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Geodatabase and Health Risk Assessment of Avenue Trees on Selected Roads in a Tertiary Institution in Ibadan, Nigeria

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ABSTRACT: Campuses of Nigerian universities, especially the older ones, are home to aged trees that were originally planted for environmental beautification and aesthetics. However, due to the current global climate change and increased vulnerability to abiotic and biotic stressors, the old trees could pose threats to pedestrians, structures, and roads within the university campus environments. Therefore, the objective of this paper is to develop a geodatabase and evaluate the health risk assessment of avenue trees on selected roads in a tertiary institution in Ibadan, Oyo State, Nigeria using appropriate standard methods. Results obtained reported a total of 121 individual avenue trees belonging to 14 species along the study roads. The geospatial distribution analysis revealed that Emotan road had a lower density of avenue trees compared to Benue and Oduduwa roads. Furthermore, the health risk assessment indicated that 17.35% of the individual avenue trees had defects, posing potential hazards and risks of tree failure, and potential damage to pedestrians, vehicles, and neighboring utilities. The developed geodatabase is user-friendly and allows for easy data storage and quick information retrieval on the avenue trees, enhancing their maintenance and risk management. Furthermore, this study shows that systematic replacement, replanting, and management of avenue tree species could be a proactive initiative for the expansion of the geodatabase and to reduce negative health impacts.

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Rapid urbanization has negatively impacted climate, environments, and human well-being, increasing interest in urban greening/forestry among urban planners and managers (Zhao *et al.*, 2006; Oluwajuwon, 2022). Avenue trees, or roadside trees, are crucial in urban environments. These trees, lining roadsides, pathways, and highways, offer significant environmental and economic benefits. They provide shade, create visual contrast, and enhance aesthetics and utility (Schroeder, 2011; Desai and Nandikar, 2012). They help in reducing air temperature, cooling urban areas, leading to energy cost savings for cooling buildings (Gallagher *et al.*, 2015; Baldauf, 2017; Agbelade *et al.*, 2022). They also improve air quality by removing pollutants and particulate matter (Killicoat *et al.*, 2002; Isaifan and Baldauf, 2020). Avenue trees also mitigate noise pollution, increase property values, control wind speed, reduce runoff, and provide resources like fruits to urban dwellers and road users (Killicoat *et al.*, 2002; Agbelade *et al.*, 2022). Properly integrated, avenue trees can manage traffic by serving as natural signage, enhancing safety with careful design (Wolf and Bratton, 2006). Regarding their health benefits, roadside trees can

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reduce mental and physical fatigue and provide psychological satisfaction (Beyer *et al*., 2014; Elsadek *et al*., 2019).

Despite the numerous benefits, avenue trees can pose significant threats when branches or entire trees fall on buildings, properties, or pedestrians. Aging trees or those weakened by pests, diseases, or other stresses can become hazardous, especially in urban settings. Therefore, tree risk assessment is essential for tree owners or managers to evaluate the level of risk and decide on necessary modifications (Koeser *et al*., 2016; Eludoyin *et al*., 2021). Risk is defined as the combination of the likelihood and extent of potential hazards. Tree risk assessment is a systematic procedure for identifying, analyzing, and evaluating tree risks (APA, 2016). It involves objectively evaluating risks, considering potential tree hazards and uncertainties to ensure effective health and safety management. A hazard tree is any tree or tree part that can cause injury, death, or damage to a valuable target within striking distance, such as a building, vehicle, or people (Eludoyin *et al*., 2021). There is limited information on spatial distribution of avenue trees, which is crucial for understanding tree locations, distances between trees, arrangements, and health status. Spatial inventory information is essential for informed decisions on tree management, enrichment or replacement planting, and risk assessment. Avenue trees can pose health risks and challenges to pedestrians and adjacent infrastructures, particularly in areas with high anthropogenic pressures, inadequate maintenance, and poor management (Klein *et al*., 2019; Suchocka *et al*., 2022). They are vulnerable to mechanical damages from pedestrians and vehicles, and abiotic and biotic stressors like insect pests and pathogens. These stressors can cause defoliation, staining, boring, branch loss, and deformities such as hollows, cavities, and decay, increasing the risk of failure and potential harm and disruption to people, cars, properties, utilities, and activities (Adesoye and Dondofema, 2021; Li *et al*., 2022; Suchocka *et al*., 2022).

