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Plant species distribution in Lake Chilwa floodplain, Zomba, Malawi.

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Abstract

Lake Chilwa, an endorheic shallow lake, experiences significant fluctuations in water levels due to seasonal weather changes and landscape features.The research investigated plant species distribution in its floodplain, focusing on environmental features shaping it, thus vital for ecosystem conservation. Belt transects were used across six sites with varied slopes, each comprising three 50 m x 6 m plots, to sample remnant vegetation, and collect soil samples for texture, pH, and nutrient content analysis. Correlation and Principal Component analysed soil properties relationships. Non-Metric Multidimensional Scaling and Similarity percentage assessed species dissimilarity among sites, while Indicator Species analysis identified species in distinct hydroperiod zones. Results showed the highest species dissimilarity of 67.75% between sites on higher slopes and lower slopes. *Oryza longistaminata* A. Chev. & Roehr, predominantly present in lower slope sites, and *Typha domingensis* Pers, across all sites, demonstrated significant influence of environmental features on species composition and distribution. Soil analysis revealed sand as the main constituent, with a significant positive correlation between potassium and pH, and a significant negative correlation between potassium and magnesium. The landscape features influencing the water regime within the floodplain were key to the variation of species distribution and soil nutrient dynamics.

Keywords: Correlation analysis, environmental features, soil analysis, soil parameters, vegetation sampling, wetland ecosystems.

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1.Introduction

Wetland ecosystems have unique ecological features that differentiate them from terrestrial and marine ecosystems. These features include shallow water, either seasonal year-round, soil with a high-water content leading to depleted oxygen levels due to microbial activity, and the prevalence of macrophytes adapted to hydric conditions (Cronk and Fennessy, 2001; and Collins, 2005). However, wetlands are not homogenous ecosystems; their landscape features influence variation in hydrological conditions, affecting their ecological characteristics and functions. The hydrology encompassing sources of water, movement within the wetland, and outflow, is non-uniform due to variations. The increase landscape or decrease in flooding conditions affects species composition and distribution, productivity, nutrient cycling, and inflows (Capers et al., 2010; Van der Valk, 2012; and Ondiba et al., 2018). Flooding triggers a reduction reaction in soil, leading to a decrease in soil pH, which in turn changes the availability of nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur (Mitsch and Gosselink, 2000). Species richness is limited in areas with prolonged inundation, necessitating specific adaptations to endure extreme conditions such as saturated soil. Conversely, peripheral or ephemeral zones harbour greater vegetation diversity, benefiting from rich ecological niches that mitigate pressure from extreme conditions (Connell, 1978) cited in (Crandall et al., 2003). Inadequate or excessive soil moisture restricts plant growth by reducing oxygen and nutrient availability, including nitrogen and soil carbon, as microbial activities decline under such conditions (Porporato et al., 2003). Furthermore, heightened inundation diminishes organic matter decomposition rates, increases nutrient leaching, and alters phosphate dynamics, affecting soil nutrient balance and potentially leading to eutrophication and ecological disruptions. Moreover, flood pulse activates enzymes responsible for mineralizing organic phosphorus, accelerating phosphate release, thereby leading to long-lasting effects on the phosphate dynamics within the wetland ecosystem even after receding (Collins, 2005; Song et al., 2007; Muneepeerakul et al., 2008; and Tsheboeng et al., 2014).

Lake Chilwa wetland, situated in shallow depression basins in low-lying plains and valleys, relies on surface water inflow and precipitation as its source of water, with evapotranspiration facilitating outflow (Zegeren, 1998; and EAD, 2010). The seasonal changes in temperature and precipitation in the basin and the area around the catchment lead to flood pulse in the lake. Hence, its components, including the floodplain, experience varying flooding durations because of slope gradient and proximity to water sources. Lower lying sites endure more frequent and prolonged flooding than higher lying sites, with some areas maintaining saturation even during dry periods. Likewise, inner flood zones experience more frequent and longer periods of flooding than the outer flood zone. This variation in flooding intensity and flood pulse affects soil nutrient levels, pH, and nutrient availability (Collins, 2005; Muneepeerakul et al., 2008; and Tsheboeng et al., 2014).

As an endorheic lake lacking outflow, human activities such as fishing, irrigation, and wastewater discharge originating from the surrounding landscape (Njaya et al., 2011), contribute to the accumulation of organic matter and pollutants in the lake. This accumulation disrupts soil properties and potentially favours certain plant species (Alahuhta et al., 2012; Bayley et al., 2013; Kissoon et al., 2013; and Kissoon et al., 2015). Moreover, soil pH is altered by dissolved carbon dioxide, humic acid from organic matter decomposition, and nutrients from fertilizer and sewage effluent discharge (Kamzati et al., 2020).

The research aimed to explore the distribution of plant species across the Lake Chilwa floodplain landscape and understand the environmental features shaping species distribution, which is vital for ecosystem conservation.The specific objectives of the study were to:

i. Compare the composition of plant species in different floodplain sites.
ii. Determine the relationship among soil properties in the floodplain.

