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Original Article

Land Suitability Mapping of the Most Illegally Harvested Plant Species using a GIS-based Model in Uganda

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Date Published: ABSTRACT

23 May 2026 Illegal harvesting of high-value plant species threatens biodiversity conservation and sustainable livelihoods in Uganda, particularly within and around Rwenzori Mountains National Park. This study applied a GIS-based land suitability modelling approach to identify potential areas for ex-situ conservation of selected illegally exploited species, including *Warburgia ugandensis*, *Prunus africana*, *Maesa lanceolata*, *Albizia coriaria*, *Arundinaria alpina*, and *Albizia gummifera*. A Multi-Criteria Evaluation (MCE) framework integrated climatic variables, soil properties, topographic factors, and land-use/land-cover data. The Analytic Hierarchy Process (AHP) was used to assign weights, while weighted overlay analysis in ArcGIS 10.8 generated species-specific suitability maps. Results revealed clear spatial variation in habitat suitability across Uganda, with highly suitable areas concentrated mainly in the western and south-western highlands of the Albertine Rift. Montane species such as *Prunus africana* and *Arundinaria alpina* exhibited restricted suitability ranges associated with cooler and wetter highland environments, whereas ecologically adaptable species such as *Albizia coriaria* and *Albizia gummifera* showed broader distribution patterns across multiple regions. Moderately suitable zones extended into parts of central Uganda, while northern and north-eastern regions were largely unsuitable due to higher temperatures, lower rainfall, and extensive land-use modification. The study demonstrates that GIS-based land suitability mapping is an effective decision-support tool for conservation planning. Identifying suitable habitats outside protected areas provides opportunities for ex-situ conservation, ecological restoration, and community-based cultivation. The findings offer spatially explicit guidance for policymakers and conservation agencies seeking to reduce pressure on in-situ populations while promoting sustainable management of valuable plant resources in Uganda.

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INTRODUCTION

Biodiversity, the variety of life on Earth, is fundamental for maintaining ecosystem stability, ecological resilience, and human well-being (Oliver et al., 2015). Forest ecosystems cover approximately 31% of the global land surface, with tropical rainforests accounting for nearly 45% of the world's forested area (Hansen et al., 2013). These tropical forests are among the most biologically diverse ecosystems and provide essential habitats for numerous plant and animal species (Brandon, 2014). In Uganda, the Rwenzori Mountains National Park (RMNP) represents one of the country's most important biodiversity hotspots due to its exceptional floral diversity, altitudinal vegetation zones, and high levels of species endemism within the Albertine Rift region (Katswera et al., 2022). The park contains numerous plant species of ecological, medicinal, cultural, and economic importance to surrounding communities (Iacopino et al., 2022).

The flora of RMNP plays a critical role in supporting local livelihoods and traditional healthcare systems. Many plant species are harvested for medicinal purposes, construction materials, fuelwood, handicrafts, and food (Muhumuza et al., 2022). For example, *Prunus africana* is internationally recognised for its medicinal value in the treatment of prostate-related illnesses (Jimu, 2011), while *Arundinaria alpina* (bamboo) is widely utilised for construction and household needs (Miller et al., 2020). These plant resources are deeply embedded within the socio-cultural practices of neighbouring communities and contribute significantly to household welfare and indigenous knowledge systems (Ochen, 2012). Consequently,

sustainable management of these species is essential not only for biodiversity conservation but also for sustaining local livelihoods and cultural heritage.

Despite the protected status of RMNP, illegal harvesting of valuable plant species remains widespread and continues to threaten biodiversity conservation efforts (Jones, 2013). Increasing human population pressure, poverty, limited livelihood alternatives, and continued dependence on natural resources have intensified unauthorised extraction of medicinal and economically valuable plant species from the park (Tumusiime, 2006). Unsustainable harvesting practices, including debarking, uprooting, and indiscriminate cutting, have contributed to habitat degradation, reduction in plant regeneration capacity, and decline in species populations (Bulafu et al., 2021). Inadequate enforcement capacity, limited conservation resources, and weak community involvement further exacerbate the problem (Tumusiime et al., 2011).

Although illegal harvesting of plant species in RMNP has been documented, there remains limited spatial information regarding the suitability of alternative areas for ex-situ conservation and sustainable cultivation of the most exploited species in Uganda. The absence of such information constrains conservation planning and limits the development of targeted restoration and species management interventions. Identifying environmentally suitable areas for cultivation and conservation outside protected areas is therefore critical for reducing harvesting pressure on natural populations while supporting sustainable utilisation of these important plant resources.

Geographic Information System (GIS)-based land suitability modelling has emerged as an effective tool for identifying suitable habitats for species conservation and sustainable land management (El Baroudy, 2016). GIS-based approaches integrate environmental variables such as climate, topography, soil characteristics, and land cover to determine areas that are ecologically appropriate for species establishment and survival. Applying GIS-based suitability modelling to illegally harvested plant species can therefore provide valuable spatial information to guide ex-situ conservation initiatives, restoration planning, and community-based resource management.

This study, therefore, aims to map the land suitability of the most illegally harvested plant species in Uganda using a GIS-based model. Specifically, the study seeks to: (i) identify the most illegally harvested plant species within and around RMNP; (ii) determine the environmental factors influencing their distribution; and (iii) generate spatial suitability maps identifying potential areas for ex-situ conservation and sustainable cultivation. The findings of this study will contribute to biodiversity conservation planning, sustainable natural resource management, and the development of alternative conservation strategies aimed at reducing illegal exploitation of plant species in Uganda.

