

# Spatial Pattern and Distribution of *Adansonia* Species in the Sahel Savanna Ecosystem of Yobe State, Nigeria

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## Article Info

### Article history:

Received March 12, 2025

Revised May 20, 2025

Accepted July 10, 2025

### Keywords:

Adansonia species  
Spatial distribution  
Sahel savannah  
Nearest neighbour  
Quadrat

## ABSTRACT

Adansonia species, particularly baobab, are ecologically and socioeconomically significant in the Sahel Savanna, yet their spatial distribution patterns remain underexplored in Nigeria. This study employed a reconnaissance survey to delineate the study area and inform the establishment of purposively selected quadrats ranging from 100 x 100 m to 500 x 500 m, based on local Adansonia density and distribution. All individual trees were identified and measured for structural attributes, with their geographic coordinates collected using calibrated GPS devices and validated through multiple readings and inter-observer checks. Nearest Neighbour Analysis (NNA) in ArcGIS 10.8 was used to analyze the spatial patterns by comparing observed mean distances to expected values under random distribution. Results revealed that Adansonia species, predominantly *A. digitata* and *A. kilima*, exhibited a dispersed distribution pattern across 19 of 20 quadrats, with only one quadrat showing randomness. This pattern suggests influences from resource competition, seed dispersal strategies, environmental heterogeneity, and human management. The study provides critical insights for conservation planning and sustainable management of baobab in arid environments.

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## 1. INTRODUCTION

*Adansonia*, commonly known as baobab, represents a genus of long-lived tree species native to Africa's semi-arid and sub-humid regions, with *Adansonia digitata* L. being the most widespread and ecologically significant species, especially within the Sahel savanna [1]. As keystone species, baobabs play a critical role in ecosystem functioning by supporting biodiversity through nutrient cycling, soil enrichment, and providing resources for pollinators, birds, and mammals [2][3]. In Nigeria, *A. digitata* is a prominent feature of the landscape, shaping both ecological dynamics and rural livelihoods [1][4]. The tree's fruits, leaves, and bark are essential for food security and cultural practices, offering nutrient-rich products and medicinal benefits that are deeply integrated into local traditions [1]. Baobab's remarkable water-storing capacity and resilience to drought make it indispensable in arid regions such as Yobe State, where it helps buffer communities against environmental stressors. Across West Africa and India, studies have highlighted the baobab's role in agro-ecosystems, where its hollow trunks provide shelter for wildlife and serve as cultural gathering sites [5]. However, the species faces threats from isolated distributions and anthropogenic pressures, which jeopardize its genetic diversity and underscore the urgent need for conservation strategies that integrate ecological and socio-economic considerations [2]. The adaptability of *Adansonia*, as demonstrated in research from Africa and Asia, positions it as a model organism for investigating spatial patterns in savanna ecosystems.

The distribution of plant species, including *Adansonia*, is shaped by a complex interplay of environmental and anthropogenic factors. Models of plant distribution frequently consider variables such as soil type, topography, climate, human activities, and biotic interactions—particularly those involving birds and insects that facilitate seed dispersal [6]-[9]. These factors are widely recognized for their significant influence on natural distribution patterns. *Adansonia*, for example, is typically associated with tropical savannas, where it thrives in drier climates, exhibits limited tolerance for waterlogging and frost, and avoids areas with deep sandy soils [10]. Its distribution is closely linked to rainfall patterns, with notable populations in both the Sahel region and along the Atlantic coast, possibly reflecting historical cultivation and subsequent spread. The species is scarce in Central Africa and is found only in the northernmost parts of South Africa. In East Africa, baobabs are present not only in savannas but also in shrublands and coastal zones, while in Angola and Namibia, they flourish in woodlands

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and coastal regions in addition to savannas [11][12]. Within the Sahelian study area, factors such as soil type, temperature, and the duration of annual rainfall are likely pivotal in shaping the spatial distribution of *Adansonia* species [13][14].

Understanding spatial patterns in plant distribution requires not only ecological insight but also robust methodological approaches. [15] provides a practical comparative example through their study of *Sasa borealis*, a clonal dwarf bamboo, in Korean forests. Their research employed detailed field surveys to examine how elevation, slope, topography, and aspect influence the distribution of *S. borealis*. They found that the species thrives at elevations of 800–1,200 meters, particularly on gentle, lower, and north-facing slopes in valleys. *S. borealis* often dominates areas with *Quercus mongolica*, especially in late-successional mixed stands, leading to significant declines in species diversity, richness, and evenness. At the same time, this study offers valuable insights into the ecological impacts of a dominant plant species, its focus on a specific region and species, which limits the generalizability of its conclusions. Moreover, the authors' recommendation of ecological control measures following synchronized flowering events highlights the need for management strategies tailored to local environmental contexts. The study's methodology, relying on spatially explicit field surveys and statistical analysis, provides a template for investigating the spatial distribution of other plant species, but also reveals limitations in addressing broader landscape-level processes and long-term dynamics.

*Adansonia digitata* (baobab) serves as a keystone species in the Sahel savanna ecosystem, providing crucial ecological services and sustaining rural livelihoods through its nutritional and medicinal properties. These trees influence ecosystem structure by supporting biodiversity through nutrient cycling, soil enrichment, and providing resources for wildlife. In Nigeria, *A. digitata* dominates landscapes, shaping local ecological dynamics by providing nutrient-rich fruits, leaves, and medicinal products critical for food security and cultural practices [10]. Despite its significance, research on its spatial distribution in Nigeria remains limited. [4] highlighted the socio-economic importance of baobab in Nigerian, Niger state communities, while [11] emphasized the urgent need for improved conservation strategies in response to climate change threats. [16] demonstrated how baobab distribution varies across land use systems in Kenya, revealing the complex interplay between environmental factors and human activities. However, these studies have geographical limitations and methodological constraints. The gap in understanding baobab's spatial patterns in Yobe State is particularly concerning given the region's vulnerability to environmental degradation and the species' importance for food security. The most relevant local study was conducted by [17], who investigated genetic diversity for nutritional traits in *A. digitata* across northeastern and northwestern Nigeria, revealed significant variability among populations and suggested potential for breeding programs aimed at enhancing nutritional quality and stress tolerance. However, this study focused on genetic and nutritional diversity rather than spatial distribution patterns. This knowledge gap is particularly critical given the heterogeneous nature of Sudano-Sahelian communities, where understanding spatial patterns can inform conservation strategies. Most existing research on baobab trees in Africa has concentrated on their medicinal and nutritional value rather than distribution [18][19], underscoring the need for studies that address spatial patterns and their influencing factors

