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Analysis of Terrain and Vegetation Distribution in Wawa Zange Woodland, Gombe State, Nigeria

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ABSTRACT

This study analyzed the complex connection between the topographic attributes of the Wawa Zange Forest Reserve and the spatial distribution of its vegetation. The study analyzed topographic attributes, classified the various geomorphic units and assessed the relationship between topographic and vegetation distribution within Wawa Zange woodland reserve. The study methodology employed on-site observations, Digital Elevation Model (DEM) utilization, satellite image interpretation, and Geographic Information System (GIS) analysis. The examination of topographical attributes within the Wawa Zange Woodland Reserve revealed a multifaceted landscape. Elevation range analysis showcased a diverse elevation gradient, with mid-elevation ranges dominating the area, 90.63% of the total area falls within the mid-elevation ranges of 301 to 600 meters. The largest portion of the reserve is characterized as "Valley" with slopes of less than 5 degree, covering 2093.36 square kilometers. Aspect analysis highlighted the influence of compass direction on sunlight exposure and microclimatic conditions. Meanwhile, curvature categories concave covering 53.22% and convex covering 46.78% indicated areas of potential water collection and soil erosion susceptibility. These topographical attributes collectively inform strategic forest management and conservation efforts, resource allocation, erosion control measures, and habitat preservation, ultimately contributing to the sustainable management of the Wawa Zange Woodland Reserve's rich and diverse ecosystems.

Keywords: Digital Elevation Model, GIS, Topography, Vegetation, Attribute, Wawa Zange, Gombe

1. INTRODUCTION

The conservation of biodiversity has become a major concern with the international community ever since the Secretariat of the Convention on Biological Diversity (CBD) drafted its conservation treaty in Rio de Janiero on June 1992. Forests and woodlands cover nearly 40% of the earth's land surface, and they are the most biologically diverse ecosystems in most part of the World (World Resources Institute WRI; the International Union for Conservation of Nature IUCN and United Nations Environment Programme UNEP, 1992). Forests harbor most of Earth's terrestrial biodiversity, the conservation of the world's biodiversity is thus utterly dependent on the way in which humans interact with and use the world's forests (FAO 2020). According to Forest Resources Assessment (2015), forests currently cover 30.8 percent of the global land area. The total forest area is 4.06 billion hectares, or approximately 0.5 ha per person, but forests are not equally distributed around the globe (FAO 2020).

Terrain is the fundamental object that significantly influences the geomorphic, hydrologic, and ecological processes of the Earth's surface (Evans, 2012, Drăgu & Dornik 2016;). Various topographic characteristics carried by different surfaces provide information for landform classification, environmental evolution, terrain analysis, and hydrological analysis (Li, Xiong, Tang & Strobl 2020). The Dgital Elevation Model (DEM) plays an important role in transferring geographical knowledge to computer-processable information (Hu et al. 2021). Geomorphic terrain has profoundly control the redistribution of surface materials and energy, and it impacts the evolution and development of surface landscape systems and ecosystems, which also influence and determine the form and scale of human activities to a certain extent (Yang *et al.,* 1989; Pan, Li and Cao, 1996; Zhang*, Wu & Wang,* 2006; Cui*, Chen & Zhu* 2011; Chen*,* Dong,& Zhang, 2015). The land surface is varied in nature because it has undulations and features such as mountains, hills, valleys, rivers, vegetation, and many other features.

Vegetation is the aggregate of all the plants growing in an area and, as such, is the most conspicuous feature of most landscapes, already recognized by the early Greeks as a way of distinguishing one region from another. Vegetation involves populations of species of the local flora, which in turn involve different genetic, migration, historical or ecological elements. Vegetation is also composed of various plant forms and ecological plant types, reflecting various sizes, shapes and combinations (Elgene & Kazue, 2013).

Several authors have quantified various aspects of the relationship between topography and vegetation distribution, such as coverage (Florinsky and Kuryakova, 1996), plant growth (Wang, Jiao, Su, & Chen, 2014), forest productivity and plant species (Garca-Aguirre, Ortiz, Zamorano, & Reyes, 2007) Some studies identified one main topographic factor influencing vegetation distribution at a specific site. For example, slope was the only non-soil factor correlated with plant species in southeastern Oregon in the USA (Davies *et al.,* 2007) and was a principal constrained factor in the hot and dry Jinsha River valley in China (Lin*.,* Cui, Ge, Chen, & Wang, 2014).

