FROM THEORY TO PRACTICE: EXPLORING FOREST DYNAMICS THROUGH MENSURATION: A CASE STUDY OF JALLO PARK, LAHORE

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ABSTRACT: Forests, as unpredictable environments, are basic to worldwide biodiversity and biological system administration. Understanding their systems and elements is fundamental for maintainable administration and protection. This article gives a thorough outline of the difficulties and methods in wood mensuration and the discipline of estimating backwoods credits. Inherent complexity of forest ecosystems is what the study is delving into; it demands accurate measurement techniques due to the diversity of species and growth patterns. Upon an evaluation of the basic principles of accuracy and precision in forestry mensuration, standard methods like DBH are considered. To overcome measurement difficulties, novel instruments like the Total Station and D-Tape have been used in the study. Moreover, the article investigates instrumental techniques for tree-level estimation, emphasizing mathematical standards, and utilizing innovative optical device like the Total Station. Data visualization was done by utilizing R Studio, ggplot2 and Arc Map 10.8 to investigate tree attributes. The findings highlight the distribution of tree species and families within Jallo Park, the connection between DBH and tree height, and the significant variation in above-ground biomass. This research advances our understanding of forest ecology and enables more informed forest management and conservation decisions.

Key words: Tree Mensuration, Field survey, Diameter at Breast Height, Tree Height, R studio, Total Station.

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INTRODUCTION

Forests, as unpredictable ecosystems, are indispensable for worldwide biodiversity and environmental administration. Comprehending their composition and dynamics is fundamental for economic administration and preservation (Brockerhoff *et al*., 2017; Mori, Lertzman, & Gustafsson, 2017; Myers, 1997). Key to this understanding is their mensuration, which includes the estimation and evaluation of different tree attributes (Kimsey Jr, Strimbu, & McGaughey, 2021). This article gives an outline of the difficulties and methods in forest management that were encountered during the field surveys. The complex nature of trees presents huge difficulties in precisely estimating and measuring their attributes (Farnsworth, 1989). Forests, in contrast to standardized commodities, are made up of numerous species that have distinct growth patterns, distributions of biomass, and spatial arrangements (Brockerhoff *et al*., 2017; Mori *et al*., 2017; Myers, 1997) which imposes precise measurement methods to accurately record the structure and composition of forests. Forest mensuration comprises two fundamental ideas that are accuracy and precision (Martin & Forestry, 2022; Van Laar & Akça, 2007). Accuracy reflects the closeness towards true value, while precision reflects the consistency of readings around a mean value. Both are crucial for effective forest management and decision-making (Martin & Forestry, 2022; Van Laar & Akça, 2007). However, achieving these objectives is quite difficult because of the complexities of forest biomes (Farnsworth, 1989). Due to Tree's irregular shapes, elliptical cross-sections, tapering and environmental variability, distance across and volume estimations are greatly influenced (Munalula, 2010). Standardized techniques, like estimating DBH at 1.37 meters above ground level, guarantee consistency and relationships with other parameters. Besides, this assessment gives bits of information into tree morphology and biomass estimation (Kramer, Sillett, Van Pelt, & management, 2018). Even with standard methods, it is challenging to get precise tree measurements because of things like thick canopies, shape tapering, and environmental inconsistency (Munalula, 2010). Instruments like Total Station (Min-xia & Hao, 2014; Yu, Feng, Cao, & Jiang, 2016; Zhao, Feng, Gao, Zheng, & Wang, 2014) and D-Tape offer innovative solutions to enhance measurement accuracies for field surveys (Weaver *et al*., 2015; Wilson, Murray, Ryding, & Mont, 2007).

An important feature of this research is providing complete methodology and techniques form theory to practice for conducting field surveys (D. J. Nowak & Crane, 2002). Urban forests provide twofold benefits in alleviating atmospheric carbon levels. Regardless of its significance, there has been inadequate attention on measuring the precise carbon retention and release dynamics of urban trees and the influence of energy preservation policies on these procedures (D. J. J. J. o. e. m. Nowak, 1993). A big tree can deliver adequate oxygen for 2 persons and absorb 48 pounds of CO_2 per annum (Z. B. Mirza 2008). Urban areas release large extents of anthropogenic carbon dioxide (Pargal *et al*., 2017). Urban areas should be planned to offer ecosystem facilities such as carbon storage (Bastin *et al*., 2019). Approximately 66% of the world's inhabitants are expected to reside in cities in 2050, therefore, understanding urban forest structure is ever more vital (UN 2014) as cited by (Blood *et al*., 2016). Trees enhance health by absorbing contaminants and decreasing the urban heat island (UHI) effect (Akbari, Pomerantz, & Taha, 2001), thus reducing heat-related diseases. Researches suggests that urban vegetation can decrease stress and enhance recovery from disease (Ulrich *et al*., 1991). Urban vegetation are also responsible for economic aids by storing carbon and compensating releases from urban activities (Hutchings, Lawrence, & Brunt, 2012). Owing to their potential to alleviate CO_2 emissions, awareness in urban greening has grown, making appropriate surveying methods its mensuration essential (Hyvönen *et al*., 2007).

