential functions such as filtering nutrients and sediments, stabilizing riverbanks, and providing habitat to different organisms. Riparian vegetation also provides essential services such as recharging groundwater and mitigating floods. These ecological roles are dependent on riparian vegetation width, composition and structure. (Naiman and Décamps,1997;Tabacchi et al., 1998 and Rood et al., 2020).

It is challenging to predict the composition and distributional patterns of species richness and diversity for riparian vegetation communities along longitudinal gradients (upstream-downstream movement) because there is enormous variation. Various patterns have been discovered by many researchers worldwide due to different conditions impacting riparian vegetation in their zones. Some studies have discovered a monotonic decrease pattern when moving downstream (Renöfält, 2005 and Pielech, 2021), while others showed an increasing pattern downstream (Statzner and Higher, 1985 and Giberti et al., 2021). However, most studies discovered the unimodal pattern with a maximum number of species at the midstream to be more dominant than other patterns (Vannote et al., 1980; Nilsson et al., 1989; Tabbachi et al., 1996 and Surmacz et al.,2024).

Studies worldwide have also discovered a high level of biodiversity in riparian ecosystems due to constant changes that occur in their environment (Nilsson, 1986,1992; Nilsson et al., 1989; Tabacchi et al., 1990; Gregory et al., 1991; Naiman et al., 1993 and Surmacz et al., 2024).

They also contain more threatened endemic species than their adjacent environments (Naiman and Décamps, 1997).

Malawi is a relatively smaller country (118,424 km^2) in the eastern section of South Tropical Africa with a wealthy flora biodiversity of about 5000–6000 plant species that have been discovered (Msekandiana and Mlangeni, 2002). This high biodiversity is attributed to rich mosaic habitats that are influenced by varying topography, altitude and rainfall (Msekandiana and Mlangeni, 2002; GoM, 2010 and Klopper et al.,2012).

The modified classification of vegetation in Malawi was done in 2001, and it discovered eight major vegetation types namely: Zambezian woodland, transition woodland, deciduous forest and thickets, evergreen forest, undifferentiated Afromontane forest, Afromontane bamboo, Afromontane evergreen bushland and thicket, and Afromontane shrubland (Dowsett-Lemaire, 2001; Msekandiana and Mlangeni, 2002 and GoM, 2010). The riparian vegetation belongs to evergreen forest vegetation.

Zomba Mountain is the second largest mountain in Malawi rising over 1,800m above sea level (asl) with the highest peak at 2,085m asl and it offers a significant contribution to the total flora biodiversity of Malawi (Zomba District Council, 2010). Zomba Mountain is the source of eight rivers that lie in the catchment area of Lake Chirwa (Figure 1B). Mulunguzi River is one of these rivers that has been selected to be used for this study because its riparian zone is less disturbed from an elevation range of 950–1800m asl and has diverse natural riparian vegetation on its courses.

Several studies have been conducted in Zomba Mountain but most of them are biased towards studying animals (zoological) (Happold and Happold, 1986; 1989a; 1989b and Happold et al., 1987). This has been observed by Lawton (1999) to be a common phenomenon globally that studies have sidelined essential plant communities that support these animals by provision of food and shelter.

Generally, fewer studies on plant communities of Zomba Mountain have been conducted (Jackson, 1969a;1969b; Chapman and White, 1970 and Dowsett-Lemaire, 2001). At present limited studies have been conducted on this essential natural riparian vegetation on the courses of Mulunguzi River. Such being the case, there is a broader gap in knowledge of plant communities that inhabit this riparian zone which can be beneficial for the conservation of ecosystems.

To close this gap in studying plant communities, this study aimed at discovering the composition of riparian species, patterns of species richness distribution and diversity on the courses of the Mulunguzi River.

Although the Riparian vegetation along the Mulunguzi River is among the least studied vegetation, it plays significant roles as any other riparian vegetation, such as stabilizing riverbanks, purifying water and recharging groundwater (Naiman et al., 1993; Tabacchi et al 1998 and Rood et al., 2020). The Mulunguzi River is a significant source of quality potable water for Zomba City residents that is purified by riparian vegetation along its banks. Therefore, this riparian vegetation needs to be safeguarded so that portable water continues to be abstracted from the Mulunguzi Dam in the river's middle course.

There has been a series of water shortage problems annually during the dry season due to reduced water levels in the river channel likely caused by disturbances from anthropogenic activities. These activities include farming on the upper course that promotes soil erosion and siltation of riverbeds, and reforestation projects that promote the replacement of natural vegetation with fast-growing exotic ones that pump more water from the soil such as *Pinus sp.* and *Eucalyptus sp.*

The study helped to discover natural species that must be conserved and protected on each course so that they can continue maintaining an aquifer and stabilize water flow in watersheds, thereby conserving the water source that is used for different activities by the Zomba City residents (Chimphwamba et al., 2009). This water shortage problem can be minimized by ensuring that there is healthy riparian vegetation, that enables the continuous flow of quality water throughout the year.

It will also add necessary information to the database of plant species composition and communities that play various significant roles in the river's courses and can be used for further studies.

This study had been set out to answer if there was any variation in plant communities' composition and distribution of species on the courses of the Mulunguzi River. It hypothesized that there is no variation in species composition and diversity for riparian vegetation on different courses of the Mulunguzi River.

MATERIALS AND METHODS

Study site

The study was conducted on the riparian zone along Mulunguzi River courses between 15°19'–15° 22' S and 35° 17'–35°20' E. The Mulunguzi River is about 24 km long, with a catchment area covering about 20 km^2 of the Zomba Mountain occurring only in the Zomba Forest Reserve (Dias, 2008). Mulunguzi River and its catchment is a part of the catchment area of Lake Chilwa (Figure 1B). It stretches from the top of Zomba Plateau to Cham'mande Village, where it joins with the Likangala River near Likangala Bridge, then flows to empty its water into Lake Chilwa.

The upper course contains Mulunguzi Marsh, which happens to be the Mulunguzi River's origin at the plateau's top. The Mulunguzi River is formed after the joining of crisscross streams that flow from the marsh (Bloomfield and Young, 1961). It then passes through a series of waterfalls on the same course and flows down to Mulunguzi Dam in the middle course. Mulunguzi Dam is the primary source of potable water for Zomba City (Figure 1C). After the dam, water flows through the gorge to the lower course and continues flowing downhill through Zomba City until connecting with the Likangala River.

The study site for this research was about 15 km long with elevation ranging from 950–1800m asl, which occurred from the foot of the mountain to its top (Figure 1C). Many study plots occurred in Zomba Natural Reserve, while the remaining occurred in Zomba Botanical Garden. These plots were selected due to less human disturbance in their surroundings and the presence of more natural relic vegetation on them. The lower, middle and upper courses had different elevation ranges from 950–1200m asl, 1250–1500m asl and 1550–1800m asl, respectively.