The Sahel Savanna ecosystem presents unique challenges and opportunities for tree growth and survival, making it a focal point for research on plant distribution in arid and semi-arid environments. Rapid population growth and increasing pressures on vegetal resources have led to widespread deforestation and desertification, which are major drivers of biodiversity loss and pose significant threats to global ecological systems [20]–[23]. Vegetation is a fundamental component of the physical environment, defining the resources and character of a place while providing essential goods such as food, shelter, and medicine [24][25]. Inhabitants of the Sahel have long relied on *Adansonia* for sustenance and health, with its leaves used in popular dishes like "miyan kuka" and "danwake," and its pulp, seeds, and bark utilized for juice, oil, condiments, and traditional medicine [26][27]. These diverse uses, however, have led to significant disruptions in the natural distribution of *Adansonia*, particularly in areas where demand is high and conservation measures are lacking.

Geographically, the study area falls within the Sudano-Sahelian vegetation zone, characterized by an arid climate and frequent droughts that negatively impact the already scant vegetation cover. *Adansonia*'s remarkable adaptability to harsh conditions enables its survival and localized distribution, making it a defining species of the region [2][28]. Yet, the high demand for its food and medicinal products, coupled with limited research on its spatial distribution, highlights a critical gap in our understanding of its ecology. Addressing this gap is essential for developing effective conservation and management strategies that ensure the sustainable utilization of *Adansonia* resources. The ecological significance of the species, combined with the region's vulnerability to environmental degradation, underscores the importance of research focused on mapping and understanding the spatial patterns and distribution of *Adansonia* in the Sahel savanna ecosystem of Yobe State. Such research will not only inform conservation efforts but also support sustainable livelihoods and the resilience of local communities in the face of ongoing environmental change.

## 2. METHODS

### 2.1 The Study Area

The study area is situated between latitudes 11°00'00" N and 12°25'40" N and longitudes 10°50'00" E and 11°50'00" E, covering a land area of 8,695 km<sup>2</sup> within the Sudano-Sahelian region of Nigeria. The study area is bordered to the north by Jaskusko and Tarmuwa Local Government Areas (LGAs) of Yobe State, to the east by Damaturu and Gujba LGAs, to the west by Garumawa and Damboa LGAs, and to the south by Darazo, Nafada, and Gulani LGAs of Bauchi, Gombe, and Yobe States, respectively (see Figure 1). The area is highly susceptible to desertification, with the process of Sahelization posing a serious threat to both the local ecology and the livelihoods of its inhabitants. In response, there has been significant investment in tree planting initiatives, with *Adansonia* (baobab), a xerophytic species valued for its food and medicinal uses, emerging as a preferred choice due to its resilience and ecological benefits. Vegetation in the region is characterized by trees, shrubs, and grasses, and is broadly classified as part of the Sudano-Sahelian vegetation zone, which is experiencing rapid Sahelization [29][30]. Rainfall is limited to three or four months annually, resulting in sparse vegetation cover of just over 4% [31][32]. According to [33], the area fits the category of sparse woodland with herbaceous layers, shrubs, and emergent species. These environmental challenges and the strategic importance of *Adansonia* in combating desertification highlight the need for detailed research on its spatial pattern and distribution to inform effective conservation and sustainable management strategies.

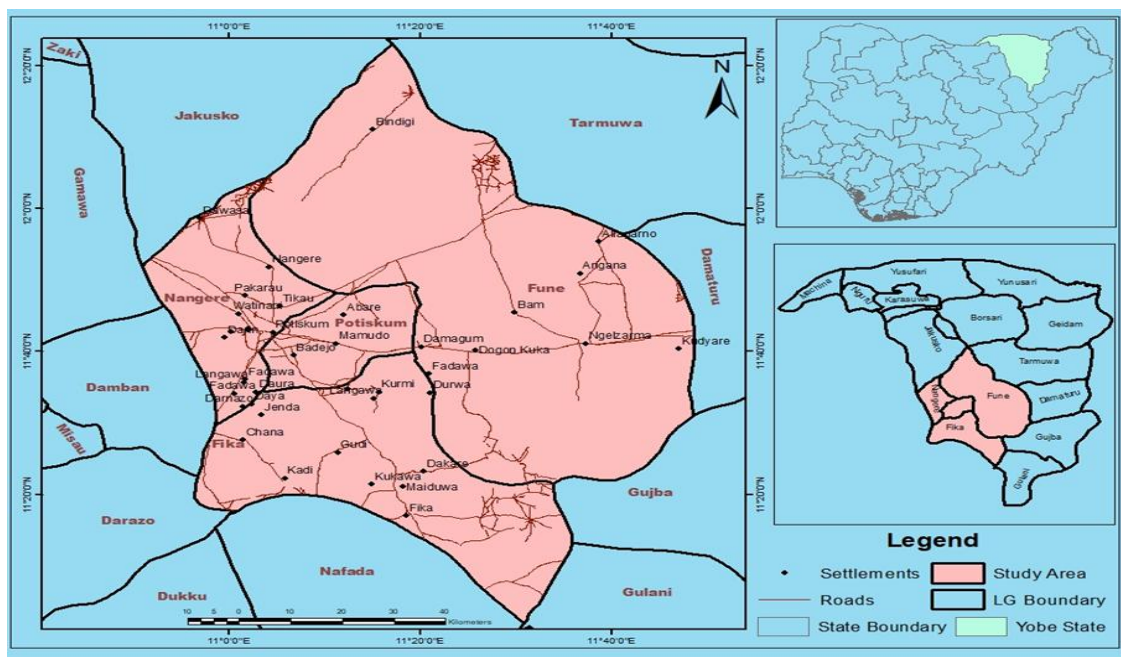


Figure 1. Yobe State, showing the study area

Source: Adopted from the administrative map of Yobe State (2023)