Study Area: Jallo Forest Park, located at 31°34'21" North and 74°28'38" East, is just 0.5 km from the Canal Branch that is 20 km east side of Lahore nearby the Wagha-Amritsar railway line. It is well-known for its ironic socio-economic benefits, environment services, and recreational services. In past it was known as Tehra Forest, comprising 837 acres before Pakistan's Independence on August 14, 1947. It was renamed after the nearby village of Jallo. Nowadays, the forest provides recreational, silvicultural, cultural, and research activities. (SHAHZADI & SHIRAZI).

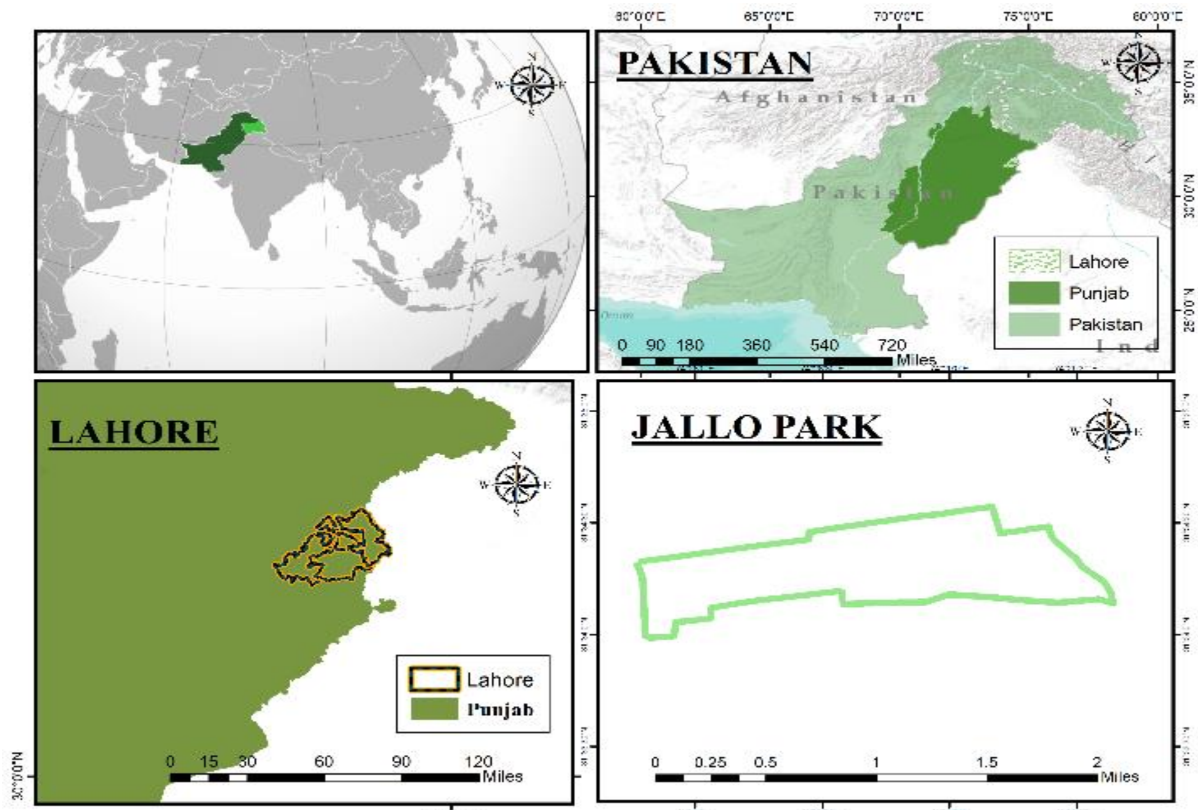

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Fig. 1 Study Area Map

MATERIALS AND METHODS

Estimation of DBH is crucial for several forestry applications, along with assessing carbon sequestration, biomass, and growth rates (Lutz, Larson, Freund, Swanson, & Bible, 2013). This part of research summarizes the procedures utilized for quantifying DBH, along with the tools used for precise measurements (Wilson *et al*., 2007).

DBH Estimation Techniques: According to the international standards of forest mensuration, DBH was taken at a height of 4.5 feet or 1.37m above ground level to ensure uniformity and to minimize differences produced by terrain irregularities and root abnormalities (Lutz *et al*., 2013).

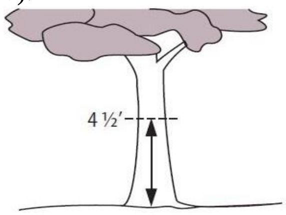

Fig. 2 Standard Height of taking DBH

In the case of leaning trees, readings were taken perpendicular to the ground at the upside point of the stem in case of an uphill slope (left side) or on the shorter side of the lean if on flat ground (right side) to accurately represent their true diameter besides the tilt. (Lutz *et al*., 2013; Stewart & Salazar, 1992).