The remaining 9 km of the Mulunguzi River was not included due to the disturbed state of its riparian zone by human activities. Part of it passes through Zomba City, where buildings were constructed near the banks, while the other part is used for farming due to fertile soil along the banks. Sand mining is another activity experienced by this part and is increasing due to the construction of new buildings, still underway in the city.

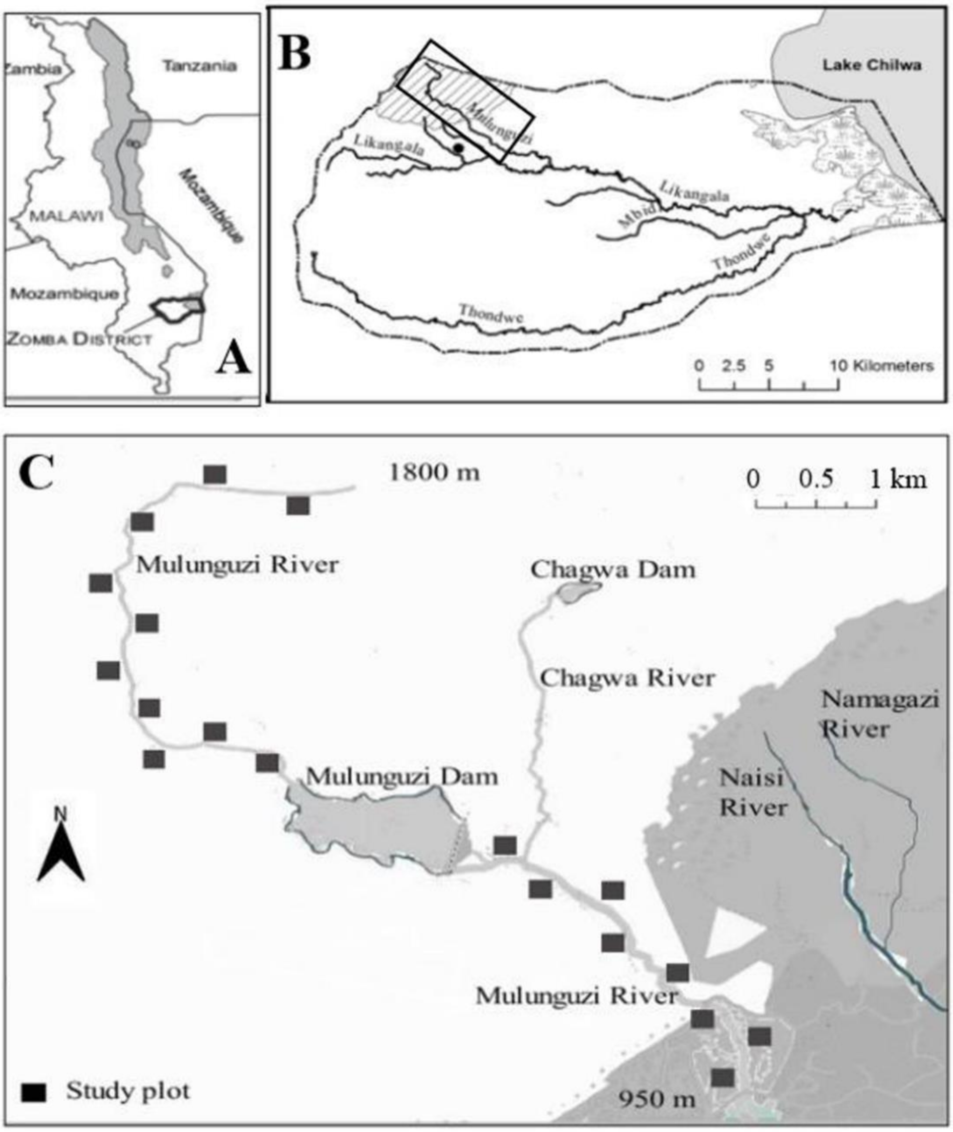

Figure 1. Map of Malawi. A. Location of Zomba District in Malawi (Source, Pullanikkatil et al., 2018). B. Lake Chilwa catchment area (Modified from Pullanikkatil et al., 2018). C. Mulunguzi River showing positions of study plots (Modified from https://latitude.to/map/mw/malawi/cities/zomba).

Topography and Climate

The headwater of the Mulunguzi River at the top of the Zomba Plateau has a basin-shaped area in the centre that contains the Mulunguzi Marsh. This uppermost part of the river has a gentle slope, then passes through steep slope gradients characterised by a series of waterfalls. There is a V-shaped valley on the other part of the upper course that joins with the middle course.

The middle course has a moderate to gentle slope and contains Mulunguzi Dam. There is a gorge after the dam formed by a deeply cut valley with a steep slope from the middle course to the lower course. The lower course has a gentle slope and a more expansive basin-shaped valley (Bloomfield and Young, 1961).

Mulunguzi River is in the Zomba Mountain, which has a typical highland climate in tropical Africa which experiences tropical climate with three main seasons: cold-dry, hot-dry and hot-wet that ranges from April to July, August to October and November to March, respectively. (Happold and Happold, 1989b, Zomba District Council, 2010).

In the cold-dry season, intermittent light rain falls during "Chiperoni" weather when the trade winds blow from the southeast. The hot-dry season has minimal rainfall, but the plateau is frequently covered in clouds and mist (Happold and Happold, 1986).

The rain-bearing system in this region is the Inter-tropical Convergence Zone (ITCZ) which is active between November and April with maximum rainfall occurring in January or February. The annual rainfall in different areas of the Mulunguzi River riparian zones varies from 1400–1,800mm. (Dias, 2008)

The highest mean temperature ranging from 28–30^{O}C is experienced in October, during the summer period and the lowest temperature as low as 10 ^{O}C is experienced either in June or July within the winter period.

Vegetation Sampling Method

Following the preliminary survey, the nested quadrat method was selected to be used for this study. Eighteen study plots were demarcated on the three courses of the Mulunguzi River with an elevation range of 950–1800m asl. Six plots measuring 30m x 30m from the edge of the riverbanks were demarcated on each course with half of them located on either side of the river. Each plot but one was preceded by another on the opposite side at an elevation interval of 50m asl to maximize the data collection of different plant species that were changing over short distances. The first plot was placed on a lower course at an elevation of 950m asl. (Figure 1C)

The study plots were purposively selected to be where more natural relic plant communities occurred. The nested quadrats with different sizes were used to demarcate sub-plots within the main plot for studying different life forms (Figure 2).

At each study plot, the main quadrat covering an area of 400 m^2 with dimensions of 20m x 20m was demarcated for studying tree species. This main quadrat was measured by a 100m tape measure, and the strong rope was tied to small poles at all corners to demarcate the quadrat.

To study shrubs, two nested quadrats covering an area of 25m^2 each were demarcated with ropes and small poles on the main quadrat. These nested quadrats had dimensions of 5m x 5m and were measured and demarcated at two diagonal corners of the main quadrat.

In the same main quadrat of trees, four nested quadrats were demarcated on all four corners to be used for studying herbaceous species. Each nested quadrat covered an area of 1m^2 with 1m x 1m dimensions that were demarcated by ropes and small poles at the corners (Figure 2).