2. Materials and methods

2.1. Study area and plots

The study was conducted in the floodplain of Lake Chilwa, the second largest lake in Malawi, located about 100 km away from Lake Malawi at latitude 15°30"S and longitude 35°30"E (see Figure 1a). Its basement consists of metamorphic and igneous rocks, including quartz, feldspar, and biotite gneisses, with Precambrian granitic rocks forming its highlands landscape. These rocks resist erosion, resulting in little sedimentation in the bed layer, a distinctive feature not found in other lake basins in East Africa. Furthermore, its shores comprise lacustrine and alluvial

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deposits carried by highland rivers, with clay and silt soil predominant in the south and the east and the sandy soil deposited by floods in the north (Rivett et al., 2020). The tectonic depressed endorheic freshwater lake basin has a mean altitude of 627 m above sea level and is less than 5 m deep. A 25 m high sandbar, shaped by southeast winds from the Indian Ocean 8000 years ago, encloses lake outlets in the north. Phalombe Plain also surrounds the lake to the south, Mulanje Mountain to the southeast, Zomba Plateau to the west, and Mozambican mountains and hills to the east (Figure 1b).

The study covered a total area of 5400 m^2 comprising six sites: Swang'oma (S1), Kachulu (S2), Namasalima (S3), Mposa (S4), Chipakwe (S5), and Namanja (S6). Due to the absence of drainage channels, the accumulated water within the lake flooded more in the low-lying northern and western areas, which are 627 m above sea level, where Mposa (S4), Chipakwe (S5), and Namanja (S6) sites are located. In comparison, Swang'oma (S1), Kachulu (S2), and Namasalima (S3) sites in the southern part of the lake, which are at 631 m above sea level with a slightly higher slope, experience less flooding (see Table 1). Therefore, as shown in Figure 1a, the northern and western floodplain areas are marshier than the southern and eastern floodplain areas. In particular, the Lake Chilwa floodplain is bounded in the west by Chikala Hill, which has small perennial rivers that feed water into the lake (Njaya et al., 2011).

The climate is influenced by the inter-tropical Convergence Zone (ITCZ) and tropical cyclone winds, resulting in a tropical savanna climate with three seasons: cool-dry season, hot-dry season, and rainy seasons (Chavula, 2000). The average annual temperature varies between 21℃ and 24℃ but increases gradually towards open water areas, where the maximum temperature can reach 39℃ (Kambombe et al., 2021).The annual rainfall across the lake basin ranges from 1000 mm to 1600 mm and 2500 mm in its surrounding highland areas (Kambombe et al., 2021). Most of the open water in the lake originates from these highlands and is fed into the lake by six perennial rivers: Domasi, Likangala, Namadzi, Phalombe, Sombani, and Mnembo (Zegeren, 1998; and Dowsett-Lemaire et al., 2001).

