Soil properties influence on diversity and structures of dominant woody species in riparian forests in Southwestern Nigeria

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Abstract

Interplay between soil variables with structural and diversity indices of riparian vegetation needs to be explicated towards the conservation of this highly productive riparian forest ecosystems amidst pronounced anthropogenic activities in Southwestern Nigeria. The study was carried out in Osun State, Southwestern Nigeria. Nine sites were used for this study, within each site, ten plots (0.25 ha in size) were marked out and each plot was placed systematically, giving a total of 90 plots. Ten soil samples were collected in each plot at top (0-15 cm) and sub (15-30 cm) soil levels using soil auger and to analysed for the physicochemical properties. Woody species were identified and classified. Euphorbiaceae and Apocynaceae are the most occurring families with *Musanga cecropioides, Pterocarpus santalinoides, Rothmannia hispida* and *Jateorhiza macrantha* being dominant in the riparian sites. The soil variables correlated positively with structural parameters markedly density rather than diversity indices across study sites. Soil pH, P, TOC, OM were key edaphic factors that affected the vegetation dynamics of these ecosystems. Policies and decision making should take cognisance of these key nutrients supporting dominant species, towards conservation amidst ecological succession ongoing across the riparian forest sites.

Introduction

Intensive ecological interactions between terrestrial and aquatic environment occurs frequently within the riparian zones, providing vital ecosystem services. The zone remains a fragile system vulnerable to land use change and other anthropogenic activities (Manfrin et al. 2018; Borisade et al. 2021). Riparian soils and vegetation form the basis of several ecosystem services being vital for overall biodiversity and biogeochemistry of river/stream ecosystems (Hale et al. 2018). Understanding the complex and dynamic nature of nutrient cycling processes in riparian soils and its effect on environmental variable, is important for forecasting the succession of ecosystems and crucial for management of riparian zones (Zhao et al. 2020). Soil properties can vary among ecosystems even at slight scales, and can be linked with the structure and composition of plant communities (Metzeger et al. 2017). Studies associating the stabilization factor in soils within intact and degraded riparian forests could test organic matter and contribute to improve techniques that aim to increase carbon fixation (Fernandes et al. 2021). The connections between the cycle of soil N and P with soil C cycle marks the distribution of soil organic carbon which unvaryingly, hints the environmental effects of the riparian zones (Qian et al. 2017). Soil properties in riparian zones, such as soil moisture, carbon, nitrogen and phosphorus, are important variables that condition many ecological processes, including carbon sequestration, nitrogen mineralization, litterfall decomposition and water purification (Qian et al. 2018; Fernandes et al. 2021).

Soil physicochemical properties can affect vegetation due to their effects on chemical reactions and biological processes which are typically used as an indicator of quality of plant life in the riparian environment. More importantly, riparian soils and vegetation can be used as ecological indicators to measure the advancement of riparian management practices used to maintain structures and diversity of plant species and restore soil ecosystem services (Saint-Laurent et al. 2014). Tree species richness and canopies are known to have positive effect on soil organic carbon and bioavailability of phosphorus (Wu et al. 2019). It is generally believed that because of the interaction between vegetation and soil through metabolites such as roots and litters, the dominant plant species, often determine the direction of development of the whole community, and the influence of the community on the environmental quality (Cybill et al. 2020). The relationship between biodiversity index driven by succession and soil properties dominated by riparian habitat is an important factor that determines ecological stability of the zones (Tengfei et al. 2021). Studies revealed temporal changes in soil characteristics were mostly driven by soil moisture, although the magnitude of these changes varies between canopy species and that protecting riparian forested areas and planting native species will improve the soil fertility and stability in restoration of these vegetations (Saint-Laurent et al. 2014; Perez-Corona et al. 2021). Replacement of riparian forests to other land forms due to anthropogenic impact is being reflected in the physical and mechanical properties of the soils, invariably deteriorating its quality. This is pronounced in Southwestern, Nigeria where these productive riparian zones are converted to agricultural lands as means of livelihood for the native dwellers.

The floristic composition, structure and diversity, regeneration status of woody species and nutrient status in herbaceous layer, as well as, impact of land use change on the vegetation dynamics of the riparian forests in Southwestern Nigeria have been studied (Borisade and Odiwe 2022; Borisade and Odiwe 2021; Borisade et al. 2021; Borisade 2020). However, the relationship between the soil properties and biodiversity indices, structures and their influence on dominant plant species in the riparian forests have not been documented. Key soil properties responsible for the vegetation dynamics and influence of environmental variables on the soils of these zones needs to be identified, towards developing strategies projecting ecosystem succession and the information will be critical for management of these riparian forests in Nigeria. This study therefore, aims to:

1. evaluate the soil nutrient status and being impacted by anthropogenic activities
2. establish the relationship between soil properties and dominant species and;
3. determine the influence of soil properties on the structures and diversity indices of riparian forest sites

Materials and Methods

Description of study area

The study was carried out in Osun State, Southwestern Nigeria. The State lies within 7°30'N and 4°30'E. The sites are situated in Ilesha West, Atakumosa West, Ife North, Ife North East, Ife South and Ayedade Local Government Areas of Osun State, Southwestern Nigeria. Nine riparian forest sites located in Ifetedo, Ilesha, Osu, Famia, Ibodi, Tonkere, Gbongan, Edunabon and Ipetumodu were selected and designated as site I–IX respectively. These riparian zones were selected because they are areas with flooding patterns of Southwestern Nigeria and have high plant species diversity, despite varying ongoing anthropogenic activities (Fig. 1). The detailed climate, soil and vegetation of the study area has been described by Borisade (2020).

Assessment of dominant woody species

In each community, forest stands within the selected sites was sampled on transect, 150 m long extended perpendicular to and across the streams/river. A total of nine sites were used for this study, within each site, ten plots (0.25 ha in size) were marked out and each plot was placed systematically at an interval of 10 m along the transect, thereby giving a total of 90 plots across the study sites. Each plot was demarcated by narrow-cut thin lines to mark boundary of the plot.

Structural and diversity indices assessment

Stem diameters were measured using a diameter tape at breast height (dbh, 1.3 m), diameter was measured above the buttresses for individuals with buttresses or other stem irregularities at breast height, and this was done following the usual forestry procedures. Height of woody species were measured using Haglof clinometer. Frequency in at least four out of nine sites studied were considered, dominance of woody species was assessed based on dbh > 10cm, Simpson's index of dominance, and species important value index. The structural parameters and diversity indices were evaluated as follows:

Density

The density of each species, D_i, was calculated as the number of individuals in a unit area:

$$D_i = \frac{n_i}{A}$$

where D_i is the density for species i; n is the total number of individuals counted for species i, and A is the total area sampled.

Frequency

The frequency for each species was calculated as

$$f_i = \frac{j_i}{k}$$

where f_i is the frequency of species i, j_i is the number of occurrence of species i and k is total number of samples including species i.