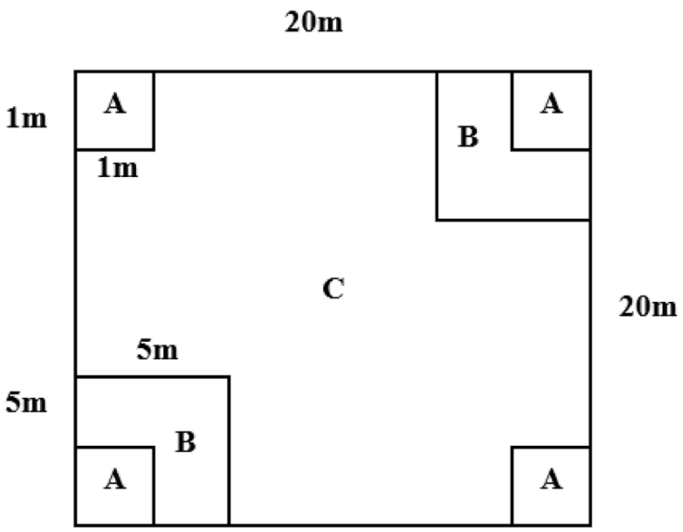

Figure 2. Arrangement of demarcated nested quadrats at a study plot. A. Nest quadrat for studying herbaceous plants. B. Nest quadrat for studying shrubs. C. Main quadrat for studying trees

Data collection

Plant surveys and data collection were carried out soon after the end of the rainy season when most species were in existence for easy identification. An altimeter was used to measure the elevations on the river courses to determine the position of the study plot.

At each quadrat, every individual plant was identified, the number of species present and its abundance were also recorded for further analysis. At the main demarcated quadrat, every tree with a diameter at breast height (DBH) greater than 10cm was selected for the study and shrubs were also selected in their nested plots when their DBH was less than 10cm. All herbaceous plants present in demarcated nested plots were selected for the study.

The identification of each plant species was done with the help of experts from the National Herbarium and Botanical Gardens of Malawi (NHBG).

Data analysis

The plant communities were distinguished after cluster analysis based on Bray-Curtis's similarity under the unweighted pair group method with arithmetic mean (UPGMA) using the software Paleontological Statistics (PAST) version 4.03. Graphs were generated after computing data using R version 4.3.2 by the R Core Team (2023). The Kruskal–Wallis Test was conducted to check the validity of the hypothesis since it had three categorical independent groups (courses of the river).

When analysing data for diversity, species richness was equal to the number of species present in an area.

The following indices were also used when analysing data for diversity.

a. Shannon–Weiner diversity index was used to determine species diversity on river courses.

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Where ***pi*** is the proportion of individuals that belong to species ***i***, ***s*** is the number of species in the sample, and (***ln***) is the natural log (Shannon and Weaver, 1963).

b. Pielou's evenness index was used to determine the evenness of species on each river course.

$$E = \frac{H'}{\ln(S)}$$

Where H' is the Shannon–Weiner index of species diversity, and [***ln(s)***]is the natural log of the total number of species.

RESULTS

Floristic composition

A total of 151 plant species belonging to 99 genera, 24 families and 2 plant groups were observed in this study. 146 of the 151 species were angiosperms (88 eudicot species and 38 monocot species) and 5 species were monilophytes. The most diverse families discovered in this study were Fabaceae (23 species), followed by Asteraceae (22 species) and Poaceae (20 species) (Figure 3). The families of Cyperaceae and Malvaceae had 11 species each and were followed by other families with species equal to or less than 10. Some families had only 1 or 2 species, but they were relatively more abundant on all the courses, for example, Myrtaceae (*Syzigium cordatum*), Dennstaedtiaceae (*Pteridium aquilinum*) and Rosaceae (*Rubus ellipticus* and *Rubus rigidus*).

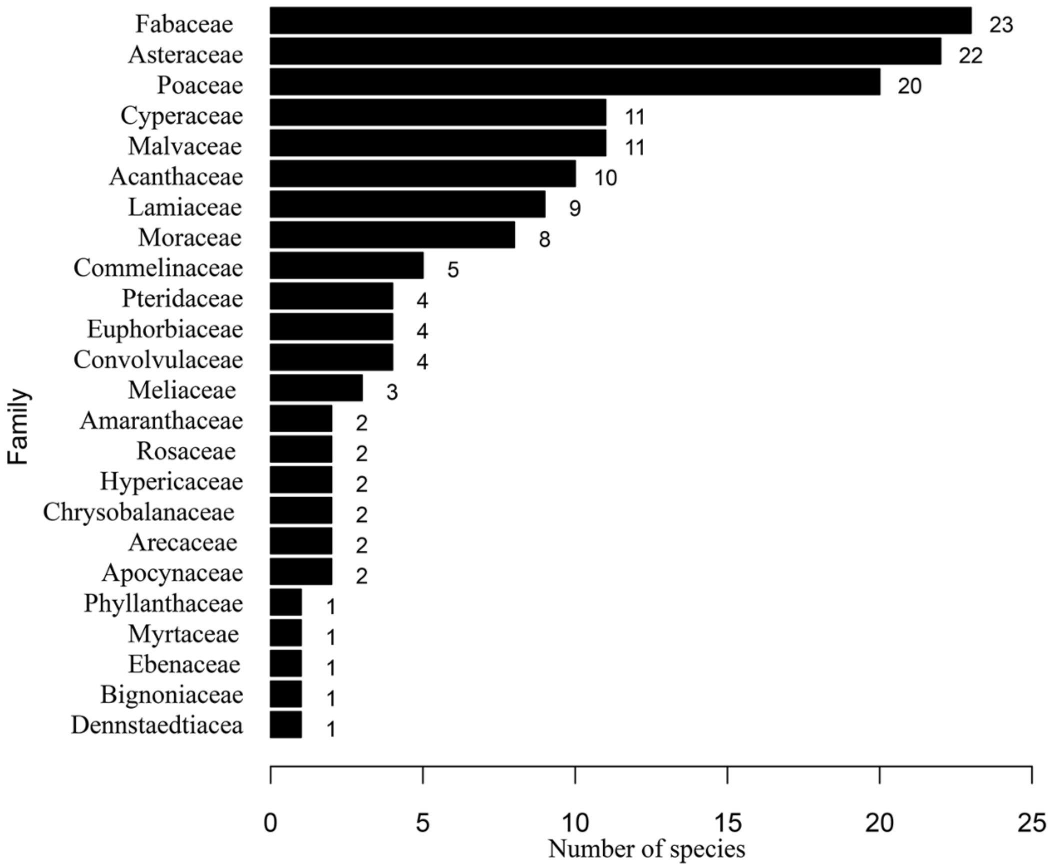

Figure 3. The number of species observed in each family on courses of Mulunguzi River. Families of Fabaceae, Asteraceae and Poaceae were most diverse.