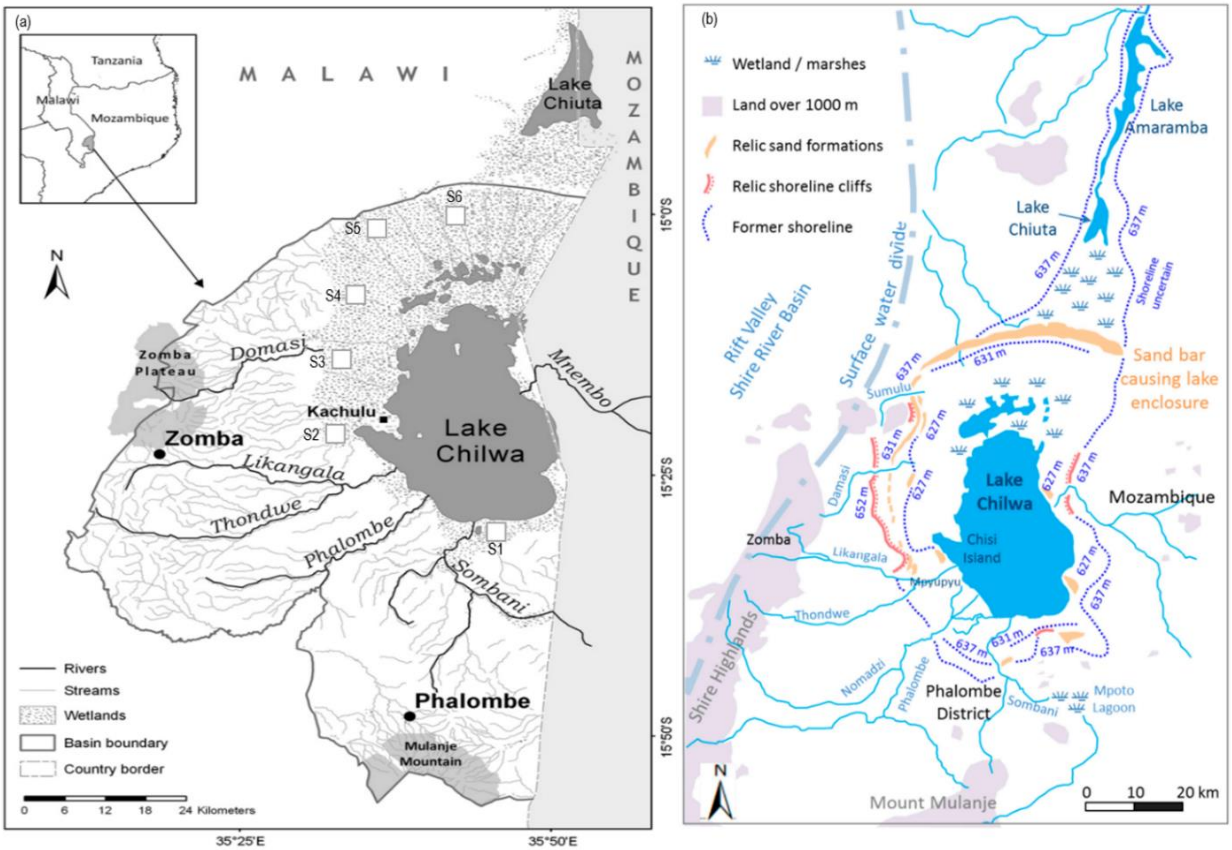

*Figure **1**: Map of Lake Chilwa Basin:(a) showing some physical features. Source: (Njaya et al., 2011), (b) showing the altitude of different sites and former (relict) lake shorelines. Source: (Rivett et al., 2020). The geographical location and* global positioning system *(GPS) device readings shows Swang'oma (S1), Kachulu (S2) and Namasalima (S3) located at slightly higher slope-635 m asl, 631 m asl and 630 m asl respectively. In contrast, Mposa (S4), Chipakwe (S5), and Namanja (S6) are located at a lower slope (627 m asl).*

2.2.Vegetation sampling technique

Six sample sites with varying slopes were selected based on subjective judgment regarding the likely presence or ecological significance of remnant vegetation (a subjective sampling method).

At each site, three plots 50 m x 6 m each, representing different hydroperiod zones, were demarcated along a 150 m × 6 m belt line transect. Within these plots, quadrats measuring 4 m × 2 m each were systematically laid out. The number of plant species and their abundance were recorded within each quadrat. Species identification was conducted towards the end of the rainy season to maximize the number of species recorded.

2.3.Laboratory soil analysis

Soil samples were collected using the grid method from three plots at each study site soon after the rainy season to minimize the effect of dissolved nutrients on soil properties. The samples were air-dried, sieved, and analyzed for soil texture, soil pH, as well as calcium, magnesium, potassium, phosphorus, nitrogen, and organic matter content levels at Forestry Research Institute of Malawi (FRIM) Zomba office.

Table**1:** Soil parameters and analytical techniques used to analyze the soil parameters.

Soil parameters	**Unit**	**Analytical techniques**
Soil texture	%	hydrometer method to determine sand, silt, and clay % followed by textural classification using the textural soil triangle.
Soil pH	-log $[H^+]$	calcium chloride extraction and pH meter analysis.
Total organic carbon	%	Walkley-Black chromic acid wet oxidation method.
Total Nitrogen	%	Kjeldahl Digestion method.
Total phosphorus	meq%	Flame photometry.
Total potassium	meq%	Flame photometry.
Total Calcium	%	Titration with EDTA (Ethylenediaminetetraacetic acid) after extraction with ammonium acetate.
Total Magnesium	%	Titration with EDTA (Ethylenediaminetetraacetic acid) after extraction with ammonium acetate.

2.4. Data analysis

Using Paleontological Statistics software (PAST) version 4.14 (Hammer et al., 2001), similarity percentage (SIMPER) was used by the Bray–Curtis method to identify species that contributed to dissimilarity in species composition among the sites. Thus, these sites provide an understanding of ecological processes or factors influencing species composition and distribution.

The correlation analysis in R software version 4.3.3 (R Core Team, 2021) identified relationships among these soil parameters. Additionally, Principal Component Analysis (PCA) in R software explored relationships among soil parameters and their association with sites. Furthermore, the non-metric multidimensional scaling (NMDS) in R software calculated the dissimilarity in species composition among the six sites based on species abundance and presence measured by the Bray-Curtis metric. Indicator species analysis in Past 4.14 software identified indicator species within distinct hydroperiod zones across the floodplain. The species indicator value percentage (IndVal %) is calculated by multiplying specificity and fidelity and multiplying by 100 (Bakker, 2008). Hence, species with higher IndVal % showed a strong association (high specificity) with a particular hydroperiod zone and a higher probability of occurrence in that specific zone (Fidelity).

