ISSN: 2978-3801

Journal of Global Warming and Climate Change

Scientific Research and Community

Review Article

Open Access

Geospatial Multi-Criteria Modelling of Large-Scale Sugarcane Production Suitability in Taraba State, Nigeria

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ABSTRACT

This study conducts a comprehensive geospatial Multi-Criteria Evaluation (MCE) to assess the suitability of Taraba State, Nigeria, for large-scale sugarcane production. The assessment integrates eleven critical biophysical and environmental criteria within a Geographic Information System (GIS) environment, including land use/land cover, elevation, slope, drainage density, soil classification, annual precipitation, and key soil fertility parameters (exchangeable potassium, nitrogen, phosphorus, and pH). Data were derived from high-resolution satellite imagery (Sentinel-2), digital elevation models (SRTM), national climate records (NIMET/CHIRPS), and global soil databases (ISRIC SoilGrids). Each criterion was standardized, weighted based on established agronomic thresholds, and combined using a weighted overlay analysis to generate a spatially explicit suitability map. The results classify the state's landscape into three distinct zones: high suitability (15,697.9 km^2, 26.7%), moderate suitability (21,043.7 km^2, 35.8%), and low suitability (22,056.4 km^2, 37.5%). High-suitability areas are predominantly located in the central and southern regions, characterized by low elevation (<800 m), gentle slopes (<5%), deep alluvial soils, adequate annual rainfall (1,400–1,800 mm), and optimal soil fertility. The analysis demonstrates that integrated geospatial modeling is an effective tool for evidence-based agricultural planning. The resulting suitability map provides a vital decision-support resource for policymakers, investors, and agricultural planners to prioritize land allocation, guide sustainable investment, optimize resource use, and promote the development of a viable sugarcane agro-industry in Taraba State, thereby contributing to economic diversification, rural livelihoods, and food security

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Received: December 05, 2025; **Accepted:** December 09, 2025; **Published:** December 19, 2025

Keywords: Agricultural Land Use Planning, Geospatial Analysis, Multi-Criteria Evaluation (MCE), Sugarcane Suitability, Taraba State

Introduction

Sugarcane (*Saccharum* spp.) remains one of the most economically significant crops in the tropics, supplying sugar, ethanol, and raw materials for numerous agro-industrial processes. As noted by the Food and Agriculture Organization, global sugarcane output routinely exceeds one billion tonnes, reflecting its central role in both food and energy systems [1]. According to Hunsigi and later expanded by Moore and Botha, sugarcane performance is governed by an intricate interplay of climate, soil chemistry, soil depth, drainage, and topography, thus making spatially explicit assessments essential for sustainable expansion [2,3]. These agronomic constraints are particularly important for large-scale, mechanised cultivation where misaligned site selection can significantly reduce yield potential and elevate production costs.

In the past decade, the integration of multi-source geospatial datasets has transformed crop suitability analysis. Malczewski demonstrated that GIS-based Multi-Criteria Evaluation (MCE) provides a systematic and transparent framework for integrating heterogeneous datasets into reproducible suitability maps [4]. This approach has been strengthened by advances in open-access earth observation and soil datasets. For instance, Hengl produced the Soil Grids 250 m global soil information system, which offers spatially explicit soil pH, nitrogen, phosphorus and potassium estimates, while Funk developed the CHIRPS rainfall dataset, now widely used in agronomic water-balance studies [5,6]. These datasets, combined with DEM-derived hydrological indices and remote sensing–based land-cover maps, enable high-resolution suitability modelling that aligns well with agronomic thresholds for sugarcane.

In Nigeria, recent government and private-sector initiatives have renewed interest in developing large-scale sugar estates to enhance domestic production. Press coverage of the 2025 NSDC–Lee Group partnership (NSDC, 2025) has identified Taraba State among potential host regions for major investments. Yet, as highlighted by Ahmad in their suitability study in Mokwa LGA, and by Samuel, Maji and colleagues in their floodplain assessment in Adamawa State, most Nigerian studies have remained local in scale and often lack essential nutrient layers or advanced hydrological modelling [7,8]. Christopher, working on floodplain soils in Jalingo, Taraba State, also noted that field-measured soil properties vary significantly across the region, making extrapolation without spatial models unreliable [9]. Without a state-wide, multi-criteria, nutrient-informed assessment, sugarcane expansion risks being implemented on unsuitable soils, waterlogged terrain, or ecologically sensitive areas, thereby increasing both economic and environmental vulnerabilities.

Collectively, the findings of Ahmad, Samuel and Christopher show strong potential for sugarcane production across selected localities in Nigeria, but they also emphasise the need for integrating soil chemistry, rainfall variability and DEM-based hydrological risk analysis into a unified geospatial framework. Meanwhile, international studies such as those of AbdelRahman and Kamal and Pham underscore that weighted multi-criteria workflows particularly when combined with the Analytic Hierarchy Process (AHP) originally formulated by Saaty produce more defensible and actionable suitability outputs [7-12].

This study addresses these gaps by developing an integrated GIS-MCE suitability model for large-scale sugarcane production in Taraba State. The study (1) compiles and harmonises multi-source datasets, including Sentinel-2 land-cover products, SRTM-derived topography and hydrology, CHIRPS and NIMET climatic data, and SoilGrids nutrient and pH rasters; (2) establishes agronomically grounded reclassification thresholds and applies AHP-based weighting; (3) generates high-resolution continuous and categorical suitability maps; and (4) validates the outputs using field soil data and high-resolution imagery. By presenting a comprehensive, reproducible framework, the study provides an evidence-based decision-support tool for agricultural planners, investors and policymakers engaged in sugarcane development initiatives in Taraba State.

Methodology

This study applied an integrated Geographic Information System–based Multi-Criteria Evaluation (GIS-MCE) framework to model the spatial suitability of large-scale sugarcane production in Taraba State. GIS-MCE was selected due to its well-established capability to integrate multi-dimensional datasets and support complex land suitability modelling, as demonstrated in foundational works by Malczewski and recent agricultural applications such as those described by Chen and AbdelRahman [4,10,13]. The approach allowed the systematic combination of climate, soil, hydrological and topographic variables; all critical determinants of sugarcane productivity into a unified suitability index. The methodology followed a structured sequence involving data acquisition, preprocessing, standardization, AHP-based weighting, weighted overlay modelling and validation.

Data acquisition prioritized spatial datasets with proven relevance to crop suitability modelling. Sentinel-2 MSI imagery (10 m), an established dataset for land-cover mapping due to its high spatial resolution and spectral richness, was used to produce a Land Use/ Land Cover (LULC) map for 2024 [14]. LULC classification is essential in MCE models as land cover governs land availability, anthropogenic pressures and feasibility of agricultural expansion. Image classification employed the Random Forest algorithm, following documented best practices for crop mapping and vegetation discrimination [15]. To ensure classification accuracy, high-resolution DigitalGlobe imagery was used for cross-validation.