Urban (avenue) tree failures are common in municipal areas globally (Suchocka *et al*., 2022), including Nigerian metropolises (Eludoyin *et al*., 2021). In locations like the University of Ibadan, occasional tree failures along roads can obstruct vehicular movement for days before clearance. Documentation on the health status and risk level of avenue trees in the study area is generally scarce and lacks an organized data bank for efficient storage and retrieval of relevant information. Eludoyin *et al*. (2021) assessed the risk levels of trees within the University of Port Harcourt, finding that a high proportion (up to 63%) posed moderate risks. Onefeli *et al*. (2012) selectively classified and investigated the physical health of some avenue trees in the University of Ibadan's environment, reporting considerable tree diversity. However, there is a lack of comprehensive study on the geospatial distribution, health, and risk assessment of avenue trees along the frequented roads within the study area. No database management system has been developed for avenue trees in this region. Managing trees along pedestrian routes effectively requires a system enabling adequate inventory, updating, and retrieval of tree information. Up-to-date spatial information on the trees could potentially enhance the accuracy of risk assessment. Therefore, the objective of this paper is to develop a geodatabase and evaluate the health risk assessment of avenue trees on selected roads in a tertiary institution in Ibadan, Oyo State, Nigeria using appropriate standard methods.

MATERIALS AND METHOD

Study area: The study was conducted along Oduduwa, Emotan, and Benue roads within the University of Ibadan, located in the Ibadan North Local Government Area of Oyo State. This area sits approximately 277 meters above sea level and experiences distinct rainy and dry seasons. The rainy season lasts from late March to late October, with an average annual rainfall of about 1220 mm. The dry season, influenced by the North-East trade winds, lasts from November to March. Relative humidity is high during the rainy season and decreases during the dry season. The soil is predominantly sandy loam, with pockets of clay and scattered large stones and gravel. Although the soil texture is generally poor, it is well-drained, with rock outcrops within some areas in the university. The terrain consists of wavelike slopes running from west to east (Olajuyigbe *et al*., 2013).

The selected roads are among the busiest on the campus environment, with diverse woody vegetation, comprising both native and exotic tree species, including *Casuarina equisetifolia*, *Delonix regia*, *Eucalyptus camaldulensis*, *Gliricidia sepium*, *Peltophorum pterocarpum*, among others. Individual avenue trees vary in growth, reaching diameters at breast height (DBH) and heights up to 70 cm and 30 m, respectively. The university’s Biodiversity Management Committee (BMC) manages the avenue trees, many of which are hazard trees—aged and deteriorating due to diseases, defects, and anthropogenic damages—necessitating regular management and maintenance to prevent tree failures (BMC, 2017) (Figure 1).

Fig 1: Hazard avenue tree failures leading to A) road obstruction and B) building damage in the university environment (Source: BMC, 2017).

Data collection: Data were collected on all the avenue trees along the selected roads, covering their dendrometric, spatial, and health status. Primary tree data included coordinates, crown height (m), crown diameter (cm), DBH (cm), diameters at the base, middle, and top (cm), and total height (m). These were measured using tools such as diameter tape, Spiegel Relascope, meter tape, and a Global Positioning System (GPS). A taxonomist assisted in identifying the species name of each avenue tree, and a complete enumeration of all trees was conducted.

Assessing tree risk and vitality involves various methods, ranging from basic visual inspections to more advanced techniques. Commonly used methods, as reported by Suchocka *et al*. (2022), include Visual Tree Assessment (VTA), Tree Visual Evaluation for Diseases (TVED), and ISA Tree Risk Assessment Qualification (TRAQ). For this study, VTA and TVED methods were utilized to determine the risk rate for each tree, involving the expertise of an experienced arborist. Evaluation involved examining visible signs of decays, termite attacks, cracks, and inspecting crown status. Indicators such as leaning towards buildings or roads, presence of cracked branches, root infestation by termites, and basal or branch decay were considered for risk rate assessment. Risk rate was categorized as low, medium, or high, depending on potential targets such as humans, vehicles, buildings, and utilities.