3. Results

3.1. Species distribution across the sites

129 species were identified across all six sites of the study area. These species mainly comprised herbs (50.4%), grass (31%), and sedge (12.4%). The most dissimilar sites were S1 and S5, with a dissimilarity percentage of 67.75%, followed by S2 and S5 (62.39%), S1 and S6 (62.16%), and S1 and S4 (60.34%), as calculated by SIMPER statistical multivariate technique in PAST software (see Table 2). The ordination space shown in Figure 2 illustrates differences in plant species composition across varying slopes on the floodplain. The analysis revealed distinctions in species composition between sites on lower slopes (specifically plots 2, 3, 5 and 6) compared to those on higher slopes (notably plots 12, 13,14, 15,16,17 and18).

Additionally, the analysis revealed species composition dissimilarities based on the floodplain's hydroperiod zones. All plots located within the waterlogged zone (lying on the -2 value of NMDS1 axis), those within the seasonally waterlogged zone (lying on the 0 value of NMDS1 axis), as well as plots located in the temporally waterlogged zone (lying on the +2 value of NMDS1 axis), exhibit distinct species compositions from one another. This suggests that the duration and frequency of inundation in these different hydroperiod zones influence plant species that can thrive in each zone. Grass species such as *Oryza longistaminata* A. Chev. & Roehr, *Panicum maximum* Jacq, *Panicum hygrocharis* Steud, *Panicum repens* L, *Pennisetum unisetum* (Nees) Benth, along with the herb *Aeschynomene abyssinica* (A. Rich.), were found unique in sites S3, S4, S5, and S6. These and other species (see Table 3) accounted for 22.45% of

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the observed dissimilarity in species composition among the sampled sites. Notably, *Oryza longistaminata* A. Chev. & Roehr was the most significant individual contributor to this dissimilarity, with a dissimilarity percentage of 3.3%. On the other hand, *Typha domingensis* Pers was found across all sampled sites despite being among the species that contributed highly to the dissimilarity percentage.

3.2 Relationships among soil parameters across sites

Analysis of soil samples revealed sand particles as the main texture of the soil in the floodplain, constituting an average composition of 94.2%, with 2.4% clay and 3.3% silt. The results also indicated a strong linear relationship between potassium, soil pH, and total magnesium. As shown in Table 4, Pearson correlation coefficients ($r = 0.972$) demonstrated a significant positive correlation between potassium and soil pH, while ($r = -0.849$) showed a significant negative correlation with total magnesium. Additionally, although not significant, negative correlations were observed between total magnesium and total calcium, total organic carbon, and total nitrogen, as well as between calcium and total potassium, as shown with negative correlation coefficient values. Conversely, total organic carbon, nitrogen, soil pH, calcium, and potassium exhibited non-significant but positive correlations, as indicated by positive correlation coefficient values.

Principal Component Analysis (PCA) results illustrated in Figure 3 explained 78.8% of the variations in soil variables across the dataset, with Principal Component 1 accounting for almost 58.9% and Component 2 for 19.9%. Just like Pearsons' correlation coefficients correlation analysis, a strong positive correlation between soil pH and total potassium and a strong negative correlation with total magnesium was also evident by PCA analysis. The PCA plot illustrated small angles between each pair on the same and opposite sides of the biplot's origin. Furthermore, a positive correlation was observed among organic carbon, nitrogen, potassium, and soil pH, as they clustered on one side of the biplot's origin. Conversely, a negative correlation was evident between total magnesium and all other soil parameters except phosphorus, as indicated by their positioning on opposite sides of the biplot's origin with magnesium. Sites S3 and S4 were found close to the biplot's origin, suggesting a strong association with all soil parameters, indicating consistent characteristics across all measured parameters, and explaining little variation. Conversely, S6 was furthest from the biplot's origin, followed by S5 and then S1, indicating weaker correlations with all soil parameters and explaining much of the variation in some of the soil parameters.

