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Original Research Article

Impact of Invasive Species from Different Land Use on Vegetation Structure and Soil Microbial Dynamics in Warwade, Sudan Savanna, Jigawa State, Nigeria

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KEYWORDS
Invasive,
Plant Species,
Diversity,
Spatial Distribution,
Sudan Savanna.

ABSTRACT
This study assessed the vegetation structure which was classify into indigenous and exotic to determine invasive plant species and microbial population across ecological zones. Randon sampling using twenty quadrats across three ecological zones. Plant species encountered within each quadrat were identified, enumerated, and classified using Plant NET and iNATURALIST. Coordinates of invasive species were recorded using a Global Positioning System receiver to determine their spatial distribution. A total of 29 plant species, 256 individuals and 33 occurrences were recorded. Plantation had the highest species richness 14 and abundance 124 individuals, followed by Fallow 13 species, 82 individuals, while Agricultural landscape had the lowest 12 species, 64 individuals. Fabaceae 43.5% dominated plant families. Plantation recorded the highest diversity indices, indicating greater species evenness and reduced dominance. Exotic species 52.2% slightly outnumbered natives 47.8%, reflecting anthropogenic influence. Sorensen similarity indicated substantial species overlap among zones. *Prosopis farcta*, *Portulaca oleracea*, *Physalis angulata, Euphorbia hirta, Setaria verticillata, Boerhavia erecta, Euphorbia heterophylla, Amaranthus spinosus, and Spigelia anthelmia* were identified as invasive species. Forest Land recorded the highest bacterial count at 3.4×108 CFU/g, but differences were not significant. *Bacillus sp.* occurred in all land uses, while Klebsiella and Enterobacter indicated anthropogenic inputs. Five fungal genera were recorded, with Aspergillus, Penicillium, and Rhizopus present in all zones. Study area supports diverse plant community despite the occurrence of invasive exotic species. Continuous monitoring, early detection, and appropriate management strategies are recommended to minimize the spread of invasive species and conserve the indigenous flora of the plantation.

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INTRODUCTION

Invasive alien plant species pose substantial threats to agriculture, biodiversity and the delivery of ecosystem services globally. Frequency and distribution are essential starting point that would enable the quantification of these threats, and inform the development of appropriate responses. These plant species are considered one of the greatest threats to long-term conservation of biological diversity in both terrestrial and aquatic habitats (Lee and Macdonald, 2016). According to Syliver *et al.,* (2020)., IPSs pose a significant threat to many of Africa's conservation areas. Among the most widely distributed invasive plants is *Lantana camara* which occurs across many protected areas. The plant occurs in diverse habitats and on a variety of soil types in many continents (Corlett, 2016). Thus, its diverse and broad geographic distribution is a reflection of its wide ecological tolerance. These invasive plants, invades and impacts severely on natural ecosystems, threatening the survival of many species (Sharma *et al.,* 2016). It's allelopathic qualities can selectively increase mortality of other plant species (Osunkoya *et al.,* 2012).

Invasive plant species is one of the world's conservation challenges that affect protected areas (Wittenberg and Cock, 2001). However, the impact of IPSs in protected areas such as National Reserves is currently poorly understood and the magnitude of the problem is not well appreciated. In this regard, biodiversity in protected areas is adversely affected and its long-term survival is threatened by IPSs. The features that are associated with invasive plants species are: (i) they show large seeding and early age of fast reproduction, (ii) have unpalatable foliage, can easily establish in degraded environments, (iii) have an ability to regenerate directly from seeds, stems or roots. These features make them good competitors amongst other plant species and allow their survival and abundant establishment (Ahimbisiwe, 2014). An introduced plant species might become invasive if it can out-compete native species for resources such as nutrients, light, water or food. Invasive species compete for space or resources, dominating the niches occupied by native species and excluding them from the natural environment. The competitive exclusion of these species can compromise the existence of rare species and even other trophic levels, keeping communities in a constant state of disruption. Invasive plant species invasions can have devastating population, community and ecosystem impacts (Parker *et al.,* 2017). Such impacts may include loss of native species, disruption of energy and nutrient webs and unstable production systems (Davis *et al.,* 2015). As a potential threat to native biological diversity, IPSs need to be controlled to ensure that the food plants of all herbivores are in large supply, maximize productivity decrease their vulnerability to extinction. Thus, in addition to wildlife restocking and creation of new reserve boundaries, successful management and conservation of the reserves and other protected areas can be achieved if invasive plant species are managed to allow proper pasture to wildlife and manage entire habitat health through avoiding compromising their food resource base (Adcock *et al.,* 2017). Other invasive plants species like *Lantana camara* were utilized for ornamental purposes. In some regions, these plant species are more prevalent in the landscape (Thapa *et al.,* 2014). It is widely acknowledged that good information and understanding about IPSs is the basis for sound policy and management. Therefore, the study focused on the invasive plant species, spatial distribution and microbial count in Sudan savanna, Jigawa Sate, Nigeria

MATERIALS AND METHODS

Study Area

This study was carried out at Warwade Forest Reserve, Dutse Local Government about 6km away from capital city of Jigawa State. Reserve is located between latitude 11^0.43' 30"N - $11^0$46'30"N and longitude $9^0$11'30"E - 9^0 16'30"E. The relief is flat with little undulation (Salami *et al.,* 2021). The soil type is sand-loam, loamy and clay-loam soil respectively (Salami *et al.,* 2021). The optimum day temperature at day time is 29-33^0c and declined to 19-23^0C at night, annual rainfall per year is 1200 to 1500mm (Ahungwa *et al.,* 2026). Warwade plantation was established for the purposes to reduce water evaporation from the dam. It serves as habitat to many bird species and reptiles within the dam. They also act as a giant filter clearing the air we breathe. Warwade Dam plantation was established in the 1970's to support diverse vegetation of plant species including shrubs, herbs, and tree. Some important plant species are Neem (*Azadirachta indica*), which are dominants species and some shrubs species include, Kharroub (*Piliostigma reticulum*), Kapok tree (*Calotropis procera*) and grass species: Coco grass (*Cyperus rotundus*), Sickle pod (*Cassia tora*) and Cane grass (*Eragrostis tremula*). Different plant species and shrubs dominated are: *Acacia species*, *Adansonia digitata, Azadirachta indica and Mangifera indica a*re found within the study area.