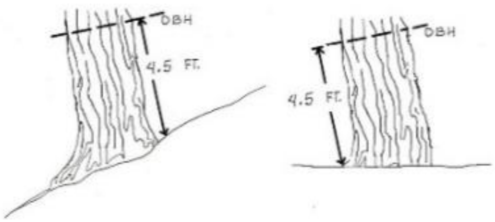

Fig. 3 Considerations for Leaning Trees

All the trees that had stem bulges, the diameters were taken below or above the bulge, and the mean of both measurements was considered as the diameter. For trees with prominent butt swell, diameters were taken 1½ feet above the swell to ensure accuracy (Walker *et al*., 2011).

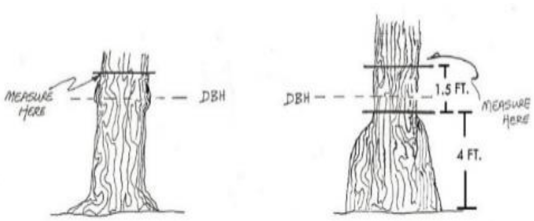

Fig. 4 Dealing with Bulges

In the case of trees with forked stems below 1.37 meters, two separate measurements were taken per stem, and the average was considered as the diameter. Forked trees were measured as one tree if the fork was at or above 4.5 feet, and as two trees if the fork was below that point (Magarik, Roman, Henning, & Greening, 2020; Walker *et al*., 2011).

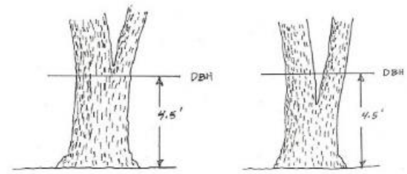

Fig. 5 Considering Forking Trees

In the presence of buttressed trees with roots above ground, measurements were taken above the buttress (Walker *et al*., 2011).

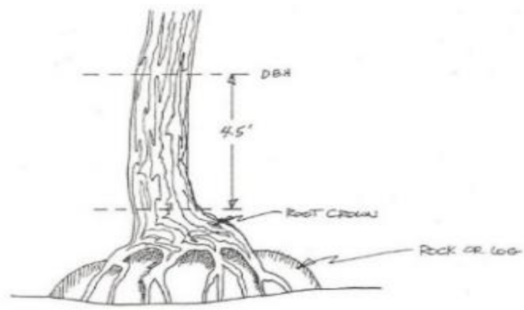

Fig. 6 Buttress Adjustment

Trees which were grown together, counted as two trees, halfway around each tree, with the measurement doubled (Walker *et al*., 2011).

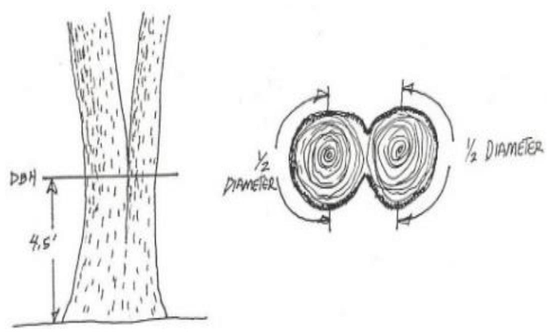

Fig. 7 Considering Twin Trees

Instruments Used for Diameter Measurement

A. **Diameter Tape or D-Tape Measure:** A standard tape measure calibrated in both centimeters and inches was employed for DBH measurements and circumferential measurements of trees. Measurements were taken at the specified height, and the circumference was later converted to diameter using the appropriate formula. This technique was used for majority of the observations during survey (Weaver *et al*., 2015; Wilson *et al*., 2007).

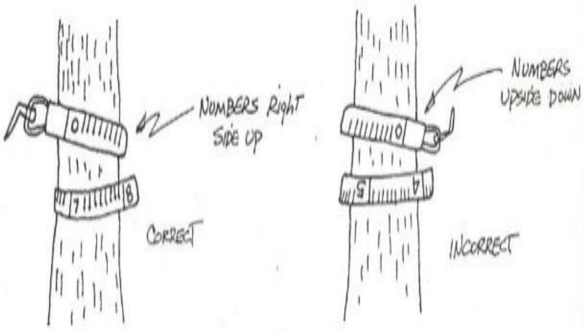

Fig. 8 Measuring Diameter with D- Tape

Instruments and Techniques for Tree Height Measurement: To understand forest dynamics and assist effective forest management techniques, measuring tree height is a critical component of forest mensuration (Pariyar, Mandal, & Sciences, 2019). This article introduces trigonometric-based instruments and builds on geometric principles to investigate the use of instrumental techniques for measuring tree height. The primary objective is to examine and illustrate the useful application of these instruments in forest mensuration.

Trigonometry: In forest mensuration, trigonometry is important because it provides mathematical techniques for estimating tree height indirectly (Demir & Heck, 2013). To precisely calculate height, trigonometric principles need measuring angles and distances (Menz, from Lyryx'textbook, & an Open). The foundation for height computations is the sine, cosine, and tangent trigonometric functions, which enable foresters to take different terrain conditions into account. (Menz *et al*.).