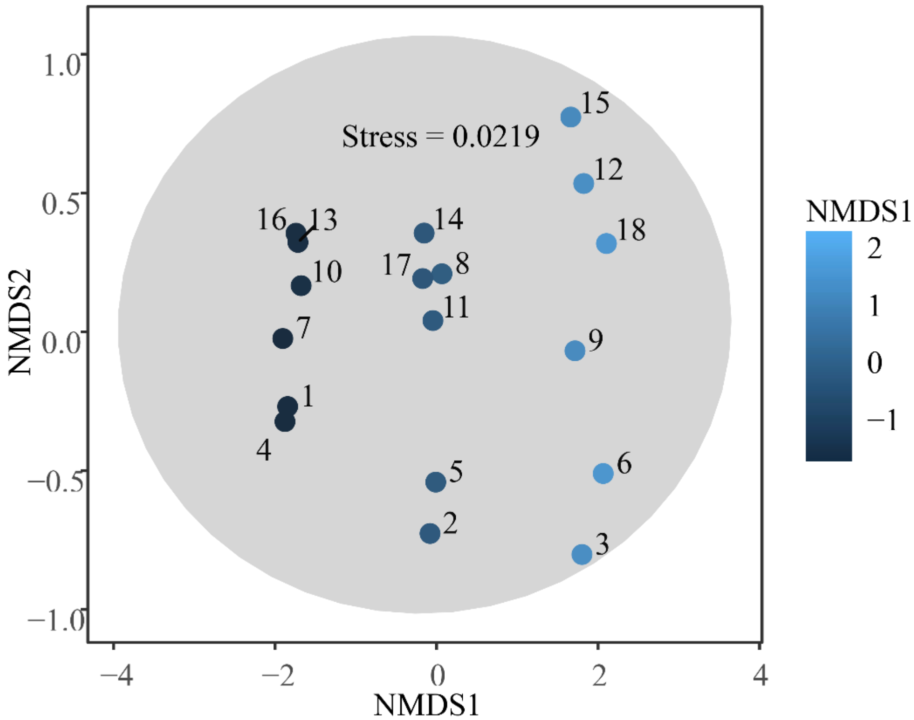

Figure 2: Non-metric multidimensional scaling (NMDS) calculated based on dissimilarity measured by Bray-Curtis metric with a stress value of 0.0219 below the critical P-value (P < 0.05) thus an excellent fit model. High dissimilarity level seen between higher slope plots 2,3,5 and 6 of sites- S1 and S2 with lower slope plots 12, 13,14,15,16, 17 and 18 of sites- S5 and S6.

Table **2**: Shows dissimilarity % between paired sites sampled in the Lake Chilwa floodplain.

	S1	**S2**	**S3**	**S4**	**S5**	**S6**
S1						
S2	32.93					
S3	50.98	50.02				
S4	**60.34**	58.6	46.03			
S5	**67.75**	**62.39**	48.68	37.95		
S6	**62.16**	56.47	46.9	32.71	37.37	

*The Table **2** shows sites S1 and S5 exhibiting the highest dissimilarity between them at 67.75%, followed by sites S2 and S5, S1 and S6, and S1 and S4. Sites S1 and S2 are located on higher landscape while sites S4, S5 and S6 are located on the lower landscape of the floodplain.*

Table **3**: Shows species contributed most to dissimilarity among the sites.

Family	**Species Name**	**Life form**	**Dissimilarity %**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Poaceae	*Oryza longistaminata* A. Chev. & Roehr.	Grass	3.3				✓	✓	✓
Poaceae	*Panicum maximum* Jacq.	Grass	1.881			✓	✓	✓	
Poaceae	*Panicum hygrocharis* Steud.	Grass	1.79				✓	✓	✓
Poaceae	*Panicum repens* L.	Grass	1.696				✓	✓	✓
Poaceae	*Pennisetum unisetum* (Nees) Benth.	Grass	1.49			✓	✓	✓	✓
Cyperaceae	*Cyperus rotundus* L	Sedge	1.475	✓	✓	✓			✓
Fabaceae	*Aeschynomene elaphroxylon* (Guill. & Perr.) Taub.	Shrub	1.423	✓			✓		
Poaceae	*Panicum dregeanum* Nees	Grass	1.39	✓	✓		✓		✓
Cyperaceae	*Cyperus esculentus* L	Sedge	1.358	✓		✓	✓		✓
Cyperaceae	*Cyperus articulatus* L	Sedge	1.235	✓		✓	✓	✓	
Poaceae	*Leersia hexandra* Sw.	Grass	1.226		✓	✓	✓	✓	✓
Poaceae	*Imperata cylindrica* (L.) Raeusch.	Grass	1.107		✓	✓	✓	✓	✓
Typhaceae	*Typha domingensis* Pers.	Grass	1.056	✓	✓	✓	✓	✓	✓
Asteraceae	*Pseudognaphalium luteoalbum* (L.) Hilliard & B.L. Burt	Herb	1.018	✓	✓	✓			✓
Fabaceae	*Aeschynomene abyssinica* (A. Rich.) Vatke	Herb	1.005				✓	✓	✓

*Table **3** shows 15 of the 129 sample species contributing collectively to a high dissimilarity of 22.45%. The similarity percentage (SIMPER) using the Bray–Curtis method considered both abundance and presence or absence of the species in each site. The (✓) sign indicate the presence of the species in a particular site.*