MATERIALS AND METHODS

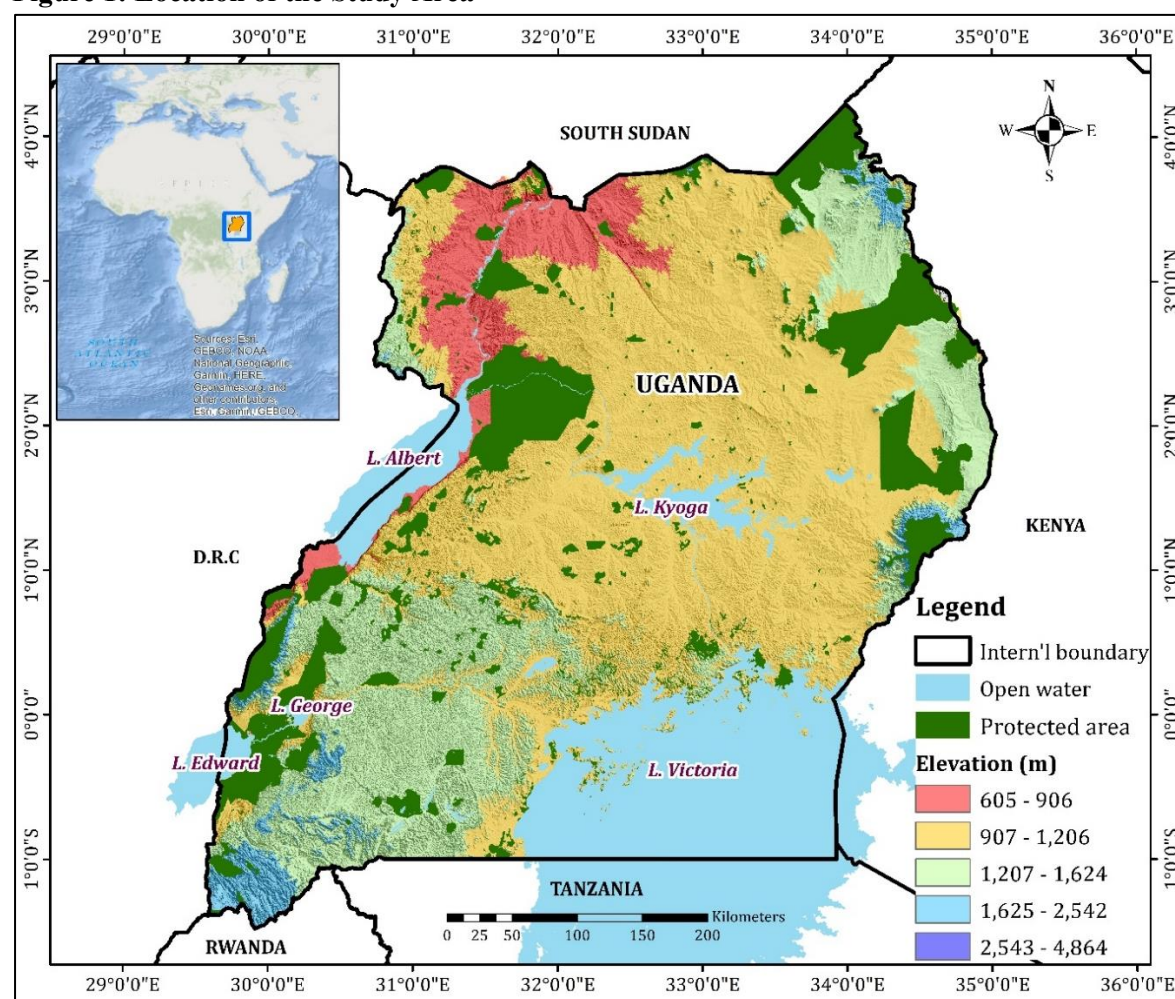
Study Area Description

Uganda is a landlocked country located in East Africa, situated between latitudes 1°29' S and 4°12' N and longitudes 29°34' and 35°00' E (Figure 1), covering a total land area of approximately 241,038 km² (UBOS, 2022). It is bordered by South Sudan to the north, Kenya to the east, Tanzania and Rwanda to the south, and the Democratic Republic of Congo to the west. Uganda lies within the Albertine Rift region, a globally significant biodiversity hotspot known for its high levels of plant species richness and endemism (Plumptre et al., 2007; UNEP-WCMC, 2016).

The country's topography is predominantly a plateau ranging between 1,000 and 1,300 m above sea level, punctuated by mountainous regions such as the Rwenzori Mountains in the west, Mount Elgon in the east, and the southwestern highlands. These altitudinal variations exert strong controls on climate, soil development, and vegetation patterns, which are key determinants of plant species distribution and habitat suitability (NEMA, 2019). Uganda experiences a tropical climate with generally bimodal rainfall patterns, averaging between 1,000 and 1,500 mm annually, while mean temperatures range from 18°C in highland areas to over 30°C in lowland regions (World Bank, 2021).

Uganda supports diverse vegetation types, including tropical moist forests, woodland savannahs, grasslands, wetlands, and montane ecosystems. These ecosystems provide habitats for numerous plant species that are widely harvested for medicinal use, timber, fuelwood, and other non-timber forest products (Cunningham, 2001; Kalema & Beentje, 2012). Increasing demand for these resources, combined with population growth, agricultural expansion, and poverty, has led to widespread illegal harvesting of high-value plant species, particularly outside protected areas (NEMA, 2019).

Soil types across Uganda range from fertile volcanic soils in the eastern and southwestern regions to sandy and loamy soils in central and northern areas, further influencing plant productivity and spatial suitability patterns (MAAIF, 2016). Human activities such as settlement expansion, road development, and proximity to markets intensify pressure on natural vegetation, making Uganda a complex landscape where biophysical and anthropogenic factors jointly shape the land suitability of illegally harvested plant species. This study, therefore, considers Uganda as a heterogeneous ecological and socio-economic setting for modelling land suitability and identifying priority areas for conservation and enforcement interventions.

Figure 1: Location of the Study Area

Study Design

The study employed a quantitative research design. This involved the use of land suitability with a multi-criteria evaluation (MCE) approach with the help of GIS and remote sensing technologies. This process involved the integration of various biophysical and socio-economic factors that influence the growth and survival of the target species. Key factors included soil type, climate conditions, altitude, and human disturbance levels. Data for these factors were collected from field surveys, satellite imagery, and existing databases. The Analytic Hierarchy Process (AHP) was used to weight the importance of each factor, and GIS tools were applied to create suitability maps highlighting potential areas for ex-situ conservation. The maps guided the selection of sites for establishing conservation plots or botanical gardens (Malczewski, 2004).

Study Selection

The study area was selected because it represents one of the most biologically diverse yet highly threatened landscapes in Uganda, where intense human dependence on forest resources has accelerated the illegal harvesting of economically and medicinally important plant species such as *Prunus africana*, *Warburgia ugandensis*, *Albizia coriaria*, and *Arundinaria alpina*. The area encompasses diverse altitudinal gradients, climatic conditions, soil types, and vegetation zones that strongly influence species distribution and habitat suitability, making it scientifically appropriate for GIS-based spatial modelling. In addition, the landscape experiences increasing anthropogenic pressures, including agricultural expansion, fuelwood extraction, grazing, and encroachment, which have contributed to habitat fragmentation and declining populations of vulnerable plant species. The presence of

protected areas alongside adjacent community lands also provides an ideal setting for evaluating how environmental and human-induced factors interact to determine suitable habitats for conservation and restoration planning. Furthermore, limited spatially explicit information exists regarding the ecological suitability and potential distribution of illegally exploited plant species in Uganda, yet such information is essential for evidence-based conservation, sustainable resource management, and prioritisation of restoration interventions. Therefore, selecting this study area provides an opportunity to generate scientifically robust geospatial data that can support biodiversity conservation, reduce pressure on natural populations, and guide ex-situ and in-situ management strategies for threatened plant species.