Terrain characterization has been found useful and applied in forestry management and studies in different parts of the world (Ikusemoran, Biyama, & Bello 2013), but the questions that arose are: Where has the terrain of forest reserves in Gombe State been conducted? Are the existing data on the terrain of forest reserves in Gombe State current and reliable? Unfortunately, on the basis of literature review no comprehensive study on Terrain and Vegetation Distribution in forest reserves of Gombe State. Thus, this study is designed to fill this gap. The study objectives include; analysis of topographic attributes within the forest reserve, Classification different geomorphic units present in Wawa Zange forest reserve and assessment of the relationships between topographic attributes and vegetation distribution in the study area.

2. MATERIALS AND METHODS

Wawa Zange Woodland Reserve is in Gombe State (figure 1), North-Eastern Nigeria. It lies between latitude 10^0 25 ' 00" N to 11^0 01 ' 00" N and longitude $10^0$25 ' 00"E to $11^0$17 ' 00"E with an altitude of 500m to 650m above sea level and it cut across Dukku, Funakaye, Kwami and Nafada Local Government Areas of Gombe State, occupying a total area of 779.70 $km^{2,}$ (Hayatu & Aba 2021). It was gazette in 1962 and is located in the Sudan Savannah Vegetation of Sub -Saharan Africa, the temperature is high throughout the dry season beyond 40^0C during the hottest months (March-April) while during wet season the average temperature is usually within 24^0 to 26^0C (Mbaya & Hashidu 2017).

The Sudan Savannah ecological zone's woodland dominates the reserve, with a concentration of woodlands in the south-east and southwestern regions. These woodlands have a light-closed canopy made up of stunted shrubs and trees that are 4.87 m to 6.09 m high, along with sparse growth of grasses (Abba, Yuguda, Yila & Zhigila, 2022). The vegetation is characterized by shrubs, scattered trees and grasses. There is substantial number of Forest flora and fauna, important birds and wildlife. Tree species found in these reserve include but not limited to; *Acacia spp, Anogeisusleiocarpus, Combretumspp, Detariummicrocarpum, Entanda Africana, Raphiasudanica, ProsopsisAfricana, Sterculiasetigera, Vitexdoniana, Vitaleriaparadoxum, Khayasenegalensis, Parkiabiglobosa, Ficusspp, and Ximenia Americana* (Mbaya & Hashidu, 2017).

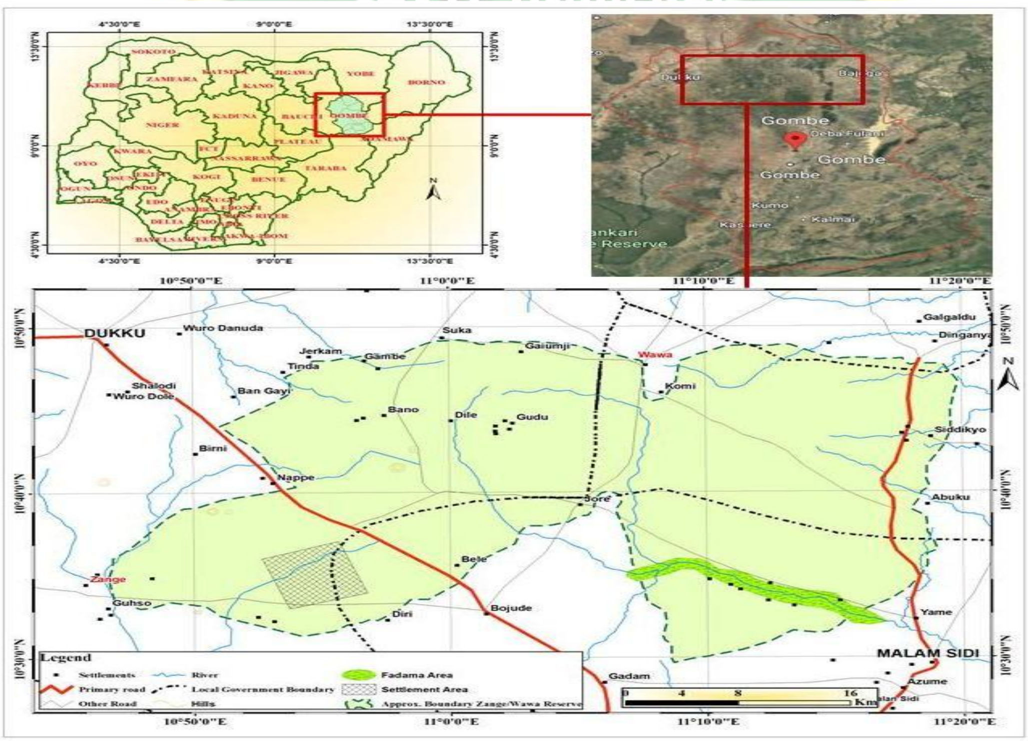

Figure 1: Wawa Zange Forest reserve
Source: Gombe State University, Department of Geography – GIS Unit (2024)

The data required for this study were; Topographic data including elevation, slope, curvature and aspect. Geomorphic data which include various landforms within the study area. The data were collected through; Field surveys, Satellite imagery/GIS analysis and Digital Elevation Model (DEM).The data for the study was analysed using Terrain analysis tools in ArcGIS 10.2.

