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Determination of Slenderness Coefficient and Physiognomic Characteristics of Tree-Species in Kano Zoological Garden, Kano State Nigeria

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Abstract
This research was carried out to Determine the slenderness coefficient and Physiognomic Characteristics of Tree Species in Kano Zoological Garden. The area was stratified in to four strata. Fourteen (14) temporary sample plots of size (30x30m^2) were laid at random covering all stratum. Trees with Diameter at Breast Height (DBH) ≥ 10cm were identified, measured and recorded. Individual trees were grouped in to species and families. The results revealed diameter class 21-40 exhibits the highest cumulative values for DB, DM, DT, TH, SLC, BA, and SV indicating that trees within the 21-40cm diameter range contribute the most to the overall size, height, slenderness, basal area, and stem volume. Trees in the 81-100cm diameter range have the lowest cumulative values, suggesting they are relatively smaller and contribute less to the overall forest dimensions. Height Class (21-30) recorded the highest values for all parameters indicating that trees in this height class have the largest diameters, slenderness coefficient, basal area, and stem volume. SLC, BA, and SV are significantly higher compared to other height classes. The 41-60m height classes show lower values representing smaller or less mature trees. The "1-69 Low" trees have a slightly tapered but balanced form and more stable to windthrow. The "70-99 Moderate" trees exhibit a more pronounced taper in their shape while the ">100 High" trees have a tall and slender form with a significant taper making them vulnerable to windthrow compared to the moderate and low classes. Positive correlation was observed between all the variables with the exception of SLC which display negative relation with all the variables signifying inverse relationship.

Keywords: Slenderness Coefficient, Physiognomy, Wind, Stability, Height and DBH

1. Introduction

Vegetation serves as a fundamental component of the Earth's ecosystem, connecting soil, air, water, and other environmental elements (Liu *et al*., 2021) [14]. As the primary constituent of terrestrial ecosystems, vegetation acts as a sensitive indicator of ecosystem health. Its crucial role in dry areas cannot be overstated, influencing climate regulation, water availability, and soil stability, upon which the livelihoods of many of the 40 billion people in these regions depend (Mishra *et al.*, 2015). Given vegetation's critical importance to human life in drylands, numerous studies have investigated changes in vegetation and the factors contributing to widespread biodiversity loss in these areas. Krosby *et al*. (2018) [12] outlined four key aspects for assessing vegetation: understanding the broad ecological characteristics of the site, monitoring biodiversity trends at both community and species levels, tracking changes in biodiversity, and evaluating its potential to contribute to regional conservation targets related to trend and change. Mohammed *et al.* (2016) [15] emphasizes that assessing the condition and type of vegetation cover is essential for managing land cover changes sustainably and ensuring the responsible use of natural resources.

Forest trees offer a diverse array of benefits that increase human reliance on forests (Kazoora *et al.*, 2020) [11]. This dependence spans individual, household, community, and regional levels. Past research has extensively categorized and identified the values associated with forests (Price *et al*., 2022) [20], typically distinguishing between instrumental and non-instrumental, material and non-material, and anthropogenic and biocentric categories. Fisher (2020) [8] elaborates on forest value typologies and categories, including distinctions like ecosystem outputs versus amenity and protection values. There exist numerous forest values that fit into these categories, encompassing ecological/environmental, economic, recreational, aesthetic, cultural, intrinsic, spiritual, therapeutic, scientific, and respect and admiration values (Fisher, 2020) [8]. All community trees and forests hold significant value as they provide a multitude of goods and services crucial to the majority of North America's population. The majority of Americans (Dias, 2022) [7] and Canadians (Roman, 2022) now reside in urban and suburban areas, underscoring the importance of these forest values. These values can be defined as attributes, components, or qualities considered significant by stakeholders in relation to identified forest elements (Barona, 2022) [3], benefiting tree owners, local communities, and society at large (Colinas, 2019) [5]. Residents in urban areas interact extensively with urban forests—they plant, maintain, conserve, and highly value trees due to their various benefits (Turner-Skoff & Cavender, 2019) [23]. These benefits can stem from individual tree attributes or collective functions of tree groups (Colinas, 2019) [5]. They are often categorized into ecosystem, economic, and social benefits (La Notte, 2019; Ordóñez, 2022), contributing significantly to urban living conditions. The value of urban forests can be defined as the net benefits society derives from them (Nyelele & Kroll, 2020) [16]. Urban trees serve diverse functions and provide numerous benefits, ranging from straightforward to less apparent, offering ample opportunities to enhance urban environments (Großmann, 2020) [9]. The key concept is that urban dwellers not only derive single-use values from community trees and forests but also enjoy multiple benefits across various dimensions.