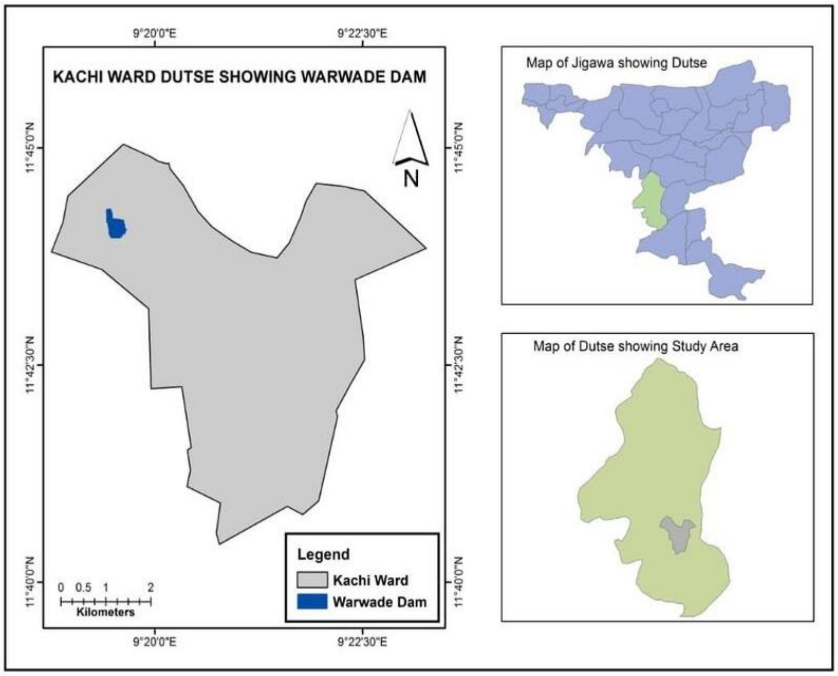

Figure 1: Map Showing Warwade Plantation
Source: Salami *et al*., (2024)

Field Survey

The study adopted a descriptive ecological survey design, combining field observation, random vegetation sampling, and spatial analysis. This design was considered appropriate for assessing the composition, diversity, abundance, and spatial distribution of indigenous and exotic invasive plant species within Warwade Plantation.

Reconnaissance Survey

A reconnaissance survey was carried out prior to the main fieldwork to obtain preliminary knowledge of the study area. This involved a general walk-through of the plantation to identify vegetation types, assess accessibility, delineate the three sampling zones (Plantation, Fallow Land, and Agricultural Land), and observe the occurrence of invasive plant species. Information obtained during the reconnaissance survey guided the selection of sampling locations within each zone.

Plant Collection and Enumeration

All plant species encountered during the random survey within the three sampling zones were identified, classified, enumerated, and recorded. The recorded plant species were categorized as indigenous or exotic. Exotic species were further assessed and classified as either naturalized or invasive based on their establishment status and ecological behaviour within the study area. The geographic coordinates of each identified invasive plant species were recorded using Global Positioning System (GPS) receiver to facilitate the analysis of their spatial distribution within Warwade Plantation. The data collected were used to assess the diversity, abundance, and spatial distribution patterns of indigenous and exotic invasive plant species in the study area.

Sampling Layout and procedure

The study area was divided into three sampling zones, namely Plantation, Fallow Land, and Agricultural Land. Random sampling was conducted within each zone to identify, enumerate, and record all plant species encountered. The recorded species were classified as either indigenous or exotic, while the exotic species were further categorized as naturalized or invasive.

Sampling Techniques

Random sampling technique was adopted for this study. The survey will be carried out within the three identified habitat zones of Warwade, namely Plantation Zone, Fallow Land Zone, and Agricultural Land Zone. Plant species encountered during random movement within each zone was identified, counted, and recorded. The use of random sampling is considered appropriate because the study area is relatively flat and allows unbiased sampling of vegetation across the different habitat types.

Data Analysis

Objective 1: Descriptive statistics, including tables, frequencies, percentages, and charts, were used to present the checklist, composition, and abundance of indigenous and exotic plant species recorded within the three sampling zones. Exotic species were further classified as naturalized or invasive.

Objective 2: The collected data were subjected to the Shannon–Wiener Diversity Index (H') and Simpson's Diversity Index (D) to determine plant species diversity within the study area.

Shannon-Wiener Diversity Index (H')

The Shannon-Wiener Diversity Index (H') is given in equation (1) by (Yager *et al.,* 2017):

$$H' = -\sum P_i \ln P_i \quad (1)$$

Simpson's Diversity Index (D)

Simpson diversity index was employed for assessing the diversity of Tree.

Products as adopted by Saka *et al*. (2020)

Simpson index $D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right)$ (2)

Where:

n = total number of organisms of a particular species,

N = the total number of organisms of all species

Sorensen's species similarity index (SSI) between six forest reserves was calculated using equation as adopted by Saka *et al*. (2020)

SSI= $\frac{2C}{A+B}$ X 100%

Where:

C = Sum of number of species in both sites A and B

A = number of species at sites A,

B = number of species at sites B

Objective 3: The spatial distribution of indigenous and invasive plant species was analyzed using Geographic Information System (GIS) software to produce distribution maps and identify invasion hotspots across the Forested/Plantation, Fallow Land, and Agricultural Land zones.