Data Collection

Determine the land suitability mapping for the illegally harvested species for ex-situ conservation in Uganda.

Land suitability mapping for ex-situ conservation of illegally harvested species was performed using

a multi-criteria evaluation (MCE) approach in GIS (El Baroudy, 2016). Key criteria for suitability included climatic conditions, soil types, topography, and aspect (El Baroudy, 2016). Data on these factors were collected from various sources, including satellite imagery, soil maps, and climatic databases such as <https://climateknowledgeportal.worldbank.org>. The climatic datasets included temperature, rainfall, and relative humidity (Figure 2).

Each criterion was assigned a weight based on its importance to the growth and survival of the targeted plant species. GIS layers representing these criteria were overlaid to produce a composite suitability map, identifying areas across Uganda that are most suitable for ex-situ conservation. The updated GIS layers were obtained from <https://www.nfa.go.ug/> and <https://www.ubos.org>. Field verification through ground truthing was conducted in selected high-suitability areas to validate the model's predictions and to ensure the chosen sites meet all necessary conditions for successful cultivation and conservation of the target species (Ali et al., 2022).

Figure 2: GIS-based Multi-Criteria Approach for Land Suitability Mapping of the Illegally Harvested Plants

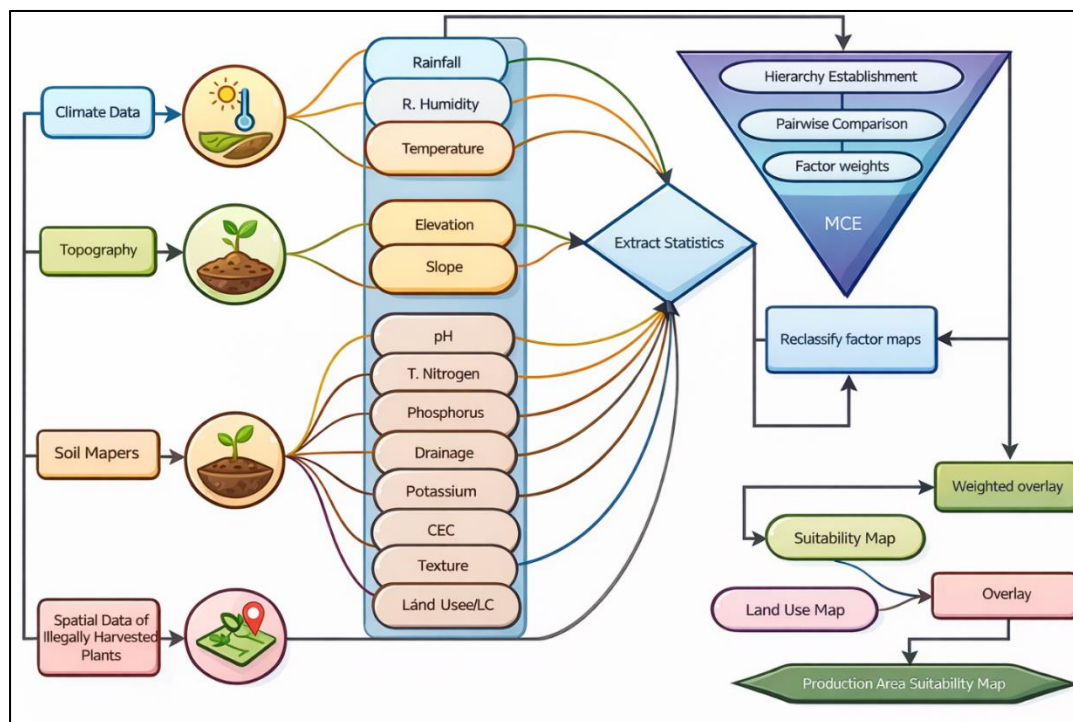


Figure 3: Elevation, Slope, Relative Humidity (RH), and Temperature

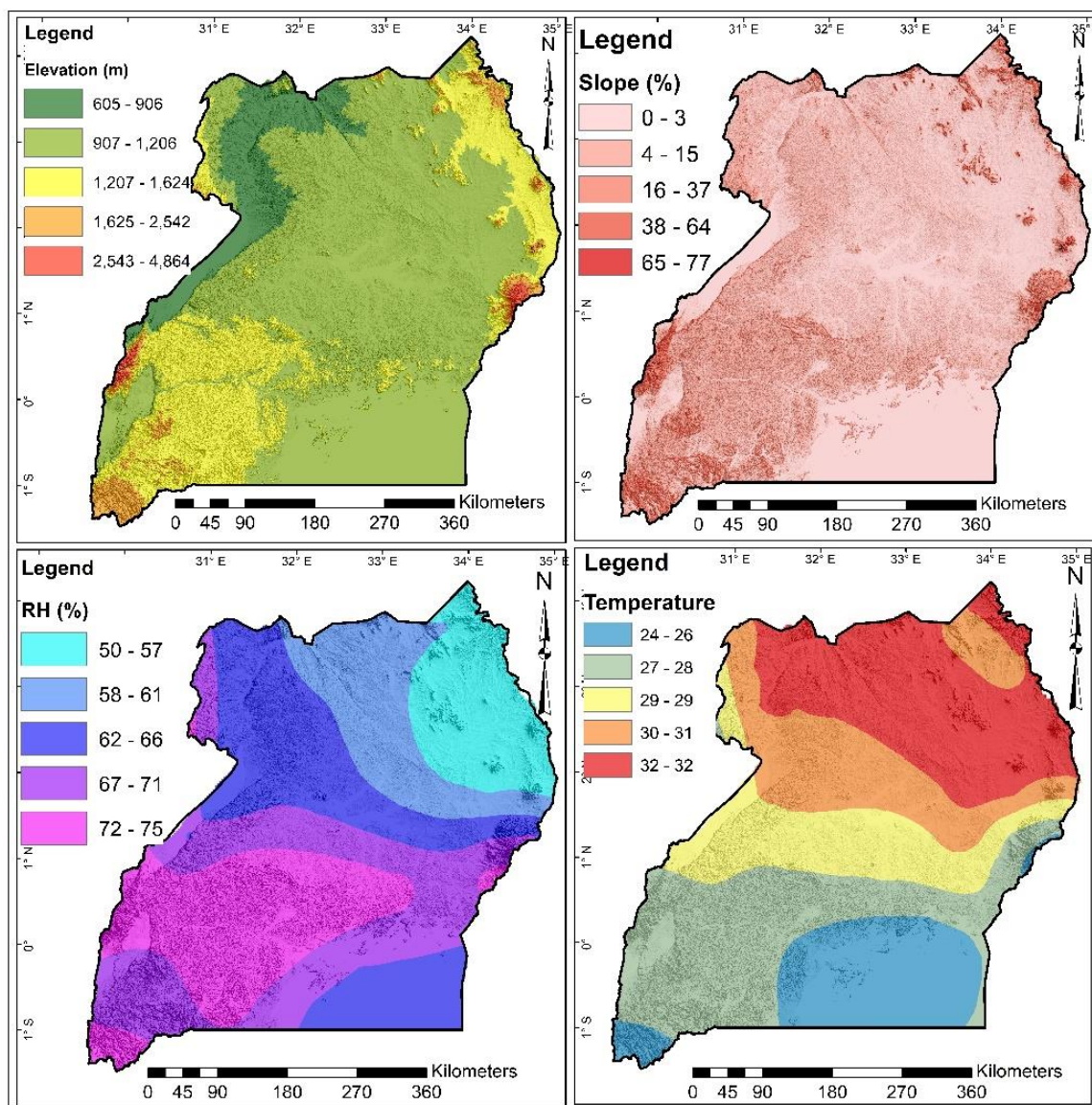


Figure 4: Cation Exchange Capacity, Nitrogen, Phosphorus, Potassium

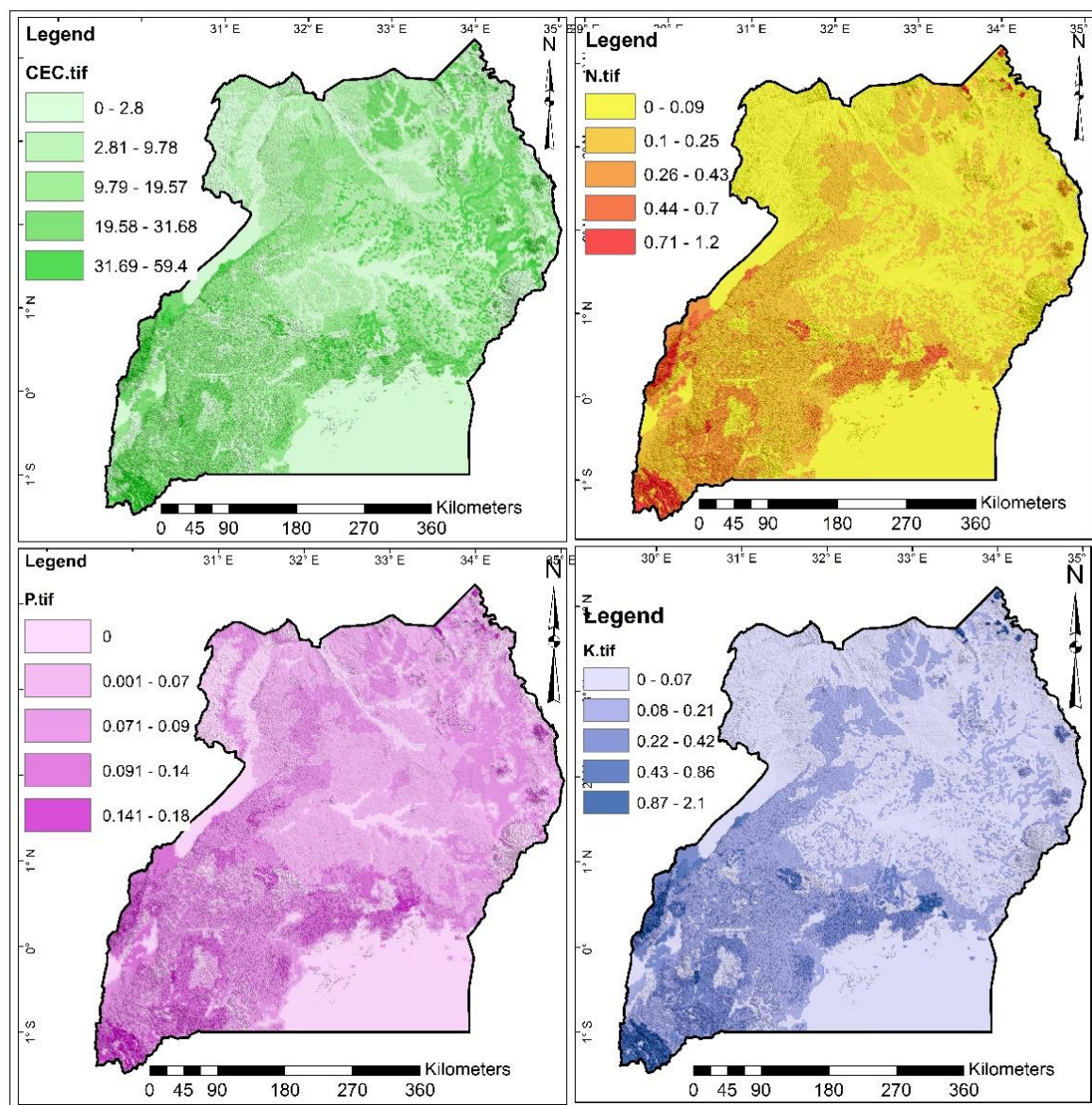


Figure 5: pH, Sand, Silt, and Clay

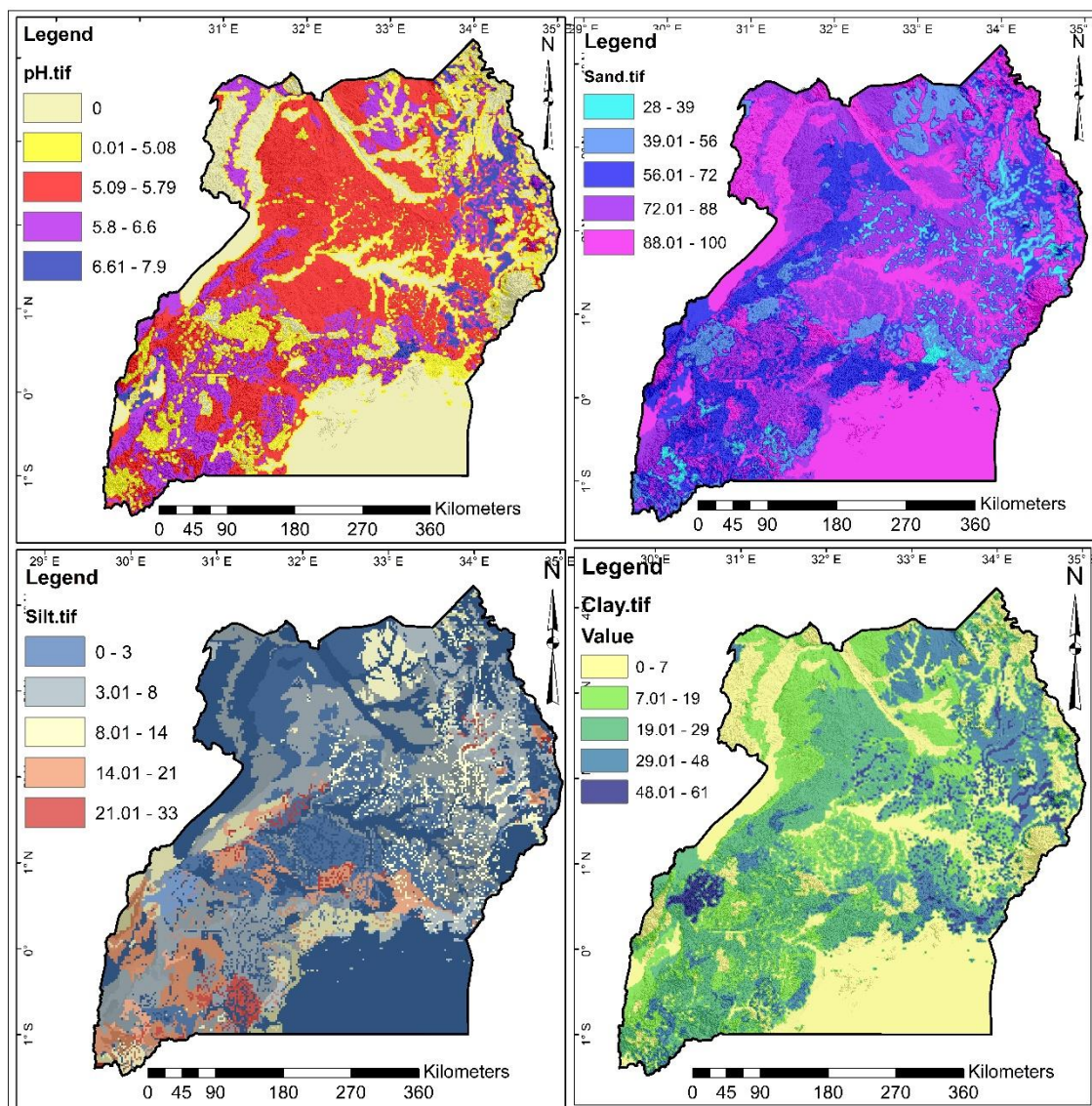
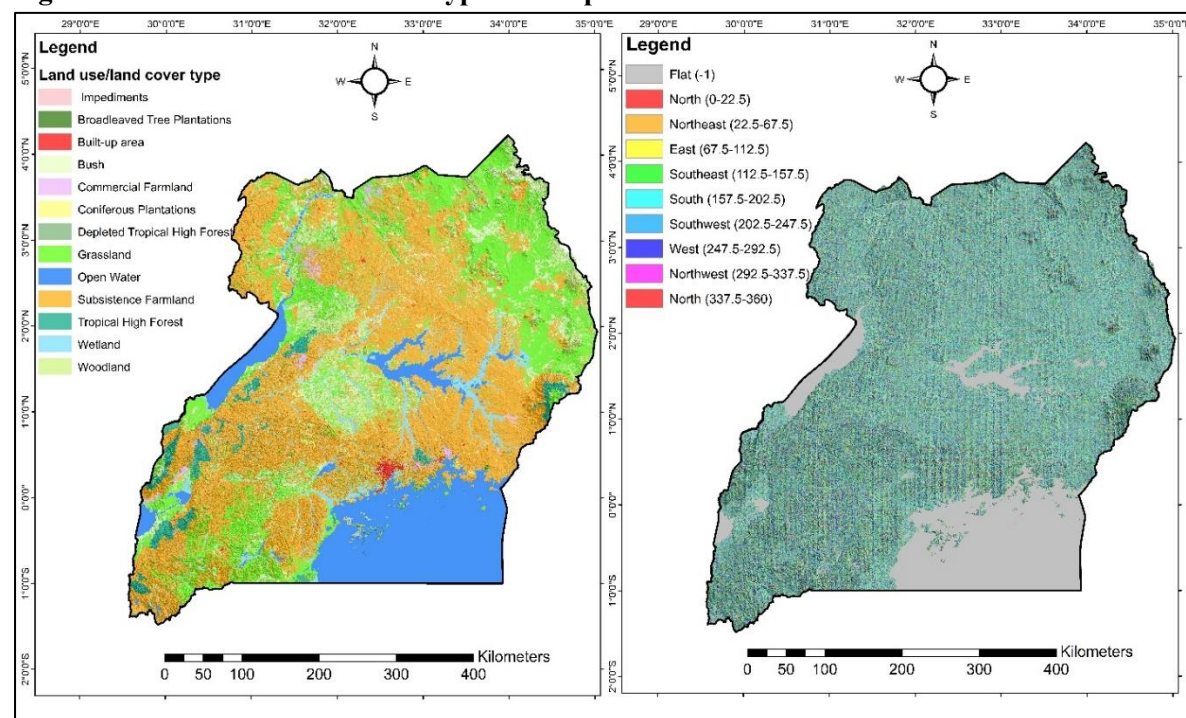


Figure 6: Land-Use/Land-Cover Type and Aspect



Data Analysis

Multi-Criteria Evaluation (MCE) with the weighted overlay in ArcGIS 10.8 was performed to assign weights to each criterion (climatic conditions, soil types, land use type, topography, and aspect) based on their importance for the growth and survival of the target species (Hassan et al., 2020). The composite suitability map involved overlaying the weighted GIS layers to produce a composite suitability map. This map showed areas with varying degrees of suitability for ex-situ conservation. Validation was done during field verification in selected high-suitability areas to validate the model's predictions. Adjustment for the criteria weights and model parameters was based on the field data.

Ethical Consideration

This study sought approval from Mulago Hospital REC (MHREC) in Uganda, with approval number MHREC 2816. In addition, it acquired permission from Uganda Wildlife Authority (UWA) REF: COD/96/05 to conduct this study in Rwenzori Mountains National Park. More so, approval was

also obtained from the National Council for Science and Technology (UNCST).

RESULTS

Land Suitability Mapping of *Warburgia ugandensis*

The map (Figure 7) illustrated the land suitability distribution of *Warburgia ugandensis* across Uganda, with specific emphasis on the Rwenzori Mountains National Park.

Land suitability was classified into three categories: highly suitable, moderately suitable, and not suitable, each represented by distinct colours. Highly suitable areas were mainly concentrated in the western and southwestern regions, particularly around the Rwenzori Mountains and other montane forest zones, reflecting favourable climatic and ecological conditions for the species. Moderately suitable areas were widely distributed across central and parts of eastern Uganda, while unsuitable areas were scattered throughout lowland and heavily modified landscapes.