The sine, cosine, and tangent functions with regard to the sides of a right triangle can be remembered by using the abbreviation "SOH-CAH-TOA" (Menz *et al*.). The three fundamental functions of sine (opposite over hypotenuse), cosine (adjacent over hypotenuse), and tangent (opposite over adjacent) are made easier to learn with this mnemonic (Demir & Heck, 2013; Menz *et al*.).

1. **Sine (sin)**:
- $\boldsymbol{sin\theta} = Opposite \div Hypotenuse$ $\textbf{Cosec}(\boldsymbol{\theta}) = \text{Hypotenuse} \div \text{Opposite}$

2. **Cosine (cos)**:
- $\textbf{cos}\boldsymbol{\theta} = \text{Adjacent} \div \text{Hypotenuse}$ $\textbf{sec}(\boldsymbol{\theta}) = \text{Hypotenuse} \div \text{Adjacent}$

3. **Tangent (tan)**:
- $\textbf{tan}(\boldsymbol{\theta}) = \text{Opposite} \div \text{Adjacent}$ $\textbf{cot}(\boldsymbol{\theta}) = \text{Adjacent} \div \text{Opposite}$

Using these formulas, foresters can compute tree height based on angles and distances observed, taking into account the unique geometry of each tree's location about the observer. Trigonometric theorems improve height measuring even further by illuminating the relationships between angles in non-right triangles (Demir & Heck, 2013). A complementary angle theorem (90° - θ) allows for tree placements above or below the line of sight of the observer to be adjusted. According to (Demir & Heck, 2013), these theorems make it easier to calculate height accurately by taking into consideration the complicated tree orientations found in forests and one such instrument is Total station (Fan, Chen, Li, Liu, & Fan, 2019).

Total Station in Field Survey: Some of the issues with current forest surveys arise from the time and money needed to measure trees using external instruments. Thus, creating a novel, time- and money-saving technique for ground measuring that can be used in a forest geographic information system (GIS) survey is crucial. This study covers the design and execution of a novel ground measurement tool that heavily relies on electronic distance measuring (EDM) in an effort to achieve a better solution. Diameter at breast height (DBH), tree positioning, tree height species are among the key forest structural elements that the tool helps forest GIS surveys gather. It is based on terrestrial photogrammetry, location-based services (LBS), electronic transit theodolite and computer vision that calculates slopes, other horizontal and vertical angles (Fan *et al*., 2019). It contains an internal scale, a horizontal alignment line, and a sighting device that makes it user friendly for taking measurements (Min-xia & Hao, 2014; Yu *et al*., 2016; Zhao *et al*., 2014).

Data Analysis: Every research has been impacted by the use of open source software, which has been continuously changing since the mid-2000s. This technological advancement has impacted disciplines that use data from remote sensing (RS) and geographic information systems (GIS) significantly. Scholars utilizing these datasets have started utilizing open source software extensively. With the use of open source software, it is now possible to analyze and visualize spatial data and create new features that are both affordable and modifiable by other users (Kaya, Agca, Adiguzel, Cetin, & Journal, 2018). R provides the typical range of commonly used quantifiable plots, including as pie charts, box plots, and bar graphs. Every kind of graph has specific implementation requirements. The user must select the appropriate graphs based on his needs and the type of data (Herawan, Sekhar, & Rao31). In this article, Arc Map 10.8 and R Studio both have been utilized to make map and different graphs like pie charts, bar plot and scatter plot to show results of the data (Kronthaler & Zöllner, 2021).

RESULTS AND DISCUSSION

A. Above Ground Biomass (AGB): The illustration presented as Figure 9 displays the spatial delineation of Above-Ground Biomass (AGB) in kilograms across two specific zones within Jallo Park denoted as A (eastern side) and B (western side). The legend on the figure points out that varying sizes and colors of circles portray different ranges of biomass which are representative of the AGB values; with darker hues indicating higher values. Ranging from 1,571 kg to 213,387 kg, these diverse biomass ranges are depicted by circles of distinct sizes and colors. The AGB distribution forms what can be described as a predominantly horizontal corridor on the eastern side, with notable patches around the lake area showing high amounts of biomass— illustrated by numerous dark green circles (some reaching values as high as 213,387 kg). Lighter green circles representing lower biomass values (ranging between 1,571 - 15,000 kg) are more sparsely located towards the borders. The location of AGB can be traced to the west cluster at Jallo Park. A substantial amount up to 213,387 kg is found in the northern region, evidenced by numerous dark green circles in that area. These High Biomass Areas sharply contrast with Moderate to Low Biomass Areas represented by light and medium green circles dispersed across the cluster (1,571 - 30,001 kg). Conversely, on the eastern side, there exists a continuous distribution of AGB with larger concentrations around lakes— natural features. These findings indicate suitable biomass accumulation conditions, which also point to separate clusters of high AGBs on the western side: a sign of localized favorable climatic conditions that may lead to increased biomass production. The results indicate that local environmental conditions play an important role in influencing biomass variability, which has implications for conservation planning and vegetation management.