3. RESULTS AND DISCUSSION

Topographic Attributes within the Forest Reserve

The findings in figure 2 revealed a diverse range of elevation within the Wawa Zange Woodland Reserve, spanning from the lowest point at 260 meters to the highest point at 624 meters. This variation in elevation plays a critical role in shaping the reserve's ecosystems and ecological characteristics. The eight elevation/relief ranges provided in figure 2 offer a comprehensive breakdown of the reserve's topography, detailing the extent of each range in square kilometers of the total area it covers. The distribution of relief ranges provides valuable insights into the composition of the Woodland reserve. It's evident that a significant portion of the reserve (approximately 90.63% of the total area) falls within the mid-elevation ranges of 301 to 600 meters. This expansive range suggests a diverse landscape that may support a wide array of vegetation types and wildlife habitats.

The range of 401 to 550 meters, covering nearly 59.43% of the total area, is particularly noteworthy. It encompasses a substantial portion of the reserve and likely includes areas with diverse ecological characteristics. These areas could be of particular interest for conservation efforts and biodiversity studies. On the other hand, the highest elevation range of 601 to 650 meters, although representing the highest points within the reserve, covers only a small percentage (0.52%) of the total area. These high-elevation areas may have unique ecological features and challenges, such as specialized alpine vegetation or limited accessibility, which merit specific attention in forest management strategies. The analysis of elevation uncovers substantial altitudinal diversity from 260 meters at the lowest point to 624 meters at the highest, a pattern that resonates with global observations documented in similar studies (Scholten et al., 2017; Chun, Ali & Lee, 2020; Zekeng et al., 2021) which revealed topographic factors play key roles in regulating forest structure, diversity, forest carbon storage. This alignment underscores the universal significance of comprehending these topographic features in the broader context of ecological studies and reinforces the relevance of the Wawa Zange Woodland Reserve as a microcosm reflecting broader ecological distribution.

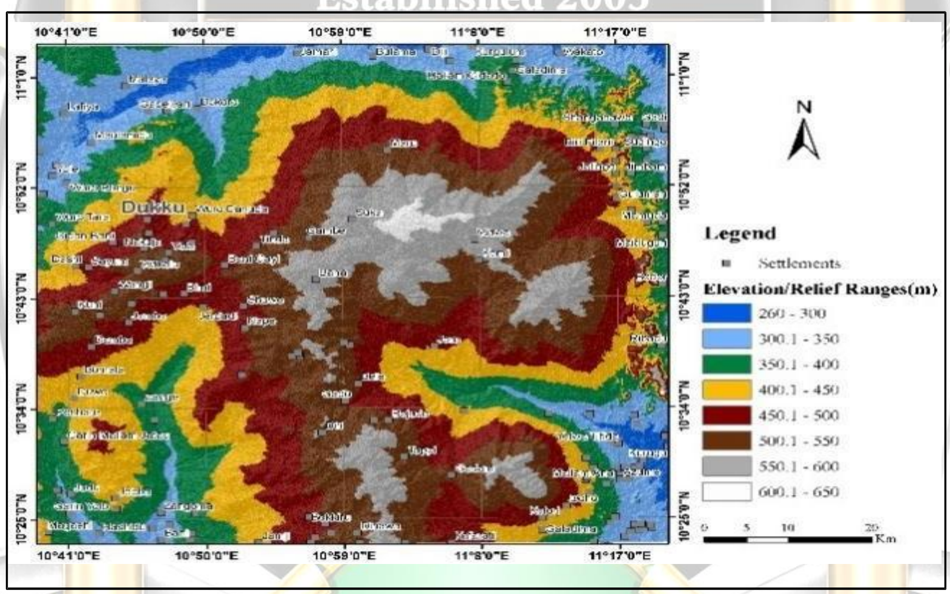

Figure 2: Elevation of Wawa Zange

Source: Author's Compilation, (2024)