Data analysis: The data collected on avenue trees were analyzed primarily in the Quantum Geographic Information (QGIS) environment. The analysis involved several steps, including mapping the selected roads using GPS coordinates, representing individual avenue trees on the generated map as points, digitizing roads as lines and other land uses as polygons. The data set of individual avenue trees was developed into a database file using MySQL for accessibility. Tree diameter data and total height were used to calculate volume using Newton's formula (Equation 1). MS Excel was used to conduct the computation and summarize the structural characteristics of the avenue trees, categorized by species, along the examined roads. Furthermore, the risk rate for termite infestation, butt/leaf/branch decay, leaning angle, and cracked branch was analyzed across the selected roads.

$$V = \frac{h}{6(Db + 4Dm + Dt)} \quad (1)$$

Where V = Tree volume (m^3), Db, Dm and Dt = tree cross-sectional area (m^2) at the base, middle and top of merchantable height, respectively, and h = total height (in meters).

The database development involved three phases: Back End, Interphase, and Front End. The Back End, or Data Access Layer (DAL), comprises rows and columns for tree data storage and retrieval. It utilizes Bootstrap, an open-source toolset including Hypertext Markup Language (HTML), Cascade Style Sheets (CSS), JavaScript, and Hypertext Preprocessor (PHP), to ensure error-free querying. The Interphase, or Business Logic Layer (BLL), facilitates data input, deletion, selection, and updating of the database. PHP manages this layer, transferring data between the Front End and Back End. The Front End, or the Presentation Layer (PL), enables users to directly interact with the website and database and obtain information about the avenue trees. Users can access information without using a structured query language (SQL).

RESULTS AND DISCUSSION

Geospatial Distribution and Structural Attributes of Avenue Trees: Figure 2 shows the spatial distribution of avenue trees along Benue, Emotan, and Oduduwa roads. Benue road is located at the north-western part of the University with the avenue trees scattered without a regular pattern. Oduduwa road is situated at the south-eastern part, while Emotan road is positioned at the center, connecting to the base of Benue road. The structural characteristics of the avenue trees are presented in Table 1. Oduduwa road recorded the highest number of species (9), followed by Benue road with 8 species. Conversely, Emotan road had the least species diversity, with only 4 individual avenue trees belonging to 2 species: *Mangifera indica* and *Peltophorum pterocarpum*. Despite having fewer individual trees (58) compared to Benue road (59), Oduduwa road had the highest total values for various tree structural variables, including volume, crown diameter, total height, and merchantable height, as indicated in Table 1. Overall, a total of 121 avenue trees were identified along the three selected roads in the university environment.