Basal area

Basal area which indicated the importance (dominance) of tree and shrub cover (Carratti et al. 2004), was determined as:

Basal area (m^2 ha^{-1}) = $\frac{c^2}{4\pi}$

Where: C = girth size (diameter at breast height in meters), π = 22/7 = 3.14.

The basal area of each species was determined by adding the basal area of individuals of the species and the plot basal area was calculated by adding basal areas of all species in each plot while the site basal area was calculated as mean woody species basal of all the sample plots.

Importance value index

This index was used to determine the overall importance of each dominant species in the community structure.

Relative Dominance = $\frac{\text{BasalAreaperspeciesorfamily}}{\text{TotalBasalArea}}$×100

Relative Frequency = $\frac{\text{Frequencyofeachspeciesorfamily}}{\text{Sumoffrequencyvaluesofallspecies}}$×100

Relative Density = $\frac{\text{BasalAreaperspeciesorfamily}}{\text{TotalBasalArea}}$×100

The three relative values were added together to obtain Importance Values (IV) for each species in each plot

Diversity indices

The total number of species recorded in the sampling plots (species richness), Shannon-Wiener diversity Index (H'), dominance and species evenness were employed to quantify and characterize species diversity and species-abundance distributions of the plant communities.

Alpha species diversity was calculated for each site as Shannon-Weiner diversity, described by (Magurran 2004) as:

$$H\prime = -\sum_{i=1}^{s} (pi)\,(Inpi)$$

Where; H'= Shannon-Weiner; s = the number of species; pi = the proportion of individuals or abundance of the i^{th} species.

Dominance was evaluated using Simpson's index of dominance (1949);

$$D = \sum (pi)^2$$

Where D = Simpson's index of dominance, pi = the proportion of importance value of the i^{th} species ($pi = {ni}/{N}$, n_i, is the importance value index of i^{th} species and N is the important value index of all the species).

The Species evenness was calculated using Pielou Index (J) (1977).

$$\text{Pielou Index (J)} = {H'}/{In\ S}$$

Where H'= Shannon-Wiener index of diversity and S - Total number of Species.

Soil physicochemical properties determination

Three core samples were randomly collected from undisturbed soil surface, in extracted core soil samples (ECSS) and weighed. From the weighed ECSS, a sub sample, 10 g was collected into a foil paper, wrapped and oven-dried at 105°C to a constant weight for a period of about 48 hours.

Soil water content of each sub sample was calculated by using the formula:

Moisture correction factor = 1 - $\frac{\text{Weightofmoistsoil} - (\text{Weightofoven} - \text{driedsoil})}{\text{Weightofmoistsoil}}$

Dry weight of ECSS was calculated by using the formula:

ECSS dry weight = Weight of moist bulk soil sample x Moisture correction factor

The Soil bulk density was determined as: soil bulk density= $\frac{\text{ECSSdryweight(g)}}{\text{Volumeofsoilcore}(\text{cm}^3)}$

Soil particle size distribution was determined using the hydrometer method. Ten soil samples were collected each at top and sub soil in the established plots of the riparian sites using soil auger. The soil samples were air-dried for 72 hours, sieved through mesh of size 2 mm and used for analysis. The pH of soil samples was determined using pH meter (Jenway model 3510) in soil-$CaCl_2$ slurry. Nitrogen, was determined using Kjeldahl acid-digestion method using a H_2SO_4-mixed catalyst and phosphorus was determined using the molybdenium-blue colorimetry method after digesting the samples with perchloric acid (Lu 2000). Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) were determined using the Atomic Absorption Spectra (SP-IAA320 Model). Soil samples were analysed for total organic matter and carbon using the procedures outlined by Maiti (2013). Total acidity was estimated using 1.0 M sodium acetate as extractant (pH 8.2) (Kappen 1934) and then titration was done by NaOH and Phenolphthalein indicator.

Statistical analysis

Mean ± standard error was employed in presenting some of the results obtained from this study. Soil properties across sites were subjected to Two-way analysis of variance (ANOVA), significant means were separated using the Fisher's Least Significance Differences (LSD) to test soil properties for factors of sites and depths, this was performed using the IBM SPSS statistics software version 19.0.0. Species with less than three entries in the data matrix (dominant species, structural parameters, diversity indices) were deleted to in order to increase definition of results (Barruch 2005) and their relationship with soil physicochemical properties as impacted by disturbance and predictors of the riparian forests in Southwestern Nigeria were subjected to Canonical Correspondence analysis (CCA). The interplay between the structural parameters of the dominant plant species and soil physicochemical properties were subjected to Principal Component Analysis (PCA) and Euclidean Non-metric multidimensional scaling to determine key edaphic factors that multidimensionally accounted for the recovery of the disturbed riparian sites as indicated by the presence of dominant species. The relationship between soil variables, structure and diversity indices of the dominant plant species were also subjected to correlation analysis. Tests were performed using the PAleontological STatistics (PAST) Version 3.17 software (Hammer et al. 2001).

Results

Floristics and structural characteristics of the woody species in the riparian forest sites

The floristics and structural parameters of the dominant woody species are shown in Table 1. The number of woody species were 56 that are distributed into different life forms; were tree (29), shrub (16) and liana (11) species. The number of genera encountered were 51, belonging to 29 families across study sites. Apocynaceae (6 species) and Euphorbiaceae (6 species) were families with the highest number of species. The heights of trees species ranged from 9.08±1.02 to 23.03±2.57m with *Musanga cecropioides* being the highest and *Olax subscorpioidea*, the smallest (Table 1). The basal area of the dominant tree species ranged from 0.27 to 6.22 m^2 ha^{-1} with *Pterocarpus santalinoides*, the highest and *Monodora tenuifolia*, the lowest (Table 1). The density of tree species ranged from 6.67 to 110 ha^{-1}, *Pterocarpus santalinoides* had the highest density while *Milicia excelsa*, *Monodora tenuifolia*, *Musanga* *cecropioides*, were the species with the lowest density (Table 1). The highest IVI important value in tree species was recorded in *Elaeis guineensis* while *Monodora tenuifolia* had the lowest across the study sites (Table 1). The heights of shrubs ranged from 3.09±0.52 to 7.31±1.24m, with *Hoslundia opposita* being the highest and *Alchornea cordifolia*, the lowest (Table 1). The basal area of shrub species ranged from 0.04 to 2.30 m^2 ha^{-1}, with *Rothmannia hispida* having the highest value and *Allophylus africanus,* the lowest value (Table 1). The density of shrub species ranged from 4.44 to 131.11 ha^{-1} with *Chassalia kolly* being the highest and *Allophylus africanus,* the lowest. *Pauridiantha hirtella* had the least IVI (4.76), while *Alchornea cordifolia* was the most important shrub species across the study sites (Table 1). The length of liana ranged from 5.31±0.91 to 14.07±2.41m, with *Pyrenacantha staudtii* being the longest and *Oncinotis gracilis*, the shortest (Table 1). The basal area ranged from 0.03 to 0.57 m^2 ha^{-1} being highest in *Jateorhiza macrantha* and lowest in *Chasmanthera dependens* and *Pyrenacantha staudtii* (Table 1). The density of liana species ranged from 2.29 to 39.99 ha^{-1} and IVI ranged 4.11 to 37.89, with *Paullinia pinnata* having the highest of two structural parameters and *Smilax anceps*, the lowest (Table 1). See data on plant species diversity and disturbance indices across study sites in Dryad Digital Repository, https://doi.org/10.5061/dryad.zgmsbccg3 .