Historically, the environmental impacts of human activities such as deforestation, bush burning, over-grazing, and the harvesting of tree leaves and fruits for food, as well as rapid urbanization, were minimal due to low population densities in the study area. However, recent population growth, coupled with insurgency and military counterinsurgency operations in North-Eastern Nigeria, is believed to have significantly altered the distribution of *Adansonia* species in the study area [2][34]. Various factors, including construction activities, farming, housing development, and road construction, further contribute to changes in plant species distribution, often with negative consequences. There is growing concern that the unique and valuable biodiversity of the Sahel Savanna is being lost due to both natural and anthropogenic disturbances, including unsustainable management practices [35][36]. The region is undergoing severe large-scale changes through harvesting, burning, and conversion to other land uses, emphasizing the need for a better understanding of plant community dynamics and quantitative changes to inform conservation and sustainable management [37][38]. Despite the vulnerability of plant species to these pressures, there is a notable lack of data on the distribution of *Adansonia* in the Sahel Savanna ecosystem of Nigeria. This context underscores the urgent need for spatial studies on *Adansonia* distribution to support effective conservation, sustainable management, and policy development in the face of ongoing environmental and anthropogenic challenges.

## 2.2 Research Methods

A reconnaissance survey was first conducted to delineate the study area's boundaries and to gain familiarity with local vegetation and soil conditions, providing essential baseline information for sampling design. Based on this preliminary assessment, we adopted a purposive sampling technique. We established quadrats ranging from 100 x 100 meters to 500 x 500 meters, with the specific size in each location determined by the density and spatial distribution of *Adansonia* species. The rationale for these quadrat size ranges is robustly supported by [39], who emphasized that larger quadrats are necessary for sampling sparse or widely dispersed tree species to capture spatial heterogeneity and reduce sampling error, while smaller quadrats may underestimate species diversity in such contexts. Similarly, [40] demonstrated that quadrat sizes within this range are effective in tropical savanna and woodland ecosystems, balancing the need to encompass sufficient individuals for statistical analysis while minimizing edge effects and logistical complexity. Within each quadrat, all *Adansonia* species were identified and measured for structural attributes, including girth, diameter at breast height (DBH), height, and crown cover, following operational definitions consistent with established ecological protocols. A tree, therefore, was defined operationally as any woody plant exhibiting an erect growth habit and reaching a minimum height of 1.5 meters. This methodological approach ensures that the spatial patterns and population structure of *Adansonia* are accurately captured, providing a reliable foundation for ecological analysis and comparison with other studies in similar environments.

Geographic locations of each quadrat's centre were obtained using a handheld GPS device, calibrated before fieldwork to minimize systematic errors [41][42]. To address GPS accuracy limitations in the Sahel's challenging terrain, we employed differential correction techniques and took multiple readings at each point, recording average coordinates only when position dilution of precision (PDOP) values was below 3.0. Observer bias was managed through rigorous pre-survey training, standardized measurement protocols, and periodic inter-observer reliability tests with a concordance threshold of 95%. The researchers randomly reassessed 15% of the quadrats to validate measurements and species identification. The GPS coordinates of all sampled *Adansonia* trees were recorded and incorporated into a nearest neighbour analysis (NNA) using ArcGIS 10.8 to calculate observed and expected mean distances, with spatial error propagation explicitly modeled in the statistical analysis. Figure 2 illustrates the distribution of sampling quadrats across the study area.

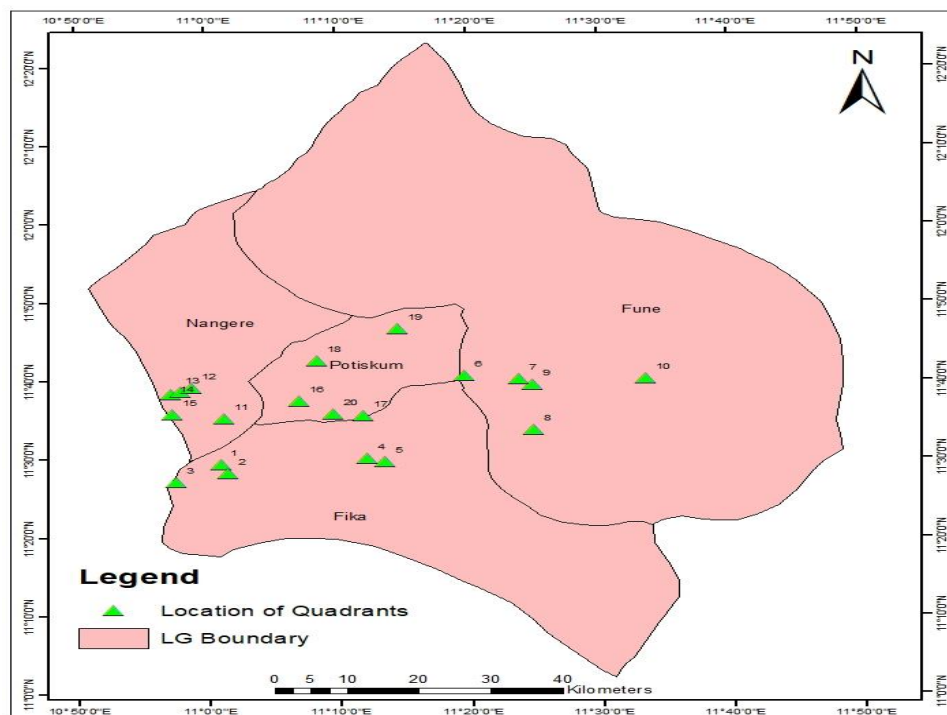


Figure 2 Map of the Study Area showing locations of quadrats  
Source: Author's analysis (2023)