The Tree Slenderness Coefficient (TSC) is defined as the ratio of a tree's total height (THT) to its diameter outside bark at 1.3 meters (4.5 feet) above ground level, commonly known as diameter at breast height (DBH). The study of TSC in quantitative forestry has gained increasing importance due to the vulnerability of many exotic tree species to natural phenomena such as wind damage, blow down, breaking, or uprooting, especially under high-intensity wind conditions. This susceptibility has led to elevated mortality rates in exotic species like *Pinus caribaea* across various ecological zones in sub-Saharan African countries, including Nigeria (Adeyemi & Taofeek, 2020) [2]. The potential for forest stands to experience wind throw or damage is significantly influenced by the tree slenderness coefficient (TSC) or taper of the trees (Shamaki & Oyelade, 2022) [22]. This vulnerability is typically assessed based on a combination of tree growth characteristics (TGCs), stand conditions, soil quality, site characteristics, topography, and wind patterns (Oyebade *et al.*, 2015) [19]. These factors collectively highlight the influence of biological and physical elements on the stability of individual trees and stands, particularly in exotic species (Osundun, 2021) [18]. Despite extensive global research on slenderness coefficient and stand stability potential (Oyebade *et al.,* 2015) [19], specific studies on TSC and its correlation with TGCs in Nigeria, particularly in conifer stands dominated by Pinus caribaea, have been lacking. Given ongoing climate changes, environmental degradation, and desert encroachment in tropical regions like Nigeria, there is a critical need for a comprehensive assessment of the relationship between TSC and TGCs to evaluate stand stability in *Pinus caribaea*. Oyebade *et al.* (2015) [19] have highlighted insufficient attention to the growth characteristics of many exotic species in Nigeria, emphasizing that silvicultural interventions without a thorough understanding of growth patterns often lead to ineffective management decisions and reduced stand productivity. Therefore, this study aims to explore the connection between tree slenderness coefficient and tree physiognomies in the context of tree species found in Kano Zoological Garden.

2. Methodology

2.1 Study Area

Kano state is located within the longitude $9^0$30 and $12^0$30N and latitude $9^0$30 and $8^0$42E. it falls within Sudan-Savanna Ecological Zone of West Africa measuring about 840km away from the edge of the Sahara-Desert and 1140km from Atlantic Ocean (Bichi *et al.,* 2016) [4]. The temperature of Kano usually ranges between a maximum of 33°C and a minimum of 18.85°C although sometimes during winter it falls down to as low as 10°C. Kano Zoological Garden is the largest zoo owned by the State Government in Nigeria. Officially launched in 1972 during military administration lead by Alhaji Audu Bako. The zoo occupies an area of about 46 hectares housing about 75 different species, comprising about 350 animals. The zoo usually opens from 7:30am to 6:30pm every day. It was registered by Pan African Association of Zoos and Aquaria (PAAZA) and International Zoo Educators (IZE) in 2007 and 2010 respectively. The zoological garden has array of species including 23 non-human primates, these are; Sooty Mangabey (*Cercocebus atys*), Tantalus Monkey (Cercopithecus tantalus), Chimpanzee (*Pan trogolodytes*), Dog faced Baboon (Papio Anubis), Red patas Monkey (*Erythrocebus patas*), Mona Monkey (*Cercopithecus mona*) (Bichi *et al.,* 2016) [4].

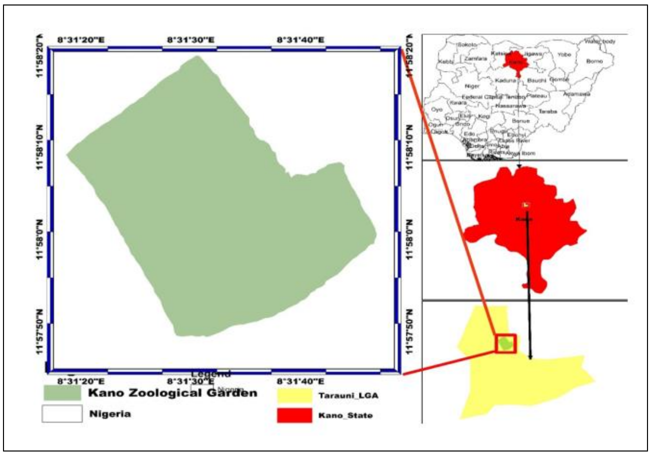

Fig 1: Map of Kano Zoological Garden

Sampling Procedure

The study area was stratified in to four (4) strata namely: Administrative area, Animal Pens, Garden and bush. Fourteen (14) temporary sample plots of size ($30x30m^2$) were laid at random covering all stratum. Trees with Diameter at Breast Height (DBH) ≥ 10 cm were identified, measured and recorded. Individual trees were grouped in to species and families.