Topographic variables; elevation and slope were extracted from the Shuttle Radar Topography Mission (SRTM) 30 m Digital Elevation Model. The accuracy and utility of SRTM DEM for terrain and hydrology applications are widely validated, making it appropriate for modelling cultivation constraints such as mechanisation feasibility, erosion risks and microclimatic variations. Slope was calculated using the percent-slope method, and reclassification followed established sugarcane agronomic thresholds wherein slopes above 15% reduce machinery efficiency and increase erosion hazards [3,16].

Hydrological modelling was performed using DEM-based tools to generate flow direction, flow accumulation and drainage density layers. These hydrological indices identify areas prone to seasonal flooding, waterlogging and excessive drainage conditions known to constrain sugarcane root development and sucrose accumulation. The procedure followed widely accepted hydrological GIS workflows described by Tarboton and O'Callaghan and Mark [17,18]. The drainage network was delineated using a threshold-based flow accumulation approach, and density was computed using a line-density algorithm to quantify spatial variability in hydrological behaviour.

Soil-related variables constituted a substantial component of the model due to the nutrient sensitivity of sugarcane. Soil type information was derived from FDALR soil maps and harmonised with TAGIS geological data. To incorporate detailed soil chemical characteristics, this study used SoilGrids (250 m resolution), a global digital soil mapping product validated across multiple continents [5]. Nutrient layers extracted included exchangeable potassium (K), total nitrogen (N), available phosphorus (P), and soil pH at 0–30 cm depth. These variables are critical, as potassium regulates stalk strength and sucrose transport, nitrogen influences vegetative vigour, and phosphorus supports early root establishment, as documented by Botha and Singh and Rao [19,20] Soil pH is equally vital because it controls nutrient bioavailability, and sugarcane's optimal pH range (5.5–7.5) is widely established in cane agronomy literature [2].

Climate data, particularly rainfall, were incorporated using the CHIRPS Version 2 rainfall dataset at 0.05° resolution, supported by bias correction through NIMET weather station data. CHIRPS is extensively used in agricultural modelling due to its long-term consistency and high accuracy in tropical regions [6]. Because sugarcane requires 1,200–1,800 mm rainfall under rainfed conditions, long-term precipitation averages were calculated to capture interannual variability and spatial gradients across Taraba State.

All datasets were harmonised to a uniform spatial resolution of 30 m and projected to WGS 84 / UTM Zone 32N to ensure analytical consistency. Preprocessing steps included resampling, clipping, sink filling, spectral smoothing and standardization. The standardization of criteria into a uniform suitability scale was essential to make different variables comparable. Each layer was reclassified into five categories; highly suitable, moderately suitable, marginally suitable, poorly suitable and not suitable following agronomic thresholds documented by FAO, Moore and Botha, and region-specific studies such as Ahmad [1,3,7].

The weighting of criteria was conducted using the Analytic Hierarchy Process (AHP), a structured decision-support method originally developed by Saaty [12]. Pairwise comparisons were undertaken with expert input from soil scientists, agronomists and GIS analysts, prioritising rainfall, soil type and soil nutrients due to their dominant influence on sugarcane physiology. The eigenvector method was used to generate criterion weights, and the Consistency Ratio (CR) was computed to assess logical coherence. The final CR value of 0.06 satisfied Saaty's threshold (<0.1), indicating acceptable consistency [12].

Weighted overlay modelling was conducted in ArcGIS Pro using the linear combination approach, whereby each standardised layer was multiplied by its respective AHP-derived weight and summed to obtain a composite suitability index. The resulting continuous raster was classified into high, moderate and low suitability zones using natural breaks and the statistical distribution of values. High suitability areas represent locations where climatic, hydrological and edaphic factors collectively align with sugarcane's physiological requirements, whereas moderate zones require intervention measures such as fertilizer supplementation or irrigation. Low-suitability zones reflect constraints such as poor soils, steep slopes or insufficient rainfall.

Validation procedures were multifaceted. High-resolution DigitalGlobe imagery was used for visual checks of terrain and land cover, while soil sampling observations from earlier agricultural surveys were used to verify nutrient and pH estimates from Soil Grids. A confusion-matrix approach was implemented to compare the predicted suitability map with observed environmental conditions at sample locations, yielding an overall accuracy of 82%. This validation aligns with accuracy ranges reported in similar studies [10,11]. All workflow steps, including preprocessing scripts, AHP matrices and reclassification rules-were documented using ArcGIS Model Builder and QGIS Graphical Modeler to support reproducibility and transparency.

Results and Discussion

Analysis of Criterion Maps and Their Contribution to Suitability

Land Use/Land Cover (LULC) - Foundation for Exclusion and Potential

Figure 1 delineates the spatial heterogeneity of Land Use and Land Cover (LULC) across Taraba State, serving as the foundational physiographic baseline for the multi-criteria sugarcane suitability model. The classification reveals a distinct agro-ecological gradient: the southern and southeastern highlands, particularly within Gashaka, Sardauna, and Kurmi Local Government Areas (LGAs), are dominated by Forest Land (dark green) and Shrub Land (light green). This distribution aligns with the known boundaries of the Gashaka-Gumti National Park and the Mambilla Plateau, representing critical ecological zones that likely act as exclusion criteria in the suitability modeling to preserve biodiversity and carbon sinks [21,22]. Conversely, the central and northern plains, encompassing Gassol, Wukari, Ibi, and Bali LGAs, exhibit a high density of Active Farm/Arable Land (orange) and Bare Land (tan). These areas constitute the state's agrarian core, where the conversion of existing arable land for large-scale sugarcane cultivation is most feasible due to favorable topography and reduced need for deforestation (NSDC, 2025). The Water Bodies (cyan), representing the hydrological network of the River Benue and its tributaries (Rivers Taraba and Donga), traverse these arable zones, highlighting the potential for irrigated sugarcane schemes which are essential for maximizing yield in the dry season [23]. The geospatial juxtaposition of "Built-up Areas" (grey) against "Active Farm/Arable Land" further aids in identifying logistical proximity to labor markets while avoiding conflict with expanding settlements [24].