RESULTS AND DISCUSSION

Plant Species Composition Across the Three Ecological Zones

The results show that the Plantation Zone had the highest biodiversity and abundance with 14 species representing 35.89% of the total species and 118 individuals representing 46.1% of the total individuals recorded. The Fallow Land Zone followed with 13 species (33.33%) and 74 individuals (28.9%), while the Agricultural Land Zone had the lowest with 12 species (30.80%) and 64 individuals (25.0%). In total, 39 species and 256 individuals were recorded across the three zones. This pattern suggests that land use intensity influences vegetation structure, with plantations providing more favorable conditions that support both a greater number of species and higher population density compared to fallow and agricultural lands, where frequent disturbance and clearing likely reduce diversity and abundance.

Table 1: Plant Species Composition Across the Three Ecological Zones

Ecological Zone	Number of Species	Percentage of Species (%)	Number of Individuals	Percentage (%)
Plantation Zone	14	35.89	124	45.26
Fallow Land Zone	13	33.33	82	29.92
Agricultural Land Zone	12	30.80	68	24.82
Total	39	100	274	100

Plant Species Composition of the Plantation Zone

Table 2 shows that a total of 14 plant species belonging to seven plant families were recorded in the Plantation Zone, with an overall abundance of 118 individuals. The family Fabaceae was the most dominant, accounting for six of the recorded species, while the remaining families were each represented by one species. The results further revealed that seven species (58.3%) were native (indigenous), whereas five species (41.7%) were exotic. Of the exotic species, four species (*Azadirachta indica*, *Senna occidentalis*, *Senna tora*, and *Dalbergia sissoo*) were classified as naturalized, while *Mimosa aculeaticarpa* was recorded as an exotic species without evidence of naturalization based on the field observations. In terms of abundance, *Azadirachta indica* recorded the highest number of individuals (15), followed by *Cyperus sphacelatus* (14), *Senna occidentalis* (13), and *Piliostigma reticulatum* (12). Conversely, *Balanites aegyptiaca* had the lowest abundance with 5 individuals recorded in the Plantation Zone

Table 2: Plant Species in the Plantation Zone

S/N	Botanical Name	Common Name	Family	Habit	Status	Category	Freq.
1	*Azadirachta indica*	Neem	Meliaceae	Tree	Exotic	Naturalized	15
2	*Balanites aegyptiaca*	Desert date	Zygophyllaceae	Tree	Native	-	5
3	*Calotropis procera*	Sodom apple	Apocynaceae	Shrub	Native	-	6
4	*Cyperus sphacelatus*	Roadside flatsedge	Cyperaceae	Graminoid	Native	--	14
5	*Dalbergia sissoo*	Indian rosewood	Fabaceae	Tree	Exotic	Naturalized	7
6	*Indigofera arrecta*	Natal indigo	Fabaceae	Herb	Native	-	9
7	*Ludwigia adscendens*	Water primrose	Onagreae	Herb	Native	-	9

8	*Mimosa aculeaticarpa*	Catclaw mimosa	Fabaceae	Shrub	Exotic	-	11
9	*Piliostigma reticulatum*	Camel's Foot	Fabaceae	Shrub	Native	-	12
10	*Senna occidentalis*	Septicweed	Fabaceae	Shrub	Exotic	Naturalized	13
11	*Senna tora*	Sickle senna	Fabaceae	Herb	Exotic	Naturalized	10
12	*Waltheria indica*	Uhaloa	Malvaceae	Shrub	Native	-	7
13	*Euphorbia hirta,*	Asthma plant	Euphorbiaceae	Herb	Exotic	Invasive	4
14	*Setaria verticillata,*	bristly foxtail	Poaceae	Herb	Exotic	Invasive	4
		Total					**124**

Plant Species Composition of the Fallow Land Zone

Table 3 presents the plant species recorded in the Fallow Land Zone of Warwade Plantation. A total of 13 plant species belonging to seven plant families were identified, with an abundance of 74 individuals. The family Fabaceae was the dominant family, contributing five species, while Combretaceae, Meliaceae, Portulacaceae, Rhamnaceae, Rubiaceae, and Zygophyllaceae were each represented by one species. The results showed that four species (36.4%) were native (indigenous), whereas seven species (63.6%) were exotic, indicating that exotic species were more prevalent than indigenous species in the Saline Land Zone. Among the exotic species, five species (*Azadirachta indica*, *Dalbergia sissoo*, *Portulaca oleracea*, *Senna occidentalis*, and *Sesbania cannabina*) were classified as naturalized, while *Prosopis farcta* was identified as an invasive species. *Ziziphus mauritiana* was also recorded as a naturalized exotic species. In terms of abundance, *Sesbania cannabina* recorded the highest number of individuals (10), followed by *Portulaca oleracea* (9), while *Dalbergia sissoo* and *Guiera senegalensis* each recorded 8 individuals. *Senna occidentalis* had the lowest abundance with 4 individuals. The higher proportion of exotic species in the Fallow Land Zone suggests that the environmental conditions of this habitat may favour the establishment and persistence of introduced plant species.