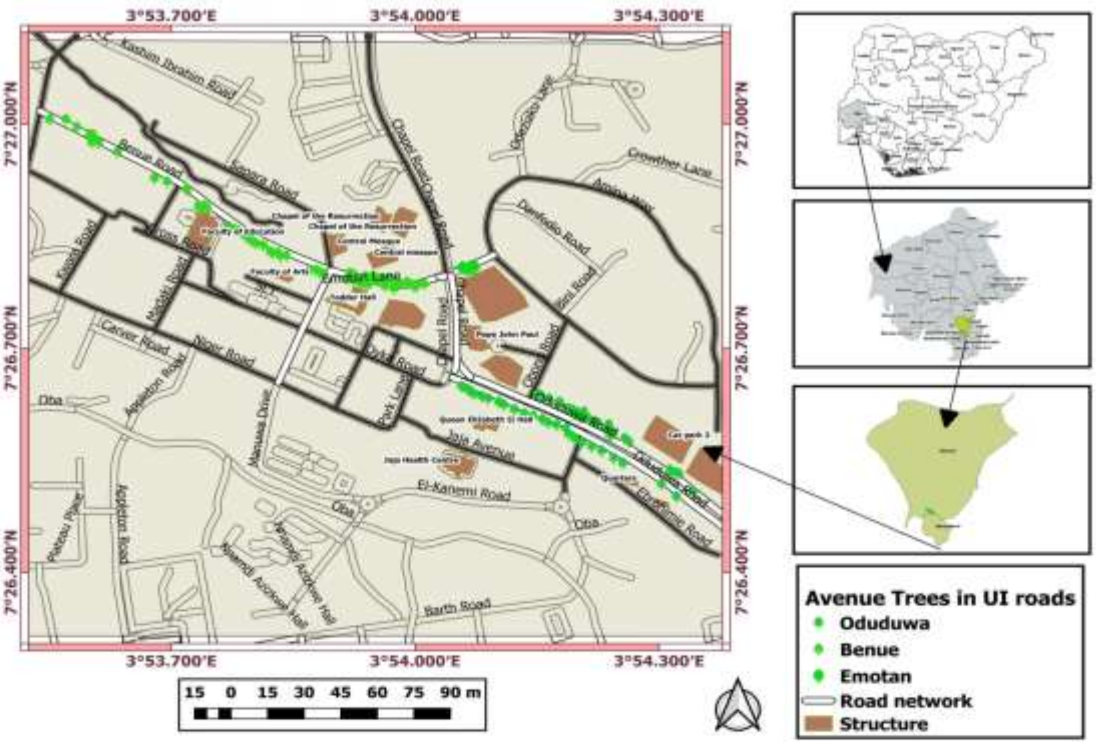

Fig 2: Geospatial distribution of avenue trees along selected roads in University of Ibadan.

Table 1: Overall dendrometric and structural characteristics of the avenue trees

Road	No. of species	No. of individual trees	Total Volume (m^3)	Total Crown Length (m)	Total Crown Diameter (cm)	Total Height (m)	Sum of Merchantable Height (m)
Benue	8	59	42.48	419.60	793.45	1112.10	629.50
Emotan	2	4	7.43	41.00	67.50	115.00	74.00
Oduduwa	9	58	84.25	619.77	1371.55	1317.77	698.00

Tables 2 to 4 further present the specific species of the roadside trees and their structural attributes along each road. *Casuarina equisetifolia* and *Samanea saman* were the most abundant species along Oduduwa road, with 16 and 14 individual trees, respectively. Quite surprisingly, these two species were absent and not found along the other two roads. On the other hand, *Peltophorum pterocarpum* dominated Benue road, with 27 individual trees, and was also found along Oduduwa and Emotan roads, albeit in small numbers. This species exhibited the widest distribution within the study area. While *P. pterocarpum* had the largest tree size in Oduduwa road, with a mean DBH of 56.25 cm, it ranked second to *Mangifera indica* (65.0 cm) in Emotan road, albeit with only one individual tree. Nonetheless, Benue road recorded the highest DBH values, with trees reaching up to 70 cm on average, exemplified by *Ricinodendron heudelottii. S. Saman* and *P. pterocarpum* reported the highest species volume (34.08 m^3 and 22.77 m^3) in Oduduwa and Benue roads, respectively, while *Taberbuia rosea* (0.17 m^3) and *Phyllanthus discoideus* (0.56 m^3) had the lowest volume yields, respectively.

Table 2: Tree species and structural characteristics of avenue trees in Oduduwa road

S/N	Tree species	Individual tree	Mean H (m)	Mean DBH (m)	Mean crown length (m)	Mean crown diameter (cm)	Total volume (m^3)
1	*Casuarina equisetifolia*	16	29.63	23.19	8.69	18.59	10.51
2	*Delonix regia*	2	17.00	30.00	7.50	37.00	1.23
3	*Eucalyptus camaldulensis*	6	18.72	30.00	9.43	11.75	4.42
4	*Gliricidia sepium*	8	18.44	28.25	6.74	28.13	4.59
5	*Peltophorum pterocarpum*	4	22.28	56.25	16.35	29.06	14.31
6	*Samanea saman*	14	22.19	52.86	15.19	28.54	34.08
7	*Spondias mombin*	1	21.00	20.00	4.00	47.00	0.38
8	*Taberbuia rosea*	1	17.00	17.00	5.00	11.50	0.17
9	*Terminalia mantaly*	6	18.70	51.67	11.37	21.71	14.56