The life form proportions of riparian vegetation along the Mulunguzi River

The study discovered that riparian vegetation on courses of the Mulunguzi River was mostly dominated by life forms of herbaceous plants, trees and shrubs (Figure 4). Herbaceous plants comprising of ferns, grasses, sedges and forbs were more diverse, with a significant contribution of 44.4% (67 species). Tree species followed herbaceous plants as they contributed 32.5% of the proportion (49 species), and shrubs contributed 17.2% (26 species). The remaining proportion of 5.9% was completed by climbers and lianas, with 5 species and 4 species, respectively (Figure 4).

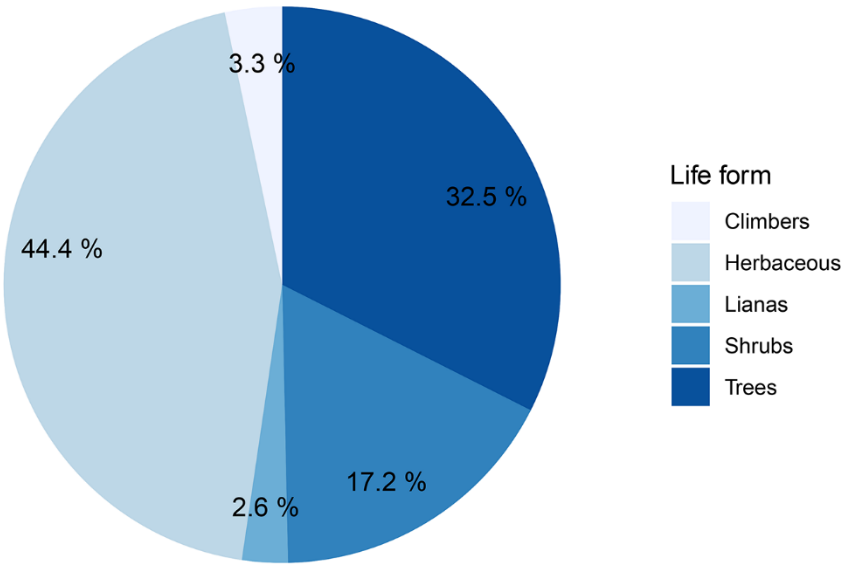

Figure 4. Percentage proportions of different life forms along the riparian zone of the Mulunguzi River. Herbaceous plants dominated the whole riparian vegetation.

Patterns of species richness distribution for life forms on the courses of the river

The relative abundance of species varied on different river courses. Some species were more abundant than others, and some were absent on other courses.

As such, they portrayed different patterns of species richness distribution on the river's courses, as shown in (Figure 5).

It was discovered that when moving downstream (from upper to lower course), species of ferns, sedges, grass, and shrubs had a decreasing pattern, with the maximum number of species in the upper course (Figure 5). Species of trees, forbs and lianas had an increasing pattern of richness when going downstream, with a maximum number of species in the lower course (Figure 5). Climbers had a hump shaped distribution with maximum number of species on middle course.

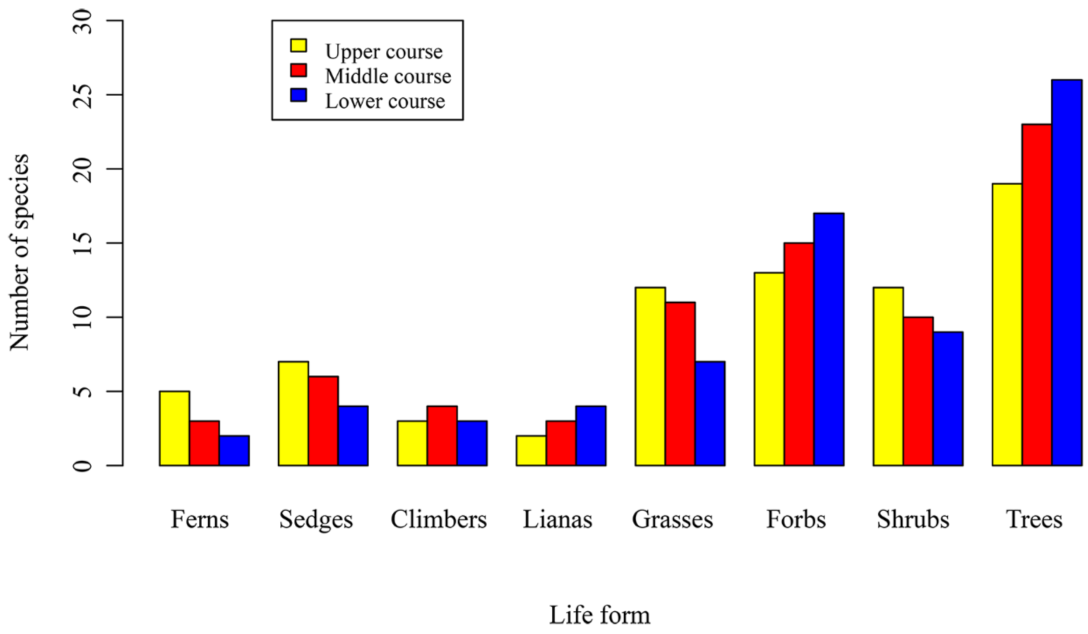

Figure 5. The patterns of species richness distribution for each life form present at each course based on their relative abundance. The species whose relative abundance was equal to or greater than the average relative abundance of each life form on the course were selected.

Species diversity on courses of Mulunguzi River

There was higher species diversity in terms of richness and evenness for riparian vegetation on all courses of the Mulunguzi River. However, there was variation in species richness, evenness and diversity in general on the courses of the Mulunguzi River which caused variations in the composition, distribution, and abundance of different species.

Species richness distribution and evenness decreased along the courses when moving downstream as depicted by the reduced number of species present at each course and Pielou’s evenness indices (Table 1).

The species diversity also showed a decreasing pattern when moving downstream, as represented by Shannon-Weiner (Table 1).

Table 1. Diversity of riparian vegetation on river courses and the whole study site

Course of the River	Number of species	Shannon-Weiner index (H')	Pielou's evenness index (E)
Upper	141	4.5367	0.9167
Middle	130	4.4411	0.9124
Lower	120	4.1447	0.8657
All courses	151	4.7943	0.9556

All courses represent the whole study site with all 18 study sites from all courses.

Plant communities of riparian vegetation along the Mulunguzi River

The cluster analysis of vegetation in study plots has identified two major groups that can characterize the riparian vegetation of the Mulunguzi River. However, one group has been subdivided into two closely related groups; therefore, three plant communities have been discovered at about 35% similarity (Figure 6). Community A consists of vegetation in plots 17 and 18; community B consists of vegetation in plots (1, 4, 8, 9, 12, 14 and 16) and community C has vegetation in plots (2, 3, 6, 7, 10, 11, 13 and 15) (Figure 6).