NNA offers a robust method for determining species distribution patterns, differentiating between clumped, uniform, or random arrangements [43]-[45]. This technique involves measuring the distance from each individual in a population to its nearest neighbour, then comparing the mean of these observed distances to the expected mean distance under a random distribution, yielding a quantitative ratio indicative of the spatial pattern [46]-[48]. By employing NNA, this study quantitatively characterizes the spatial distribution of *Adansonia* species

within the Sahel Savanna ecosystem. The mean distance between nearest neighbours is compared to the expected distance in the case of random distribution to give the ratio:

$$Rn = \frac{2d\sqrt{n}}{A} \quad (1)$$

Where:

Rn = nearest neighbour statistics  
 d = observed mean distance  
 A = area  
 N = number of points

OR

$$Rn = \frac{1}{2} \times \frac{1}{\sqrt{P}} \quad (2)$$

Where P is the density per unit area

0 = maximum aggregation/clumped/clustered  
 1 = random  
 2.15 = uniform/ regular/dispersed

If this ratio  $R$  is equal to 1, then the population is randomly dispersed. If  $R$  is significantly greater than 1, the population is evenly dispersed. Lastly, if  $R$  is substantially less than 1, the population is clumped. The number of individuals present in each sample is compared to the expected counts in the case of random distribution. The expected distribution can be found using the Poisson distribution. If the variance/mean ratio is equal to 1, the population is found to be randomly distributed. If it is significantly greater than 1, the population is found to have a clumped distribution. Finally, if the ratio is substantially less than 1, the population is found to be evenly distributed.

For this research work, ArcGIS 10.8 was employed to compute the nearest neighbor statistics, providing a robust analytical framework for spatial pattern analysis of *Adansonia* species. The process began with recording precise GPS coordinates of each tree, which were saved in Microsoft Excel comma-delimited format to ensure compatibility with the GIS software. These coordinates were then imported into the ArcGIS environment using the Add X and Y tool and subsequently converted to a shapefile for spatial analysis. This geospatial data was utilized to calculate the nearest neighbor statistics, generating critical metrics, including the observed mean distance, the expected mean distance, and the closest neighbor ratio. The results, produced as a Hypertext Markup Language (HTML) document, were further processed to illustrate the information of *Adansonia* across the study quadrats in the Sahel Savanna ecosystem of Yobe State in Tables. This methodological approach aligns with established practices for analyzing spatial patterns of keystone species, as noted in previous studies that emphasize the importance of understanding distribution patterns for conservation planning.

The Nearest Neighbor Analysis (NNA) was specifically selected to assess the degree to which the spatial point pattern of *Adansonia* departs from randomness toward either clustering or dispersion [49]-[52]. This method determines whether trees identified in each quadrat exhibit patterns of aggregation or separation by computing the distance between each tree and its nearest neighbor, then calculating the average of these measurements for each quadrat. The analysis employs the nearest neighbor index.

$$I = \frac{D_r}{D_h} \quad (3)$$

Where:

$D_r$  is the calculated average distance of the real (observed) data.

$D_h$  is the average distance of the imaginary (expected) data.

Statistical significance is determined using the Z-score, which compares observed and expected distances at a 95% confidence level (-1.96). A negative Z-score indicates clustering, while a positive value suggests dispersion or evenness. By applying this established methodology to *Adansonia* in the Sahel Savanna, this study contributes to understanding the spatial ecology of this keystone species, which is crucial for developing targeted conservation strategies in regions facing environmental degradation.

### 3. RESULTS AND DISCUSSION

#### 3.1 Spatial distribution of *Adansonia* species

Spatial distribution analysis of *Adansonia* species revealed varying densities across the study area. Quadrat one (500x500m) had the highest tree count (88), followed by quadrats two (400 by 400 meters), eleven (500 by 500 meters), twelve (400 by 400 meters), ten (500 by 500 meters), and thirteen (300 by 300 meters) with 76,70,

66,57 and 51 respectively. On the other hand, quadrats five (100 by 100 meters), six (100 by 100 meters), sixteen (100 by 100 meters), and seventeen (200 by 200 meters) showed the lowest numbers of trees with 9, 10, 12, and 19 trees respectively. These findings, detailed in Table 1, reflect the heterogeneous distribution patterns characteristic of savanna ecosystems. The findings in Table 1 demonstrate a clear dominance of *Adansonia digitata* in the study area, with 775 individuals recorded compared to only 16 individuals of *Adansonia kilima*, highlighting the rarity of *A. kilima* in the Sahel Savanna ecosystem of Yobe State. This finding corroborates with those who found that *A. digitata* was the most widespread and ecologically significant baobab species in the Sahel savanna. The absence of other *Adansonia* species (*A. grandidieri*, *A. gregorii*, *A. madagascariensis*, *A. perrieri*, *A. rubrostipa*, *A. suarezensis*, and *A. za*) aligns with broader biogeographical patterns documented in previous studies, which indicate that only *A. digitata* and *A. kilima* are native to continental Africa, with other species restricted to Madagascar and Australia.

Findings on the structural measurements revealed considerable variation across the study area, with the largest girth (12.18 meters) recorded in quadrat fifteen and the smallest (1.01 meters) in quadrat twenty. The largest DBH (11.68 meters) was found in quadrat one, while the smallest (0.82 meters) occurred in quadrats one and four. Age estimates ranged from 31 years (quadrats one and four) to 439 years (quadrat one), demonstrating the remarkable longevity characteristic of baobabs. The tallest specimen (21.33 meters) was located in quadrat one, contrasting with the shortest (2.29 meters) in quadrat seventeen. These findings are consistent with those who observed varying baobab population densities across different land-use systems in Kenya, although our study provides more detailed structural measurements. Our research will focus on nutritional traits, addresses the critical knowledge gap regarding spatial distribution patterns of *Adansonia* species in Nigeria's Sahel Savanna, essential for developing targeted conservation strategies.