The results presented in figure 3 regarding slope compositions within the Wawa Zange Woodland Reserve offers critical insights into the reserve's topography and terrain characteristics. It categorizes the landscape into four distinct slope positions based on degrees of incline, providing a comprehensive overview of the forest's topographical diversity. The largest portion of the reserve is characterized as "Valley" with slopes of less than 5 degree, covering 2093.36 square kilometers. These gentle slopes are indicative of extensive low-lying areas that could serve as water collection points, potentially influencing hydrological patterns and supporting diverse habitats. "Lower Slope" areas, with slopes ranging from 5 to 15 degrees and an extent of 1863.60 square kilometers, represent terrain that is slightly steeper than valleys. "Middle Slope" areas (15 - 30 degrees) covering 1016.40 square kilometers, and "Ridge/Upper Slope" areas (30 - 45 degrees) spanning 684.40 square kilometers, indicate increasingly steep terrain that may impact vegetation distribution, soil erosion, and water runoff. The analysis of elevation uncovers substantial altitudinal diversity from 260 meters at the lowest point to 624 meters at the highest, a pattern that resonates with global observations documented in similar studies (Scholten et al., 2017; Chun, Ali & Lee, 2020; Zekeng et al., 2021) which revealed topographic factors play key roles in regulating forest structure, diversity, forest carbon storage.

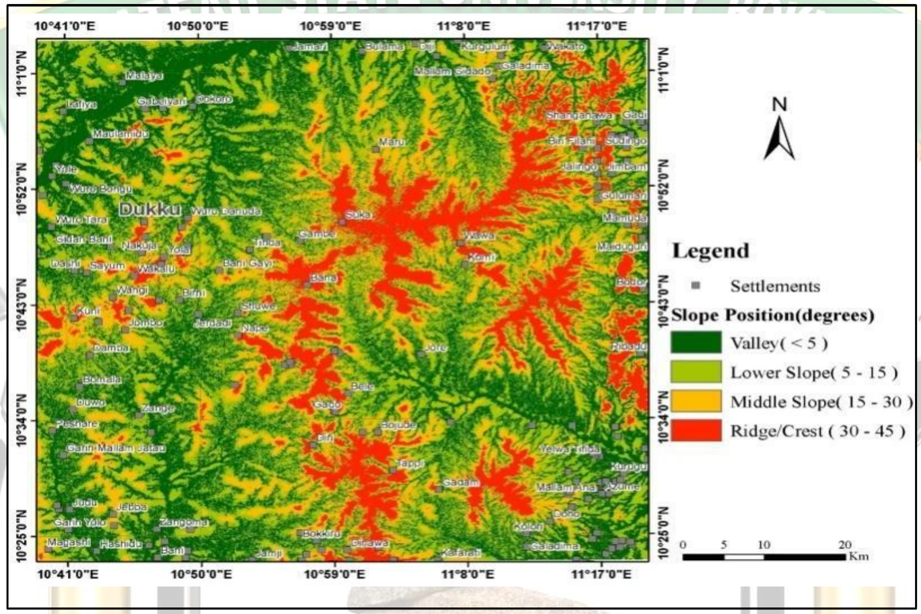

Figure 3: Slope of Wawa Zange

Source: Author's Compilation, 2024

Figure 4 presents a comprehensive view of the aspect, or the compass direction of slopes, within the Wawa Zange Woodland Reserve, shedding light on the spatial distribution and orientation of the reserve's topography. The data categorizes slopes into four primary aspects, each corresponding to a specific compass direction in degrees. The North East aspect, covering 27.09% of the total area, receives morning sunlight, potentially influencing microclimates and vegetation patterns. In contrast, the South East aspect, constituting 23.74% of the area, faces the afternoon sun, impacting temperature and moisture regimes. Similarly, the South West and North West aspects, encompassing 23.42% and 25.76% of the area, respectively, receive afternoon and morning sunlight, affecting ecological characteristics. Topographic features such as terrain relief, slope and curvature strongly influence local-scale variation in soil chemistry, hydrology and microclimate (Chadwick & Asner, 2016).