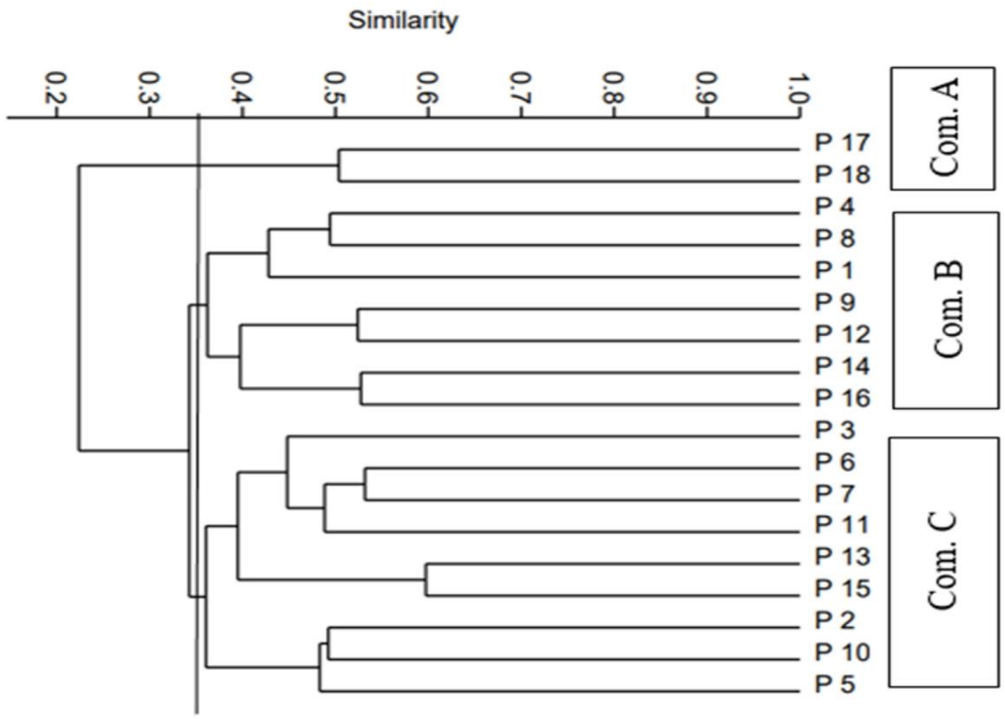

Figure 6. Cluster analysis dendrogram based on Bray Curtis similarity measure of plant species composition and their abundances in 18 study plots. Three communities were identified with 35% similarity, Abbreviations: Com. A, Community A; Com. B, Community B; Com. C, Community C.

DISCUSSION

Floristic composition

This study recorded 10,944 individual plants from the angiosperm and monilophytes groups with different life forms on all river courses. These plants belonged to 151 species, reflecting higher species richness for the relics of natural riparian vegetation. The most diverse families in this study were Fabaceae (23 species), Asteraceae (22 species), Poaceae (20 species), Malvaceae, and Cyperaceae had 11 species each; Acanthaceae, Lamiaceae, and Moraceae had 10 species, 9 species and 8 species, respectively (Figure 3).

The observed high diversity of species in Fabaceae, Asteraceae and Poaceae families is attributed to their resilience and wider tolerance to environmental changes that occur in their surroundings along the courses of the Mulunguzi River. It appears that most of their species survived the flooding disturbance in its riparian zone caused by Tropical Cyclone Freddy which occurred three months before the study. This is probably because most species in these families are herbaceous plants and shrubs that are capable of colonising and tolerating different habitats under varying extreme environmental conditions and disturbances (such as low temperatures, waterlogged soils and low soil pH).

These three families are also among the top five most diverse families worldwide, so they mostly occur in various environments around the world. The results from this study are consistent with this fact and several studies carried out in Africa on riparian vegetation (including Benin, Ethiopia, Kenya, Cameroon, Mozambique and Tanzania). However, the order of most diverse families differs from one place to another, but they generally revolve around these three families (Natta, 2003; Egbe et al., 2021; Giberti et al., 2022 and Natumanya et al., 2023).

It is worth noting that this study occurred three months after the riparian zone underwent disturbance caused by heavy flash flooding that was influenced by Tropical Cyclone Freddy. This probably had an impact on riparian vegetation because no submerged plant species were observed in the lower and middle courses during the study. These submerged plants are thought to be swept down to Lake Chilwa by higher water currents that increase in the river channel. It is also considered that the mechanical erosion of substrata on the banks carried along some species down to Lake Chilwa. This flooding is therefore thought to have reduced the total number of species that were supposed to be discovered by this study.

The life form proportions of riparian vegetation along the Mulunguzi River

Herbaceous plants (grass, ferns, sedges and forbs) have been revealed by this study to be the most species-rich life form that dominated all riparian vegetation on courses of Mulunguzi River. They contain 67 species that represent (44.4%) portion of all riparian vegetation along the Mulunguzi River (Figure 4). Poaceae happened to be the most diverse family of herbaceous plants with (20 species), followed by Asteraceae (16 species) and Cyperaceae (11 species) (Figure 3).

This dominance of herbaceous plants over all riparian vegetation might have happened due to their resilience and wider tolerance to changes in their environment. Herbaceous plants can survive extreme conditions such as low temperatures, acidic soils, low-nutrient soils and waterlogged soils likely because of their short lifespan as most of them are annuals. The recent flooding along the courses contributed to this observation, as more propagules were transferred and scattered in different locations where they quickly regenerated and developed (Decocq, 2002).

The presence of Mulunguzi Marsh in the upper course also contributed to this observation as it provides the surroundings with waterlogged, anoxic, and nutrient-deficient soils (Naiman et al., 1993). These conditions are tolerated by most species of Poaceae and Cyperaceae families and make them have a large portion of herbaceous plants because there is reduced competition with many species in these conditions.

The findings of this study concur with the discovery of studies conducted by (Tabacchi et al., 1990; Tabacchi et al., 1996; Decocq, 2002 and Brown and Peet, 2003). They discovered that most riparian flora are dominated by herbaceous plants due to their resilience when disturbed.

Tree species followed herbaceous plants in dominating Mulunguzi River riparian vegetation with 49 species which has a proportion of 32.5% of all vegetation (Figure 4). Fabaceae and Moraceae are the most diverse families of trees with 21 species and 8 species, respectively. Fabaceae is one of the most prominent families in tropical climates, with most tree species. More tree species occurred in lower and middle courses (Figures 7B and 8B), likely because of their narrow tolerance to environmental changes. Therefore, the lower and middle courses offer favourable climatic and environmental conditions required by most tree species (such as warmer temperatures, high soil fertility due to litter decomposition, and adequate soil moisture) (Acharya, 2011).

Shrubs had a proportion of 17.9% (26 species) and were dominated by families of Malvaceae (8 species) and Acanthaceae (5 species). Most shrubs were observed in the upper course of the river due to their higher tolerance to environmental changes than trees at higher altitudes (Acharya, 2011; Figure 9B).

Patterns of species richness distribution for life forms on different courses of the river

The distribution of plant species on different courses of the river varied with different life forms, and this resulted in the discovery of different patterns of species richness. The study discovered a decreasing pattern of species richness when moving downstream for life forms of ferns, grass, sedges and shrubs with a maximum number of species on the upper course (Figures 5, 9A).