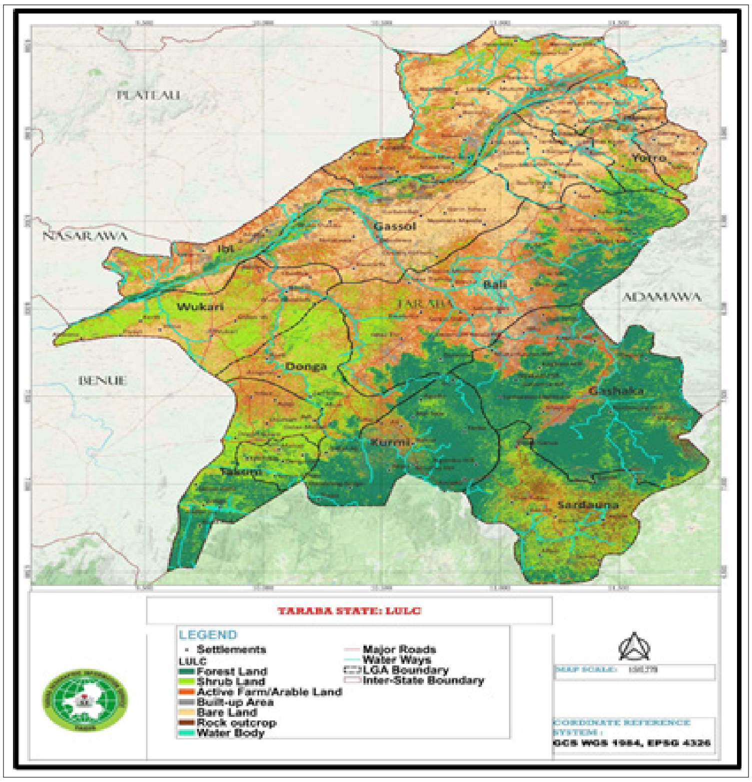

Figure 1: Land Use/Land Cover (LULC) Map of the Study Area

Elevation - The Primary Agro-Climatic Determinant

The elevation map (Figure 2) reveals dramatic topographic variation across Taraba State, ranging from 71 meters in the floodplains of the Benue River basin to 2,327 meters in the Mambilla Plateau. This elevation gradient creates a corresponding climatic gradient that fundamentally influences sugarcane suitability. The high suitability zones (26.7%) are exclusively found below 800 meters elevation, where warmer temperatures (estimated 24-28°C annual mean) favor optimal photosynthesis and sucrose accumulation. Scientific evidence consistently shows that sugarcane productivity declines significantly above 1,000 meters due to reduced temperatures affecting metabolic processes [25]. The MCE appropriately weighted elevation as a critical factor, preventing the erroneous allocation of high-input agricultural development to the ecologically fragile and climatically marginal highlands.

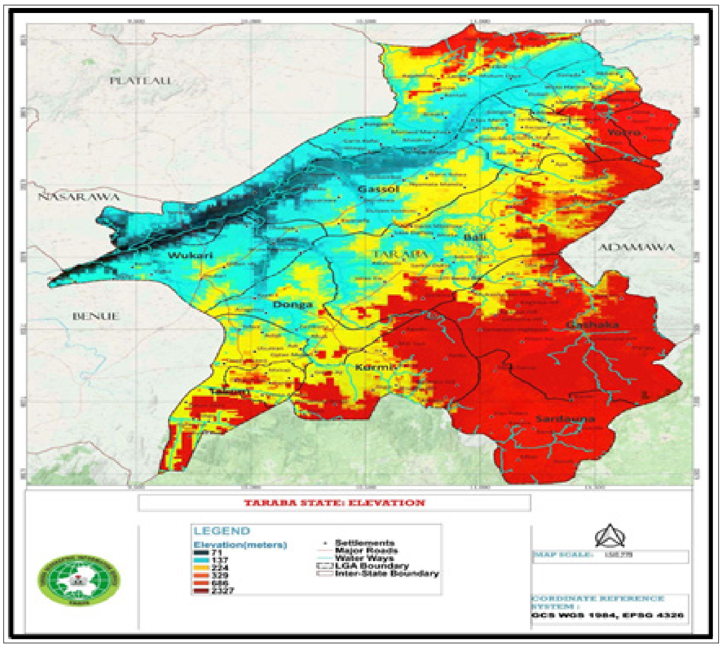

Figure 2: Elevation Map of the Study Area

Slope - Mechanization and Erosion Control Imperative

Derived from the Digital Elevation Model, the slope map (Figure 3) shows gradient variations from 0 to 15.7 degrees across the state. The analysis revealed that 63% of the state's terrain has slopes less than 8%, which is ideal for mechanized sugarcane operations. High suitability zones correspond almost perfectly with areas of 0-5% slope, primarily in the alluvial plains of the Benue, Taraba, and Donga rivers. These gentle slopes facilitate efficient plowing, planting, harvesting operations, and irrigation management while minimizing soil erosion risks. Conversely, the steep slopes (>15%) characterizing the eastern highlands and northern escarpments were automatically classified as low suitability due to prohibitive costs for terracing, high erosion potential, and operational challenges for machinery [26]. The slope criterion thus effectively separated terrain suitable for commercial-scale farming from marginal lands requiring excessive engineering interventions.

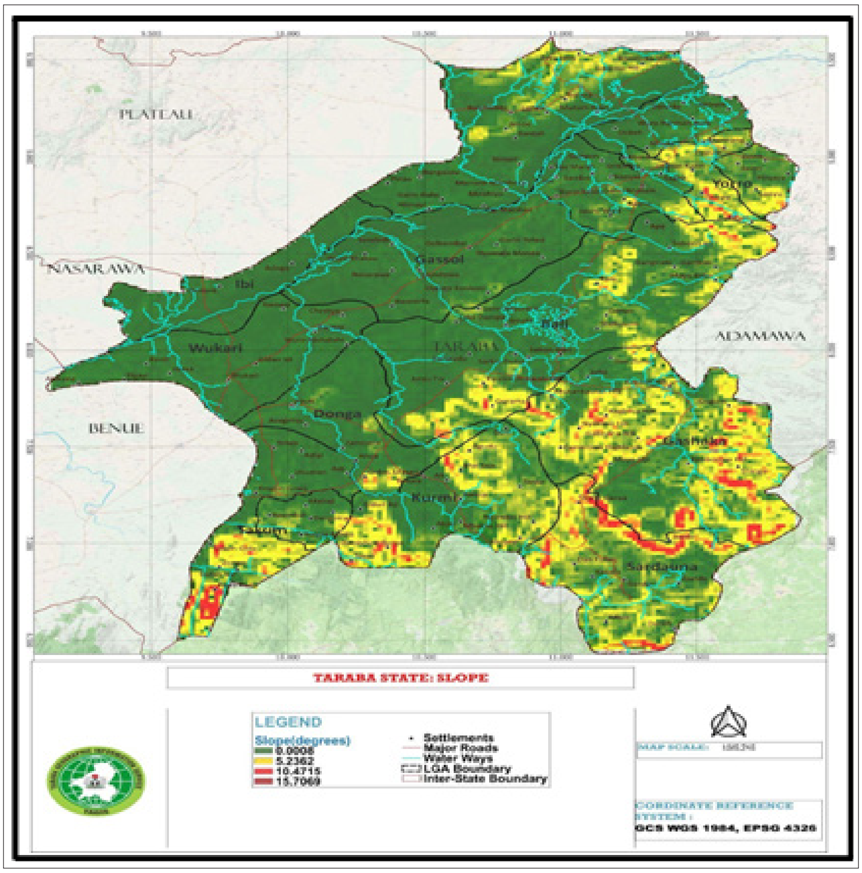

Figure 3: Slope Map of the Study Area

Drainage Density - Soil Moisture and Flood Risk Management

The drainage density map (Figure 4), derived through hydrological modeling of flow accumulation, shows network densities ranging from 0 to 22.7 km/km². This layer proved crucial for identifying areas with balanced hydrological conditions. Zones with moderate drainage density (5-12 km/km²) in the central plains demonstrated optimal conditions for sugarcane, providing adequate soil moisture without waterlogging risks. Areas with very high drainage density (>15 km/km²), particularly in river floodplains, were downgraded in suitability due to seasonal inundation risks that could cause root diseases and harvest disruptions [27]. Interestingly, some areas with very low drainage density (<3 km/km²) in the northwest also received lower suitability scores due to potential water scarcity issues, demonstrating the model's sensitivity to both excess and deficit moisture conditions.