Soil physiochemical properties of riparian forest sites

The values of soil pH across the nine sites in the top soil (0-15 cm) ranged from 4.6 -6.90 with a mean value of 5.8±0.29, while in the sub soil (15-30cm), pH ranged from 3.90-6.70 with a mean value of 5.6±0.26 (Table 2). The top soil pH was significantly ($F_{(8, 89)}$ = 17.03, p < 0.0001) higher in most sites except in II, IV and VIII where the sub soil were significantly higher than the top soil pH (Table 2). The top soil and sub soil organic carbon ranged from 1.96-2.81% with a mean value of 2.40±0.09 % and 1.81-2.65 % with a mean value of 2.30±0.11 % respectively (Table 2). The top soil organic carbon were significantly higher across sites except in Site II and VIII where the sub soil was significantly higher ($F_{(8, 89)}$ = 6.25, p < 0.0001) (Table 2). The top soil and sub soil organic matter and nitrogen content, ranged from 3.38-4.85 % with a mean value of 4.20 ±0.16 % SOM; 3.13-4.78 % with a mean value of 3.9 ±0.18 % N and 2.90-4.16% with a mean value of 3.6±0.13 SOM %; 2.68-4.01% with a mean value of 3.30±0.15 %N respectively (Table 2). The N content of the soil increased with increasing organic matter across depths in the studied sites (Table 2). The soil phosphorus content in the top and sub soil ranged from 3.1-4.2 mg/g with a mean value of 3.68 ±0.15 mg/g and 2.90-4.40 mg/g with a mean value of 3.60 ±0.16 mg/g respectively (Table 2).

The top soil and sub soil calcium content ranged from 4.20-6.00 cmol/kg with a mean value of 5.20 ±0.20 cmol/kg and 3.89-5.94 cmol/kg with a mean value of 4.80±0.23 cmol/kg respectively (Table 2). The top and sub soil magnesium ranged from 1.22-1.75 cmol/kg with a mean value of 1.50±0.06 cmol/kg, and 1.13-1.65 cmol/kg with a mean value of 1.40±0.07 cmol/kg (Table 2). The top soil and sub soil potassium content ranged from 0.71-1.03 cmol/kg with a mean value of 0.90 ±0.03 cmol/kg and 0.60-1.01 cmol/kg with a mean value of 0.80±0.04 cmol/kg respectively (Table 2). The top soil and sub soil sodium content ranged from 0.84-1.10 cmol/kg with a mean value of 0.90 ±0.04 cmol/kg, and 0.41-1.03 cmol/kg with a mean value of 0.80±0.06 cmol/kg respectively (Table 2). The total acidity in top and sub soil ranged from 0.28-0.40 cmol/kg with a mean value of 0.30±0.01 cmol/kg, and 0.26-0.37 cmol/kg with a mean value of 0.30±0.01cmol/kg respectively (Table 2). There was significant difference (p<0.05) between soil depths in organic matter, N, P, Ca, Mg, Na, K and total acidity with top soil being higher than sub soil across the studied sites except in site III, VIII and IX. The soil particle size showed that the sand fraction was dominant across study sites (Table 2). There was a significant difference in percentage sand, clay and silt across sites ($F_{(sand)}$ = 8.73, p = 2.98 E-8; $F_{(clay)}$ = 9.13, p = 1.43E-8 and $F_{(silt)}$ = 5.43, p = 8.77 E-5) (Table 2) respectively. The textural class in all sites studied was sandy clay. The soil bulk density across sites ranged from 0.25-0.65 g/cm3 with a mean value of 0.40 ± 0.04g/cm3 and moisture content ranged from 0.16-0.35 with a mean value of 0.30 ± 0.02. The moisture content of the soil across sites increased with decreasing bulk density (Table 2). Generally, there was no significant differences among all the soil physiochemical properties (pH, organic C, organic matter, N, P, Ca, Mg, K, Na, total acidity, sand and clay) across study sites except in the silt content of the soil (F (8, 89) =4.57, p=8.77 E-5) (Table 2).

The PCA further showed the most influential soil physicochemical properties across the study sites revealed that component 1 and component 2 explained 62.56% and 36.43% eigen values respectively of the interplay between the soil variables and sites (Figure 2). In the first component; pH and Soil bulk density (SB) negatively influenced the presence of the dominant woody species in sites I, IV, VIII, IX, while other properties are positively influenced on riparian sites. Calcium, OM, N and TOC were the leading variables, while Na and moisture content (MC) had the least influence on the dominance of the woody species across the study sites (Figure 2). In the second component, SB was the only parameter that negatively influenced, all other variables positively influenced, with pH showed the most and Na the least influence on the riparian sites (Fig. 2).

Relationship between species abundance and environmental variables across riparian forest sites

There is significant relationship (p<0.05) between species abundance and environmental variables across the riparian sites. In the Canonical Correspondence Analysis, axis 1 showed that the presence of some dominant life forms was largely influenced by some soil properties. For example, soil pH showed an inverse relationship with some dominant species such as *Monodora tenuifolia*, *Myrianthus arboreus, Pauridiantha hirtella*, *Brachystegia eurycoma*, *Trichilia prieureana*, in site IX (Figure 3). As pH decreased, their abundance increased in the riparian sites. The abundance of plant species such as *Albizia zygia, Jateorhiza macrantha*, *Morus mesozygia*, *Baphia nitida*, however, increased with increasing soil pH; while *Cola acuminata*, *Olax subscorpioidea*, were least positively influenced by soil pH in sites III and VI (Figure 3). In axis 2, the abundance of species such as *Mallotus oppositifolius*, *Piper guineense*, *Ricinodendron heudelotii Mallotus* increased with increasing soil P in sites II, IV, V and IX. The abundance of plant species such as *Allophylus africanus, Cnestis ferruginea*, *Allophylus africanus,* however, decreased with increasing soil P in site VII. (Figure 3). All other soil variables (TOC, OM, N, K, Mg, Ca, Na, TA) exhibited similar trends and did not show a clear pattern in terms of how they affected the abundance of the dominant plant species across the study sites (Figure 3).