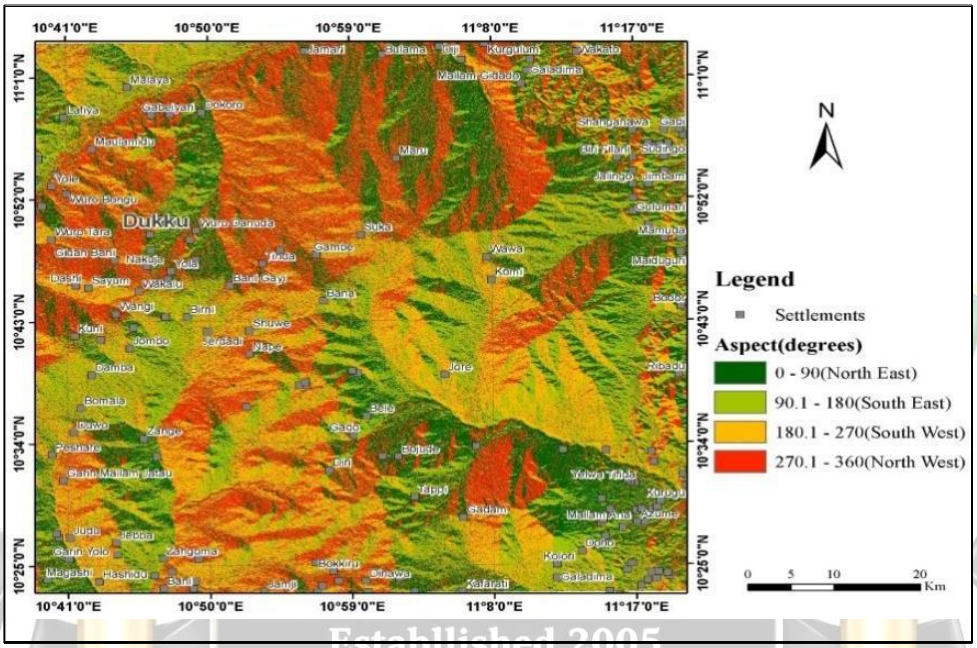

Figure 4: Aspect of Wawa Zange

Source: Author's Compilation, 2024

Figure 5 portrays a comprehensive insight into the curvature of the terrain within the Wawa Zange Woodland Reserve, a critical aspect of topography that plays a significant role in shaping the reserve's ecological dynamics. The data classifies terrain curvature into two primary categories: Concave Curvature (Curvature < 0) and Convex Curvature (Curvature < 0). Concave Curvature, covering 53.22% of the total area, denotes areas where the terrain curves inward, potentially forming depressions or basins. These areas can act as important catchment zones for water, influencing hydrological patterns and providing crucial habitats for specific plant and animal species adapted to wetter conditions. On the other hand, Convex Curvature, encompassing 46.78% of the area, represents terrain with outward-curving slopes, potentially forming ridges. Such areas may lead to faster water runoff, affecting soil stability and influencing the distribution of vegetation communities. Topographic features, such as elevation, slope angle, curvature, aspect, and indices of relative moisture, vary as continuous gradients rather than as discrete structures, limiting their utility in characterizing the spatial pattern of landscape using categorical maps (McGarigal & Cushman, 2005; Hoechstetter, Walz Dang & Thinh 2008).