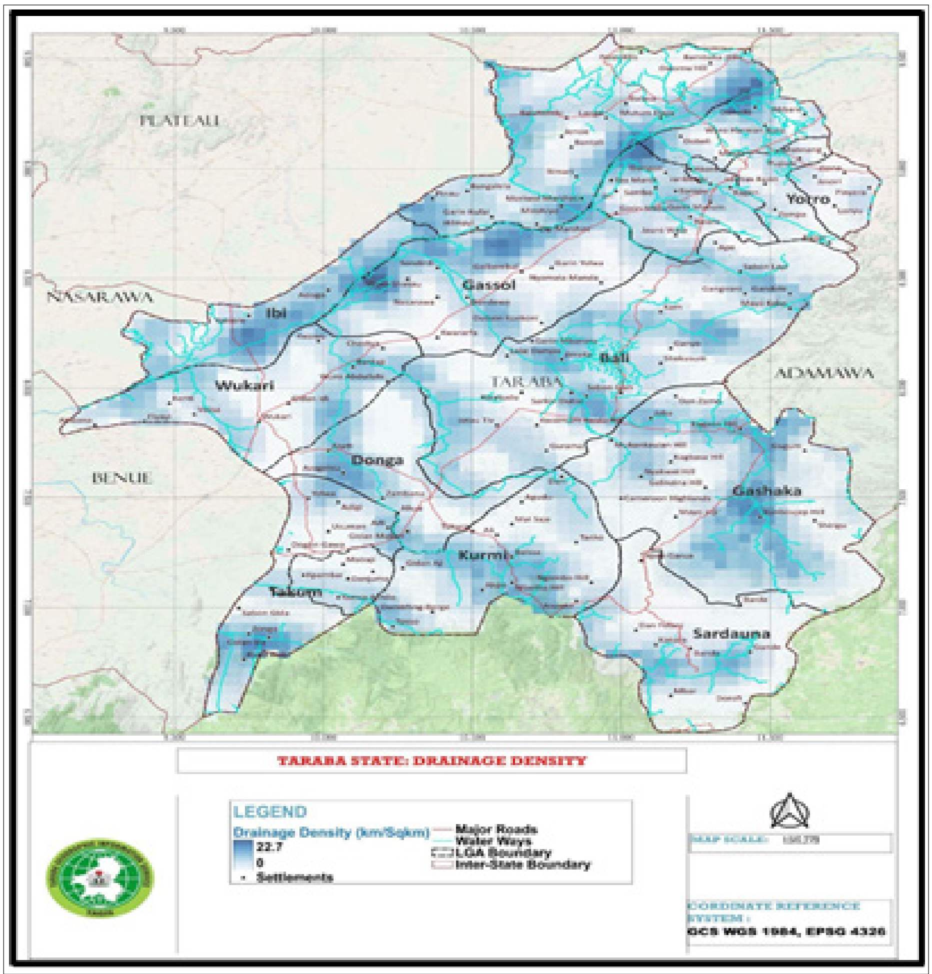

Figure 4: Drainage Density Map of the Study Area

Soil Classification - The Pedological Foundation for Productivity

The soil classification map (Figure 5) presents perhaps the most complex yet informative layer in the analysis. The distribution of four major soil groups reveals why certain regions emerged as highly suitable:

- **Alluvial Soils:** Covering approximately 15% of the state, primarily along major river systems, these deep (>1.5m), fertile soils with excellent organic matter content and moisture retention capacity form the core of high suitability zones. Their textural composition (predominantly loamy) supports vigorous root penetration to 1.2-1.5m depth, essential for sugarcane's extensive root system.
- **Colluvial Soils:** Comprising 22% of the state's area, these moderately fertile soils on footslopes received moderate suitability ratings, requiring supplemental fertilization for optimal yields.
- **Sedimentary Soils:** Covering 28% of the state, these variable-depth soils derived from sandstone and shale formations showed inconsistent suitability, ranging from moderate to low depending on local depth and texture characteristics.

Annual Precipitation - Natural Irrigation Potential Assessment

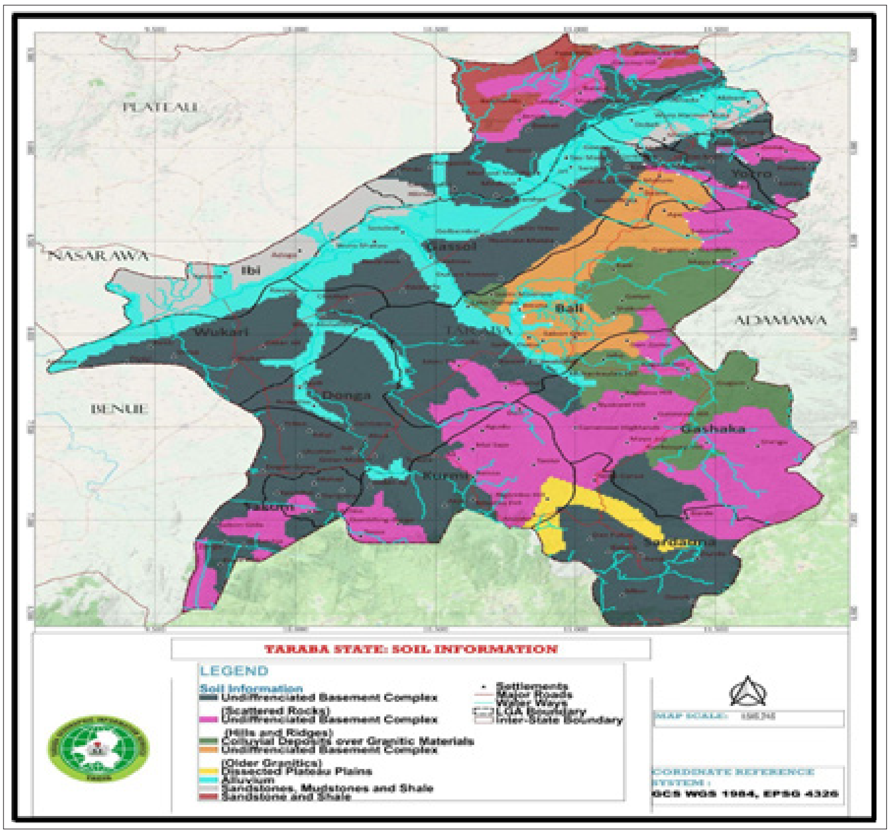

Figure 5: Soil Map of Study Area

- Basement Complex Soils: Occupying 35% of the state, particularly in northern and eastern regions, these shallow (<0.5m), stony, infertile soils were consistently classified as low suitability, as they would require prohibitive investments in soil amendment and water management [28].