Table 3: Plant Species in the Fallow Zone

S/N	Botanical Name	Common Name	Family	Habit	Status	Category	Freq.
1	*Azadirachta indica*	Neem	Meliaceae	Tree	Exotic	Naturalized	5
2	*Balanites aegyptiaca*	Desert date	Zygophyllaceae	Tree	Native	-	5
3	*Dalbergia sissoo*	Indian rosewood	Fabaceae	Tree	Exotic	Naturalized	8
4	*Gardenia ternifolia*	African Gardenia	Rubiaceae	Shrub	Native	-	5
5	*Guiera senegalensis*	Guiera, Sabara Bush	Combretaceae	Shrub	Native	-	8
6	*Piliostigma reticulatum*	Camel's Foot	Fabaceae	Herb	Native	-	7
7	*Portulaca oleracea*	Common purselane	Portulacaceae	Herb	Exotic	Invasive	9
8	*Prosopis farcta*	Syrian mesquite	Fabaceae	Shrub	Exotic	Invasive	7
9	*Senna occidentalis*	Septicweed	Fabaceae	Shrub	Exotic	Naturalized	4
10	*Sesbania cannabina*	Canicha	Fabaceae	Herb	Exotic	Naturalized	10
11	*Ziziphus mauritiaca*	Indian Jujube	Rhamnaceae	Tree	Exotic	Naturalized	6
12	*Boerhavia erecta,*	scarlet spiderling	Nyctaginaceae	Herb	Exotic	Invasive	2
13	*Euphorbia heterophylla,*	wild poinsettia	Euphorbiaceae	Herb	Exotic	Invasive	2
							82

Plant Species Composition of the Agricultural Land Zone

Total Number of Individuals is 68 has shown in Table 4 in the Agricultural Land Zone of Warwade Plantation. A total of 12 plant species belonging to six plant families were identified, with an overall abundance of 68 individuals. The family Fabaceae was the most dominant, contributing five species, while Malvaceae, Polygonaceae, Portulacaceae, Rhamnaceae, and Solanaceae were each represented by one species. The results revealed that two species (20.0%) were native (indigenous), whereas eight species (80.0%) were exotic, indicating a clear dominance of exotic plant species within the Agricultural Land Zone

Table 4: Plant Species Recorded in the Agricultural Land Zone

S/N	Botanical Name	Common Name	Family	Habit	Status	Category	Freq.
1	*Crotalaria naragutensis*	Rattlepod	Fabaceae	Herb	Native		4
2	*Dalbergia sissoo*	Indian Rosewood	Fabaceae	Tree	Exotic	Naturalized	5
3	*Melochia corchorifolia*	Chocolate Weed	Malvaceae	Herb	Exotic	Naturalized	8
4	*Persicaria senegalensis*	Senegal Knotweed	Polygonaceae	Herb	Native		8
5	*Physalis angulate*	Cutleaf Groundcherry	Solanaceae	Herb	Exotic	Invasive	6
6	*Portulaca oleracea*	Common Purslane	Portulacaceae	Herb	Exotic	Invasive	7
7	*Senna obtusifolia*	Sicklepod	Fabaceae	Shrub	Exotic	Naturalized	5
8	*Senna occidentalis*	Septicweed	Fabaceae	shrub	Exotic	Naturalized	7
9	*Sesbania cannabina*	Canicha	Fabaceae	Herb	Exotic	Naturalized	9
10	*Ziziphus mauritiaca*	Indian Jujube	Rhamnaceae	Tree	Exotic	Naturalized	5
11	*Amaranthus spinosus*	Spiny amaranth	Amaranthaceae	Herb	Exotic	Invasive	2
12	*Spigelia anthelmia*	West Indian pinkroot	Loganiaceae	Herb	Exotic	Invasive	2

Plant Family Composition

A total of 23 unique plant species belonging to 13 plant families were recorded across the three ecological zones. The family Fabaceae was the most represented, contributing 10 species (43.5%) of the total flora. This was followed by Malvaceae, which contributed 2 species (8.7%). The remaining eleven plant families (Apocynaceae, Combretaceae, Cyperaceae, Meliaceae, Onagraceae, Polygonaceae, Portulacaceae, Rhamnaceae, Rubiaceae, Solanaceae, and Zygophyllaceae) were each represented by one species (4.3%).

Table 5: Plant Family Composition of the Recorded Plant Species

SN	Plant Family	Number of Species	Percentage (%)
1	Fabaceae	10	43.5
2	Malvaceae	2	8.7
3	Portulacaceae	1	4.3
4	Rhamnaceae	1	4.3
5	Apocynaceae	1	4.3
6	Combretaceae	1	4.3
7	Cyperaceae	1	4.3
8	Meliaceae	1	4.3
9	Onagraceae	1	4.3
10	Polygonaceae	1	4.3
11	Rubiaceae	1	4.3
12	Solanaceae	1	4.3
13	Zygophyllaceae	1	4.3
	Total	**23**	**100.0**

Growth Habit Composition of the Recorded Plant Species

The growth habit composition of the recorded plant species is presented in Table 6. The identified plant species were classified into trees, shrubs, herbs, and graminoids based on their morphological characteristics. This classification provides an overview of the structural composition of the vegetation across the three ecological zones. Table 6 presents the growth habit composition of the recorded plant species in the study area. A total of 29 unique plant species were classified into four growth habit categories: herbs, shrubs, trees, and graminoids. Herbs constituted the dominant growth habit, accounting for 16 species (55.17%) of the total recorded species. Shrubs were the second most abundant growth form, comprising 8 species (27.59%), while trees accounted for 4 species (17.4%). Graminoids were the least represented growth habit, with only one species (3.45%).

Table 6: Growth Habit Composition of the Recorded Plant Species

SN	Growth Habit	Number of Species	Percentage (%)
1	Herb	16	55.17
2	Shrub	8	27.59
3	Tree	4	13.79
4	Graminoid	1	3.45
5	Total	29	100.0

Distribution of Native (Indigenous) and Exotic Plant Species

The distribution of the recorded plant species based on their origin is presented in Table 7. The identified plant species were classified as either native (indigenous) or exotic according to their occurrence and origin in Nigeria. This classification was carried out to assess the relative contribution of indigenous flora and introduced species within the study area. Table 7 presents the distribution of the recorded plant species according to their origin. Out of the 29 unique plant species identified during the study, 11 species (37.93%) were classified as native (indigenous), while 12 species (62.06%) were classified as exotic. The results indicate that exotic plant species constituted a greater proportion of the recorded flora than native species.