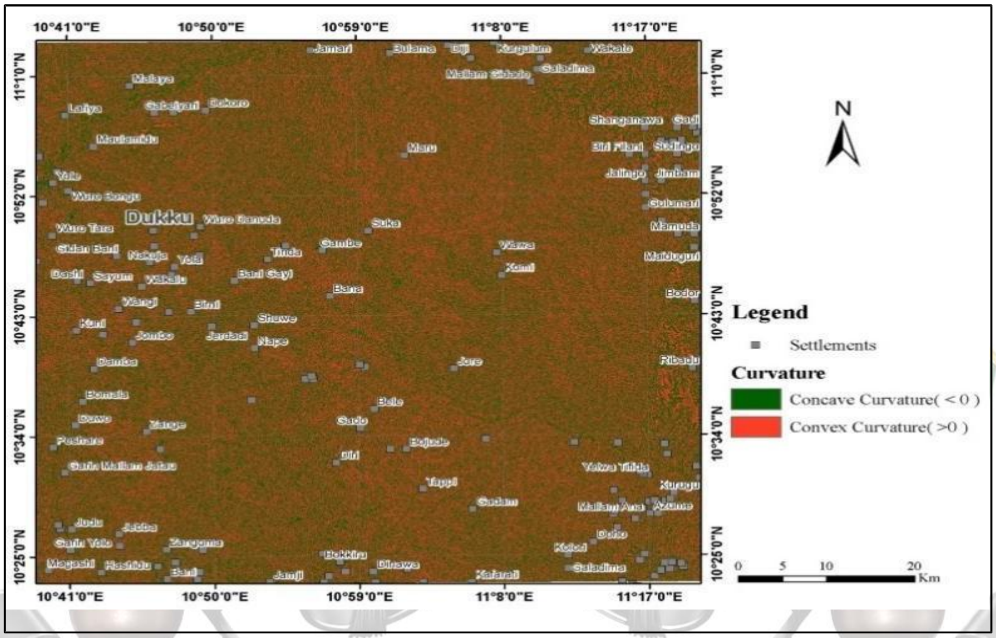

Figure 5: Curvature of Wawa Zange

Source: Author's Compilation, 2024

Classification of Geomorphic Units Present within Wawa Zange Woodland Reserve

Table 1: Geomorphic Units in the Wawa Zange Woodland Reserve

Landform/geomorphic units	Area(sqkm)	Percentage (%)
Foothill	258.80	4.57
Gorge	20.07	0.35
Mountain Slope	242.89	4.29
Peak/ridge	25.23	0.45
Plains	2616.50	46.25
Terrace	2335.35	41.28
Valley	158.92	2.81
	5657.76	100.00

The comprehensive classification of geomorphic units presented in Table 1 and figure 6 presents a profound insight into the intricate tapestry of the Wawa Zange Woodland Reserve's landscape. This diverse range of landforms provides a holistic view of the reserve's physical characteristics, each with its unique ecological significance and implications for land use planning. Foothills, occupying 4.57% of the total area, serve as critical transitional zones, fostering a rich diversity of vegetation and wildlife. Gorges, though relatively small at 0.35%, carve out steep and narrow valleys that house specialized ecosystems and contribute to the reserve's hydrology. Mountain slopes, covering 4.29%, add ruggedness to the terrain and support various vegetation communities. Peaks and ridges, while occupying just 0.45%, provide elevated vantage points for biodiversity and conservation efforts. Plains, the dominant landform at 46.25%, are essential for agriculture and human settlements. Terraces, spanning 41.28%, often hold historical significance and are crucial for agriculture due to their flat surfaces. Valleys, though covering 2.81%, play a pivotal role in water resources and biodiversity. This comprehensive classification underscores the complex interplay of nature and human activity within the reserve, emphasizing the importance of managing and preserving these diverse landforms to ensure the ecological health and resilience of this vital natural resource while addressing the needs of local communities and sustainable land use practices.

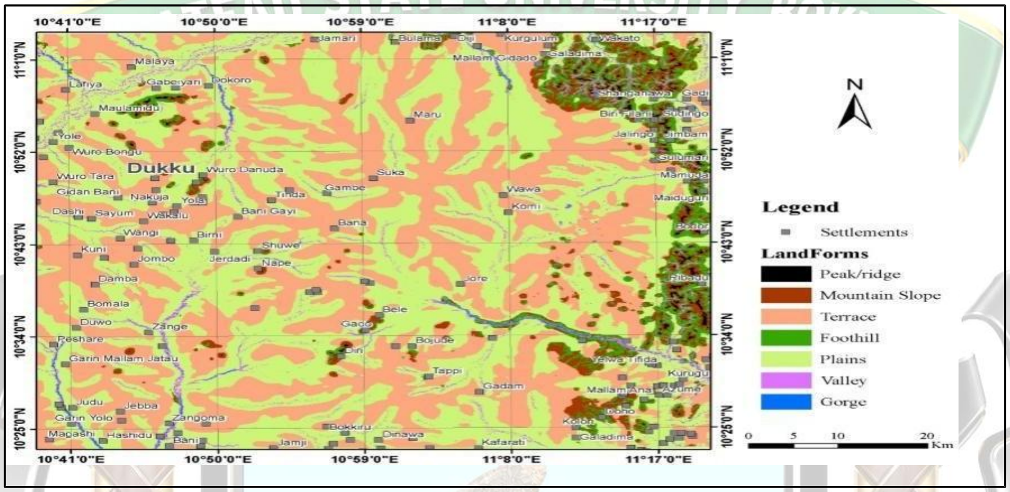

Figure 6: Geomorphic Units in the Wawa Zange

Source: Author's Compilation, 2024

Conservation Significance: Several of the geomorphic units identified hold significant conservation value. Gorges, for example, with their unique and often fragile ecosystems, are critical areas for biodiversity preservation. These narrow valleys may provide refuge for rare plant species and serve as migration corridors for wildlife. Peaks and ridges, though covering a relatively small area, are often home to specialized flora and fauna and can serve as sentinel sites for monitoring climate change impacts. Conservation efforts should prioritize protecting these geomorphic units and their associated ecosystems.