The level of anthropogenic impacts on structures and soil variables across the riparian sites, showed that the first axis had variables such as P, TOC, OM, N, exchangeable cations and TA being disturbed and indicated positive influence on the height and basal area of dominant plant species e.g. *Albizia zygia, Lecaniodiscus cupaniodies* in the study sites (Figure 3). The pH markedly dictated the species density positively across study sites. The Euclidean Non-metric Multidimensional Scaling showed that the environmental variables had influence on the dominant species and sites, with pH having the most positive influence in the first coordinate at the sites (Figure 4). Total acidity (TA) N, OM, OC were also positively coordinated across the study sites in the first coordinate. The exchangeable cations indicated Ca, Mg and Na had positive influence in the first coordinate, while P and K showed negative influence in the second coordinate on the dominant plant species across study sites (Figure 4). Dominant species e.g. *Macaranga barteri*, *Myrianthus arboreus, Trichilia prieureana*, *Paullinia pinnata* negatively correlated, while species e.g. *Ricinodendron heudelotii* positively correlated for soil variables in the study sites (Figure 5). The diversity indices of the dominant species did not correlate with soil variables across study (Figure 3 and Figure 5).

Discussion

The results from soil nutrient status being higher at top soil than sub soil and the abundance of the dominant species reported in this study, e.g. *Albizia zygia*, *Musanga cecropioides*, *Pterocarpus santalinoides, Alafia barteri, Motandra guineensis, Paullinia pinnata, Alchornea cordifolia*, align with the findings reported in several studies in African tropical riparian forests (Natta et al. 2002; Sambare et al. 2011; Tsheboeng 2016). The dominance of some species in the families Apocynaceae, Euphorbiaceae, Rubiaceae, Fabaceae in the riparian vegetations give credence to the resilience of the soil therein, despite the prevailing anthropogenic activities to the supporting species belonging to these families which contributed mainly on appreciable amount of organic matter, N and P found in the riparian soil. This supports the hypothesis that most riparian forests are highly productive and support vast plant life forms due to sufficient nutrients stored in the soil. It is thus likely that the on-going anthropogenic activities in these riparian sites has not reached a level substantial enough to deplete the available nutrients in the sites. Furthermore, the study indicated association between species abundance and edaphic factors to be positive. Some of the observed variations in soil interaction may be useful as measures of ecosystem modification, and may help to detect management inadequacies to prevent or reverse soil quality. The findings of some soil variables e.g. TA, exchangeable cations not showing clear pattern exerting similar magnitude and direction to influencing the floristic structure and distribution of dominant species in the riparian forests is consistent with the trend reported by some authors, who opined that TA and exchangeable cations do not influence dominant woody species distribution across study sites (Silveira et al. 2009; Khairil et al. 2014). Edaphic factors such as P, TOC, OM, N, exchangeable cations were found to be affected by anthropogenic activities thereby leading to the removal of litter floor where most of these nutrients are domiciled. Few studies have documented the impact of anthropogenic activities on these elements such as P, TOC, OM, N where a negative influence was recorded in the study sites (Silveira et al. 2009; Njue et al. 2016).

Soil physical properties such as bulk density and textural classes were found to influence community density, community coverage, shrub coverage and diversity indices in the riparian sites. This is in line with the findings of Dinget al. (2017) who opined that the spatial distribution of riparian forests is dependent on soil particle, bulk density and soil moisture. The soil bulk density, in this study, indicated an inverse relationship with moisture content and higher nutrient contents with decreasing depths across the study sites. This influenced the soil porosity and compaction thus enabling dominant species to have available nutrients to thrive. This, however, was contrary to the findings of some authors who reported that higher bulk density positively correlated with key edaphic factors such as SOC (Qian et al. 2017). The sandy clay textural class reported in this study is similar to the findings of some authors (Njue et al. 2016; Tengfei et al. 2021). It should be noted that despite these disturbances, these nutrients were still sufficient and reflected a significant higher value in the top soil than sub soil across the study sites. This assertion conforms with the findings of some authors on tropical riparian forests (e.g. Qian et al. 2017; Zhao et al. 2022). It has been reported that the level of anthropogenic activities influenced floristic structures, diversity and distribution in riparian forests (Borisade et al. 2021; Borisade and Odiwe 2022). This reiterates the intrinsic ability of the soil properties to influence the composition of plant species found in the riparian forests. This is probably due to the ability of the herbaceous layers of riparian forests to constantly replenish depleting nutrients in this ecosystem (Borisade 2020; Tengfei et al. 2021). Consequently, this has an impact on ecological successional pathway of plant life forms and the abundance of certain species in a seral stage, for example, *Albizia zygia* and *Pterocarpus santalinoides* with high organic matter inputs influenced the productivity of other species in the study sites. However, the relationship between forest vegetation structure and soil chemical properties is very complex (Sarah and Rodeh, 2004; Li et al. 2013; Tengfei et al. 2021). Interestingly some soil variables were found to influence the structural dynamics of the riparian forests. Height, density, and basal area of dominant species e.g. *Monodora tenuifolia*, *Rothmannia hispida*, *Alafia barteri* were influenced by soil pH, P, TOC, OM, N, exchangeable cations and TA across the study sites. Tree density, diameter, height and basal area are variables of vegetation structure demonstrated to be good proxies for soil variables that indicates ecosystem services which adopts conservation policies (Celentano et al. 2016). Several researchers have reported correlations between soil properties, such as pH or phosphorus content, with forest properties, such as above-ground biomass or species distributions; and hypothesis have been drawn that, pioneer trees may grow several meters in a year, improving soil fertility by hastening soil organic-matter accumulation, thereby enhancing P concentration, and lowering pH (Condit et al. 2013; Vleut et al. 2013 ; Schaik and Mirmanto, 2013; Antonini et al. 2022) as observed in this study.

Soil factors that limit plant diversity may be dissimilar in various regions. Therefore, the skimpy relationship between soil variables and plant diversity indices in riparian forests at a regional scale needs to be explicated, as it is of very important in increasing the understanding of the vegetation dynamics of riparian forest ecosystems. The diversity indices of the species did not correlate with soil variables across study sites as reported by other workers (e.g. Bouchard et al. 2007; Tengfei et al. 2021 Antonini et al. 2022). This might indicate, that it is not diversity indices, but rather species composition and structures, especially density that determine the interplay between key edaphic factors and dominant plant species in the riparian forest sites studied. The only soil variable that correlated with diversity matrix was soil pH. However, this finding is contrary to the report of some authors who noted that species diversity to being predictors against soil variables in a non-linear relationship to improving the riparian ecosystems functionality and productivity (Li et al. 2022). In riparian forest sites with high diversity indices, high community pliability could be preserved by the several interactions between vegetation and soil properties (Ding et al. 2017).