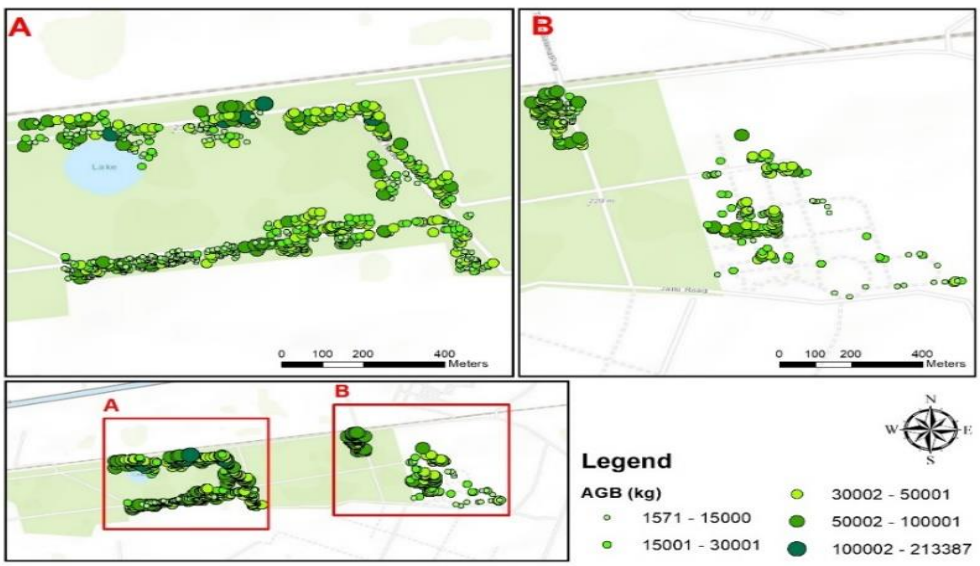

Fig. 9 Above Ground Biomass

B. Scatter Plot of DBH and Height vs AGB: For 1060 data points, the relationship between tree heights, (DBH) and AGB is depicted in this scatterplot. The individual tree dimensions are indicated by the black points, as shown in the below diagram, whereas, linear regression line that corresponds that the data is a good fit is depicted by the red line. The equation "y = m * x + b" is utilized to express the equation of the regression line, where "m" denotes the slope and "b" represents the intercept. An R^2 value, also known as the coefficient of determination, measures the proportion of the variance in the dependent variable that is predictable from the independent variable(s) in a regression model. In the fig. 10 the relation of height to AGB (left side) shows R-squared as 0.8 that depicts a very strong correlation between Height and AGB. This means more than 80 percent of the variability in Independent variable can make change in Independent variable. The relationship between DBH and AGB (right side) shows R- squared as 0.7 that depicts a very strong correlation between DBH and AGB. This means more than 70 percent of the variability in Independent variable can make change in Independent variable. Overall model shows a good fit .

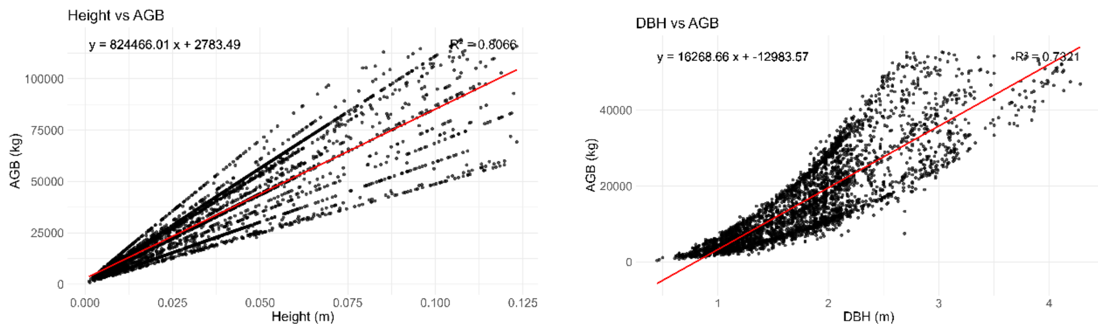

Fig. 10 Relationship between DBH Height and AGB

C. Top 25 Tree Species Counts: There were total 31 tree species in Jallo Park. The fig. 11 illustrates the spatial distribution of top 25 plant species within Jallo Forest. The *Eucalyptus Citriodora* (Sufeda) belonging to the family Myrtacea, shows a high concentration with 426 observations and other species such as *Melia azedarach* (Darek/Bakain) belongs to family Euphorbiaceae are least found. As per the results, *Alstonia scholaris*, commonly called Devil Tree, is depicted as the second most commonly found species in study area, whereas, *Bombax malabaricum*, locally knowns as Sumbal, found to be the third most species found there. The changing patterns of species distribution over the study area show a diverse ecological composition, with specific families dominating particular areas. The reason behind this could be the prevalence of Exotic species as compared to Native species.