Sustainable Land Use: Plains, which constitute a substantial 46.25% of the area, are well-suited for agriculture and human settlements due to their flat terrain. Sustainable agricultural practices can be promoted in these regions to ensure food security while minimizing environmental impacts. Terraces, covering 41.28%, can be used for agriculture as well, but their historical significance should be considered in land use decisions. Proper soil conservation measures are essential for preventing erosion and maintaining long-term fertility. Conservation planning should involve buffer zones around critical geomorphic units to protect them from the negative impacts of development.

Watershed Management: Landforms like valleys and foothills play a vital role in watershed management. Valleys, comprising 2.81%, often act as drainage basins, collecting rainwater and regulating its flow. Proper management of these areas can help prevent erosion and mitigate flood risks downstream. Foothills, at 4.57%, are transitional zones between higher elevations and lower plains, making them crucial for maintaining the health of watersheds. These areas can act as natural buffers against sedimentation and provide water storage, making them valuable for sustainable water resource management.

Ecotourism and Recreation: Certain geomorphic units, such as gorges and peaks/ridges, have the potential to become ecotourism and recreational destinations. These areas can attract tourists interested in exploring unique landscapes, observing wildlife, and engaging in outdoor activities like hiking and bird watching. Sustainable tourism development in these regions can generate income for local communities while raising awareness about the importance of conserving these pristine environments.

Climate Resilience: The diverse landforms in the reserve can contribute to climate resilience. For instance, mountain slopes can act as natural barriers against soil erosion and landslides, safeguarding downstream areas during heavy rainfall events. Additionally, grasslands, which dominate the landscape, have the potential to sequester carbon and mitigate the effects of climate change. Conservation and sustainable land use practices can enhance these natural climate resilience mechanisms.

Landforms is one of the most relevant factors that influence ecological process in tropical forests (Jucker et al.,), playing an essential role in determining soil chemistry and fertility patterns (Jucker et al., 2018).

Relationships between Terrain Characteristics and Vegetation Distribution

Table 2: Elevation and Vegetation Pattern

Elevation/ Relief Ranges	Vegetation Pattern				Total
	Cultivated lands	Forest/Woodlands	Grasslands	Waterbody/ Built up	
260 – 300	58.94	14.07	24.29	22.05	119.34
301 – 350	**369.48**	48.19	197.07	50.95	665.69
351 – 400	338.34	167.07	**453.01**	21.12	979.55
401 – 450	235.68	309.03	**543.92**	12.27	1100.91
451 – 500	273.69	317.53	**520.32**	7.82	1119.36
501 – 550	312.57	321.96	**473.50**	5.34	1113.37
551 – 600	106.93	174.12	**248.65**	0.61	530.31
601 – 650	2.11	**15.11**	12.00	0.00	29.23
Total	1697.74	1367.08	2472.77	120.17	5657.76

Table 2 provides a comprehensive insight into the intricate relationship between elevation/relief ranges and vegetation patterns within the Wawa Zange Woodland Reserve, shedding light on the complex interplay between topography and ecological dynamics. The data clearly delineates how varying elevation bands influence the distribution of different vegetation types. At lower elevations (260 - 300 meters), cultivated lands and grasslands predominate, suggesting the prevalence of agriculture and open grassy areas. As elevation rises, particularly within the 301 - 450-meter range, there is a notable shift towards natural landscapes, with forest/woodlands and grasslands becoming increasingly dominant, while cultivated lands decrease significantly. This transition indicates the influence of elevation on climate, soil characteristics, and ecological suitability for various vegetation types. The presence of water bodies/built-up areas remains relatively low across most elevation ranges. Notably, at the highest elevations (601 - 650 meters), cultivated lands are minimal, giving way to forests and grasslands, highlighting the sensitivity of vegetation to elevation-induced changes in environmental conditions.

Table 3: Slope and vegetation distribution

Slope	Vegetation Pattern				Total
	Cultivated lands	Forest/Woodlands	Grasslands	Waterbody/ Built up	
Valley	663.46	489.66	**883.71**	56.52	2093.36
Lower Slope	542.37	470.51	**815.26**	35.46	1863.60
Middle Slope	279.75	251.30	**465.80**	19.54	1016.40
Ridge/Upper Slope	212.16	155.60	**307.99**	8.65	684.40
Total	1697.74	1367.08	2472.77	120.17	5657.76