Table 7: Distribution of Native (Indigenous) and Exotic Plant Species

Plant Status	Number of Species	Percentage (%)
Native (Indigenous)	11	37.93
Exotic	18	62.06
Total	29	100.0

Classification of Exotic Plant Species Based on Their Establishment Status

Table 8 presents the classification of the exotic plant species recorded in Warwade Plantation according to their establishment status, while their distribution to 18 exotic plant species identified during the study, 8 species (44.44%) were classified as naturalized, indicating that they have esta08blished self-sustaining populations within the study area without clear evidence of aggressive spread. 9 species (50.0%) *Physalis angulata*, *Portulaca oleracea*, and *Prosopis farcta* , *Euphorbia hirta, Setaria verticillata, Boerhavia erecta, Euphorbia heterophylla, Amaranthus spinosus, and Spigelia anthelmia* were classified as invasive based on field observations, available literature, and their ecological behaviour. These species have the potential to spread beyond their points of establishment, compete with other plant species, and influence the composition and structure of 303 vegetation within the study area. Only one species (8.3%), *Mimosa aculeaticarpa*, remained unclassified because the available field observations and supporting literature were insufficient to confidently assign it to either the naturalized or invasive category within the study area.

Table 8: Classification of Exotic Plant Species Based on Their Establishment Status

S/N	Exotic Species	Naturalized	Invasive	Unclassified
1	*Azadirachta indica*	X		
2	*Dalbergia sissoo*	X		
3	*Melochia corchorifolia*	X		
4	*Mimosa aculeaticarpa*			Unclassified
5	*Physalis angulate*		X	
6	*Portulaca oleracea*		X	
7	*Prosopis farcta*		X	
8	*Senna obtusifolia*	X		
9	*Senna occidentalis*	X		
10	*Senna tora*	X		
11	*Sesbania cannabina*	X		
12	*Ziziphus mauritiana*	X		
13	*Euphorbia hirta*		X	
14	*Setaria verticillata,*		X	
15	*Boerhavia erecta*		X	
16	*Euphorbia heterophylla*		X	
17	*Amaranthus spinosus*		X	
18	*Spigelia anthelmia*		X	
	TOTAL	**08 (44.44%)**	**9 (50.0%)**	**01 (0.05%)**

Comparison of Shannon Wiener Diversity Indices and Sorensen Similarity Index Among the Three Ecological Zones

Table 9 compares the Shannon–Wiener Diversity Index values across the three ecological zones surveyed in Warwade Plantation. The Plantation Zone recorded the highest diversity index (H' = 2.434), indicating that it supported the most diverse plant community among the three ecological zones. This higher diversity is consistent with the greater species richness (14 species) and the relatively even distribution of individuals observed within the zone. The Agricultural Land recorded the second-highest diversity index (H' = 2.273). Although this zone contained fewer species (1 species) and fewer individuals (64 individuals) than the Plantation, the relatively even distribution of individuals among the recorded species contributed to its comparatively high diversity. The Fallow Land Zone recorded the lowest Shannon–Wiener Diversity Index (H' = 2.180). Although 11 species were recorded, the lower diversity value suggests that individuals were distributed less evenly among species than in the other ecological zones.

Table 9: Comparison of Shannon Wiener Diversity Indices and Sorensen Similarity Index Among the Three Ecological Zones

Ecological Zone	No of Species	Frequency	Shannon–Wiener Diversity Index (H')	Sorensen similarity index QS=2C/A+B
Plantation Zone	14	120	2.434	
Fallow Land	13	76	2.180	86.96%
Agricultural Land	12	66	2.273	

Comparison of Simpson's Diversity Indices Among the Three Ecological Zones

Table 10 shows slight variation in plant diversity among the three ecological zones of Warwade Plantation based on Simpson's Diversity Index. The Plantation Zone had the highest value (1 − D = 0.916), indicating greatest species richness and evenness with minimal dominance. Fallow Land followed closely (0.914), reflecting high diversity but slightly more dominance by a few species. Agricultural Land recorded the lowest (0.913), suggesting reduced diversity likely due to tillage, cropping, and anthropogenic disturbance that favor dominant species. Although differences were small, the trend aligns with studies showing that intensive land-use lowers diversity while less disturbed or mixed systems like plantations maintain higher species evenness and richness.

Table 10: Comparison of Simpson's Diversity Indices Among the Three Ecological Zones

Ecological Zone	Number of Species	Number of Individuals	Simpson's Diversity Index (1 – D)
Plantation	14	118	0.916
Fallow Land	13	74	0.914
Agricultural	12	64	0.913

Spatial Distribution of Invasive Plant Species

The spatial distribution of invasive plant species recorded during the field survey was determined using Global Positioning System (GPS) coordinates obtained from the sampling locations within the study site. Result showed the list of 9 plant species recorded across three ecological zones, with their botanical names, families, and latitude coordinates. The species cut across 8 families, with Euphorbiaceae being the only family represented twice (*Euphorbia heterophylla and Euphorbia hirta*). In terms of distribution, 4 species were recorded in the Agricultural Land Zone, 3 species in the Plantation Zone, and 2 species in the Fallow Land Zone. Some species such as *Prosopis farcta and Portulaca oleracea* were specific to Fallow Land, while *Physalis angulata, Spigelia anthelmia, Euphorbia heterophylla, Boerhavia erecta, and Euphorbia hirta* occurred in Agricultural Land. *Amaranthus spinosus* and *Setaria verticillata* were found in the Plantation Zone. Latitude values were only provided for the first 3 species, ranging from 11.747095°N to 11.748333°N, indicating that sampling was done within a close geographical range. Data shows that agricultural lands harbored the highest number of the listed species, followed by plantations and fallow lands, though the small sample size limits broader ecological conclusions. The recorded GPS coordinates provide a spatial reference for the occurrence of invasive plant species and can be used to produce a distribution map illustrating their locations within the study area. Such spatial information is valuable for monitoring the spread of invasive species, identifying invasion hotspots, and supporting the development of effective management and conservation strategies for Warwade.