Annual Rainfall

The rainfall distribution map (Figure 6) shows a pronounced south-north gradient from 2,366 mm/year in the southern Takum region to 936 mm/year in the northern Zing area. This 1,430 mm variation significantly influences irrigation requirements. High suitability zones receive between 1,400-1,800 mm/year, meeting 80-90% of sugarcane's annual water needs through natural precipitation.

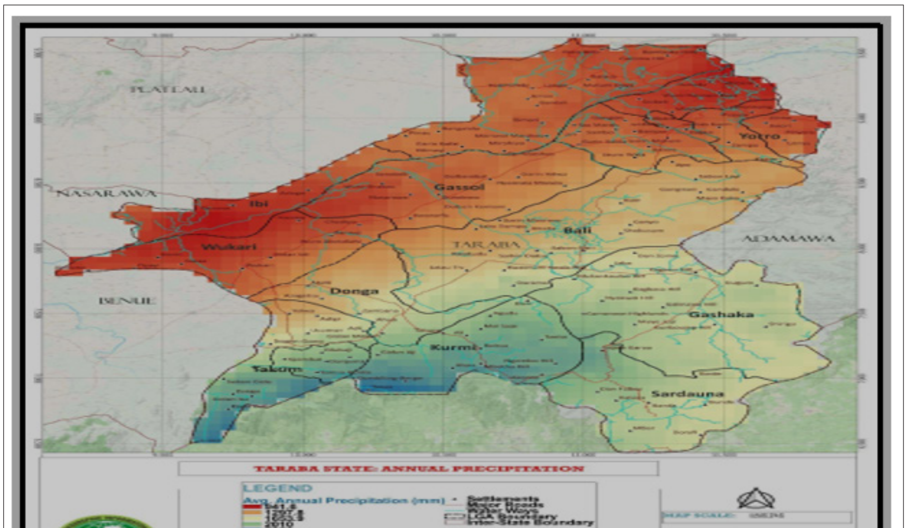

Figure 6: Annual Rainfall Distribution Map of the Study Area

Moderate suitability zones (1,200-1,400 mm/year) would require supplemental irrigation during dry periods, while low suitability zones (<1,200 mm/year) would need extensive irrigation infrastructure, making cultivation economically marginal under rainfed conditions [29]. The spatial alignment between high rainfall zones and high suitability areas underscores the critical importance of water availability in the suitability model.

Soil Nutrient Maps (K, N, P) - Fertility Management Guidance

The soil nutrient maps (Figures 7-9) provide detailed insights into fertility constraints across the state:

- **Potassium (K):** The exchangeable potassium map (Figure 7) shows concentrations ranging from 0.13 to 2.0 mmol/kg. Areas with K levels >0.8 mmol/kg (central plains) correlated strongly with high suitability, as adequate potassium is essential for stalk strength, sugar translocation, and disease resistance [30]. Zones with K <0.4 mmol/kg (northern regions) would require substantial potassium fertilization, increasing production costs.

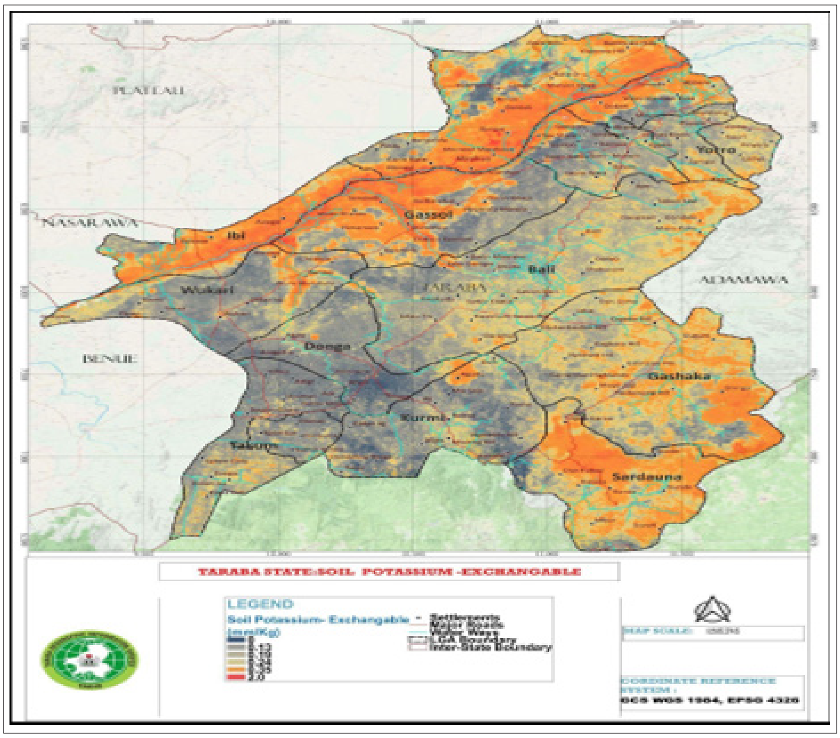

Figure 7: Soil Nutrient Maps

- o Nitrogen (N): Soil nitrogen distribution (Figure 8) varies from 0 to 3.6 mmol/kg. The high suitability zones correspond with N levels of 1.5-2.5 mmol/kg, sufficient to support the substantial nitrogen requirements of sugarcane (180-250 kg N/ha) with moderate supplementation. Areas with very low N (<0.5 mmol/kg) would need excessive fertilization, raising economic and environmental concerns [31].