2.2 Biometric Data Collection

The data obtained include

1. Counting and recording of individual all trees within each plot
2. Measuring the total height all selected plots using Haga

Altimeter
3. Diameter at the breast height (DBH) of all individual trees were measured at 1.3m, flexible measuring tape was used to determine the circumference of the boles.
4. Diameter at three different points (Base, middle, Top) were determined with the aid of Spiegel Relascope adopted by (Dantani *et al.*, 2019) [6]

2.3 Computations and Data Analysis
The data obtained from this research will be used for the computation of population parameters employing the following equations below.

2.4 Basal area computation
The basal area for each sampled tree was determined using the formula suggested by Husch *et al*., (2003) [10] and adopted Dantani *et al.*, 2019) [6]

$$BA = \frac{\pi D^2}{4} \quad (1)$$

Where: BA = Basal area in m^2; D = Diameter at breast height (m); π = Pi (3.142)

Basal area per plot were obtained by adding the basal area of all individual trees within the plot. Basal area per hectare for each age series was determined by first summing the basal areas of the 30 sample plots selected from the age series and finding their mean, then multiplying the mean basal area per plot by the number of sample plots per hectare which is 16.

Volume estimation
The stem volume of each mean tree was estimated using the Newton's formula (Husch *et al.,* 2003) [10]. The formula is expressed as:

$$SV = \frac{\pi h\left(D_b^2 + 4D_m^2 + D_t^2\right)}{24} \quad (2)$$

Where: SV = Stem volume in (m^3)
D_b = Diameter (m) at the base of the tree
D_m = Diameter (m) at the middle of the tree
D_t = Diameter (m) at the top of the tree
H = Total height of the tree (m).

Volume in a plot was obtained by summing volumes of all individual trees per plot (Vp) while mean volume per plot was obtained by adding all the volume in sampled plots divided by the number of all sampled plots. Volume per hectare was determined by multiplying plot volume with the number of plots in a hectare (Vp x 25plots)

2.5 Tree slenderness coefficient estimation
Tree Slenderness Coefficient was estimated for all trees using:

$$SC = \frac{Hi}{DBHi} \quad (3)$$

Where: Hi = total height of the ith tree; Dbhi = corresponding Dbh.

The measured trees were classified according to the SC as follows:
SC < 70: low slenderness coefficient; SC: 70 - 80: moderate slenderness coefficient;
SC > 80: high slenderness coefficient.
The number of trees/ha and percentage of trees in each of the SC categories was computed for the area. Adopted by Adeyemi and Ugo-Mbonu, (2017) [1].

2.6 Relationship Between Tree Variables
Pearson Moment Correlation was used to determine the relationship between growth and yield characteristics, the equation is as follows.

$$r = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}} \quad (4)$$

Where r = Pearson correlation coefficient; N = number of pairs of the stock; ∑xy = sum of products of the paired stocks; ∑x = sum of the x scores; ∑y = sum of the y scores; $\sum x^2$= sum of the squared x scores; $\sum y^2$ = sum of the squared y score

3. Result and Discussion
3.1 Summary Statistics
This table provides summary statistics for growth and yield characteristics of the trees. Mean: Represents the average value of each characteristic across all samples. SEM (Standard Error of Mean): Indicates the precision of the sample mean. SD (Standard Deviation): A measure of the amount of variation or dispersion of a set of values. Min (Minimum): The smallest value observed in the dataset. Max (Maximum): The largest value observed in the dataset. Sum: The total sum of each characteristic across all samples. Average of the variables, DBH = 29.722 cm, DB = 36.442 cm, DM = 25.87 cm, DT = 19.892 cm, TH = 24.333 m. SLC = 94.017% BA = 0.0842 m², SV = 13.0362 m³.