Figure 7: Land Suitability Map for *Warburgia ugandensis*

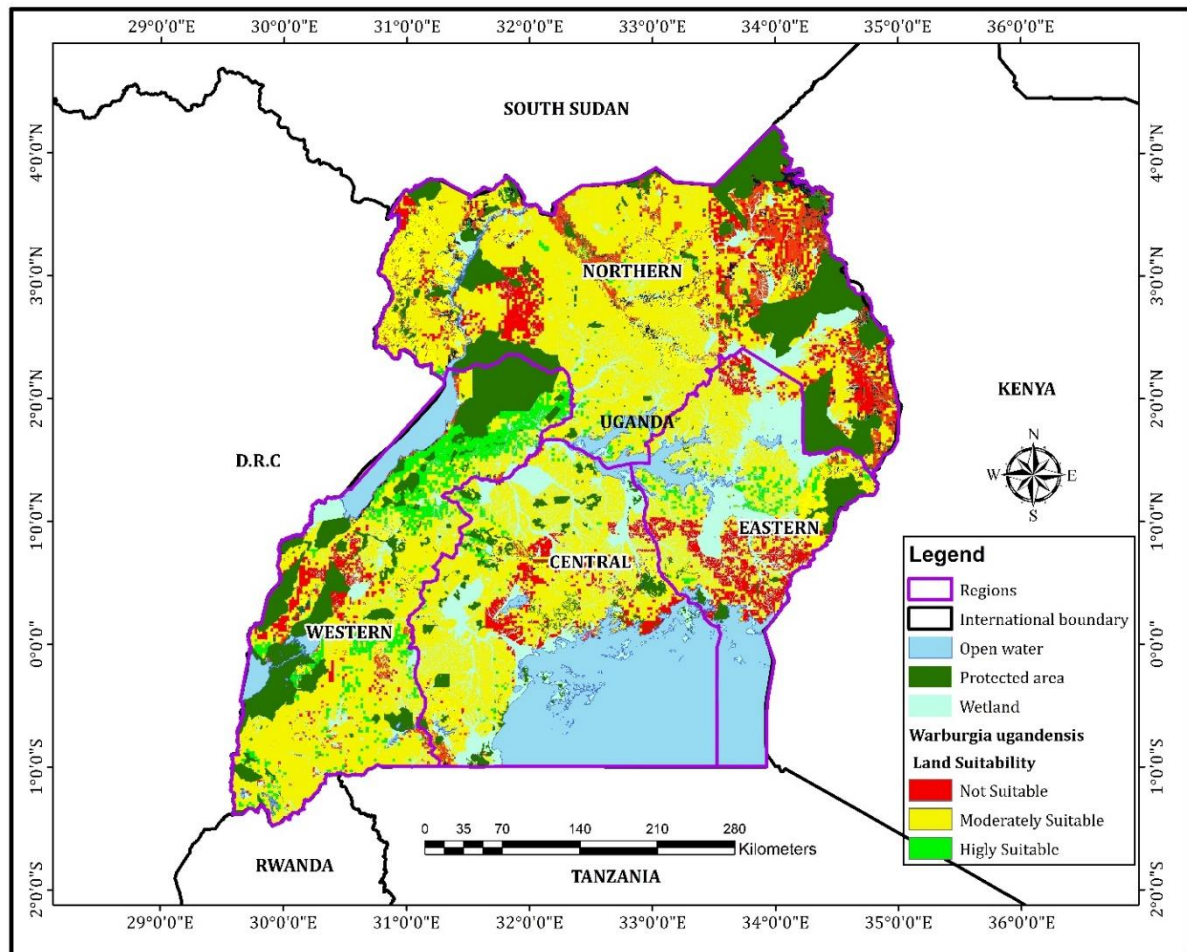
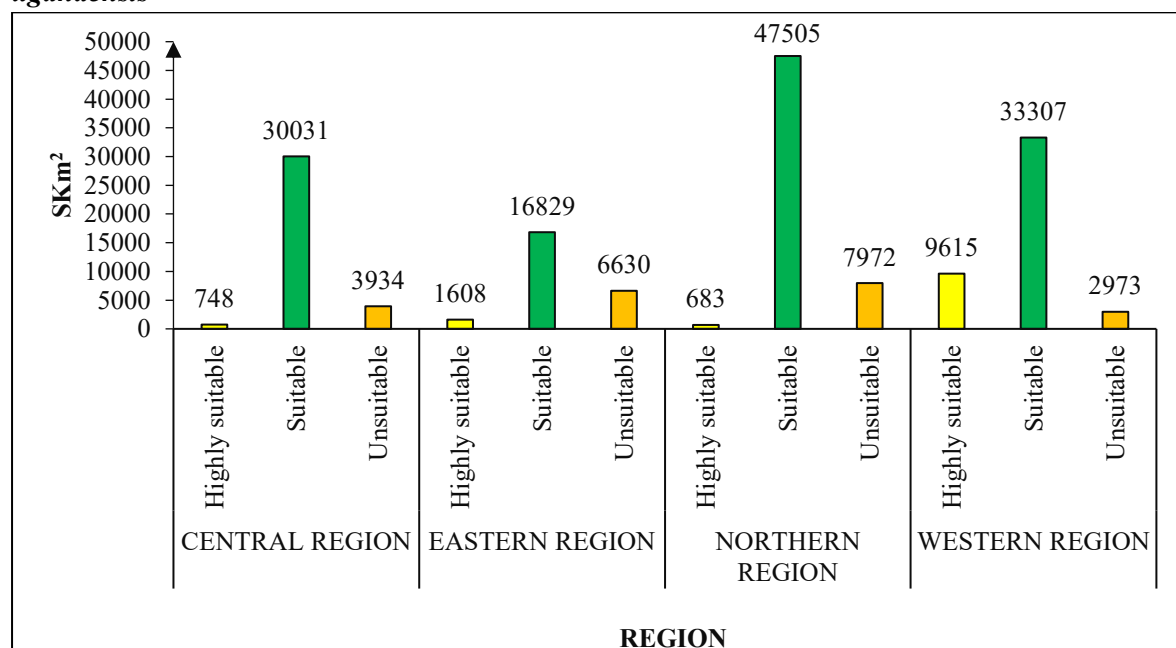


Figure 8: Regional Areas that are Highly Suitable, Suitable, and Unsuitable for *Warburgia ugandensis*



Regional areas were categorised as highly suitable, suitable, and unsuitable for *Warburgia ugandensis* across four regions (Figure 8). In the Central Region, the highly suitable area was 748

km², the suitable area was 30,031 km², and the unsuitable area was 3,934 km². In the Eastern Region, the highly suitable area measured 1,608 km², the suitable area was 16,829 km², and the unsuitable area was 6,630 km².