Conclusions

This study revealed that the soil physicochemical properties were significantly higher in the top soil of riparian forests than those of the sub soil. Although there seemed to be a site-specific interaction among edaphic variables and vegetation structural parameters, some variables such as soil pH, soil BD, soil particle size distribution and soil moisture content played a significant role in determining the presence and dominance of most of the abundant woody species across the forest. The soil variables mostly influenced by anthropogenic activities were P, TOC, OM, N, exchangeable cations, but the level of the disturbance is not substantial to deplete the nutrients, therefore the forest is still able to maintain their nutrient contents to support dominant species similar to what is obtainable in tropical riparian forests. The riparian ecosystem functionality and productivity depends mainly on the interplay between soil variables and structural parameters, especially species density rather than diversity indices. Soil pH, P, TOC, OM were key edaphic factors that influenced the vegetation dynamics of these ecosystems. Therefore, in the face of increasing climate change resulting from land use e.g. forest conversion to urbanization and clearance as observed in this study. This presents evidences of the resilience of riparian forests, and therefore provided important findings that are needed in maintaining ecological succession, services and enhance proper decision-making policies towards conservation of the riparian forest ecosystems in Nigeria.

Declarations

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Authors' contribution

TVB conceived the design of the work and drafted the manuscript. AIO supervised the fieldwork and reviewed the original manuscript. NOU and AAO was involved in providing primary data, statistical analysis and review of the original manuscript

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Data availability

The authors declare that there is no additional dataset other than the ones presented in this research work

Code availability Not applicable

Ethics approval Not applicable

Consent to participate Not applicable

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Conflict of interests

There are no conflicts of interest

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Tables

Table 1 Floristics and structural characteristics of the woody species in the riparian forest sites

S/N	SPECIES	ABV.	FAMILY	H (m)	BA (m^2 ha^{-1})	DEN (Ha^{-1})	IVI
	A		TREES				
1	*Albizia zygia*	Alb.zy	Fabaceae	14.53±1.63	5.11	55.56	15.42
2	*Brachystegia eurycoma*	Bra.eu	Fabaceae	17.41±1.95	7.38	8.89	5.007
3	*Cola acuminate*	Col.ac	Sterculiaceae	11.06±1.24	1.42	22.22	5.16
4	*Cola millenii*	Col.mi	Sterculiaceae	14.55±1.63	1.18	11.11	4.21
5	*Elaeis guineensis*	Ela.gu	Palmae	14.31±1.59	4.73	85.56	21.23
6	*Funtumia elastica*	Fun.el	Apocynaceae	13.25±1.48	4.18	35.56	8.25
7	*Lecaniodiscus cupaniodies*	Lec.cu	Sapindaceae	11.08±1.24	2.02	24.44	8.09
8	*Macaranga barteri*	Mac.ba	Euphorbiaceae	10.47±1.17	0.92	8.89	2.51
9	*Mallotus oppositifolius*	Mal.op	Euphorbiaceae	12.12±1.36	0.72	20.00	4.45
10	*Milicia excelsa*	Mil.ex	Apocynaceae	14.17±1.59	1.17	6.67	3.42
11	*Millettia thonningii*	Mil.th	Papilionaceae	14.49±1.62	2.92	35.56	8.33
12	*Monodora tenuifolia*	Mon.te	Annonaceae	10.02±1.12	0.27	6.67	2.14
13	*Morus mesozygia*	Mor.me	Moraceae	12.07±1.35	0.74	8.89	4.85
14	*Musanga cecropioides*	Mus.ce	Urticaceae	23.03±2.57	2.01	6.67	2.50
15	*Myrianthus arboreus*	Myr.ar	Moraceae	11.31±1.26	1.85	20.00	4.17
16	*Napoleona imperialis*	Nap.im	Lecythidaceae	12.78±1.43	0.27	8.89	2.20
17	*Napoleona vogelii*	Nap.vo	Lecythidaceae	10.96±1.23	0.69	17.78	5.55
18	*Newbouldia laevis*	New.la	Bignoniaceae	17.54±1.96	1.63	42.22	10.42
19	*Olax subscorpioidea*	Ola.su	Olacaceae	9.08±1.02	3.82	22.22	6.64
20	*Pterocarpus santalinoides*	Pte.sa	Fabaceae	18.58±2.08	6.22	110.00	19.67
21	*Pycnanthus angolensis*	Pyc.an	Myristicaceae	10.42±1.17	1.72	17.78	4.62
22	*Rauvolfia vomitoria*	Rau.vo	Apocynaceae	12.13±1.36	0.30	13.33	2.36
23	*Ricinodendron heudelotii*	Ric.he	Euphorbiaceae	14.18±1.59	5.23	17.78	4.47
24	*Spondias mombin*	Spo.mo	Anacardiaceae	12.51±1.02	1.89	20.00	4.08
25	*Sterculia tragacantha*	Ste.tr	Sterculiaceae	12.18±1.36	2.82	18.89	7.43
26	*Strombosia pustulata*	Str.pu	Olacacaeae	11.90±1.33	0.45	8.89	2.86
27	*Trichilia heudelotii*	Tri.he	Meliaceae	13.43±1.27	1.72	15.56	2.49
28	*Trichilia prieureana*	Tri.pr	Meliaceae	16.38±1.83	2.29	44.44	6.300
29	*Uapaca heudelotii*	Uap.he	Euphorbiaceae	11.16±1.25	3.36	8.89	3.50
	B		SHRUB				
1	*Alchornea cordifolia*	Alc.co	Euphorbiaceae	3.09±0.52	1.74	67.78	27.82
2	*Alchornea laxiflora*	Alc.la	Euphorbiaceae	4.07±0.69	1.12	22.22	15.47
3	*Allophylus africanus*	All.af	Sapindaceae	3.69±0.62	0.04	4.44	15.47
4	*Baphia nitida*	Bap.ni	Fabaceae	4.84±0.82	1.10	40.00	11.21
5	*Byrsocarpus coccineus*	Byr.co	Connaraceae	4.01±0.68	0.69	13.33	15.44

Table 1 contd. Floristics and structural characteristics of the woody species in the riparian forest sites