The decreasing pattern for grass and sedge species richness is attributed to the presence of their several species around Mulunguzi Marsh at the top of the plateau. This makes them have the maximum number of species due to their survival in this less competitive zone which provides extreme environmental conditions. These conditions include low temperatures at higher altitudes, low-nutrient soil due to leaching, and anoxic and waterlogged soils (Naiman et al., 1993). These conditions aid in reducing competition with other species of different life forms, thereby promoting the survival of grasses and sedges adapted to these conditions (Naiman and Décamps, 1997). When moving downstream the number of species decreases due to increased competition for resources with other life forms. In the Rocky Mountains in western Colorado, Baker (1990), discovered the same pattern for herbaceous plants and shrubs after analysing longitudinal patterns across the watersheds.

Most shrub and fern species occurred in other plots away from the marsh as they did not withstand anoxic and waterlogged conditions. However, most shrub and fern species discovered in the upper course are adapted to survive at higher altitudes with low temperatures, nutrient-deficient soils and reduced canopy. There is reduced competition for resources such as light with other plants due to the reduced canopy caused by the reduction of tree species at higher elevations. Moving downstream, their distribution decreases as most of them are not able to compete for resources and they are not shade-tolerant (Acharya, 2011).

The species richness pattern for trees, lianas and forbs increased when moving downstream with a maximum number of species that occurred on the lower course (Figures 5, 7A and 7B). This is probably caused by the deposition of alluvium and organic matter eroded from an upper course that mainly occurred on the floodplain of lower courses. This accumulation of organic matter in the lower course causes changes in the soil's structure, texture and composition after decomposition. It also increases soil fertility and moisture, which provides a conducive environment that promotes the growth of different species of trees, lianas and forbs.

Lianas had the same pattern as trees because they depended on trees for their support to reach higher heights hence there is a direct relationship between them.

Most species of forbs discovered in this study were shade tolerant as they thrive well under the canopy above them and can survive in various habitats. The partially opened canopy offers them enough sunlight for their survival.

The findings of this study concur with the observations that were discovered by Statzner and Higler (1985), Baker (1990) and Giberti et al. (2022) when they investigated riparian vegetation of different rivers. Their studies showed the same increasing pattern regarding the species richness of trees, lianas and forbs on moving downstream.

Climbers had a hump-shaped pattern with more species at the middle course. This is probably because they are not well adapted to survive in low temperatures with low-nutrient soils on the upper course. On the lower course, the climber species are reduced probably due to their failure to compete for resources with other species.

Some species were present in all courses of Mulunguzi River, with large abundance, as shown in (Figures 7A, 8A, and 9A). These species include *Rubus rigidus* Smith, *Achyranthes aspera* L., *Rubus ellipticus* Smith, *Ageratum conyzoides* (L.) L., *Vernonia colorata* (Willd.) Drake, *Syzygium cordatum* Hochst. Ex Krauss.

Other species were only observed in specific courses, for example, *Trichilia emetica* Vahl and *Afzelia quanzesis* Welw on the lower course; *Crotalaria lachnophora* A. Rich and *Cyathula uncinulata* (Schrad.) Schinz on the middle course; and *Gymnanthemum myrianthum* (Hook.f.) H. Rob, *Aristida recta* Franch and *Cyperus baronii* C.B. Clarke on the upper course (Figures 7A, 8A, 9A).

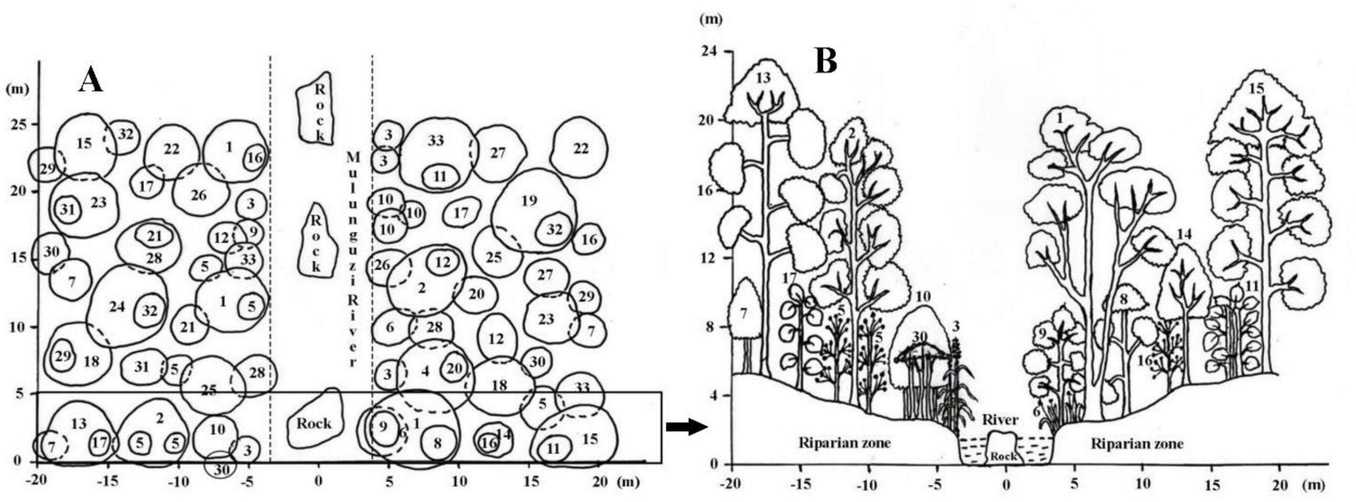

Figure 7. The schematic profile diagram of the lower course of the Mulunguzi River shows the distribution of some abundant species. A. Generalized horizontal view. B. The transect vertical section view. (Negative numbers represent the left side of the river, and positive numbers represent the right side. Zero is the center of the river for a horizontal view or the bottom of the river for a vertical view).

1. *Khaya anthotheca.* 2. *Syzygium cordatum.* 3. *Phragmites mauritianus.*

4. *Parinari curatelifolia.* 5. *Ageratum conyzoides.* 6. *Cyperus compressus.*

7. *Rinicus communis.* 8. *Dombeya burgessiae.* 9. *Haumaniastrum villosum*.

10. *Rubus rigidus.* 11. *Carduus nyassanus.* 12. *Achyranthes aspera.* 13. *Toona ciliata.*

14. *Gymnanthemum amygdalidum.* 15. *Newtonia buchananii.* 16. *Bidens Pilosa.*

17. *Aneilema johnstonii.* 18. *Julbernardia globiflora.* 19. *Bauhinia petersiana.*

20. *Senecio auriculatissimus.* 21. *Helichrysum forskahlii.* 22. *Raphia farinifera.* 23. *Erythrina abyssinica.* 24. *Afzelia quanzensis.* 25. *Ficus sur.* 26. *Ficus thonningii*.