Table 1. Distribution of *Adansonia* Species in the Study Area

Quadrat	Number Of Trees	<i>Adansonia Digitata</i>	<i>Adansonia Kilima</i>	Others
1	88	83	5	0
2	76	72	4	0
3	34	32	2	0
4	21	21	0	0
5	9	9	0	0
6	10	10	0	0
7	22	22	0	0
8	35	35	0	0
9	44	41	3	0
10	57	56	1	0
11	70	70	0	0
12	66	66	0	0
13	51	51	0	0
14	36	36	0	0
15	41	41	0	0
16	12	12	0	0
17	19	19	0	0
18	31	31	0	0
19	34	33	1	0
20	35	35	0	0
<b>Total</b>	<b>791</b>	<b>775</b>	<b>16</b>	<b>0</b>

Source: Field work (2023)

### 3.2 Nearest Neighbour Analysis of the distribution of *Adansonia* species

Appendix 1 presents the spatial pattern analysis results for *Adansonia* species across twenty quadrats, using NNA with the null hypothesis that the species are randomly distributed. The NNA output, summarized in an HTML file, includes observed mean distance, expected mean distance, nearest neighbor index, p-values, and Z-scores (Table 2). The expected mean distances, calculated by ArcGIS 10.8, ranged from 7.6520 to 36.6904 meters, while observed mean distances varied between 10.9187 and 43.3128 meters. These findings indicate deviations from randomness in tree distribution across most quadrats, providing critical insights into the spatial ecology of

*Adansonia* in the Sahel Savanna ecosystem. The findings from Table 2 underscore a distinctly dispersed distribution pattern of *Adansonia* species across 19 of the 20 quadrats, with only one quadrat exhibiting a random pattern and none showing clustering. The dispersed pattern observed in this study likely results from competition for limited resources, effective seed dispersal mechanisms, and environmental heterogeneity, corroborating broader literature that emphasizes the influence of both ecological and anthropogenic factors on baobab distribution. Overall, these results reinforce that *Adansonia*'s spatial ecology is shaped by a complex interplay of natural and human-driven processes, with dispersion being the prevailing pattern in the Sahel Savanna ecosystem.

Table 2. Observed and Expected Mean Distance, Nearest Neighbour Index, P-value and Z-score

Quadrat	Quadrat Size (M)	Number of Trees	Observed Mean Distance (M)	Expected Mean Distance (M)	Nearest Neighbour Ratio	Z-Score	P-value	Pattern
1	500*500	88	34.9471	26.0795	1.340025	6.12158	0.000000	Dispersed
2	400*400	76	33.5821	22.1338	1.517234	8.626303	0.000000	Dispersed
3	300*300	34	31.0656	24.6522	1.260158	2.902072	0.003707	Dispersed
4	200*200	21	27.1880	18.5479	1.465827	4.083811	0.000044	Dispersed
5	100*100	9	26.1321	12.8454	2.034361	5.936416	0.000000	Dispersed
6	100*100	10	21.8272	13.2742	1.644338	3.898023	0.000097	Dispersed
7	200*200	22	28.8937	18.3650	1.573299	5.144263	0.000000	Dispersed
8	300*300	35	37.3560	23.9306	1.561012	6.349462	0.000000	Dispersed
9	400*400	44	40.4266	27.2346	1.484384	6.146765	0.000000	Dispersed
10	500*500	57	39.4890	29.3469	1.345593	4.991532	0.000001	Dispersed
11	500*500	70	40.3283	28.2825	1.425912	6.817103	0.000000	Dispersed
12	400*400	66	32.4546	22.1837	1.462994	7.195791	0.000000	Dispersed
13	300*300	51	25.4167	18.5357	1.371229	5.071750	0.000000	Dispersed
14	100*100	36	10.9187	7.6250	1.431956	4.888819	0.000001	Dispersed
15	200*200	41	19.8895	14.1834	1.402304	4.987814	0.000001	Dispersed
16	100*100	12	20.9281	12.3194	1.698789	4.630923	0.000004	Dispersed
17	200*200	19	20.5192	18.0644	1.135895	1.133211	0.257126	Random
18	300*300	31	25.9177	16.2956	1.590478	6.390134	0.000000	Dispersed
19	400*400	34	43.3128	29.9317	1.447056	4.913029	0.000001	Dispersed
20	500*500	35	36.6904	36.6904	1.318936	3.609682	0.000307	Dispersed

Source: Authors Analysis (2023)

The dispersed pattern of *Adansonia* species distribution in the 19 quadrats is best described by human influence on the tree species, as most baobab trees in the study area are protected and planted or transplanted in farmland, with the tree only being found in residences on rare occasions. These findings revealed that the spatial distribution pattern of the trees of ethno-botanical interest was clustered ( $Z=-26.25$ ;  $p < 0.05$ ). Given that the pattern in quadrat 17 has a Z-score of 1.133211 and a P value of 0.257126, both of which are higher than the 95% confidence level, the pattern does not appear to be significantly different from random. In general, given that the generated nearest neighbour index is greater than one and the calculated Z-score is positive between 1.133211 and 8.626303 in the 20 quadrats for tree distribution shown in Table 1, there is less than 1% chance that the trees in the study region display random patterns, except for quadrat 17. Findings further showed that quadrat 2 is the most dispersed of the 19 quadrats in the study area, with a Z-Score of 8.626303, while quadrat 3 is the least dispersed, with a Z-Score of 2.902072.

#### 4. CONCLUSION

This study advances our understanding of the spatial ecology of *Adansonia* species in the Sahel Savanna of Yobe State, Nigeria, by shifting the focus from their well-documented nutritional and medicinal roles to their distribution patterns. The findings reveal a predominantly dispersed distribution of *Adansonia*, with *Adansonia digitata* as the dominant species and *Adansonia kilima* occurring occasionally. In contrast, other species remain absent, consistent with broader African distribution trends. These results underscore the urgent need for conservation strategies that protect individual trees and their habitats, particularly given the species' ecological importance and vulnerability to anthropogenic pressures, such as deforestation and land-use change. The dominance of *A. digitata* underscores its value not only for local livelihoods but also for enhancing climate resilience in arid environments. This research fills a critical knowledge gap in the spatial distribution of *Adansonia* in the Sahel and provides a methodological foundation for future studies in similar ecosystems. It invites policymakers, conservationists, and researchers to integrate spatial distribution data into reforestation, agroforestry, and land management initiatives, ensuring that the ecological and socio-economic benefits of *Adansonia* are sustained for future generations.