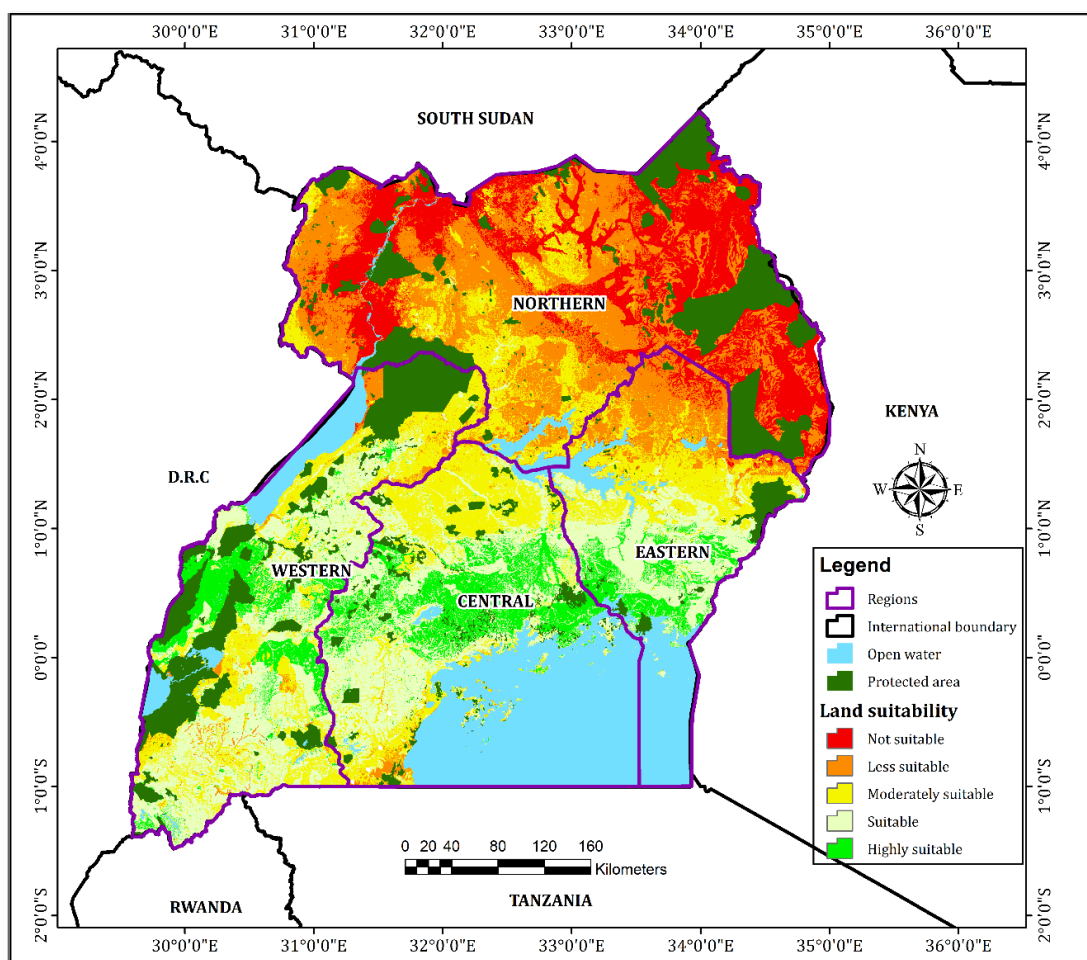
In the Northern Region, the highly suitable area was 683 km², the suitable area was 47,505 km², and the unsuitable area was 7,972 km². In the Western Region, the highly suitable area was 9,615 km², the suitable area was 33,307 km², and the unsuitable area was 2,973 km².

Land Suitability Mapping of *Prunus africana*

The map presents the land suitability distribution of *Prunus africana* across Uganda, with particular

reference to the Rwenzori Mountains National Park. Land suitability was categorised into five classes: highly suitable, suitable, moderately suitable, less suitable, and not suitable, each represented by a distinct colour gradient. Highly suitable and suitable areas were predominantly concentrated in the western and southwestern regions, especially within and around the Rwenzori Mountains and other montane forest ecosystems, reflecting the species' preference for cool, moist high-altitude environments. Moderately suitable areas extended across parts of central and eastern Uganda, while less suitable and not suitable areas were largely dominant in the northern and northeastern regions, characterised by warmer and drier conditions.

Figure 9: Land Suitability Map for *Prunus africana*



Land Suitability Mapping of *Maesa lanceolata*

The map shows the land suitability distribution of *Maesa lanceolata* across Uganda, with emphasis

on the Rwenzori Mountains National Park. Land suitability was classified into four categories: highly suitable, suitable, moderately suitable, and

not suitable, each represented by distinct colours. Highly suitable and suitable areas were largely concentrated in the western and southwestern regions, particularly within the Rwenzori Mountains and adjacent montane forest landscapes, reflecting the species' preference for

moist, forested, and mid-to high-altitude environments. Moderately suitable areas were widely distributed across central and parts of northern and eastern Uganda, while unsuitable areas appeared scattered, mainly in drier lowland zones and heavily modified landscapes.