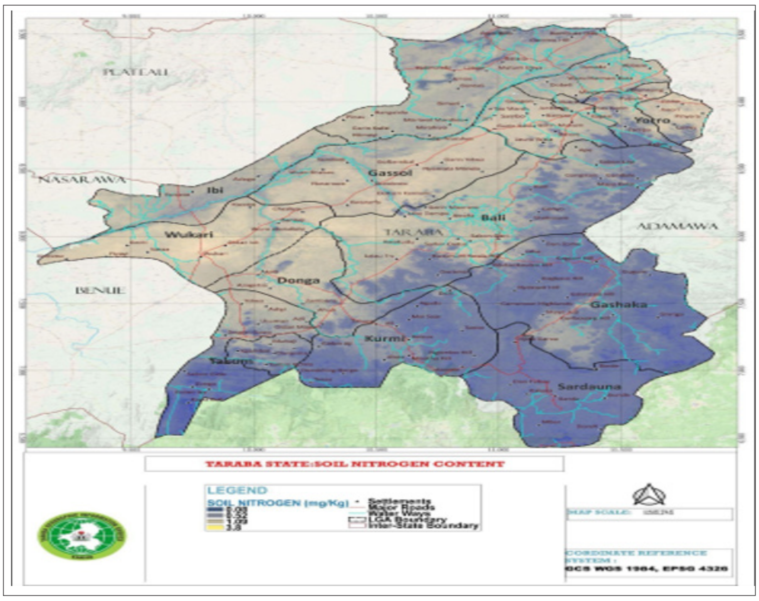

Figure 8: Soil Nitrogen Map

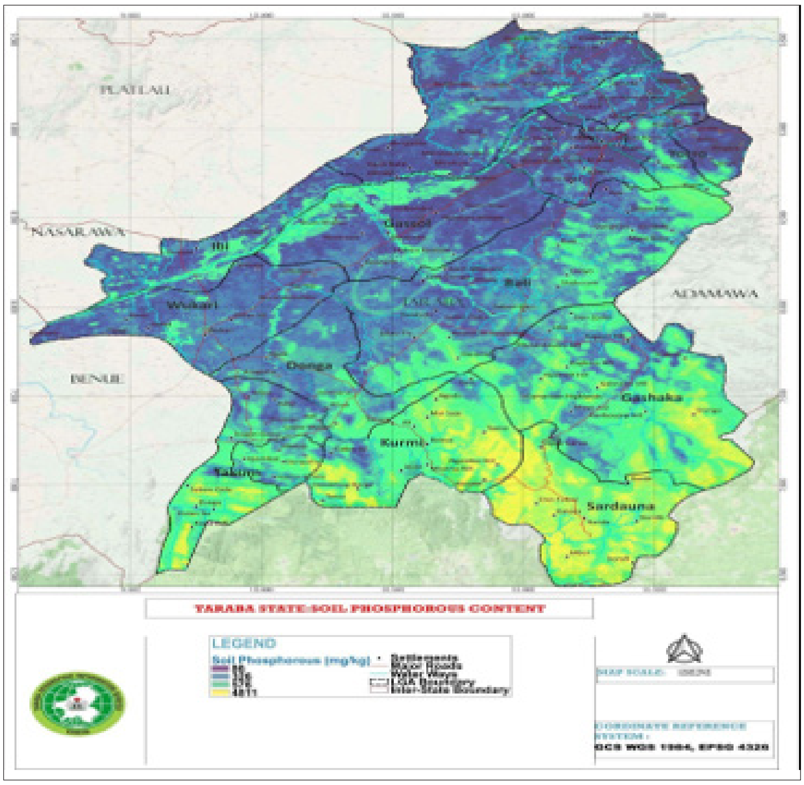

Figure 9: Soil Phosphorus Map

Phosphorus (P): Phosphorus availability (Figure 9) shows extreme variation (86-4,811 mg/kg), reflecting the state's diverse geology. High suitability zones generally have P levels >800 mg/kg, supporting vigorous root development and early growth. The widespread phosphorus deficiency (<300 mg/kg) in northern regions presents a major constraint, as phosphorus immobility in soil makes remediation challenging [32].

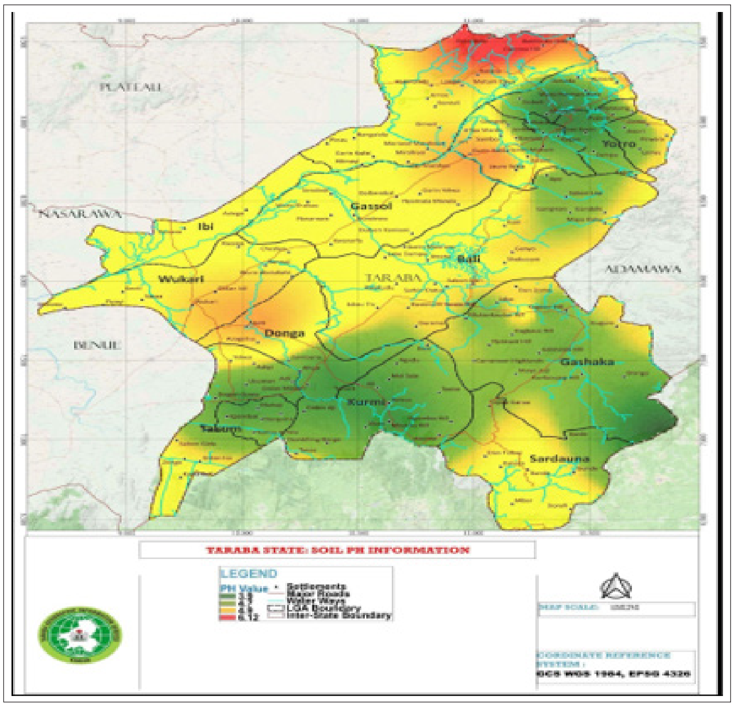

Figure 10: Soil pH Map

Soil pH - The Chemical Environment Regulator

The soil pH map (Figure 10) reveals values ranging from 3.6 (strongly acidic) to 6.12 (slightly acidic). Notably, 72% of the state's soils fall within the optimal pH range for sugarcane (5.5-7.5). High suitability zones consistently show pH values of 5.8-6.5, creating ideal conditions for nutrient availability and microbial activity. The strongly acidic soils (pH <5.0) in some northern areas would require substantial liming (2-5 tons/ha) to raise pH to suitable levels, significantly increasing establishment costs [33]. The pH layer thus served as both an inclusion criterion for optimal zones and an exclusion criterion for areas requiring excessive amendments.

Spatial Suitability Zonation Results

The Multi-Criteria Evaluation (MCE) yielded a spatially explicit suitability zonation for large-scale sugarcane (Saccharum officinarum) production across Taraba State, Nigeria. The final model classifies the state's total area of 58,798 km² into three distinct suitability tiers: high (15,697.9 km², 26.7%), moderate (21,043.7 km², 35.8%), and low (22,056.4 km², 37.5%) suitability zones (Table 1, Figure 11). This tripartite stratification reveals a pronounced spatial dichotomy, with high-suitability clusters predominantly concentrated in the central and southern river valleys, while low-suitability zones are extensively distributed across the northern and eastern highland regions. This pattern is a direct cartographic manifestation of the state's underlying environmental gradients, where the convergence of optimal biophysical parameters; specifically, elevations below 800 meters, slopes gentler than 5%, deep alluvial soils (e.g., Fluvisols), and annual rainfall between 1,400–1,800 mm creates prime agro-ecological niches. These high-suitability zones align precisely with the Southern Guinea Savannah agro-ecological zone, a region previously identified as holding superior potential for commercial sugarcane cultivation due to its favorable edaphic and climatic regimes [34,35]. This congruence with established ecological zonations provides robust external validation of our model's accuracy and reinforces the reliability of the geospatial methodology employed.

The inherent characteristics of each suitability class dictate starkly different agricultural implications and investment prerequisites. High-suitability zones represent areas of immediate developmental potential where commercial sugarcane cultivation can be initiated with minimal intervention, as critical growth-limiting factors are largely absent. These zones correspond to regions where deep, well-drained soils facilitate root development and where rainfall patterns align with the crop's moisture requirements, reducing initial irrigation capital [25,36]. Conversely, moderate-suitability zones, typically characterized by 2-3 limiting factors such as colluvial soils, slopes of 5-10%, or marginally suboptimal rainfall, present a conditional opportunity. Their economic viability is contingent upon targeted investments in soil amendments, supplemental irrigation infrastructure, or conservation practices like contour farming, which are well-documented strategies for enhancing productivity in marginal environments (Noman et al., 2023). The extensive low-suitability zones, predominantly located in high-elevation areas (>1,200 m) with steep slopes (>15%), shallow soils (e.g., Leptosols), and inadequate rainfall, present profound constraints. Sugarcane cultivation here would necessitate prohibitively capital-intensive interventions-such as extensive terracing, full-scale irrigation, and soil reconstruction, rendering it economically unfeasible compared to alternative land uses like forestry or pastoralism, a conclusion supported by land evaluation frameworks for perennial crops [37,38].