27. *Trichia emetica.* 28. *Ficus bussei.* 29. *Triumfetta rhomboidei.*

30. *Crotalaria lachnocarpoides.* 31. *Vernonia colorata.* 32. *Crassocephalum uvens.*

33. *Rubus elliptus.*

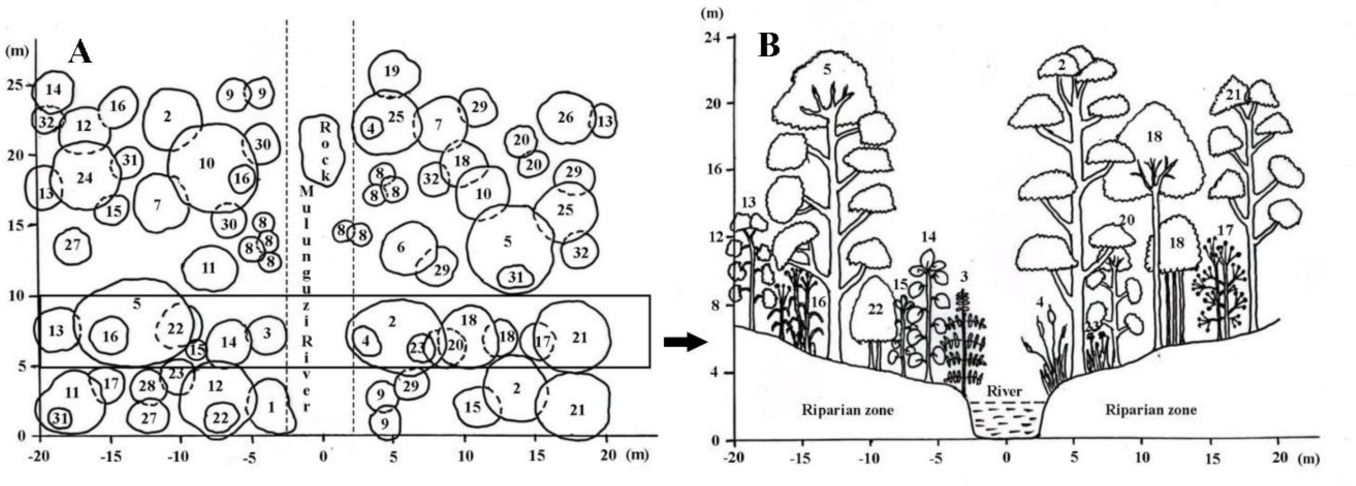

Figure 8. The schematic profile diagram of the middle course of the Mulunguzi River shows the distribution of some abundant species. A. Generalized horizontal view. B. The transect vertical section view. (Negative numbers represent the left side of the river, and positive numbers represent the right side. Zero is the center of the river for a horizontal view or the bottom of the river for a vertical view).

1. Ficus sycomorus. 2. Parinari curatelifolia. 3. Pteridium aquilinum. 4. Cyperus rotundus.

5. Khaya anthotheca. 6. Ficus natalensis. 7. Ficus sur. 8. Phragmites mauritianus.

9. Rubus elliptus. 10. Syzygium cordatum. 11. Julbernardia paniculate. 12. Toona ciliata.

13. Dombeya burgessiae. 14. Hibiscus fuscus. 15. Cyanthula uncinulata.

16. Ageratum conyzoides. 17. Aspilia mossambicensis. 18. Vernonia colorata. 19. Pteris friesii.

20. Urena lobata. 21. Newtonia buchananii. 22. Crotalaria lachnocarpoides.

23. Carduus nyassanus. 24. Faidherbia abida. 25. Ficus thonningii. 26. Vitex buchananii.

27. Pavonia urens. 28. Haumaniastrum callianthum. 29. Achyranthes aspera.

30. Rubus rigidus. 31. Aneilema aequinoctiale. 32. Senecio oxyriifolius.

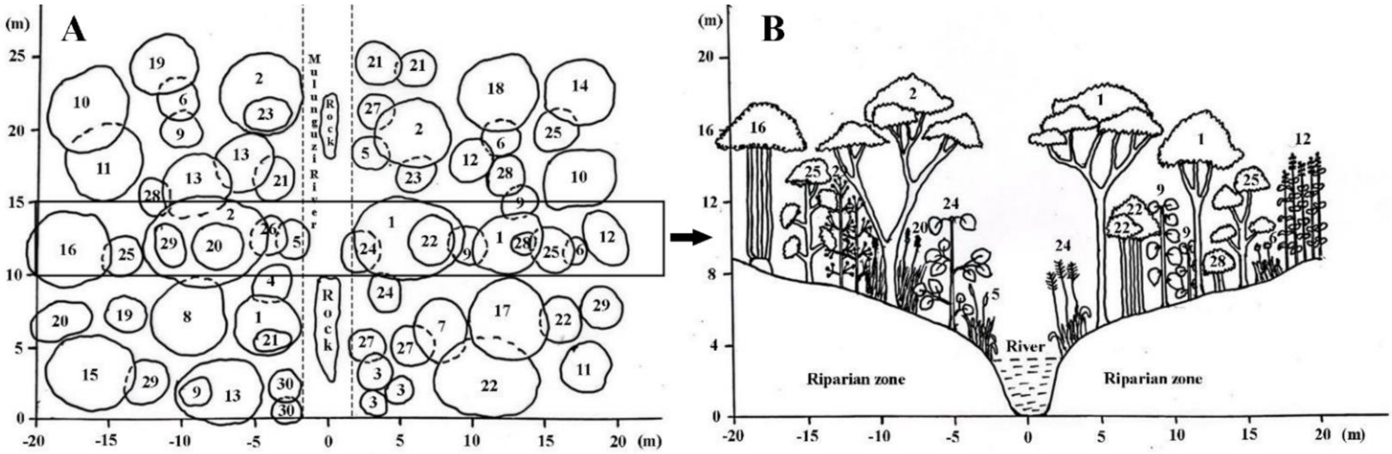

Figure 9. The schematic profile diagram of the upper course of the Mulunguzi River shows the distribution of some abundant species. A. Generalized horizontal view. B. The transect vertical section view. (Negative numbers represent the left side of the river, and positive numbers represent the right side. Zero is the center of the river for a horizontal view or the bottom of the river for a vertical view).

1. Syzygium cordatum. 2. Parinari curatelifolia. 3. Rubus rigidus. 4. Scleria melanomphala.

5. Cyperus nitidus. 6. Achyranthes aspera. 7. Aristida recta. 8. Setaria sphacelate.

9. Helichrysum foetidum. 10. Loudetia simplex. 11. Sacciolepis Africana.

12. Triumfetta rhomboidei. 13. Ficus natalensis. 14. Brachystegia boehmii.

15. Brachystegia appendiculata. 16. Gymnanthemum amygdalidum.

17. Harungana madagascariensis. 18. Senegalia polyacantha. 19. Piliostigma thonningii.

20. Koeleria capensis. 21. Pteridium aquilinum. 22. Gymnanthemum myrianthum.

23. Pteris cretica. 24. Cyperus baronii. 25. Vernonia colorata. 26. Hypoestes aristate.

27. Isolepis fluitans. 28. Emilia basifolia. 29. Ageratum conyzoides. 30. Rubus elliptus.

Species diversity on the courses of the Mulunguzi River

This study revealed high species diversity of riparian vegetation on the courses of Mulunguzi River as portrayed by several studies elsewhere which depict riparian forests to be hotspots of biodiversity (Nilsson, 1986, 1992; Nilsson et al., 1989; Tabacchi et al.,1990; Gregory et al., 1991; Tabacchi and Décamps, 1993; Naiman and Décamps, 1997 and Pielech, 2021).