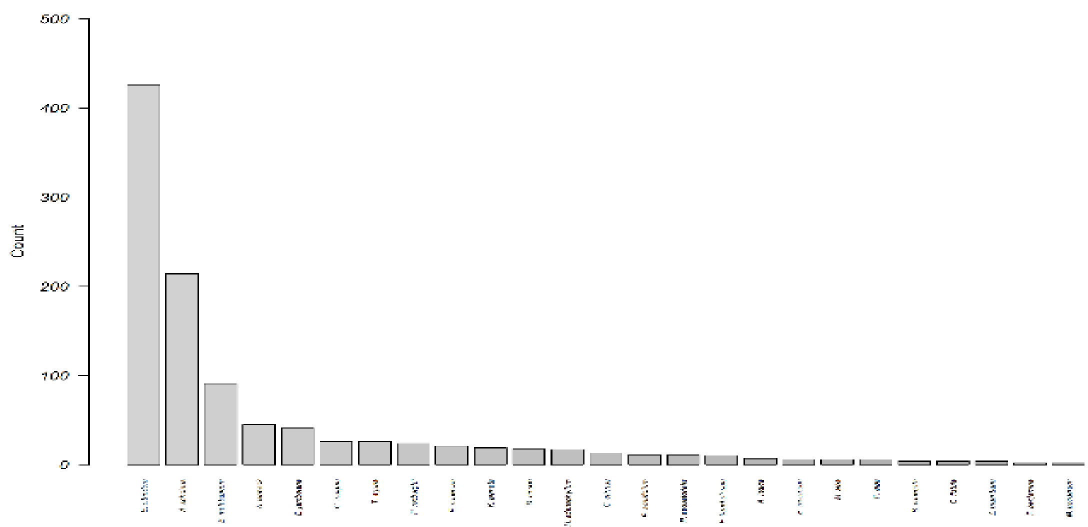

Fig. 11 Distribution of Species

D. Various Families of Tree Species: The diagram shows the structure of different families. Each different colored dot represents a particular family highlighting the ecological diversity of the region. There were a total of nineteen families, out of these, the Myrtaceae family with 480 observations, represented by red dots, is more dominant than others. Other families, such as Apocynaceae with 214 observations (vibrant pink dots) and Bombcaseae with 91 observations (light pink dots), are also present, although less concentrated as compared to Myrtaceae. Other families like Fabaceae, Mimosaceae and Bignoniaceae show less than 50 observations. Therefore, this visual diagram can help researchers indicate areas of potential interest for plant-specific research or conservation activities.

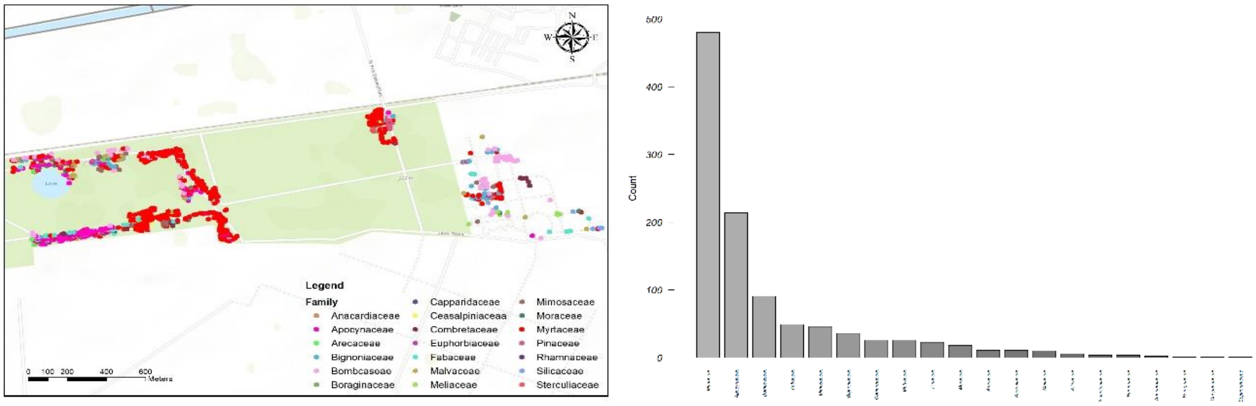

Fig. 12 Distribution of Various Plant Families

Species count based on Native and Exotic category: This pie chart shows the distribution of indigenous/native and exotic plant species within Jallo Forest Park. As per the results, there is a significantly higher number of exotic species with 750 individual trees around 83.4 percent, compared to native species hovering around 16.6 percent with 250 trees.In addition to highlighting potential ecological effects and emphasizing the need to monitor and manage the balance between native and exotic species in order to maintain biodiversity and ecosystem stability, this stark contrast between the two categories also shows that native species in the study area are in danger.