Table 3: Tree species and structural characteristics of avenue trees in Emotan road

S/N	Tree species	Individual tree	Mean H (m)	Mean DBH (m)	Mean crown length (m)	Mean crown diameter (cm)	Total volume (m^3)
1	*Mangifera indica*	1	25.00	65.00	13.00	17.50	1.71
2	*Peltophorum pterocarpum*	3	30.00	48.33	9.33	16.67	5.72

Table 4: Tree species and structural characteristics of avenue trees in Benue road

S/N	Tree species	Individual tree	Mean H (m)	Mean DBH (m)	Mean crown length (m)	Mean crown diameter (cm)	Total volume (m^3)
1	*Azadirachta indica*	1	30.50	60.00	16.50	14.50	2.12
2	*Delonix regia*	2	24.50	20.00	11.00	14.63	1.24
3	*Mangifera indica*	2	18.25	60.00	7.75	15.13	2.56
4	*Peltophorum pterocarpum*	27	19.93	31.22	7.36	12.20	22.77
5	*Phyllanthus discoideus*	1	28.00	20.00	11.00	14.00	0.56
6	*Ricinodendron heudelotii*	2	26.00	70.00	6.50	17.75	6.03
7	*Terminalia catappa*	6	17.58	23.33	5.58	11.00	2.77
8	*Terminalia mantaly*	18	15.14	19.17	6.08	15.26	4.43

Health Status of Avenue Trees: The health and risk status of the avenue trees along the three selected roads in the University of Ibadan, based on the combined VTA and TVED methods, are presented in Figure 3.A–C.

The risk rating for termite infestation, butt decay, leaf decay, leaning angle, cracked branch, and branch decay was assessed at four levels of severity. It was found that most tree species along Benue road exhibited a low rate of defects and diseases.

However, species like *P. pterocarpum* and *R. heudelottii* had medium rates of defects and infestations. Some species showed no individuals affected by specific types of decay or infestation. For example, *Delonix regia* had no termite attack, cracked branch, and branch decay, and *P. discoideus* showed no signs of defects across all health categories (Figure 3.A).

Of the two avenue tree species along Emotan road, only termite infestation and butt decay were observed among the six defects and diseases investigated (Figure 3.B). *P. pterocarpum* was affected by both defects, while *Mangifera indica* was only infested by termites.

Both issues were present at a low rate and can be managed with minimal risk to pedestrians and utilities. Figure 3.C shows that most tree species along Oduduwa road exhibited a low rate of defects, with a few species showing medium rates, posing low to moderate risks to people, buildings, and utilities. Only *P. pterocarpum* had an individual tree with a high rate of termite infestation, requiring immediate intervention. *T. rosea* showed no defects in any category.

Geodatabase for Avenue Trees: The database homepage, accessible via http://159.203.29.155/rebs/rebs.php (currently being updated), serves as the front end where users can obtain detailed information about avenue trees along the three roads.

It is organized into three main sections: locations, tree species, and health status, and includes specific details like coordinates, frequency, and geospatial distribution (Figure 4).

For example, selecting a specific tree species (e.g., *Casuarina equisetifolia* in Figure 5) navigates to its dedicated information page. The administrative section of the database, or back end, serves as storage area for all collected data on the avenue trees, which are then reflected on the homepage (Figure 6). It allows for easy updates of information. This section is password-protected to ensure only authorized data updates.