Table 1: Summary Statistics of Growth and Yield Characteristics

	DBH(cm)	DB(cm)	DM(cm)	DT(cm)	TH(m)	SLC	BA(m^2)	SV(m3)
N	335	335	335	335	335	335	335	335
Mean	29.722	36.442	25.87	19.892	24.333	94.017	0.0842	13.0362
SEM	0.7504	1.0882	0.476	0.6735	0.4175	2.2941	0.00518	0.94818
SD	13.7351	19.9165	8.707	12.326	7.6416	41.9887	0.09489	17.3545
Min	8.9	9.6	10	10.0	11.2	25.5	0.01	0.68
Max	99.1	1.0882	68	177.0	55.3	302.4	0.77	136.05
Sum	9956.9	12208.0	8668	6663.8	8151.5	31495.6	28.20	4367.12

DBH=Diameter at Breast, DB=Diameter at Base, Diameter at Middle, Diameter at Top, Total Height, SLC=Slenderness Coefficient, BA=Basal Area, SV=Stem Volume, SEM=Standard Error of Mean, SD=Standard Deviation, Min=Minimum, Max=Maximum

3.2 Diameter distribution class

The growth and yield characteristics were categorized by diameter class in Table 2 below. Different diameter classes ranging from 1-20, 21-40, 41-60, 61-80, to 81-100. DB(cm), DM(cm), DT(cm), TH(m), SLC, BA(m²), SV(m³): This diameter class 21-40 exhibits the highest cumulative values for DB, DM, DT, TH, SLC, BA, and SV. Indicates that trees within the 21-40 cm diameter range contribute the most to the overall size, height, slenderness, basal area, and stem volume of the forest. Trees in the 41-60 cm diameter range have the second-highest cumulative values for growth and yield characteristics. Contributes significantly to the overall forest structure and productivity. Trees in the 1-20 cm diameter range have the third-highest cumulative values. Represents the early stages of tree growth and development in the forest. this diameter class 61-80 has values lower than the previous classes, indicating trees in a mid-range of growth and yield characteristics. Trees in the 81-100 cm diameter range have the lowest cumulative values, suggesting they are relatively smaller and contribute less to the overall forest dimensions.

Table 2: Diameter distribution class

DBH-class)	DB(cm)	DM(cm)	DT(cm)	TH(m)	SLC	BA(m²)	SV(m³)
1-20	1916.20	1954.75	1466.0	238.00	247.00	1.91	319.95
21-40	7220.66	5023.00	3763.8	568.00	374.00	13.84	2065.09
41-60	1925.62	1090.00	839.0	116.00	43.00	6.67	920.76
61-80	826.80	446.25	415.0	35.00	11.00	3.57	695.90
81-100	318.75	153.75	180.0	11.00	3.00	2.20	365.43
DBH=Diameter at Breast, DB=Diameter at Base, Diameter at Middle, Diameter at Top, Total Height, SLC=Slenderness Coefficient, BA=Basal Area, SV=Stem Volume							

3.3 Height class distribution

The Table (3) below provides information on the growth and yield characteristics categorized by height class. Different height classes ranging from 11-20, 21-30, 31-40, 41-50, to 51-60. DB(cm), DM(cm), DT(cm), SLC, BA(m²), SV(m³), DBH(cm): Height Class (11-20): Highest Value: DB(cm) at 3725.30, indicating a diverse range of tree diameters within this height class. Other Notable Values: DM(cm), DT(cm), BA(m2), and SV(m3) are also relatively high. Height Class (21-30) recorded the highest values for all parameters indicating that trees in this height class have the largest diameters, slenderness coefficient, basal area, and stem volume. SLC, BA, and SV are significantly higher compared to other height classes. Height Class (31-40): Presents moderate values across all parameters. DBH(cm) is relatively lower than the other height classes. Shows a balance between diameter, slenderness, basal area, and stem volume. Height Class (41-50): Represents the lowest values for all parameters. Trees in this height class have the smallest diameters and contribute less to overall basal area and stem volume indicating that this height class may consist of smaller or younger trees. Height Class (51-60): Low Values similar to the 41-50 class, but with even smaller diameters and reduced contributions to basal area and stem volume. Reflects the presence of smaller or recently established trees. The 21-30-meter height class stands out with the highest values, suggesting that this range has the most substantial contribution to forest structure and productivity. The 41-60-meter height classes, on the other hand, show lower values, indicating the presence of smaller or less mature trees.