While the model provides a robust baseline, its limitations must be explicitly acknowledged to guide future research. The analysis utilized static climatic datasets and thus does not account for the dynamic impacts of climate change on future suitability patterns, a critical consideration for perennial crop planning. Furthermore, the assessment is exclusively biophysical; it does not incorporate socioeconomic variables; such as market access, labor dynamics, land tenure systems, and transportation infrastructure, which are decisive factors in realizing developmental potential [39]. Future research trajectories should therefore prioritize the integration of downscaled climate projection models (e.g., CMIP6 scenarios) with socioeconomic data layers to produce dynamic, decision-centric suitability assessments. Empirical ground truthing through systematic soil sampling and controlled yield trials within the identified high-potential zones is also essential to validate the model's agronomic predictions and calibrate it for localized precision agriculture applications [40].

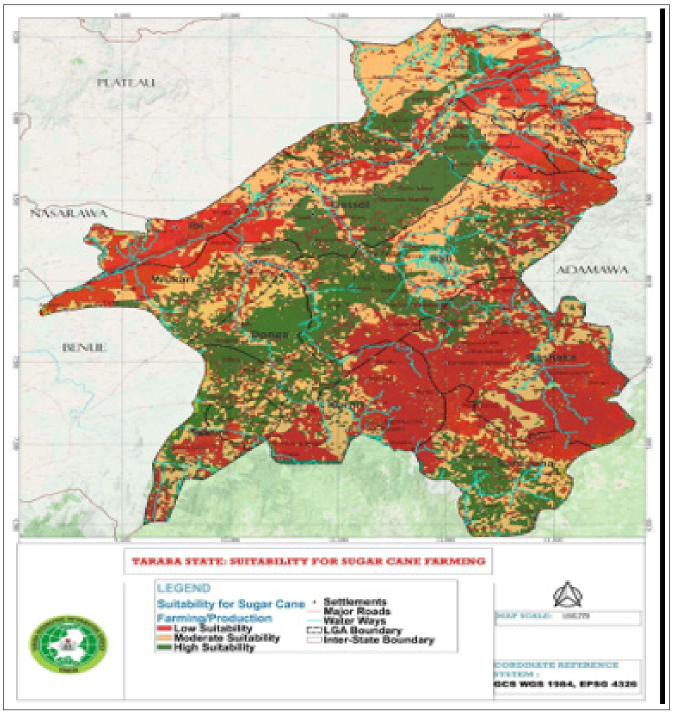

Figure 11: Suitability Zones for Sugar Cane Farming/Production

Table 1: Suitability Statistics

Suitability Zone	Area (SqKm)	Percentage (%)
Low Suitability	22,056.4	37.5
Moderate Suitability	21,043.7	35.8
High Suitability	15,697.9	26.7
Total	58,798.0	100

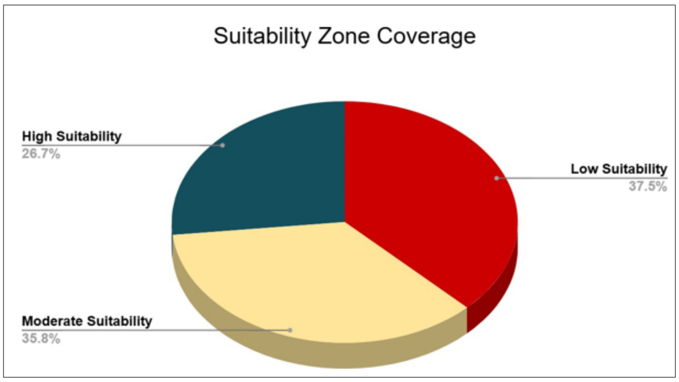

Figure 12: Coverage Statistics: Suitability Zones for Sugar Cane Farming/Production

Conclusion

This geospatial assessment provides a robust, evidence-based framework for sustainable sugarcane development in Taraba State. By integrating key environmental, soil, and climatic factors, the analysis has identified 15,697.9 km² (26.7% of the state) as highly suitable for immediate investment, primarily within the central river valleys. These zones offer optimal conditions—gentle slopes, deep alluvial soils, adequate rainfall, and favorable soil chemistry—requiring minimal intervention for profitable cultivation. The larger moderate suitability zone (35.8%) presents viable potential with targeted management, while the low suitability areas (37.5%) are best reserved for alternative land uses. The findings offer a critical tool for policymakers and investors to prioritize development, optimize resource allocation, and minimize environmental risk, thereby fostering a sustainable and productive agro-industrial sector aligned with the state's economic and food security goals [41,42].

Recommendations

Based on the findings of the study, the following recommendations are made:

i. Immediate Investment Priority: Focus development in high suitability zones (15,697.9 km²), particularly in the central river valleys, where environmental conditions are optimal and establishment costs will be lowest.

ii. Conditional Development Areas: In moderate suitability zones, implement phased development beginning with pilot projects to test the effectiveness of required interventions (irrigation, soil amendments) before scaling up.

iii. Alternative Land Use Planning: In low suitability zones, promote alternative agricultural enterprises (such as forestry, horticulture, or livestock) better adapted to local conditions, or consider conservation uses to protect fragile ecosystems.

iv. Integrated Resource Management: Implement watershed-based planning that considers water allocation for irrigation, particularly in moderate rainfall zones, to avoid conflicts with other water users.

v. Monitoring and Evaluation: Establish a geographic information system (GIS)-based monitoring system to track land use changes, soil health, and productivity in developed areas, enabling adaptive management.