6	*Carpolobia lutea*	Car.lu	Polygalaceae	5.38±0.91	1.02	33.33	7.14
7	*Chassalia kolly*	Cha.ko	Rubiaceae	3.92±0.66	1.01	131.11	19.30
8	*Cnestis ferruginea*	Cne.fe	Connaraceae	4.89±0.83	1.05	20.00	23.88
9	*Coffea ebracteolata*	Cof.eb	Rubiaceae	4.53±0.77	1.15	13.33	14.89
10	*Deinbollia pinnata*	Dei.pi	Sapindaceae	4.78±0.81	1.45	11.11	7.73
11	*Hibiscus surattensis*	Hib.su	Malvaceae	4.11±0.69	0.71	20.00	16.19
12	*Hoslundia opposite*	Hos.op	Labiatae	7.31±1.24	0.40	8.89	6.54
13	*Pauridiantha hirtella*	Pau.hi	Rubiaceae	5.66±0.96	0.08	28.89	4.76
14	*Rothmannia hispida*	Rot.hi	Rubiaceae	4.49±0.76	2.30	17.78	17.34
15	*Triumfetta cordifolia*	Tri.co	Tiliaceae	3.42±0.58	0.54	28.89	17.62
16	*Urena lobata*	Ure.lo	Malvaceae	4.02±0.68	0.17	11.11	20.48
	C		LIANA				
1	*Alafia barteri*	Ala.ba	Apocynaceae	8.05±1.38	0.39	33.13	33.13
2	*Baissea axillaris*	Bai.ax	Apocynaceae	6.45±1.11	0.29	29.07	29.07
3	*Chasmanthera dependens*	Cha.de	Menispermaceae	4.37±0.75	0.03	8.94	8.94
4	*Clerodendrum volubile*	Cle.vo	Verbenaceae	11.31±1.94	0.36	8.77	8.77
5	*Jateorhiza macrantha*	Jat.ma	Menispermaceae	9.05±1.55	0.57	6.11	6.11
6	*Motandra guineensis*	Mot.gu	Apocynaceae	6.88±1.18	0.31	23.73	23.73
7	*Oncinotis gracilis*	Onc.gr	Periplocaceae	5.31±0.91	0.08	7.96	7.96
8	*Paullinia pinnata*	Pau.pi	Sapindaceae	6.21±1.06	0.20	39.99	39.99
9	*Piper guineense*	Pip.gu	Piperaceae	5.08±0.87	0.11	7.80	7.80
10	*Pyrenacantha staudtii*	Pyr.st	Icacinaceae	14.07±2.41	0.03	19.64	19.64
11	*Smilax anceps*	Smi.an	Smilacaceae	5.39±0.92	0.07	2.29	5.16

H= Height; BA=Basal area; DEN=Density; IVI=Important Value Index

Table 2 Soil physiochemical properties of riparian forest sites in Southwestern Nigeria

		Site (n=5)								
	Soil property	I	II	III	IV	V	VI	VII	VIII	IX
1	pH (1: $Cacl_2$)									
	Top soil (0-15 cm)	6.80±0.33[a]	5.40±0.06[b]	6.10±0.01[b]	4.60±0.16[b]	4.90±0.17[a]	5.80±0.19[a]	6.60±0.30[a]	5.00±0.19[b]	6.9±0.34[a]
	Sub soil (15-30 cm)	6.00±0.30[b]	5.70±0.24[a]	6.20±0.12[a]	5.50±0.2 [a]	3.90±0.13[b]	5.50±0.05[b]	5.40±0.22[b]	6.70±0.29[a]	6.00±0.31[b]
2	SPSD (%)									
a	Sand									
	Top soil (0-15 cm)	68.00±1.15[b]	82.00±2.37[a]	78.00±2.31[a]	81.00±2.36[a]	68.00±1.15[b]	76.00±2.28[a]	79.00±2.34[a]	75.00±2.05[a]	66.00±1.08
	Sub soil (15-30 cm)	79.00±2.34[a]	80.00±2.34[b]	66.00±1.08[b]	75.00±2.05[b]	77.00±2.30[a]	75.00±2.05[b]	68.00±1.15[b]	59.00±1.03[b]	68.00±1.15
b	Silt									
	Top soil (0-15 cm)	8.00±0.06[ab]	7.00±0.05[bc]	9.00±0.08[b]	7.00±0.05 [bc]	6.00±0.06[cd]	7.00±0.05 [bc]	5.00±0.04 [cd]	8.00±0.06 [ab]	11.00±0.10
	Sub soil (15-30 cm)	9.00±0.08[b]	8.00±0.06[ab]	11.00±0.10[ab]	8.00±0.06[ab]	9.00±0.07[b]	11.00±0.10[ab]	13.00±0.12[a]	16.00±0.14[a]	7.00±0.34[c]
c	Clay									
	Top soil (0-15 cm)	24.00±2.04[a]	11.00±0.99[b]	13.00±1.11[b]	12.00±1.10[b]	26.00±2.15[a]	17.00±1.76[a]	16.00±1.75[b]	17.00±1.76[b]	23.00±2.07
	Sub soil (15-30 cm)	12.00±1.10[b]	12.00±1.10[a]	23.00±2.07[a]	14.00±1.13[a]	14.00±1.13[b]	14.00±1.13[b]	19.00±1.78[a]	25.00±2.03[a]	25.00±2.03
d	Textural Class									
	Top soil (0-15 cm)	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay
	Sub soil (15-30 cm)	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay
3	Bulk Density (g/cm^3)									
	Top soil + sub soil (0-30cm)	0.33	0.44	0.45	0.25	0.40	0.38	0.26	0.65	0.54
4	Moisture content	0.29	0.21	0.27	0.35	0.25	0.22	0.34	0.16	0.17
5	Organic matter									
	Top soil (0-15 cm)	3.93±0.15[a]	4.53±0.16[a]	3.38±0.14[b]	4.20±0.16 [a]	4.85±0.12[a]	4.30±0.18[a]	4.62±0.17[a]	3.70±0.10[b]	3.88±0.1 [b]
	Sub soil (15-30 cm)	3.13±0.12[b]	3.56±0.12[b]	4.78±0.18[a]	3.30±0.12 [b]	4.57±0.14[b]	3.99±0.14[b]	3.64±0.13 [b]	3.92±0.1 [a]	4.15±0.1 [a]

Table 2 contd. Soil physiochemical properties of riparian forest sites in Southwestern Nigeria