Table 3: Height class distribution

Height-class	DBH(cm)	DB(cm)	DM(cm)	DT(cm)	SLC	BA(m²)	SV(m³)
11-20	207.00	3725.30	2805.65	2109.5	184.00	7.49	799.97
21-30	290.00	5629.92	3911.25	3047.0	335.00	11.93	1793.75
31-40	124.00	2375.84	1615.85	1245.3	130.00	7.24	1419.66
41-50	19.00	344.2	260.00	199.5	25.00	.99	208.53
51-60	7.00	132.94	75.00	62.5	4.00	.55	145.21
DBH=Diameter at Breast, DB=Diameter at Base, Diameter at Middle, Diameter at Top, Total Height, SLC=Slenderness Coefficient, BA=Basal Area, SV=Stem							

Slenderness coefficient

In forestry and ecological studies, the slenderness coefficient (SLC) is a measure of the shape and taper of a tree. It is calculated as the ratio of tree height to diameter at breast height (DBH). Slenderness coefficient values can provide insights into the form and stability of trees within a forest stand. This indicates that the trees in the "1-69 Low" category have a slenderness coefficient slightly above 1, suggesting a relatively balanced and uniform shape. The height is slightly greater than the DBH, indicating a moderate taper. 70-99 Moderate (SLC): The "70-99 Moderate" category has a slenderness coefficient of 1.5, suggesting a more tapered shape. The height is 1.5 times the DBH, indicating a significant taper in tree form >100 High (SLC): The ">100 High" category has a relatively high slenderness coefficient of approximately 2.304, indicating a tall and slender tree shape. The height is more than twice the DBH, suggesting a pronounced taper. The "1-69 Low" trees have a slightly tapered but balanced form. The "70-99 Moderate" trees exhibit a more pronounced taper in their shape. The ">100 High" trees have a tall and slender form with a significant taper making them vulnerable to windthrow compared to the moderate and low classes.

Table 4: Slenderness coefficient

SLC	DB(cm)	DM(cm)	DT(cm)	BA(m²)	SV(m³)	DBH(cm)	TH(m)
1-69Low	5233.13	3255.40	2559.0	16.26	2246.01	279.00	281.00
70-99Moderate	3815.72	2567.35	2040.3	7.51	1218.37	200.00	300.00
>100High	3159.17	2845.00	2064.5	4.42	902.74	168.00	387.0
DBH=Diameter at Breast, DB=Diameter at Base, Diameter at Middle, Diameter at Top, Total Height, SLC=Slenderness Coefficient, BA=Basal Area, SV=Stem							