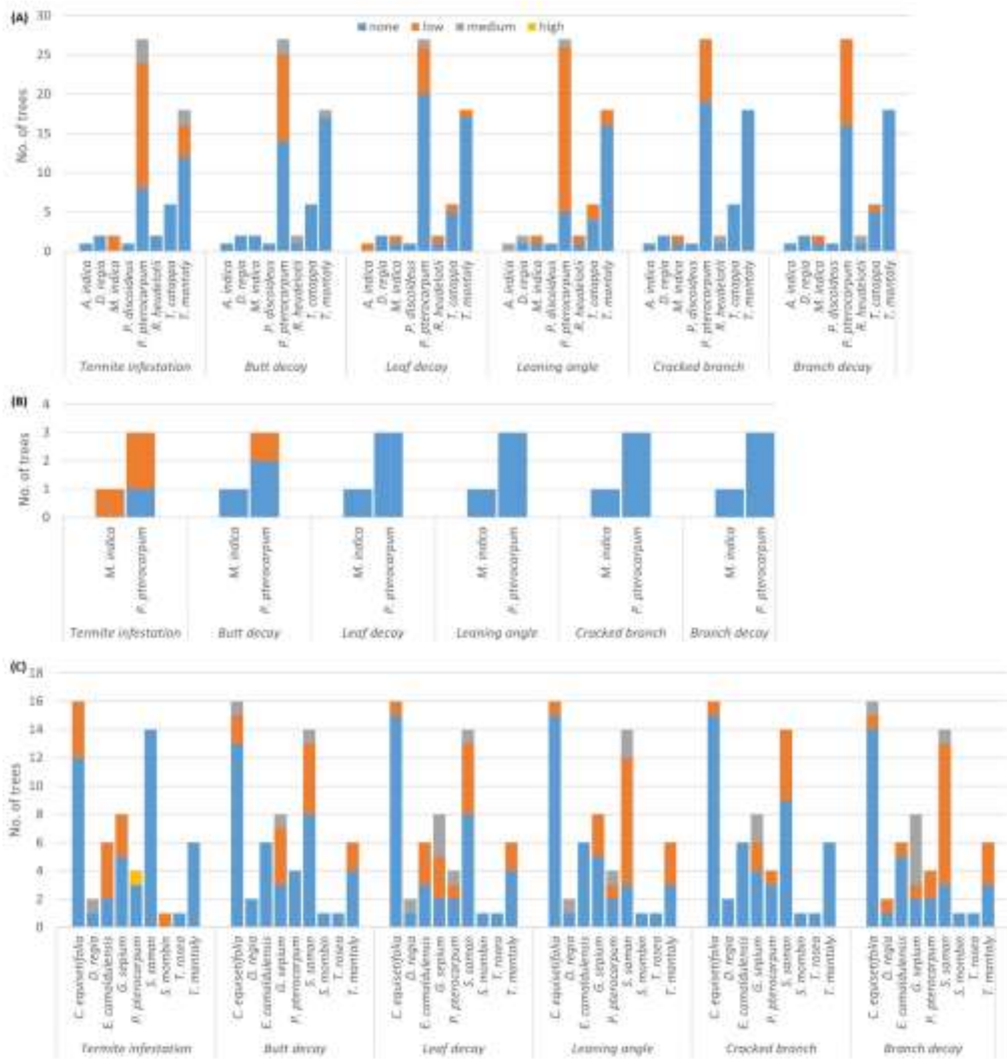

Fig 3: Health status of avenue trees in A) Benue Road, B) Emotan Road, and C) Oduduwa Road.