Table 3 presents a comprehensive analysis of the intricate relationship between slope positions and vegetation patterns within the Wawa Zange Woodland Reserve, offering critical insights into how the steepness and orientation of slopes influence the distribution of different vegetation types. In valley areas, the presence of cultivated lands and grasslands highlights their suitability for agriculture and open grassy spaces. However, the significant presence of forest/woodlands underscores a complex landscape with both natural and human-modified habitats. As the terrain ascends to lower slopes, a marked reduction in cultivated lands signifies the decreasing suitability for agriculture, while forest/woodlands and grasslands continue to thrive. This suggests a transition to more natural vegetation, reflecting the ecological preferences of these slope positions. In the middle slopes, cultivated lands diminish even further, giving way to forest/woodlands and grasslands, emphasizing the propensity of moderate slopes to support natural ecosystems. At the ridge and upper slope positions, cultivated lands are minimal, while forest/woodlands and grasslands dominate, underscoring the strong association between steeper slopes and natural vegetation. The presence of waterbodies and built-up areas remains relatively low across all slope positions.

Table 4: Aspect and Vegetation Distribution

Aspect	Vegetation Pattern				Total
	Cultivated lands	Forest/ Woodlands	Grasslands	Waterbody/ Built up	
North East	443.83	371.77	679.54	37.36	1532.51
South East	415.43	319.87	576.75	30.90	1342.96
South West	412.75	318.33	573.59	20.36	1325.03
North West	425.72	357.10	642.88	31.55	1457.26
Total	1697.74	1367.07	2472.77	120.17	5657.75

Table 4 provides a comprehensive analysis of the intriguing relationship between the aspect, or compass direction of slopes, and the distribution of vegetation within the Wawa Zange Woodland Reserve. This data unveils how the orientation of slopes influences the prevalence of various vegetation types. In areas with a north-east aspect, the coexistence of cultivated lands, forest/woodlands, and grasslands suggests a balanced ecosystem where human activity interacts harmoniously with natural habitats. As the aspect transitions to the south-east, cultivated lands decrease, indicating that slopes facing this direction tend to support more natural vegetation. Similarly, the south-west and north-west aspects exhibit a clear preference for natural ecosystems, with forest/woodlands and grasslands dominating while cultivated lands gradually recede. Waterbodies and built-up areas maintain a limited presence across all aspects.

Table 5: Curvature and Vegetation distribution

Curvature	Vegetation Pattern				Total
	Cultivated lands	Forest/Woodlands	Grasslands	Waterbody/Built up	
Concave	915.10	725.78	1302.74	67.51	3011.13
Convex	782.64	641.29	1170.03	52.66	2646.63
Total	1697.74	1367.07	2472.77	120.17	5657.76

Table 5 offers a compelling examination of the intriguing relationship between terrain curvature and vegetation patterns within the Wawa Zange Woodland Reserve, providing vital insights into how the shape of the land influences the distribution of various vegetation types. In areas characterized by concave curvature, where the terrain forms depressions or basins, cultivated lands are notably prominent, signifying the suitability of these lower-lying regions for agriculture. The substantial presence of forest/woodlands and grasslands underscores a complex landscape with a harmonious blend of human-modified and natural habitats. Waterbodies and built-up areas contribute to this ecological mosaic but remain relatively limited. On the other hand, slopes with convex curvature, potentially including ridges and outward-curving terrain, still accommodate cultivated lands but to a slightly lesser degree compared to concave curvature areas. This suggests that even in areas where the land curves outward, natural ecosystems, represented by forest/woodlands and grasslands, can thrive. Waterbodies and built-up areas maintain a limited presence across convex curvature terrain.

4. CONCLUSION

In conclusion, the study in Wawa Zange Woodland Reserve provided critical information for conservation planning and sustainable development. Certain units hold significant conservation value and should be protected, while others are suitable for various land uses if managed responsibly. Topographical attributes collectively informed strategic forest management and conservation efforts, resource allocation, erosion control measures, and habitat preservation, ultimately contributing to the sustainable management of the Wawa Zange Woodland Reserve's rich and diverse ecosystems.

5. RECOMMENDATIONS

Based on the findings and conclusion, it is recommended that forest management and conservation efforts in the Wawa Zange Woodland Reserve be strengthened through strict enforcement of existing laws and regulations, alongside the adoption of sustainable practices that reduce degradation and promote long-term ecological balance. In addition, forest monitoring and assessment systems should be enhanced by integrating remote sensing and GIS technologies to track changes in forest cover and condition more accurately and efficiently. Finally, the findings and implications of this study should be disseminated to key stakeholders, including government agencies, non-governmental organizations, researchers, and policymakers, to support evidence-based decision-making. This will also help promote forest restoration and rehabilitation activities within the reserve to recover lost vegetation and improve overall ecosystem health.

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