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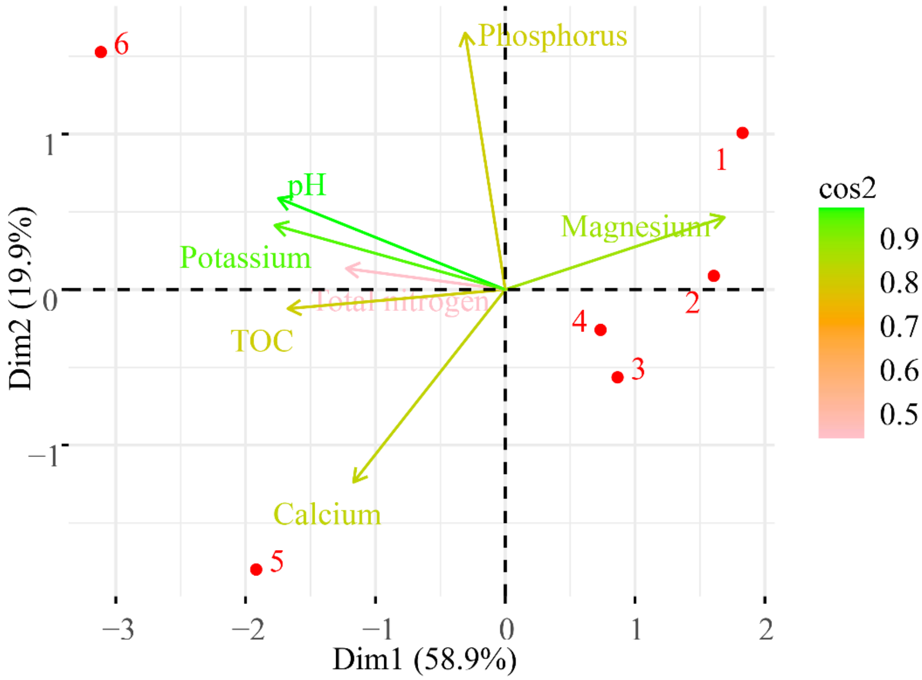

*Figure **3**:PCA plot showing soil physiochemical properties in study sites. The correlation matrix from the soil variables for the squared cosine values (**cos2**) represents the quality of representation of the variables in the principal components' space. Therefore, total Potassium, soil pH, and magnesium explain the variance. The proximity of S3 and S4 to the biplot's origin shows a strong association with soil parameters. In contrast, the furthest S6, S5 and S1 from the biplot's origin shows a weak association with some soil parameters.*

Table **4**: Correlation matrix of soil parameters of the study site.

	pH	**TCa**	**TMg**	**TOC**	**TN**	**TP**	**TK**
pH	1						
TCa	0.297	1					
TMg	-0.745	-0.617	1				
TOC	0.766	0.756	-0.735	1			
TN	0.602	0.283	-0.441	0.337	1		
TP	0.337	-0.275	0.108	0.266	0.021	1	
TK	**0.972****	0.314	**-0.849***	0.714	0.632	0.229	1

Table 4 shows correlation between the different soil parameters of the study site. The values in the table represent the Pearson correlation coefficients, which range from -1 to 1. '',correlation is significant at $P < 0.05$ level and '**',correlation is significant at $P < 0.01$ level. TCa stands for total calcium, TMg for total magnesium, TOC for total organic carbon, TN for total nitrogen, TP for total phosphorus, and TK for total potassium.*

4. Discussions

4.1. Species distribution across the sites

Figure 2 depicts a noticeable ordination space between lower slope sites (S4, S5, and S6) and higher slope sites (S1 and S2), indicating significant species composition differences. Despite the Permutational Multivariate Analysis of Variance (PERMONOVA) yielding a non-significant P-value of (0.998) concerning dissimilarities among the sites, the stress value in the NMDS plot (0.0219) falls below the threshold of 0.025. This suggests a perfect fit of the NMDS model in representing the observed dissimilarities among the original data points (Dexter et al., 2018). This indicates that landscape slope variation across the floodplain likely influences species assemblage among the sites. Sites situated at lower slopes, compared to those at higher slopes, experience frequent and prolonged floods, thus providing niches for the growth and abundance of rushes, sedges, reeds, and obligated wetland grass species. The increased soil moisture and nutrient levels, particularly nitrogen and phosphorus, in periodically inundated permanently waterlogged and seasonally waterlogged floodplain zones might provide optimal ecological conditions for certain species, including Cyperus species, Panicum species, Aeschynomene species, *Oryza longistaminata* A. Chev. & Roehr, *Typha domingensis* Pers, *Leersia hexandra* Sw and *Imperata cylindrica* (L.) Raeusch, to be prominent in the lower floodplain of permanently waterlogged and seasonally waterlogged zones. *Oryza longistaminata* A. Chev. & Roehr emerges as crucial in driving differences in species composition among the sites, given its high individual dissimilarity percentage and predominant distribution within sites 4, 5, and 6 (see Table 3). This species typically favours moderately to highly flooded habitats with soil pH ranging from slightly acidic to slightly basic (Mufarrege et al., 2011; Fynn et al., 2015; and Hyde et al., 2024). Although *Typha domingensis* Pers was distributed across all sampled floodplain sites, its relative impact on overall dissimilarity (see Table 3) may be attributed to its higher abundance in lower floodplain sites than in higher slope sites. The frequent and prolonged flooding in the lower sites enriches soil nutrients through sediment deposition, organic matter decomposition, and inputs from inorganic fertilizers and wastewater discharge, particularly nitrogen and phosphorus. Being a heavy feeder, *Typha domingensis* Pers may have thrived in nutrient-rich sites (S4, S5, and S6).