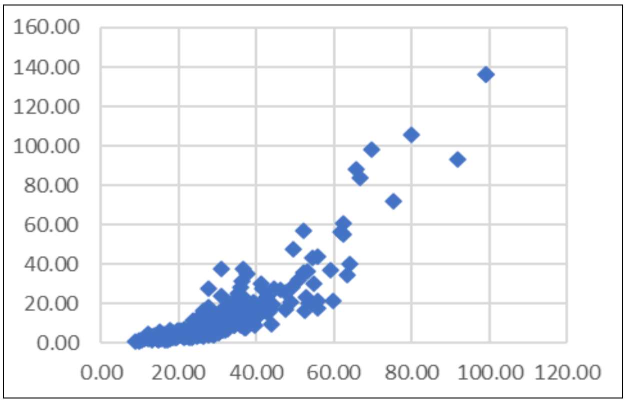

Fig 2: SV &DBH

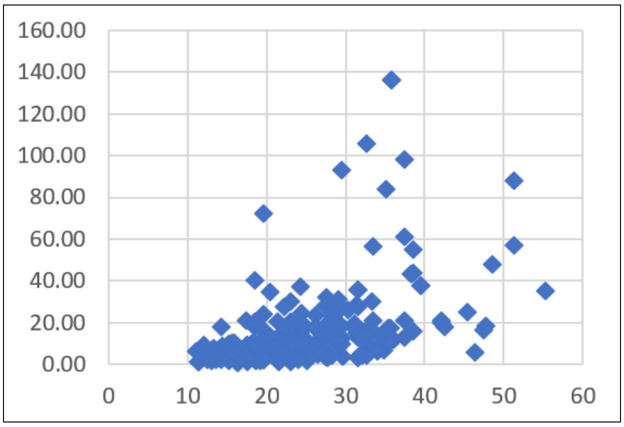

Fig 3: SV & TH

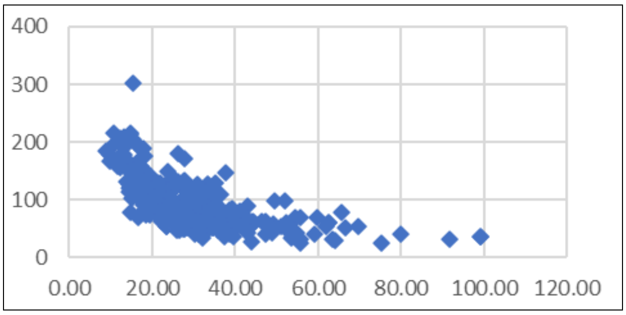

Fig 4: SLC & DBH

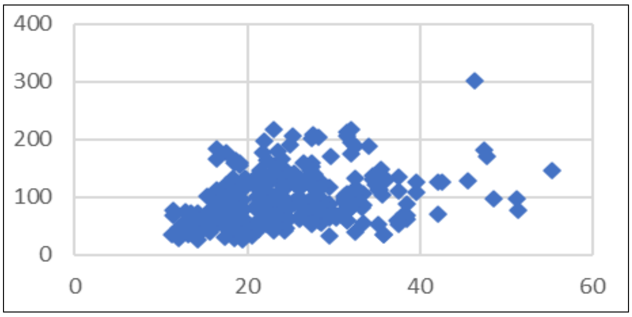

Fig 5: SLC & TH

3.4 Correlation Matrix

Strong positive correlations exist between DBH and DB (Diameter at the Base), DM (Diameter at the Middle), DT (Diameter at the Top), TH (Total Height), BA (Basal Area), and SV (Stem Volume). This indicates that as DBH increases, these variables tend to increase as well. Positive correlations are observed between DB and DM, DT, TH, SLC (Slenderness Coefficient), BA, and SV. An increase in DB is associated with increases in these variables. These variables show a positive correlation, suggesting that an increase in DM is associated with an increase in DT. There is a positive correlation between TH and SV, indicating that taller trees tend to have larger stem volumes. Negative Correlations: Strong negative correlations exist between SLC and DBH, DB, DM, DT, and BA. This implies that as the slenderness coefficient increases (indicating a slender shape), these diameter and basal area variables tend to decrease. The correlation matrix highlights the relationships between various tree growth characteristics. The positive correlations indicate coherent growth patterns, while negative correlations suggest trade-offs or differences in certain characteristics. The strong associations provide insights into how changes in one variable may be reflected in others.

Table 5: Correlation Matrix for Tree Growth Characteristics

	DBH(cm)	DB(cm)	DM(cm)	DT(cm)	TH(m)	SLC (%)	BA(m^2)	SV(m^3)
DBH(cm)	1							
DB(cm)	0.729**	1						
DM(cm)	0.547**	0.400**	1					
DT(cm)	0.439**	0.319**	0.605**	1				
TH(m)	0.340**	0.239**	0.252**	0.189**	1			
SLC (%)	-0.628**	-0.457**	-0.280**	-0.197**	0.351**	1		
BA(m^2)	0.952**	0.701**	0.539**	0.467**	0.313**	-0.492**	1	
SV(m^3)	0.867**	0.687**	0.535**	0.468**	0.488**	-0.323**	0.930**	1

DBH=Diameter at Breast, DB=Diameter at Base, Diameter at Middle, Diameter at Top, Total Height, SLC=Slenderness Coefficient, BA=Basal Area, SV=Stem Volume

4. Conclusion

The growth characteristics of different tree families, allowing for comparisons and insights into the structure and composition of the studied ecosystem. The results revealed diameter class 21-40 exhibits the highest cumulative values for DB, DM, DT, TH, SLC, BA, and SV indicating that trees within the 21-40cm diameter range contribute the most to the overall size, height, slenderness, basal area, and stem volume. Trees in the 81-100cm diameter range have the lowest cumulative values, suggesting they are relatively smaller and contribute less to the overall forest dimensions. Height Class (21-30) recorded the highest values for all parameters indicating that trees in this height class have the largest diameters, slenderness coefficient, basal area, and stem volume. SLC, BA, and SV are significantly higher compared to other height classes. The 41-60m height classes show lower values representing smaller or less mature trees. The "1-69 Low" trees have a slightly tapered but balanced form and more stable to windthrow. The "70-99 Moderate" trees exhibit a more pronounced taper in their shape while the ">100 High" trees have a tall and slender form with a significant taper making them vulnerable to windthrow compared to the moderate and low classes. Positive correlation was observed between all the variables with the exception of SLC which display negative relation with all the variables signifying inverse relationship.

5. Acknowledgement

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