Table 11: GPS Coordinates and Spatial Distribution of Invasive Plant Species

S/N	Botanical Name	Family	Ecological Zone	Latitude (N)	Longitude (E)
1	*Prosopis farcta*	Fabaceae	Fallow	11.748333	9.218154
2	*Portulaca oleracea*	Portulacaceae	Fallow	11.747123	9.218249
3	*Physalis angulata*	Solanaceae	Agricultural	11.747095	9.217985
4	*Spigelia anthelmia*	Loganiaceae	Agricultural	11.747028	9.218551
5	*Amaranthus spinosus L*	Amaranthaceae	Plantation	11.747025	9.218551
6	*Euphorbia heterophylla L.*	Euphorbiaceae	Agricultural	11.747033	9.218559

7	*Boerhavia erecta L.*	Malvaceae	Agricultural	11.747094	9.218583
8	*Setaria verticillata (L.) P.Beauv*	Poaceae	Plantation	11.747239	9.218249
9	*Euphorbia hirta*	Euphorbiaceae	Agricultural	11.747095	9.217985

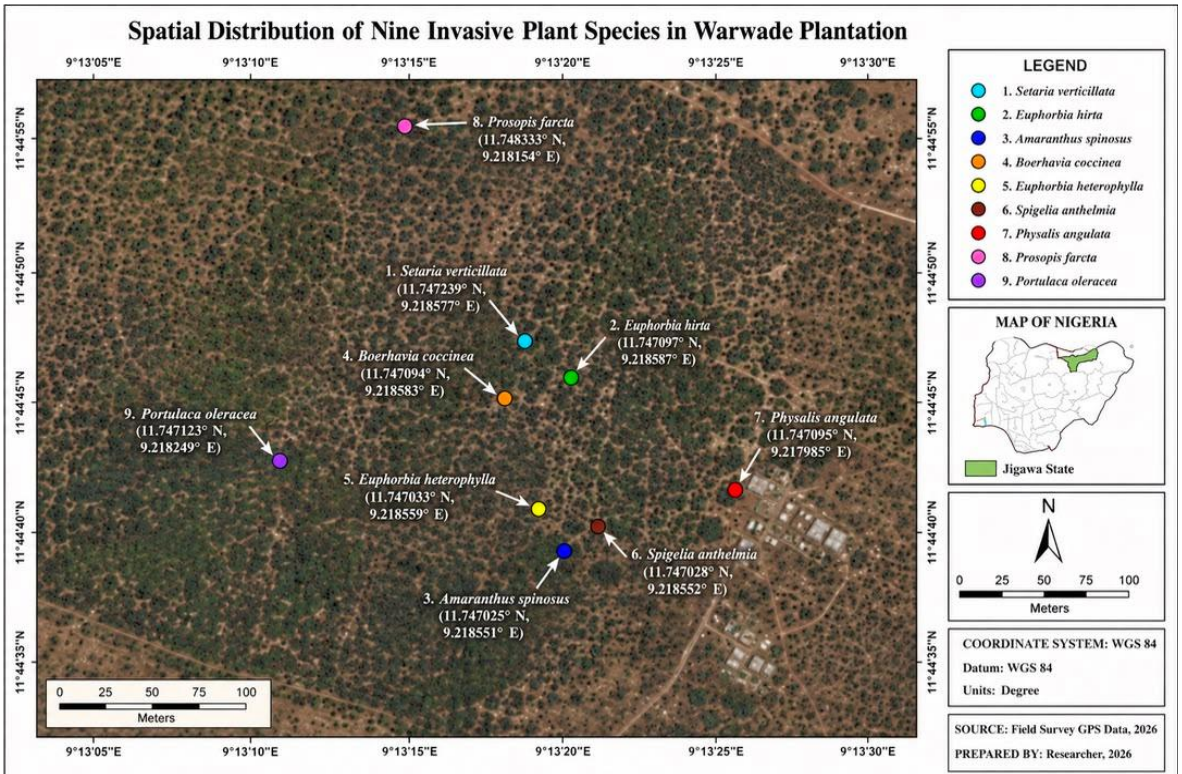

Figure : Spatial distribution of nine invasive plant species in Warwade Plantation.

Figure 2: Spatial Distribution of Selected Invasive Plant Species in the Study Area
Source: Google Satellite Imagery, 2025

Table 12 shows total viable bacterial counts from Fallow, Agricultural, and Forest Land soils using 102 dilution and 0.1 ml plating. Mean colony counts were 81.67, 49.67, and 67.33 respectively. Converted to CFU/g, Forest Land had the highest load at 3.4×108, followed by Agricultural Land at 4.5×106, and Fallow Land the lowest at 1.2×105. Despite these numerical differences, statistical analysis showed no significant difference among land-uses (p = 0.83 > 0.05). This indicates land-use did not significantly affect bacterial counts. Higher counts in Forest Land likely reflect more organic matter and less disturbance.