However, there is a decreasing pattern of species diversity on the courses of Mulunguzi River when moving downstream as represented by the diversity parameters of species richness and evenness (Table 1).

The species richness decreased when moving downstream as the number of observed species decreased. The maximum species richness observed on the upper course was likely due to the existence of the Mulunguzi Marsh, which contained numerous species of the Poaceae and Cyperaceae families, suited for saturated soil conditions and higher altitude environmental conditions. Combining these species with other species of different life forms on the remaining plots gives maximum richness values on this course.

The species evenness shown by Pielou’s evenness index also decreased on moving downstream (Table 1). The species’ evenness ranges from 0–1; when it is 0, the area is dominated by a single species. When the value is 1, the species are evenly distributed in an area and are more diverse (Natumanya et al., 2023). In this study, the evenness index was getting closer to 1 (0.92, 0.91, 0.87 for upper, middle and lower courses, respectively) signifying that the species’ distribution is almost even on each course. However, they diverged from perfect evenness when moving downstream. This leads to a decrease in diversity when moving downstream as index values decrease.

There is a high diversity of riparian vegetation along the Mulunguzi River as the Shannon–Weiner diversity index values which deal with both richness and evenness were higher than three. The value of three is considered to be the lowest boundary index value of higher diversity (Natumanya et al., 2023).

This study discovered that the Shannon–Weiner diversity index value in all courses and overall study sites was more than four, which is very high (Table 1). This high diversity was probably caused by variations in soil attributes, topography, climate and disturbance of riparian zones by natural disasters such as flooding that occurred in this zone. These factors promote the growth and development of different species (Naiman et al., 1993).

Although the diversity is very high in all the courses, it showed a reduced pattern when moving downstream due to reduced richness and evenness. The overall diversity of the whole study site was also very high (Table 1)

The general pattern for species diversity and richness distribution discovered for riparian vegetation of Mulunguzi River agreed with the discovery of other researchers, who detected the same reduced pattern when moving downstream (Nilsson, 1989; Renöfält 2005; Pielech 2021 and Giberti et al., 2022).

Plant communities of riparian vegetation along the Mulunguzi River

The study revealed that the riparian vegetation on the courses of the Mulunguzi River has two major vegetation groups namely: grassland and Afromontane forest based on the cluster analysis dendrogram (Figure 6). In these groups, three communities were discovered at 35% similarity namely KoCa–LoSi–SeSp (Community A), PaCu–VeCo–NeBu (Community B) and SyCo–PaCu–VeCo (Community C) (Figure 6).

KoCa–LoSi–SeSp Community

This community is named after three dominant species in this course, *Koeleria capensis, Loudetia simplex* and *Setaria sphacelata* that occur in the grassland and is comprised of more grass and sedge species that are adapted to anoxic conditions. The community occurs in the upper courses near the Mulunguzi Marsh where soils are waterlogged, nutrient-deficient due to leaching and have low pH (Naiman et al., 1993). The temperatures of this community are low due to higher altitudes (1700–1800 m), and they experience frequent rainfall. This community has less competition with plant species due to their environmental conditions which makes it difficult for other species to survive. Some species that dominated this community were discovered by indicator species analysis. Species with an individual value percentage greater than 65% and p-value < 0.01 were selected including *Aristida recta* (75%), *Koeleria capensis* (69%), (67%), (66.67%), *Eragrostis exelliana* (66.67%) and *Sacciolepis Africana* (66.67%) (Figure 9A).

PaCu–VeCo–NeBu and SyCo–PaCu–VeCo Communities

These two communities were discovered to be very similar to each other as they both belong to the Afromontane forest and their species overlap with each other.

The Afromontane forest is subdivided into Mid-altitude Afromontane forest where community B was observed and Low-altitude Afromontane forest where community C was revealed (Figure 6).

Community B is named after three dominant species with high Important value index (IVI) namely, *Parinari curatelifolia*, *Vernonia colorata* and *Newtonia buchananii* likewise Community C is named after *Syzygium cordatum*, *Parinari curatelifolia* and *Vernonia colorata*.

PaCu–VeCo–NeBu and SyCo–PaCu–VeCo communities are mostly dominated by tree species (Figures 7B and 8B). However, SyCo–PaCu–VeCo Community has more tree species than PaCu–VeCo–NeBu Community probably due to slight variations in altitude, soil composition and moisture content. SyCo–PaCu–VeCo community is considered to be more nutrient-rich than PaCu–VeCo–NeBu community as most of the litter and alluvium accumulate in this region to add fertility to the soil. With more litter accumulation, soil moisture content increases due to higher water retention. Altitude causes changes in temperatures in the surrounding environment, which are warmer in these communities. The soil pH and nutrients may also be slightly different for these communities, which may result in minor variations. The most dominant and abundant species in these two communities with higher IVI are *Syzygium cordatum* (12.75), *Parinari curatelifolia* (9.48), *Vernonia colorata* (8.22) and *Newtonia buchananii* (7.54) (Figures 7A and 8A).

CONCLUSION

This study has revealed that riparian vegetation is dominated by herbaceous plants, they are key to essential functions in maintaining an ecosystem. However, it has been noted during the study that they are regarded as weeds because the major focus is given to trees which benefit people directly therefore, there are no measures to conserve them. Their availability is purely due to their resilience to survive through many disturbances.

It is necessary to carry out measures that protect every vegetation to have a healthy riparian vegetation that can execute its roles appropriately in an ecosystem. Anthropogenic activities also need to be checked to ensure that they help in conserving and protecting riparian vegetation.

When evaluating the differences in species composition and diversity in riparian vegetation across three courses of the Mulunguzi River, the Kruskal–Wallis Test was used.

The results from the test revealed that there was significant variation among the courses in terms of species richness. After analysis the H-value (0.8538) was greater than the Chi-squared value (0.1026) and p-value ($p = 0.6525$), then the hypothesis was rejected in favour of an alternative. This means that the courses had different species composition and diversity.

Proper conservational management needs to be maintained to preserve an aquifer for a constant supply of potable water throughout the year to Zomba City residents who depend mostly on this source of water for various uses. It is suggested by several ecologists and natural conservatives that proper conservation can be done by letting vegetation recover itself after some time to promote the growth of natural species rather than planting exotic species which also changes the ecosystem they occur. This area can be another area for further study to check its validity in this riparian zone of the Mulunguzi River.

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