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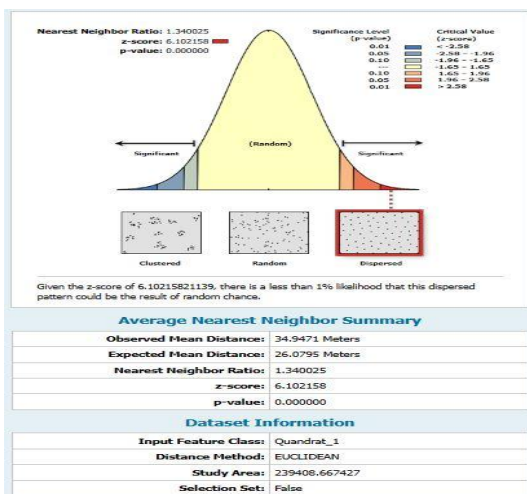


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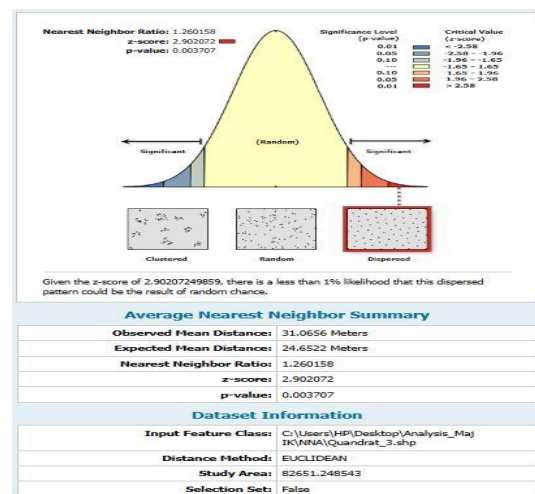


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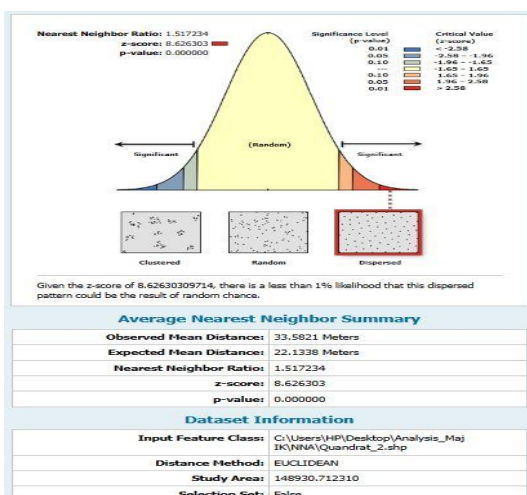
**Appendix 1: The spatial pattern analysis for *Adansonia* species across quadrats one through twenty**



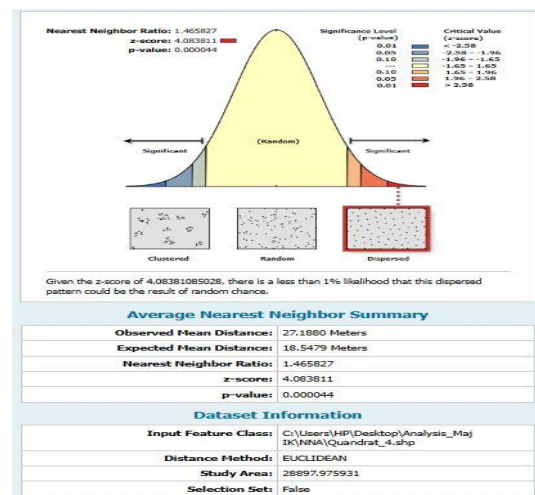
Quadrat One  
 Source: Authors Analysis (2023)