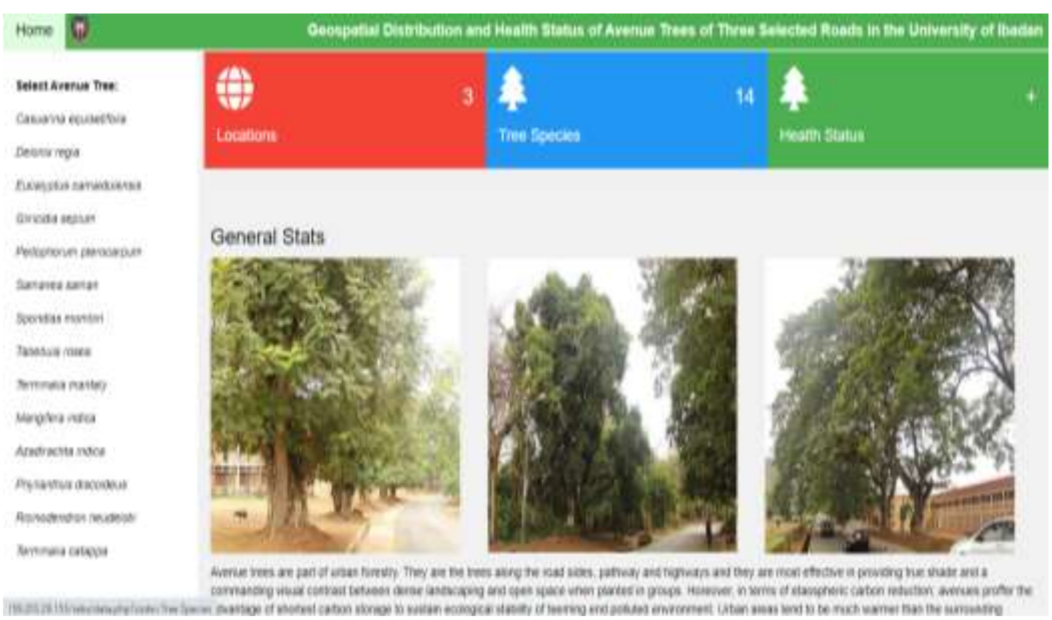

Fig 4: Homepage of geospatial distribution and health status of avenue trees along selected roads of University of Ibadan.

Fig 5: Information of a specific avenue tree (*Casuarina equisetifolia*) on the geodatabase homepage.

Fig 6: The administrative page of geospatial distribution and health status of avenue trees along selected roads of University of Ibadan.

The growth of avenue and urban trees can vary considerably within and between species, influenced by multiple factors. These may include species-specific characteristics (due to species selection and genetics), site conditions (such as environmental factors, soil, and climate), management practices (like planting, pruning), and other pertinent anthropogenic factors such as compaction and vandalism (Hodge, 1993; Jutras *et al*., 2010; Monteiro *et al*., 2017; Oluwajuwon *et al*., 2022). In this study, it was observed that even within the same species, the avenue trees exhibited different structural characteristics. Trees on Oduduwa Road had the highest tree volume, a key parameter for determining tree size, biomass storage, and economic value. They also exhibited the greatest crown length, influenced by total height and merchantable height, indicating well-branched trees with substantial crowns that provide essential urban shade – a critical ecosystem benefit of urban trees (Killicoat *et al*., 2002; Agbelade *et al*., 2022). Additionally, trees along Oduduwa Road displayed a large crown diameter, enhancing canopy cover and aesthetic value offered by the trees. Avenue trees with larger leaves and high crown diameter tend to have greater crown length and crown volume, potentially improving their efficiency in cooling, ameliorating microclimates, and filtering or depositing air pollution. However, the effectiveness of these cooling benefits is mediated by the trees' crown shape, age, and local environment (Franceschi *et al*., 2022).

The total height of an avenue tree is crucial for ecosystem benefits such as wind control and noise reduction in urban or roadside areas. The slenderness coefficient –the ratio of tree's total height to DBH– is a useful index for determining tree stability against wind throw and wind damage (Oladoye *et al*., 2023). Trees with lower total height relative to DBH generally have a lower slenderness coefficient (Nunes *et al.*, 2010; Oladoye *et al*., 2023). Some species, such as *Phyllanthus discoideus* along Benue Road and *Casuarina equisetifolia* along Oduduwa Road, exhibited high total height relative to their diameter, making them more slender and potentially more prone to failure, especially if defective, infected, or infested. Among the surveyed roads, Oduduwa Road had the largest values for all tree structural attributes, likely due to its longer length (746 m), providing more roadside area for tree growth compared to Emotan Road (98 m). Although Benue Road is the longest (1,020 m), much of it was occupied by the construction of Millennium Park. Nonetheless, Benue Road recorded the highest abundance of avenue trees from various species (9) but had lower dendrometric, structural, and growth values compared to Oduduwa Road.