Additionally, the flood pulse—alternating dry and wet conditions—may influence soil nutrient dynamics across the floodplain, impacting species distribution across all sites. *Typha domingensis Pers* is adapted to fluctuating shallow water habitats and can tolerate soil with low pH and total organic carbon, demonstrating its ability to adapt to nutrient-imbalanced soils. This adaptation contrasts with comparable East African wetland habitats dominated by *Cyperus papyrus*, which thrives in permanently inundated areas (Ondiba et al., 2018).

Similarly, in Figure 4, the distribution of species across floodplain zones shows the dominance of obligate wetland species, such as *Typha domingensis* Pers, *Phragmites mauritianus* Kunth, and *Oryza longistaminata* A. Chev. & Roehr, in permanently waterlogged zones. This dominance can be attributed to their adaptation to prolonged periods of high water levels, providing conditions conducive to their growth compared to other species, which might drown or suffocate in such conditions. Conversely, in zones experiencing seasonal waterlogging, species such as *Hygrophila schulli* M.R. Almeida & S.M. Almeida, *Imperata cylindrica* (L.) Raeusch, and *Leersia hexandra* Sw likely thrive due to their ability to tolerate both wet and dry conditions. In temporarily flooded zones, a mixture of wetland and terrestrial species like *Ageratum conyzoides*. L, *Chamaecrista mimosoides* (L.) Greene, and *Hyperthelia dissoluta* (Steud.) Clayton, flourish in short flooding periods.

4.2. Relationships between soil parameters in sites

Due to a high percentage of sand particles compared to clay and silt particles, the floodplain mostly constituents sandy soil. According to the soil triangle chart, soil with at least 90% sand particles and less than 10% clay or silt particles is classified as sand soil (Dewangan et al., 2023). Flooding likely carried alluvial deposits with more river sand particles into the floodplain. However, due to lower slopes, frequent flooding, and strong winds, more sand particles from the rivers and lakebed could have been deposited at sites S4, S5, and S6 compared to S1 and S2, resulting in a relatively lower proportion of sand in S1 and S2 (Rivett et al., 2020). Even across the floodplain zones, the variation in high flooding intensity between the lower and upper zones results in unequal composition of soil particles and unequal distribution of soil nutrients. The permanent flooding zone has higher sandy particles and nutrient levels than the temporary seasonal floodplain zone (Bonyongo and Mubyana, 2004; and Tsheboeng et al., 2014).

The dynamics of soil nutrient levels resulting from flood pulses and geological features may have influenced the correlations amongst soil parameters and their association with specific sites. Shallow flooded sites like S1 and S2 might have minimized the leaching of magnesium, thus showing a stronger association with magnesium than the highly intense flooded sites S5 and S6 (see Figure 3). The frequent, prolonged flooding in S5 and S6 due to lower slopes might have introduced more organic materials, which increase levels of total organic carbon, potassium, and total nitrogen upon decaying, thus influencing their strong associations. Moreover, potassium can bind strongly to soil particles under high inundation conditions. Additionally, the basement of Lake Chilwa consists of phosphorus-rich rocks, such as igneous rock and mica pyroxenites (Garson, 1962) as cited in (Kamzati et al., 2020), which may have enriched phosphorus in the sites. Thus, these conditions might have influenced a significant negative correlation between total magnesium and total potassium, a strong association between potassium and soil pH, and a weak positive relationship between soil pH and phosphorus. This is consistent with other research findings that indicate increased soil moisture content strongly correlates with total potassium, total organic carbon, and total nitrogen, except for the latter relationship, which contrasts with the typically strong positive correlation reported in most studies (Porporato et al., 2003; and Mar et al., 2021).