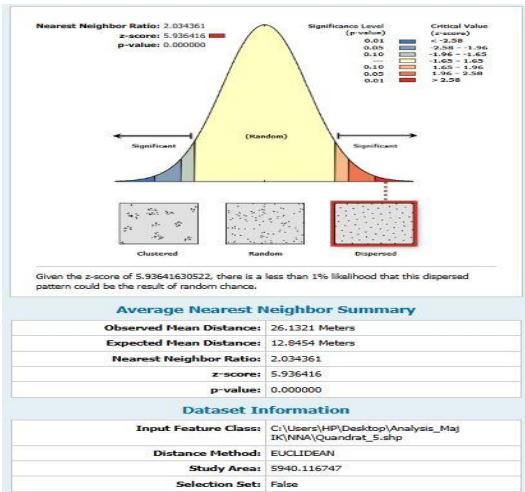
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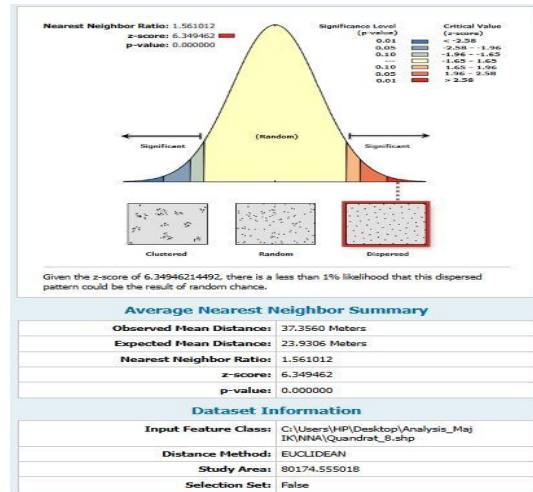
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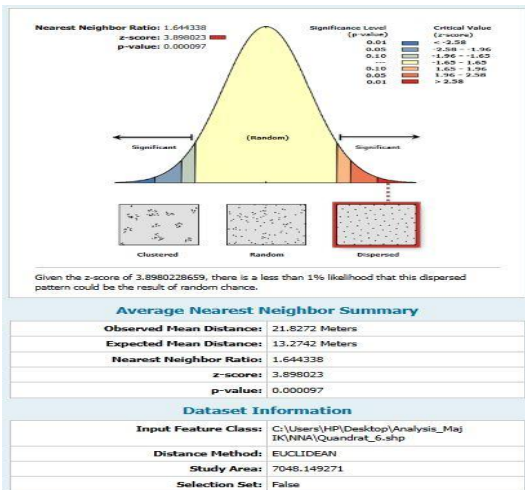
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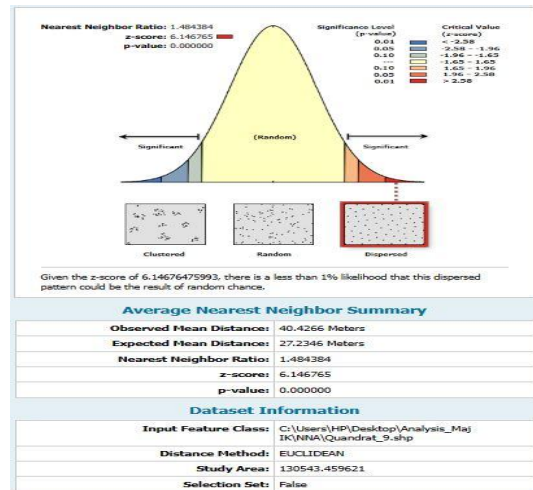
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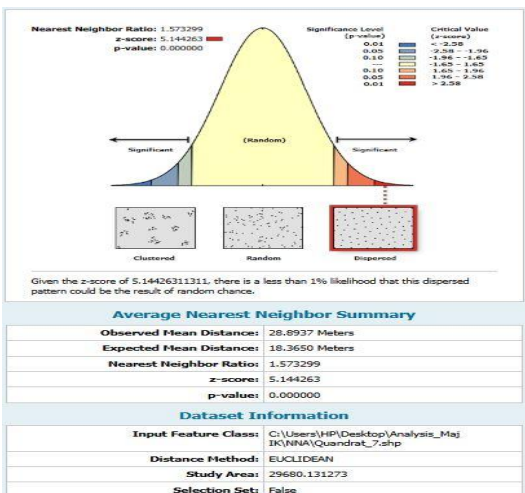
Quadrat Eight  
Source: Authors Analysis (2023)