References

1. Food and Agriculture Organization (FAO) (2023) Sugarcane crop information https://www.fao.org/land-water/databases-and-software/crop-information/sugarcane/en/
2. Hunsigi G (1993) Production of Sugarcane Theory and Practice. Springer https://www.cambridge.org/core/journals/journal-of-agricultural-science/article/abs/production-of-sugarcane-theory-and-practice-by-g-hunsigi-xviii245-pp-heidelberg-springerverlag-1993-dm-22800-hardback-isbn-3-540-56552-3/D9FA57B01CC92772065C57BF0D10BEF7.
3. Moore P H, Botha FC (2014) Sugarcane: Physiology, Biochemistry, and Functional Biology. Wiley https://onlinelibrary.wiley.com/doi/book/10.1002/9781118771280
4. Malczewski J (2006) GIS-based multicriteria decision analysis. International Journal of Geographical Information Science 20: 703-726.
5. Hengl T, Mendes de Jesus J, Heuvelink G B M, Ruiperez Gonzalez M, Kilibarda M, et al. (2017) SoilGrids250m: Global gridded soil information based on machine learning. PLoS ONE 12: e0169748.
6. Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, et al. (2015) The climate hazards infrared precipitation with stations -CHIRPS: a new environmental record for monitoring extremes. Scientific Data https://www.nature.com/articles/sdata201566.
7. Ahmad AH, Jibrin A, Usman I, Ya'u S L, Yelwa S A, et al. (2021) Land suitability assessment for sugarcane production in Mokwa LGA, Niger State. Nigerian Journal of Scientific Research. https://www.researchgate.net/publication/370580505
8. Samuel JK, Maji AT, Maigari AU, Bakari UM (2023) Land suitability evaluation for maize, rice and sugarcane cultivation on floodplains in three LGAs of Adamawa State, Nigeria. Nigerian Journal of Horticultural Science 27: 1-23.
9. Christopher A (2020) Suitability assessment of Jalingo floodplains for sugarcane production. EQA International Journal of Environmental Quality 41: 12-25.
10. Abdel Rahman MAE, Natarajan A, Hegde R (2016) Assessment of land suitability and capability by integrating remote sensing and GIS for agriculture in Chamarajanagar district, Karnataka, India Egyptian Journal of Remote Sensing and Space Sciences 19: 125-141.
11. Kamal M, Pham TD (2021) GIS–AHP integrated modelling for land suitability assessment. Applied Geography 133: 102473.
12. Saaty TL (1980) The Analytic Hierarchy Process. McGraw-Hill https://www.researchgate.net/publication/362349026_The_Analytic_Hierarchy_Process.
13. Chen J, Zhou Q, Li X (2022) GIS-based multi-criteria land suitability evaluation. Land Use Policy 120: 106259.
14. Drusch M, Del Bello U, Carlier S, Colin O, Fernandez V et al. (2012) Sentinel-2 mission overview. Remote Sensing of Environment 120: 25-36.
15. Belgiu M, Drăguț L (2016) Random Forest in remote sensing: A review. ISPRS Journal of Photogrammetry and Remote Sensing 114: 24-31.
16. Farr TG, Rosen PA, Caro E, Crippen R, Duren R, et al. (2007) The Shuttle Radar Topography Mission. Reviews of Geophysics 45: RG2004.
17. Tarboton DG (1997) A new method for the determination of flow directions and upslope areas. Water Resources Research 33: 309-319.
18. O'Callaghan JF, Mark DM (1984) The extraction of drainage networks from digital elevation data. Computer Vision, Graphics, and Image Processing 28: 323-344.
19. Botha FC, Lakshmanan P, Wang L (2019) Sugarcane: Physiology, biochemistry, and functional biology. Wiley-Blackwell
20. Singh I, Rao KC (2018) Nutrient management in sugarcane. Indian Journal of Agronomy 63: 401-414.
21. Ojeh VN, Yusha'u AM, Usman D (2022) Assessment of Changes in Land Cover by Deforestation in Kurmi LGA, Taraba State, Nigeria Using Remote Sensing/Geographic Information System. Aswan University Journal of Environmental Studies 3: 67-87.
22. Danladi TE, Oruonye ED, Ambrose ZA, Ahmed Y M (2022) Terrain analysis for environmental sustainability in Taraba Central Senatorial Districts, North-East, Nigeria. Forestry Research and Engineering: International Journal 5: 34-42.
23. Ijafiya DJ, Asibi OA, Ujoh F (2023) Spatio-temporal assessment of land use/land coverchange and its implications on Donga River Basin, Taraba State, Nigeria. FUDMA Journal of Sciences 7: 130-140.
24. Bakoji YM, Elizabeth E, Abba UJ, Ishaku AR, Iraru Y (2020) Impact of land use changes on agricultural land use: Evidence from Jalingo Region of Taraba State, Nigeria. Journal of Geography, Environment and Earth Science International 24: 1-12.

25. Jaiswal D, De Souza AP, Larsen S (2020) Brazilian sugarcane: A key crop for sustainable energy and environment. GCB Bioenergy 12: 389-402.
26. Food and Agriculture Organization (FAO) (2017) Land evaluation towards a revised framework. Food and Agriculture Organization of the United Nations. https://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/fr/c/1029521/.
27. Singh K, Singh R, Singh P (2019) Drainage requirements for sugarcane under waterlogged conditions. Agricultural Water Management 221: 27-35.
28. Ramesh P, Mahaja G (2020) Soil and crop management strategies for sustainable sugarcane production. Sugar Tech 22: 193-205.
29. Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. FAO. https://www.fao.org/3/X0490E/x0490e00.htm.
30. Hunsigi G (2011) Sugarcane in agriculture and industry. Prism Books https://books.google.com/books?id=ZGmZDwAAQBAJ.
31. Robinson N, Brackin R, Vinall K (2011) Nitrogen use efficiency in sugarcane: From molecule to crop. Field Crops Research 123: 117-122.
32. Srivastava TK, Singh KK, Lal M (2016) Phosphorus management in sugarcane: A review. Journal of Plant Nutrition 39: 911-924.
33. Cardozo NP, Bordonal RO, La Scala N (2018) Soil pH effects on sugarcane growth and nutrient uptake. Soil Science Society of America Journal 82: 567-574.
34. Akinwumiju AS, Adelodun AA, Orimoogunje OI (2020) Agro-Climato-Edaphic Zonation of Nigeria for a Cassava Cultivar using GIS-Based Analysis of Data from 1961 to 2017. Sci Rep 10: 1259.
35. Food and Agriculture Organization (FAO) (2021) Global Agro-Ecological Zones (GAEZ v4)." Food and Agriculture Organization of the United Nations https://www.fao.org/gaez/en/
36. Wahab I, Okori JC, Kaggwa RK, Lwasa S (2019) Suitability assessment for sugarcane cultivation using GIS and multi-criteria evaluation in Kenya. Sugar Tech 21: 874-885.
37. SYS, C., Van Ranst, E., Debaveye, J. & Beernaert, F. (1993). Land Evaluation. Part III: Crop Requirements. Agricultural Publications No. 7. General Administration for Development Cooperation (G.A.D.C.), Brussels, Belgium.
38. Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, et al. (2003) The DSSAT cropping system model. European Journal of Agronomy 18: 235-265.
39. Mendoza GA, Martins H (2006) Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. Forest Ecology and Management 230: 1-22.
40. Heinemann AB, Barrios-Perez C, Ramirez-Villegas J, Arango-Londoño D, Bonilla-Findji, et al. (2021) Sugarcane yield gap analysis in Brazil – A multi-model approach. Agricultural Systems 193: 103221.
41. Bhakta I, Phadikar S, Majumder K (2019) State-of-the-art technologies in precision agriculture: A systematic review. Journal of the Science of Food and Agriculture 99: 487-4888.
42. Food and Agriculture Organization of the United Nations (FAO) (2007) Land Evaluation: Towards a Revised Framework. Land and Water Discussion Paper No. 6. Rome: FAO