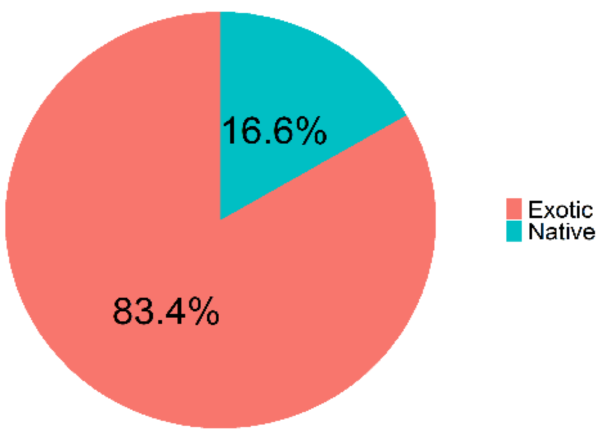

Fig. 13 Tree species based on their Origin

E. Species Count based on Fruit or Non Fruit category: As per the results, species reveal a large disproportion concerning fruit and non-fruit category, with non-fruit species significantly more numerous than fruit species. There are a total of 997 non-fruit species making up 94.1 percent, whereas the count of fruit species is considerably lower, decreasing to 63 observations that make up 5.9 percent only. This imbalance reflects the dominance of nonfruit species in this study area and indicates that it is necessary to grow fruit varieties for domestic purposes, mitigating environmental harm by providing other biodiversity or improving ecosystems through introducing more types of fruit.

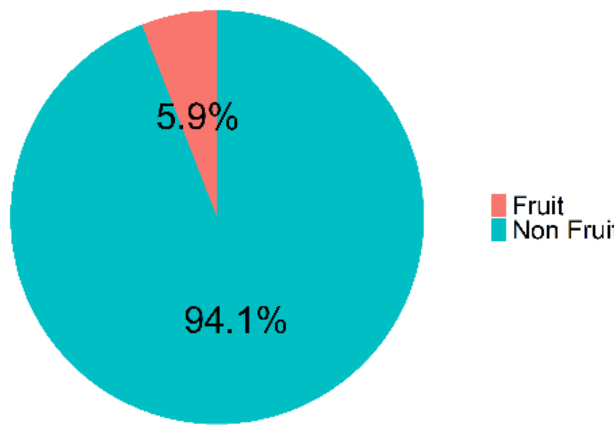

Fig. 14 Tree Species based on Fruit and Non- Fruit Category

Conclusion: The research highlights the significance of precise forest monitoring for effective management and sustainable utilization of forests. By utilizing field data and R Studio, it has also identified a valuable method to enhance the precision of estimating aboveground biomass (AGB). During the field survey, there were significant measurement difficulties due to the complex nature of forest biomes, which are characterised by variability in growth patterns and species diversity. The improvement of new, optical instruments such as Total Station and international standards used for DBH mensuration will contribute to a precise inventory of forests. . Finally, in order to achieve a large scale inventory of forests, continuous improvement of materials and methods should be adopted. In order to encourage such initiatives by researchers in the field of sustainable urban management, governments should provide financial and labour support.

Recommendations: A review of the current progress in quantifying the potential of urban forests to mitigate climate change and urban heat island effect should involve a comprehensive literature review, an evaluation of study quality, a synthesis of findings, identification of gaps in the literature, use of accurate and precise instruments, advance software like R studio for analysis and conclusions based on the state of knowledge.

Increasing the number of trees planted in urban areas can help to store more carbon. Planting trees in strategic locations such as parks, sidewalks, and public spaces can increase the carbon storage capacity of urban areas.