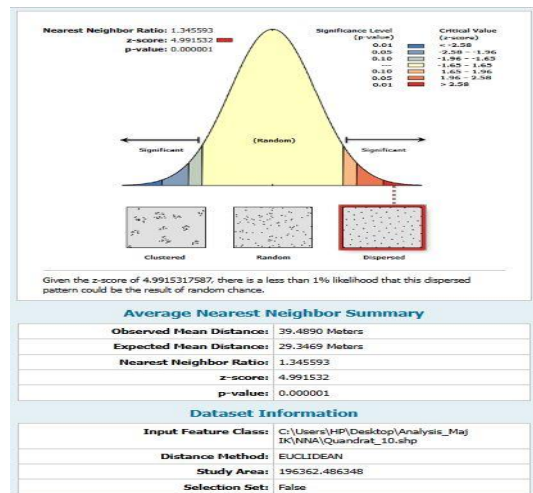
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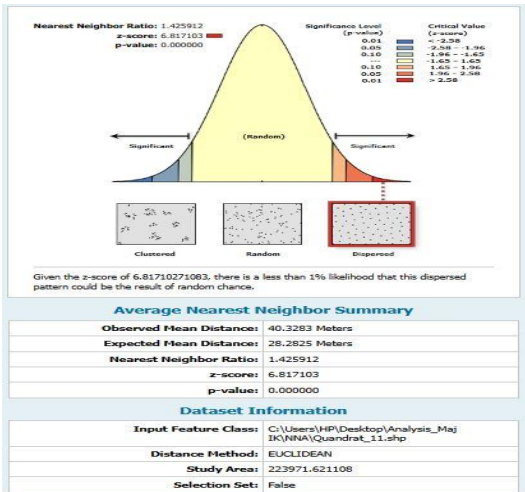
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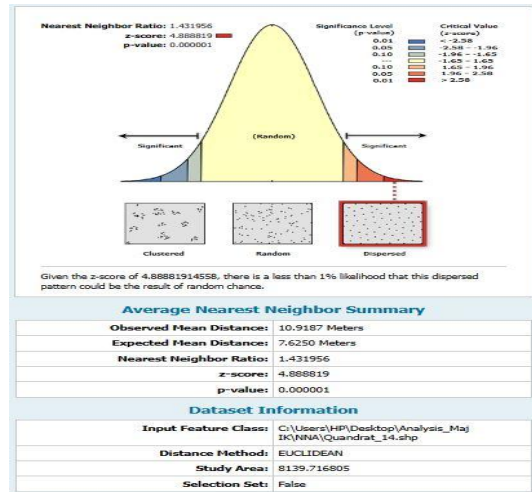
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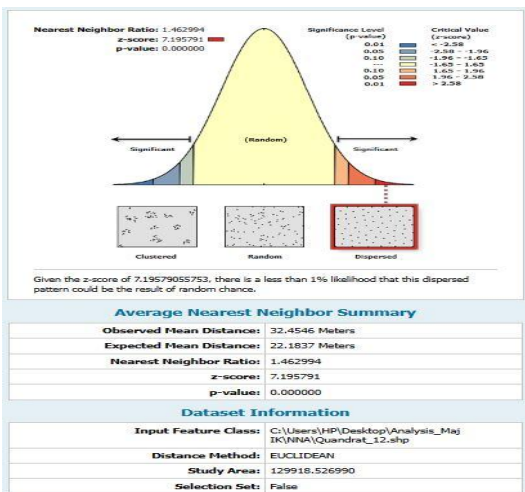
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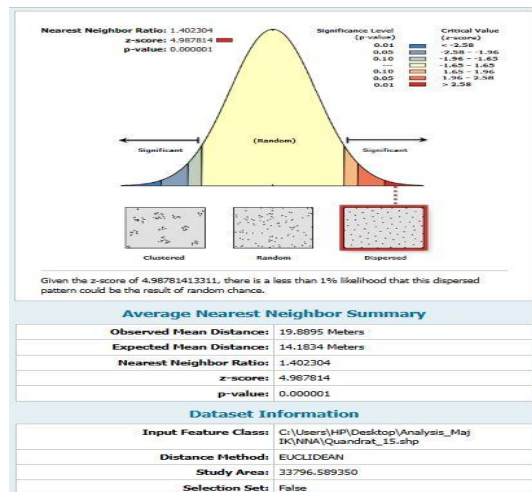
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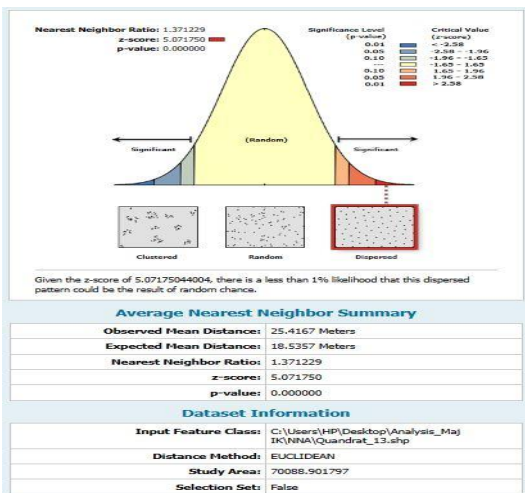
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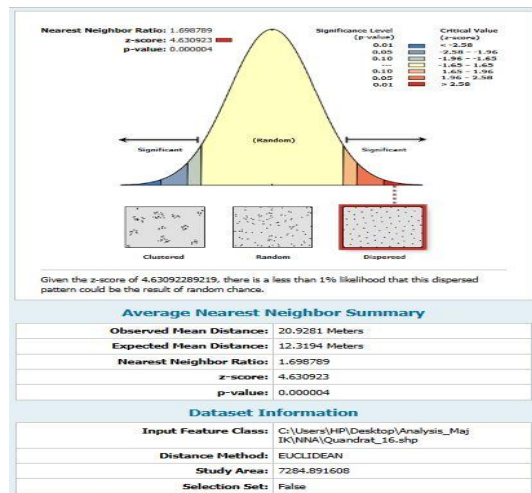
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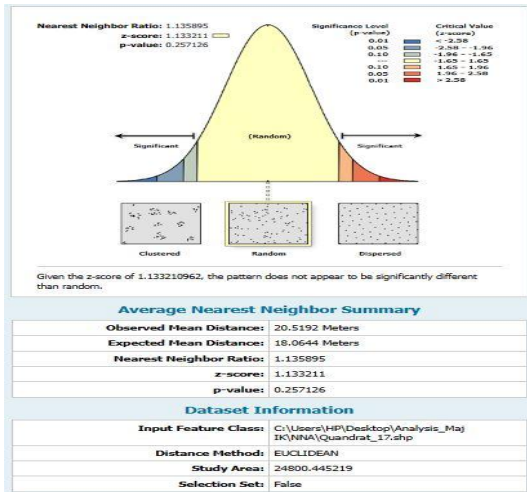
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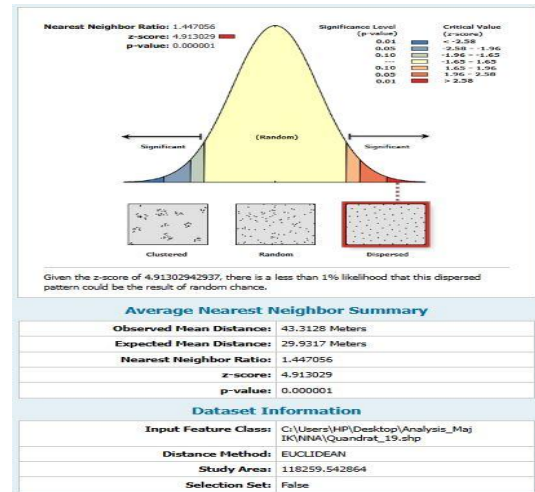
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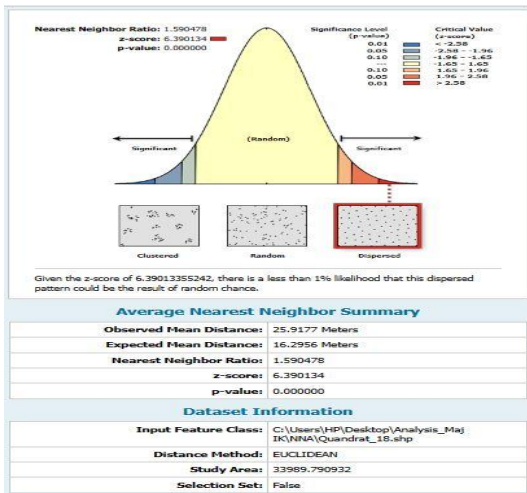
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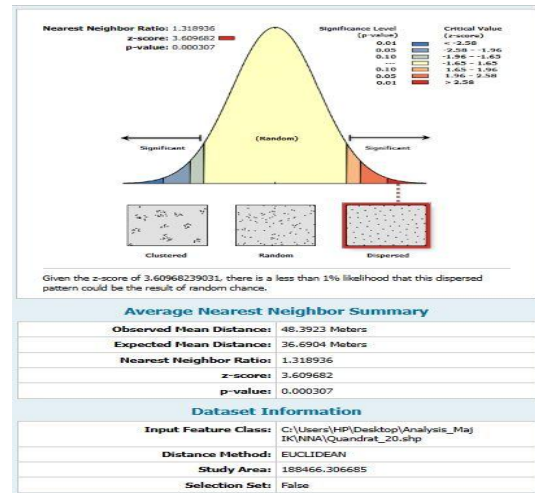
Quadrat Seventeen  
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Quadrat Nineteen  
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Quadrat Eighteen  
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Quadrat Twenty  
 Source: Authors Analysis (2023)