Peltophorum pterocarpum was the most widespread avenue tree species across the study area and the most abundant along Emotan and Benue roads. It is widely favoured and planted as a roadside tree and in urban environments for several reasons. These reasons include its fast growth rate; its ability to fix atmospheric nitrogen; its deep root architecture that stabilizes slopes, controls soil erosion, and provides wind firmness; its aesthetic appeal with beautiful orange-yellow flowers; and its shade provision from its spreading crown (Osman *et al*., 2013; CABI, 2019). Other avenue tree species like *Terminalia mantaly*, *Casuarina equisetifolia*, and *Samanea saman* were also relatively abundant but more localized to one or two roads.

Tree failures can cause substantial property damage, disrupt services, activities, and movement, and threaten public safety (Li *et al.,* 2022; Suchocka *et al.,* 2022). A visual health assessment, considering termite infestation, decay, leaning angle, and cracked branches, found that few avenue tree species in the university environment had high or severe rates of infestation and decay. Most of the avenue trees showed no critical signs of infestation, decay, or deformity. Out of 121 trees assessed, only 21 exhibited defects, posing moderate potential hazards to pedestrians, vehicles, and nearby utilities. However, *P. pterocarpum* had a high rate of termite infestation, requiring urgent risk management intervention.

According to Klein *et al.* (2019), even low-risk urban trees require proper management and maintenance. Based on this study's findings, it is recommended that tree management practices are implemented for avenue trees in the three locations studied and other areas within the urban university environment. These practices could include conducting large-scale inventories of avenue trees, replacing large and defective trees with healthier ones, restricting the planting of hazard-prone trees, and selecting species that are more tolerant of urban and roadside conditions. These recommendations align with Onefeli *et al.* (2012), who assessed trees within the Faculty of Agriculture and Forestry on the same campus and emphasized the need for prompt intervention to ensure public safety and prevent tree-related damage. Similarly, Adesoye and Dondofema (2021) assessed the health and risk status of avenue trees at the University of Venda in South Africa. They found that up to 25–35% of avenue trees were unhealthy or hazardous, with common defects such as basal decay, excessive lean, and weak branches. The developed database system in this study is internet-based and hosted at http://159.203.29.155/rebs/rebs.php. It provides valuable information on the geospatial distribution and health risk assessment of avenue trees along the selected roads. The database serves as an efficient tool for assessing and retrieving information on the structural and geospatial dynamics, as well as health and risk status, of individual avenue tree species. Accessible information will facilitate prompt and efficient maintenance and management decisions by the University's Biodiversity Management Committee. The database can be easily updated as new information is gathered and allows for modifications through http://159.203.29.155/phpmyadmin/. Access is password-protected to ensure the information is verified and reliable. Currently, the database is undergoing revamping to improve its functionality, and access may be restricted during this period.

Conclusions: Taking the University of Ibadan as a case in-point, this study has provided the spatial distribution and health status of avenue trees along three commonly used roads within the campus. The longer roads, namely Benue and Oduduwa roads, showed higher abundances and species richness of avenue trees, exhibiting diverse ranges of structural and growth attributes. Overall, most of the surveyed avenue trees in the university environment fell under low to moderate health risk categories, with only a few classified as severe hazard trees. However, to prevent further deterioration in the health and stability of these trees avoid potential hazards, it is essential to implement adequate risk management and tree maintenance practices. The study also presents a geodatabase for the avenue trees, containing profiles and essential information required for their management, maintenance, academic, and further research purposes. The internet-based database developed in this study is adequate and allows for regular and easy updates, subscription, and retrieval of avenue tree health and structural information. The data integrity is high, and users' activities can be monitored through the internet as they subscribe to the database. This study had bridged the knowledge gap by providing information on the identification, spatial distribution, health, and risk assessment of avenue trees along selected roads in the oldest Nigerian university.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the corresponding author.

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