REFERENCES

1. Akbari, H., Pomerantz, M., & Taha, H. J. S. e. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *70*(3), 295-310.
2. Bastin, J.-F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., . . . Crowther, T. W. J. S. (2019). The global tree restoration potential. *365*(6448), 76-79.
3. Blood, A., Starr, G., Escobedo, F., Chappelka, A., Wiseman, P., Sivakumar, R., . . . Greening, U. (2016). Resolving uncertainties in predictive equations for urban tree crown characteristics of the southeastern United States: Local and general equations for common and widespread species. *20*, 282-294.
4. Brockerhoff, E. G., Barbaro, L., Castagneyrol, B., Forrester, D. I., Gardiner, B., González-Olabarria, J. R., . . . Conservation. (2017). Forest biodiversity, ecosystem functioning and the provision of ecosystem services. In (Vol. 26, pp. 3005-3035): Springer.
5. Demir, Ö., & Heck, A. (2013). *A new learning trajectory for trigonometric functions.* Paper presented at the Proceedings of the 11th international conference on technology in mathematics teaching.
6. Fan, G., Chen, F., Li, Y., Liu, B., & Fan, X. J. F. (2019). Development and testing of a new ground measurement tool to assist in forest GIS surveys. *10*(8), 643.
7. Farnsworth, B. T. (1989). Overcoming the obstacles of effective photogrammetric mensuration.
8. Herawan, T., Sekhar, C., & Rao31, V. A Review on Graphs with R Studio.
9. Hutchings, T., Lawrence, V., & Brunt, A. J. T. R. A. o. F. C. (2012). Estimating the ecosystem services value of Edinburgh’s trees. 45.
10. Hyvönen, R., Ågren, G. I., Linder, S., Persson, T., Cotrufo, M. F., Ekblad, A., . . . Jarvis, P. G. J. N. P. (2007). The likely impact of elevated [CO2], nitrogen deposition, increased temperature and management on carbon sequestration in temperate and boreal forest ecosystems: a literature review. *173*(3), 463-480.
11. Kaya, E., Agca, M., Adiguzel, F., Cetin, M. J. H., & Journal, e. r. a. A. I. (2018). Spatial data analysis with R programming for environment.
12. Kimsey Jr, M. J., Strimbu, B. M., & McGaughey, R. J. J. C. J. o. F. R. (2021). Advancements in forest mensuration and biometrics in the artificial intelligence era. *51*(8), v-vi.
13. Kramer, R. D., Sillett, S. C., Van Pelt, R. J. F. e., & management. (2018). Quantifying aboveground components of Picea sitchensis for allometric comparisons among tall conifers in North American rainforests. *430*, 59-77.
14. Kronthaler, F., & Zöllner, S. J. A. E. I. (2021). Data analysis with RStudio. 7-131.
15. Lutz, J. A., Larson, A. J., Freund, J. A., Swanson, M. E., & Bible, K. J. J. P. o. (2013). The importance of large-diameter trees to forest structural heterogeneity. *8*(12), e82784.
16. Magarik, Y. A., Roman, L. A., Henning, J. G. J. U. F., & Greening, U. (2020). How should we measure the DBH of multi-stemmed urban trees? , *47*, 126481.
17. Martin, A. J. J. A., & Forestry, U. (2022). Accuracy and Precision in Urban Forestry Tools for Estimating Total Tree Height. *48*(6), 319-332.
18. Menz, P., from Lyryx’textbook, N. M., & an Open, C. E. T. Early Transcendentals.
19. Min-xia, Z., & Hao, F. J. J. o. B. F. U. (2014). A precise method to measure the trunk diameter of standing tree using total station. *36*(6), 36-40.
20. Mori, A. S., Lertzman, K. P., & Gustafsson, L. J. J. o. A. E. (2017). Biodiversity and ecosystem services in forest ecosystems: a research agenda for applied forest ecology. *54*(1), 12-27.
21. Munalula, F. (2010). *A method for the non-destructive determination of the knotty core sizes of standing Pinus patula trees, based on ring width assessments at breast height and the pruning history.* Stellenbosch: University of Stellenbosch,
22. Myers, N. J. N. s. S. s. d. o. n. e. (1997). The world's forests and their ecosystem services. 215-235.
23. Nowak, D. J., & Crane, D. E. J. E. p. (2002). Carbon storage and sequestration by urban trees in the USA. *116*(3), 381-389.
24. Nowak, D. J. J. J. o. e. m. (1993). Atmospheric carbon reduction by urban trees. *37*(3), 207-217.
25. Pargal, S., Fararoda, R., Rajashekar, G., Balachandran, N., Réjou-Méchain, M., Barbier, N., . . . Couteron, P. J. R. S. (2017). Inverting

aboveground biomass–canopy texture relationships in a landscape of Forest mosaic in the Western Ghats of India using very high resolution Cartosat imagery. *9*(3), 228.

26. Pariyar, S., Mandal, R. A. J. I. J. o. E., & Sciences, E. (2019). Comparative tree height measurement using different instrument. *1*(2), 12-17.
27. SHAHZADI, S., & SHIRAZI, S. A. ROLE OF URBAN FORESTS IN PROVISION OF THE ECO-SYSTEM SERVICES: AN ANALYSIS OF RESIDENTS PERCEPTION VISITING JALLO PARK IN LAHORE.
28. Stewart, J., & Salazar, R. J. A. s. (1992). A review of measurement options for multipurpose trees. *19*, 173-183.
29. Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. J. J. o. e. p. (1991). Stress recovery during exposure to natural and urban environments. *11*(3), 201-230.
30. Van Laar, A., & Akça, A. (2007). *Forest mensuration* (Vol. 13): Springer Science & Business Media.
31. Walker, W., Baccini, A., Nepstad, M., Horning, N., Knight, D., Braun, E., & Bausch, A. J. W. H. R. C., Falmouth, Massachusetts, USA. (2011). Field guide for forest biomass and carbon estimation. 43-49.
32. Weaver, S. A., Ucar, Z., Bettinger, P., Merry, K., Faw, K., Cieszewski, C. J. J. C. J. o. F. E. J. f. T., & Engineering, A. o. F. (2015). Assessing the accuracy of tree diameter measurements collected at a distance. *36*(1), 73-83.
33. Wilson, E. R., Murray, J., Ryding, I., & Mont, E. J. Q. J. o. F. (2007). Comparison of three tools for measuring tree diameter in stands of different age and stem size. *101*(4), 267.
34. Yu, D., Feng, Z., Cao, Z., & Jiang, J. J. T. o. t. C. S. o. A. E. (2016). Error analysis of measuring diameter at breast height and tree height and volume of standing tree by total station. *32*(17), 160-167.
35. Z. B. Mirza , A. A. C., Rizwan Mahmood, Nida Masood, Shahid Iqbal, Mohsin Saeed (2008). THE STUDY OF ECOLOGY AND ECOLOGICAL LINKAGES OF THE LAHORE CANAL BANK FROM MUSTAFAABAD BRIDGE TO THOKAR NIAZ BAIG
36. Zhao, F., Feng, Z., Gao, X., Zheng, J., & Wang, Z. J. T. o. t. C. S. o. A. E. (2014). Measure method of tree height and volume using total station under canopy cover condition. *30*(2), 182-190.