Table 12: Total Viable Bacterial Count of Soil Samples from Different Land-Use Types

SN	Land Use	Treatment	Colony count	Volume plate	CFU/g)	F-value
1	Fallow Land	10^2	81.67	0.1	1.2×10^5	
2	Agricultural Land	10^2	49.67	0.1	4.5×10^6	
3	Forest Land	10^2	67.33	0.1	3.4×10^8	
	P- value					**0.83**

Note: CFU/g is colony forming Unit

Table 13 shows the occurrence of bacterial species across three land-use types. A total of 7 bacterial genera were isolated, with 3 species recorded in each land-use type. Bacillus sp. was the only bacterium present in all three sites: Forest Land, Fallow Land, and Agricultural Land, suggesting it is widely distributed and adaptable. Forest Land hosted *Bacillus sp., Staphylococcus sp.,* and *Pseudomonas sp*. Fallow Land had *Bacillus sp., Enterobacter sp.,* and *Micrococcus sp.* Agricultural Land contained *Bacillus sp., Klebsiella sp.*, and *Pseudomonas sp.* The presence of Klebsiella and Enterobacter, which are often associated with fecal and agricultural inputs, indicates possible anthropogenic influence

Table 13: Occurrence of Soil Bacteria at Different landscape

SN	Bacteria presences	Plantation Land	Fallow land	Agricultural land
1	*Bacillus Sp.*	X	X	X
2	*Staphylococcus Sp.*	X		
3	*Pseudomonas Sp.*	X		
4	*Enterobacterial*		X	
5	*Micrococcus Sp.*		X	
6	*Klebsiella Sp.*			X
7	*Pseudomonas Sp.*			X
Total		**3**	**3**	**3**

Table 14 presents the occurrence of soil fungi across Forest Land, Fallow Land, and Agricultural Land. Five fungal genera were isolated in total. Aspergillus sp., Penicillium sp., and Rhizopus sp. were present in all three land-use types, indicating their wide distribution and adaptability to different soil conditions. Forest Land and Agricultural Land recorded the highest diversity with 4 species each, while Fallow Land had 3 species. Cladosporium sp. occurred only in Forest Land, and Alternaria sp. was exclusive to Agricultural Land, suggesting some degree of habitat specificity. The consistent presence of Aspergillus, Penicillium, and Rhizopus across sites implies that these fungi play key roles in organic matter decomposition regardless of land use.

Table 14: Occurrence of Soil Fungi at Different Landscape

SN	Bacteria presences	Forest Land	Fallow land	Agricultural land
1	*Aspergillus sp*	X	X	X
2	*Penicillium sp.*	X	X	X
3	*Rhizopus sp.*	X	X	X
4	*Cladosporium sp.*	X	-	-
5	*Alternaria Sp.*	-	-	X
	Total	**4**	**3**	**4**

Discussion

Plant Species and Family Composition Across the Three Ecological Zones

The study recorded 29 unique plant species with a total abundance of 274 individuals and 39 species occurrences across the three ecological zones. The Plantation Zone had the highest species richness with 14 occurrences 36.4% and abundance with 124 individuals 45.26%, followed by the Fallow Land Zone with 13 occurrences 33.3% and 74 individuals 29.92%, while the Agricultural Land Zone recorded the lowest richness and abundance with 1 occurrence 30.3% and 64 individuals 24.82%. This observed gradient agrees with established ecological patterns in tropical human-modified landscapes. The higher species richness and abundance in the Plantation Zone can be linked to improved habitat structure, canopy cover, and reduced frequency of disturbance, which create favorable conditions for regeneration and establishment of diverse plant species. Appiagyei and Adejoke (2021) reported that forest plantations in southwestern Nigeria support significant understory diversity and can serve as refuges for forest species when natural forests are degraded. Similarly, Adekoya (2021). found that plantation ecosystems in Edo State, Nigeria harbored higher plant species diversity compared to adjoining degraded lands due to litter accumulation and microclimatic stability. The richness in the Fallow Land Zone supports the role of fallows in biodiversity recovery. Fallow systems allow for natural regeneration through seed banks and seed rain from adjacent vegetation. Offiong *et al*., (2021) documented that fallow lands in the derived savanna of Nigeria recorded higher plant species diversity than continuously cultivated lands because of reduced soil disturbance and longer recovery periods. Muoghalu and Akanwa (2021) also emphasized that fallows in the Niger Delta region act as important reservoirs for plant biodiversity and contribute to landscape connectivity between forest patches and farmlands.

In contrast, the lowest species richness and abundance in the Agricultural Land Zone reflects the impact of intensive land-use practices. Agricultural activities such as clearing, tillage, weeding, and agrochemical application reduce habitat heterogeneity and eliminate many plant species. Salami *et al*., (2017) observed that agricultural lands in southwestern Nigeria had significantly lower plant species diversity compared to fallow and forest areas due to frequent disturbance and monocropping. This is consistent with broader findings across Sub-Saharan Africa that agricultural intensification leads to biodiversity loss. The dominance of Fabaceae 43.5% reflects its adaptability and nitrogen-fixing ability in tropical soils. High legume representation in disturbed ecosystems is common in West Africa. Low representation of other families indicates selective pressure from land use. This pattern agrees with findings on family distribution in Nigerian vegetation (Oladoye *et al.,* 2024; Salami and Akinyele, 2018)

Distribution of Native (Indigenous) and Exotic Plant Species

The finding that exotic species 52.2% slightly outnumbered native species 47.8% reflects the influence of anthropogenic activities on vegetation composition in the study area. Exotic species are often introduced through plantation forestry, agriculture, and landscaping, and they establish rapidly in disturbed habitats due to high growth rates and broad ecological tolerance. The dominance of exotics in human-modified landscapes has been widely reported in Nigeria. Onyekwelu *et al.* (2006) noted that many forest plantations are composed mainly of exotic timber species such as *Gmelina arborea* and *Tectona grandis*, which can outcompete native species. Aigbe *et al.* (2015) also reported higher proportions of exotic species in plantation and farmland ecosystems in Edo State compared to natural forests. Similarly, Gebre *et al.,* (2022). documented that agricultural expansion and land-use change in the Nigerian Guinea savanna favored the spread of exotic and weedy species at the expense of indigenous flora. This trend raises concerns about displacement of native species and loss of ecosystem services. Conservation efforts should therefore focus on enrichment planting and protection of indigenous species.