6	Organic carbon									
	Top soil (0-15 cm)	2.28±0.10^{a}	1.96±0.05^{b}	2.63±0.13^{b}	2.43±0.11^{a}	2.81±0.0^{a}	2.50±0.08^{a}	2.68±0.14^{a}	2.14±0.07^{a}	2.25±0.08^{b}
	Sub soil (15-30 cm)	1.81±0.04^{b}	2.07±0.07^{a}	2.77±0.14^{a}	1.91±0.06^{b}	2.65±0.13^{b}	2.31±0.11^{b}	2.11±0.07^{b}	2.27±0.09^{b}	2.41±0.10^{a}
7	Nitrogen (%)									
	Top soil (0-15 cm)	3.37±0.13^{a}	3.88±0.19^{a}	2.90±0.18^{b}	3.60±0.17^{a}	4.16±0.20^{a}	3.69±0.17^{a}	3.96±0.19^{a}	3.17±0.11^{b}	3.33±0.12^{b}
	Sub soil (15-30 cm)	2.68±0.12^{b}	3.05±0.14^{b}	4.01±0.20^{a}	2.83±0.10^{b}	3.92±0.19^{b}	3.42±0.14^{b}	3.12±0.10^{b}	3.36±0.12^{a}	3.56±0.18^{a}
8	P (mg/g)									
	Top soil (0-15 cm)	3.60±0.11^{a}	4.20±0.20^{a}	3.10±0.10^{b}	3.90±0.1^{a}	4.50±0.21^{a}	4.00±0.19^{a}	4.20±0.15^{a}	3.40±0.12^{b}	3.68±0.18^{b}
	Sub soil (15-30 cm)	2.90±0.98^{b}	3.30±0.12^{b}	4.40±0.19^{a}	3.00±0.10^{b}	4.20±0.20^{b}	3.70±0.17^{b}	3.40±0.12^{b}	3.60±0.13^{a}	3.80±0.19^{a}
9	Ca (cmol/kg)									
	Top soil (0-15 cm)	4.89±0.20^{a}	5.63±0.26^{a}	4.20±0.19^{b}	5.22±0.23^{a}	6.03±0.27^{a}	5.35±0.23^{a}	5.74±0.25^{a}	4.60±0.19^{b}	4.83±0.21^{b}
	Sub soil (15-30 cm)	3.89±0.16^{b}	4.43±0.17^{b}	5.94±0.22^{a}	4.10±0.18^{b}	5.68±0.25^{b}	4.96±0.21^{b}	4.53±0.20^{b}	4.87±0.20^{a}	5.16±0.24^{a}
	Top soil (0-15 cm)	1.42±0.04^{a}	1.64±0.06^{a}	1.22±0.02^{b}	1.52±0.06^{a}	1.75±0.08^{a}	1.56±0.05^{a}	1.67±0.07^{a}	1.34±0.02^{b}	1.41±0.03^{b}
	Sub soil (15-30 cm)	1.13±0.01^{b}	1.29±0.05^{b}	1.73±0.08^{a}	1.19±0.01^{b}	1.65±0.07^{b}	1.44±0.04^{b}	1.32±0.02^{b}	1.42±0.03^{a}	1.50±0.06^{a}
11	K (cmol/kg)									
	Top soil (0-15 cm)	0.83±0.03^{a}	0.96±0.05^{a}	0.71±0.01^{b}	0.89±0.03^{a}	1.03±0.05^{a}	0.91±0.04^{a}	0.98±0.04^{a}	0.78±0.02^{b}	0.82±0.03^{b}
	Sub soil (15-30 cm)	0.66±0.02^{b}	0.75±0.02^{b}	1.01±0.05^{a}	0.70±0.02^{b}	0.97±0.05^{b}	0.84±0.03^{b}	0.77±0.03^{b}	0.83±0.03^{a}	0.88±0.03^{a}
12	Na(cmol/kg)									
	Top soil (0-15 cm)	0.90±0.05^{a}	1.03±0.07^{a}	0.77±0.05^{b}	0.96±0.05^{a}	1.10±0.07^{a}	0.98±0.05^{a}	1.05±0.05^{a}	0.84±0.03^{b}	0.88±0.05^{b}
	Sub soil (15-30 cm)	0.71±0.03^{b}	0.61±0.03^{b}	1.03±0.07^{a}	0.75±0.04^{b}	0.90±0.05^{b}	0.41±0.01^{b}	0.83±0.03^{b}	0.89±0.05^{a}	0.94±0.06^{a}
13	Acidity(cmol/kg)									
	Top soil (0-15 cm)	0.32±0.03^{a}	0.37±0.03^{a}	0.28±0.01^{b}	0.34±0.02^{a}	0.40±0.03^{a}	0.35±0.02^{a}	0.38±0.02^{a}	0.30±0.01^{b}	0.32±0.01^{b}
	Sub soil (15-30 cm)	0.26±0.01^{b}	0.29±0.01^{b}	0.39±0.03^{a}	0.27±0.01^{b}	0.37±0.02^{b}	0.33±0.02^{b}	0.30±0.01^{b}	0.32±0.01^{a}	0.34±0.01^{a}