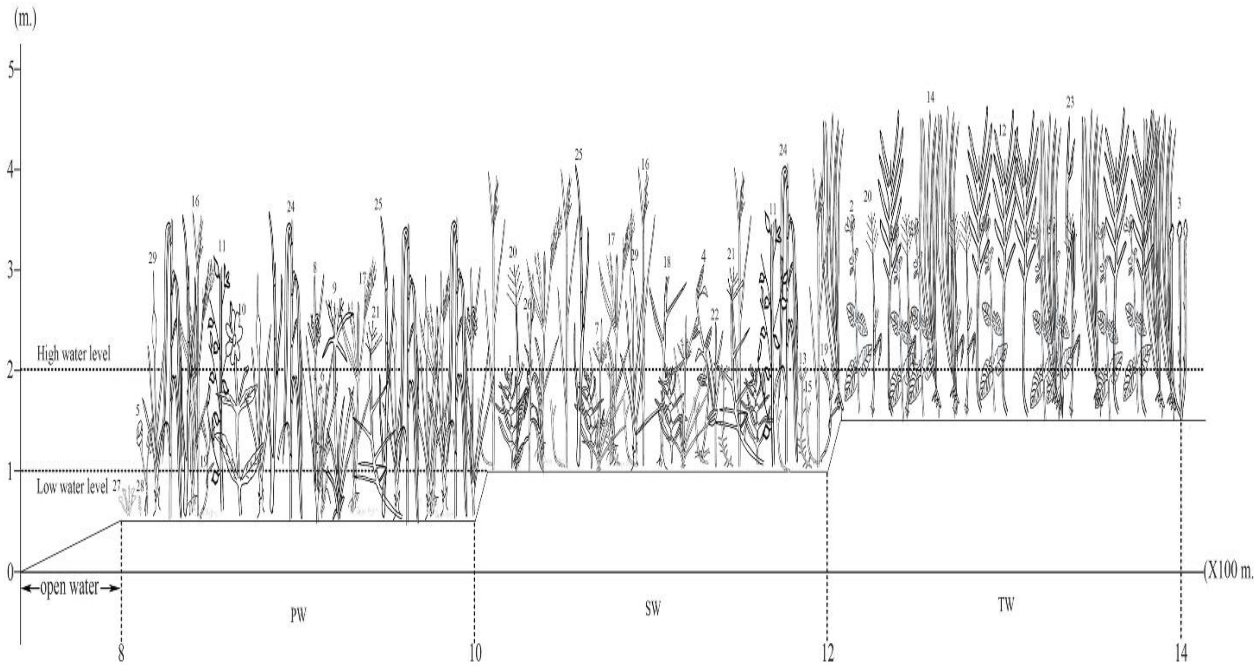

*Figure **4**: Schematic profile diagram of the Lake Chilwa floodplain showing species with indicator values exceeding 70% in each of the three zones. Each indicator species demonstrated a highly significant value below the critical P-value (P<0.05),firmly establishing them as genuine indicators of their respective zones. Additionally, species contributing most to the dissimilarity of 22.45% amongst the sites are also highlighted. In the permanent waterlogged zone, dominant species include Typha domingensis Pers, Phragmites mauritianus Kunth, and Oryza longistaminata A. Chev. & Roehr. In the seasonally waterlogged zone, notable species are Hygrophila schulli M.R. Almeida & S.M. Almeida, Imperata cylindrica (L.) Raeusch, and Leersia hexandra Sw, while the temporally flooded zone is predominantly occupied by Ageratum conyzoides. L, Chamaecrista mimosoides (L.) Greene, and Hyperthelia dissoluta (Steud.) Clayton.*

Key*:*PW-*Permanent waterlogged zone (deep flooded zone);* ***SW***-*Seasonally waterlogged zone (shallow flooded zone);* ***TW***-*Temporally flooded zone (shallow flooded zone).*

1-*Hygrophila schulli* M.R. Almeida & S.M. Almeida;**2**-*Ageratum conyzoides*. L.

3- *Pseudognaphalium luteoalbum* (L.) Hilliard & B.L. Burt.;**4**-*Commelina diffusa* Burm. F.

5-*Ipomoea aquatica* Forssk.;**6**- *Cyperus articulatus* L.; **7**-*Cyperus esculentus* L.

8-*Cyperus mauritianus* P. Willemet.; **9**-*Cyperus rotundus* L.

10- *Aeschynomene abyssinica* (A. Rich.) Vatke.

11- *Aeschynomene elaphroxylon* (Guill. & Perr.) Taub.

12-*Chamaecrista mimosoides* (L.) Greene;**13**-*Cynodon dactylon* (L.) Pers.

14-*Hyperthelia dissoluta* (Steud.) Clayton.;**15**- *Imperata cylindrica* (L.) Raeusch.

16-*Leersia hexandra* Sw.; **17**- *Oryza longistaminata* A. Chev. & Roehr.

18-*Panicum dregeanum* Nees.;**19**-*Panicum hygrocharis* Steud.; **20**-*Panicum maximum* Jacq.

21-*Panicum repens* L.; **22**-*Pennisetum purpureum* Schumach.

23-*Pennisetum unisetum* (Nees) Benth.**24**-*Phragmites mauritianus* Kunth.

25-*Vossia cuspidata* (Roxb.) Griff.

26-*Persicaria senegalensis* f. albotomentosa (R.A. Graham) K.L. Wilson.

27-*Eichhornia crassipes* (Mart.) Solms.;**28**-*Azolla filiculoides* Lam.**29**- *Typha domingensis* Pers.

5. Conclusion

In line with other research studies, such as the assessment of influence of depth, duration, and frequency of flooding on wetland plant communities (Casanova and Brock, 2000), this study observed that water regimes significantly influence the unique composition and distribution of plant species across the sites within the floodplain of Lake Chilwa. Additionally, it also influences the correlation among soil parameters, as well as associations between these soil parameters and the specific sites. The study found that the flood pulse influences the dynamics of soil nutrients and variations in vegetation distribution across floodplain ecosystems, depending on the landscape's slope. Furthermore, the shallow, enclosed nature of the lake also facilitates cyclic, regular seasonal flooding events, making it susceptible to leaching, accumulation of dissolved minerals and silt, saline conditions, and the build-up of agro-chemical pollutants. Therefore, there is need for integrated management strategies considering multiple aspects of the ecosystem such as water regimes, landscape features, and the impact of human activities like agriculture for the ecosystem conservation.

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