Diversity and Similarity Indices Across the Three Ecological Zones

The Shannon–Wiener Diversity Index results show that the Plantation Zone had the highest plant diversity, followed by Agricultural Land and Fallow Land was the lowest. The high diversity in the plantation agrees with findings that forest plantations with canopy cover and reduced disturbance provide stable microclimates that support more species and evenness. Onyekwelu *et al.* (2006) reported similar high H' values in Nigerian plantations compared to adjacent farmlands. The relatively high diversity in Agricultural Land despite low richness reflects evenness, which is common where a few weed and crop-associated species dominate uniformly. Jimoh and Haruna (2007) also observed moderate diversity in cultivated fields due to even distribution of ruderal species. The low H' in Fallow Land suggests dominance by a few pioneer species, a pattern reported by Aigbe *et al.* (2015) in early successional sites. The high Sorensen Similarity indicates substantial species overlap among zones. This reflects shared seed sources, dispersal, and similar climatic conditions within Warwade Plantation, consistent with Magurran (2004) who noted that high similarity occurs in contiguous landscapes under the same environmental filter

Spatial Distribution of Invasive Plant Species

Mapping of invasive species using GPS coordinates revealed that three exotic species: Prosopis farcta, *Portulaca oleracea, and Physalis angulata* have established within Warwade Plantation. *P. farcta and P. oleracea* were confined to the Fallow Land Zone, while P. angulata occurred in the Agricultural Land Zone. This pattern reflects habitat preference and disturbance regimes. Fallow lands with low competition, dry soils, and reduced management often favor the establishment of drought-tolerant invaders such *as Prosopis spp. and Portulaca spp.*, as reported by Witt and Luke (2017) for invasive species in West African savannas. The presence of Physalis angulata in cultivated fields agrees with Holm *et al.* (1997), who listed it among common agricultural weeds that thrive under periodic soil disturbance and high nutrient input. The high localization of these species indicates early-stage invasion, but their adaptive traits pose risks of further spread. GPS-based mapping provides baseline data for monitoring invasion hotspots and prioritizing control. Early detection and targeted management are critical to prevent displacement of native flora and loss of ecosystem services in the plantation (Richardson and Pyšek, 2006).

Total Viable Bacterial Count

Table 13 shows that Forest Land had the highest bacterial load at 3.4×108 CFU/g, followed by Agricultural Land at 4.5×106 CFU/g, and Fallow Land the lowest at 1.2×105 CFU/g. However, there was no statistically significant difference among land-use types ($p = 0.83$). This agrees with Mahajan *et al.,* (2018) who reported that while microbial biomass tends to be higher in undisturbed forest soils due to greater organic carbon and litter input, differences are not always significant across short gradients. Similarly, Obermeier, (2021) found that forest soils consistently harbor higher microbial populations because of stable microclimate and continuous organic matter supply. The moderate count in Agricultural Land may be linked to fertilizer and tillage inputs, which can stimulate microbial growth but also cause disturbance. The low count in Fallow Land aligns with Zhao *et al*. (2013), who noted reduced substrate availability in abandoned lands limits bacterial proliferation.

Bacterial Occurrence

Table 14 revealed 7 bacterial genera, with 3 species in each land-use. *Bacillus sp.* occurred in all sites, indicating its ubiquity and spore-forming resilience to environmental stress. This is consistent with Madigan and Martinko (2004), who described Bacillus as a dominant soil genus due to its ability to survive desiccation and nutrient scarcity. The presence of Staphylococcus and Pseudomonas in Forest Land, Enterobacter and Micrococcus in Fallow Land, and Klebsiella and

Pseudomonas in Agricultural Land suggests land-use influences community composition. Klebsiella and Enterobacter are often linked to anthropogenic inputs such as manure and runoff, supporting findings by Rothenheber, (2017) that agricultural activities increase fecal-associated bacteria. Overall, while land-use shaped distribution, Bacillus remained a core taxon across habitats.

Fungal Occurrence

Table 15 showed 5 fungal genera. *Aspergillus sp., Penicillium sp*., and *Rhizopus sp.* were present in all land-uses, reflecting their saprophytic nature and tolerance to varied conditions. This matches the work of Dighton (2016), who reported these genera as cosmopolitan decomposers in tropical soils. Forest and Agricultural Lands had the highest diversity with 4 species each, while Fallow had 3. *Cladosporium sp*. was restricted to Forest Land and Alternaria *sp*. to Agricultural Land, suggesting habitat specificity as also observed by Tsarelunga and Blagoveschenskaya. (2024)., who linked Cladosporium to leaf litter and Alternaria to crop residues. The dominance of Aspergillus, Penicillium, and Rhizopus across sites underscores their key role in organic matter decomposition and nutrient cycling irrespective of land-use. Invasive species like *Prosopis farcta, Portulaca oleracea, Physalis angulata* alter soil chemistry and litter quality, which can shift microbial communities. Their dominance in Fallow and Agricultural zones may reduce organic inputs from natives, potentially lowering bacterial counts. Such impacts align with Richardson and Pyšek (2006), linking invasions to reduced soil microbial biomass and diversity.

CONCLUSION

The study in Warwade Plantation revealed clear ecological gradients across the three zones. Plantation Zone had the highest species richness, abundance and diversity indices, supported by canopy cover and reduced disturbance. Fallow Land showed intermediate recovery, while Agricultural Land recorded the lowest richness and abundance due to intensive land-use. Fabaceae dominated plant families at 43.5%. Exotic species slightly outnumbered natives at 52.2% vs 47.8%, reflecting anthropogenic influence. *Prosopis farcta* and Portulaca oleracea in Fallow Land, and *Physalis angulata* in Agricultural Land. Forest Land had the highest total viable bacterial count at 3.4×108 CFU/g, followed by Agricultural Land and Fallow Land, but differences were not statistically significant ($p = 0.83$). *Bacillus sp.* occurred in all land-uses, while Klebsiella and Enterobacter indicated anthropogenic inputs. Five fungal genera were recorded, with Aspergillus, Penicillium, and Rhizopus present in all zones.

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