n=number of plots, SPSD=Soil Particle Size distribution

Figures

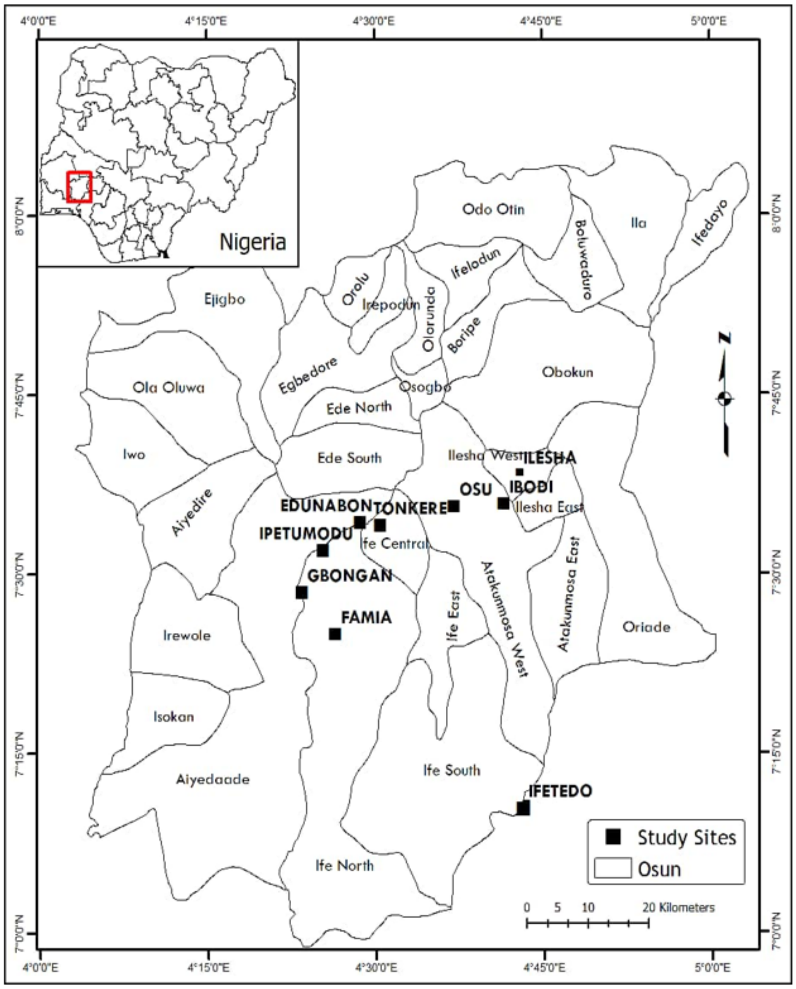

Figure 1

Study area of the riparian forest sites in Southwestern Nigeria

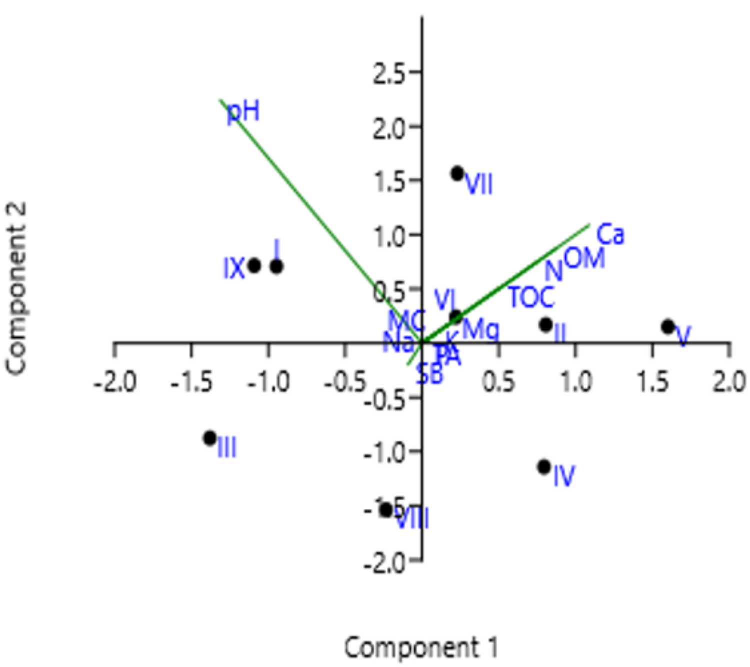

Figure 2

Principal Component Analysis of soil variables across study sites

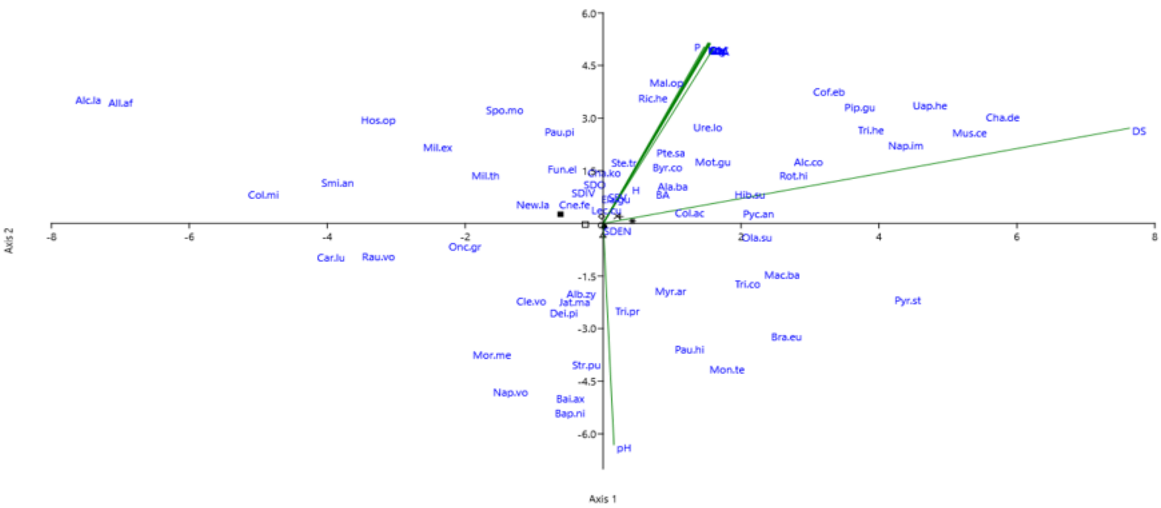

Figure 3

Canonical Correspondence Analysis of soil variables on structural and diversity indices of dominant woody species across study sites

KEYS

Dot-site I; Plus -site II; Square- site III; Fill square – site IV; X – site V; O-site VI; Diamond-site VII; Star- site VIII and Triangle- site IX

Species density – SDEN; Basal Area- BA; H-Height; DS-Disturbance Scores; Species dominance – SDO; Species diversity – SDIV. Species evenness – SEV

See full botanical nomenclature of abbreviated dominant plant species in Table 1

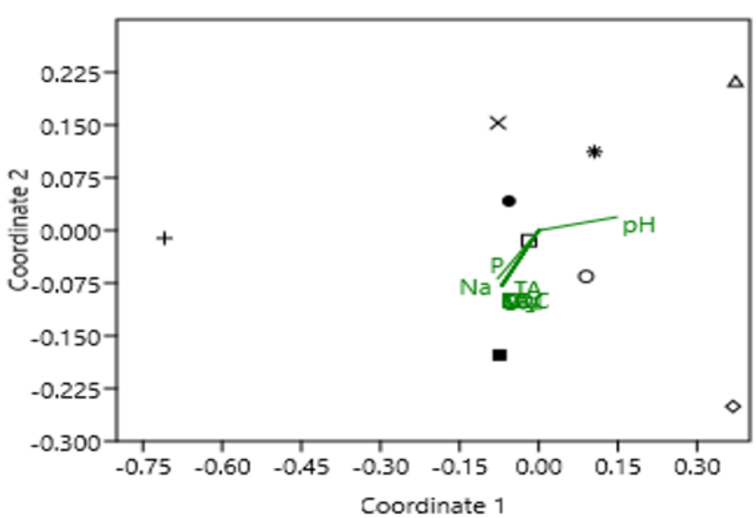

Figure 4

Non-metric dimensional scaling indicating level of soil variables on dominant species across study sites

KEYS

Dot-site I; Plus -site II; Square- site III; Fill square – site IV; X – site V; O-site VI; Diamond VII; Star- site VIII and Triangle- site IX

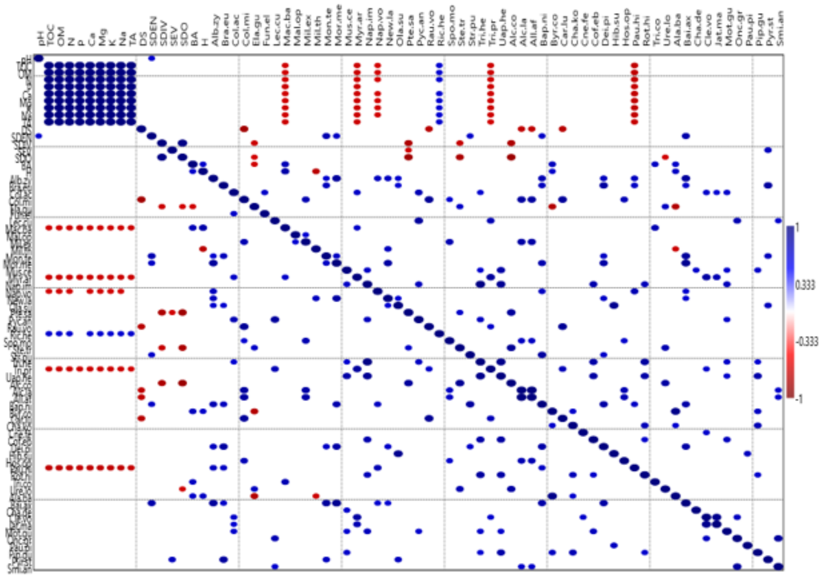

Figure 5

Pearson correlation between soil properties, structures and diversity indices of dominant species across study sites. *p>0.05 is reflected as blank