Figure 10: Land Suitability Map for *Maesa lanceolata*

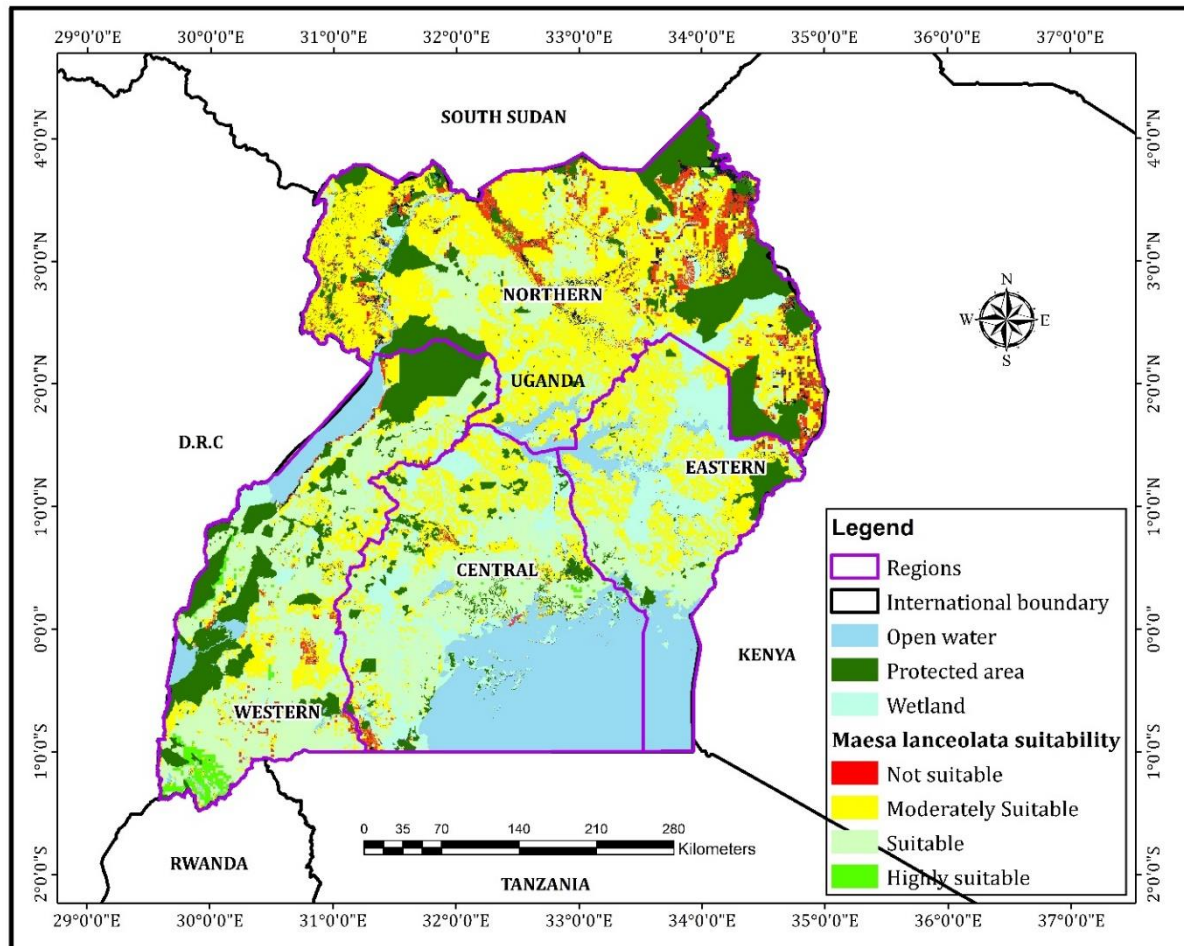
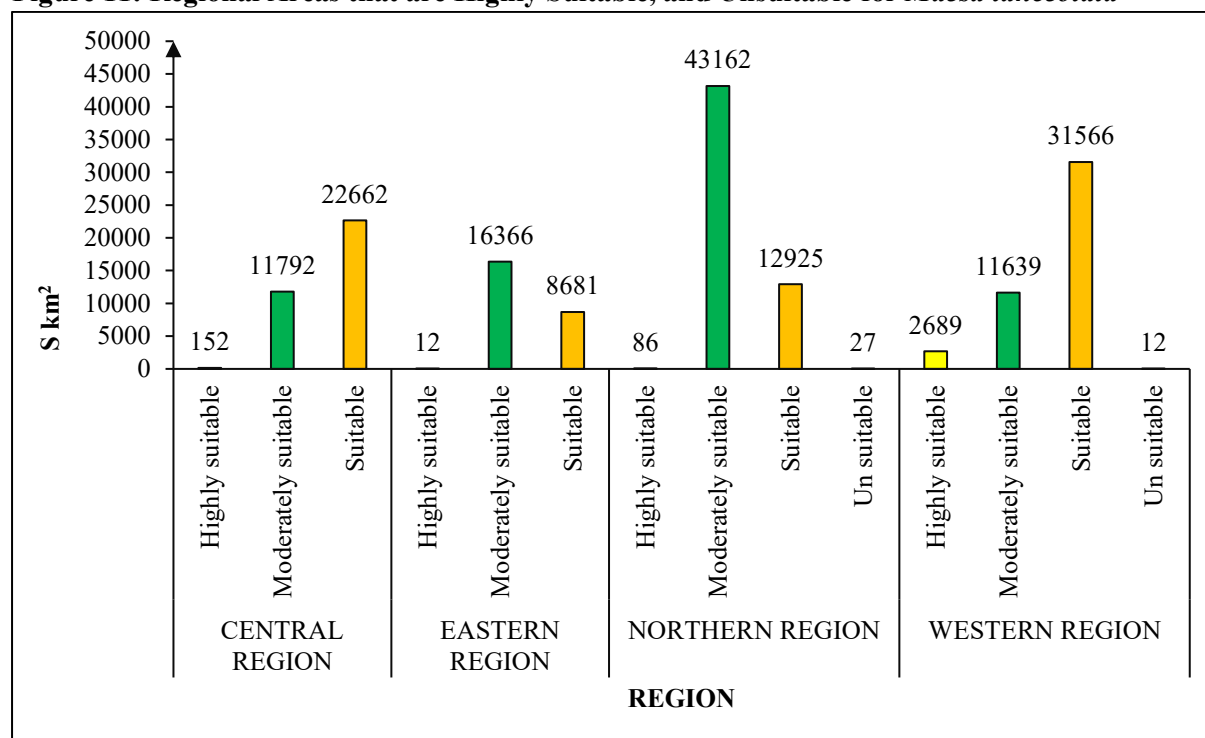


Figure 11: Regional Areas that are Highly Suitable, and Unsuitable for *Maesa lanceolata*

Regional areas were categorised as highly suitable, moderately suitable, suitable, and unsuitable for *Maesa lanceolata* across four regions (Figure 11).

In the Central Region, the highly suitable area was 152 km², the moderately suitable area was 11,792 km², and the suitable area was 22,662 km². In the Eastern Region, the highly suitable area measured 12 km², the moderately suitable area was 16,366 km², and the suitable area was 8,681 km².

In the Northern Region, the highly suitable area was 86 km², the moderately suitable area was 43,162 km², and the suitable area was 12,925 km². In the Western Region, the highly suitable area was 27 km², the moderately suitable area was 11,639 km², the suitable area was 31,566 km², and the unsuitable area was 12 km².

Land Suitability Mapping of *Albizia coriaria*

The land suitability map illustrated the spatial distribution of suitability classes for *Albizia coriaria* across Uganda, with particular emphasis on the Rwenzori Mountains National Park and surrounding regions.

Areas classified as highly suitable and suitable were predominantly concentrated in the western and central parts of Uganda, including sections adjacent to protected areas in the Rwenzori region. Moderately suitable zones were widely distributed across much of the country, forming a transitional band between highly suitable and marginal areas. Marginally suitable areas were extensive, especially in the northern and eastern regions, while unsuitable areas occurred in scattered patches throughout the country.

Wetlands and open water bodies were distinctly mapped and excluded from suitability classifications, and protected areas were prominently highlighted.

Figure 12: Land Suitability Map for *Albizia coriaria*

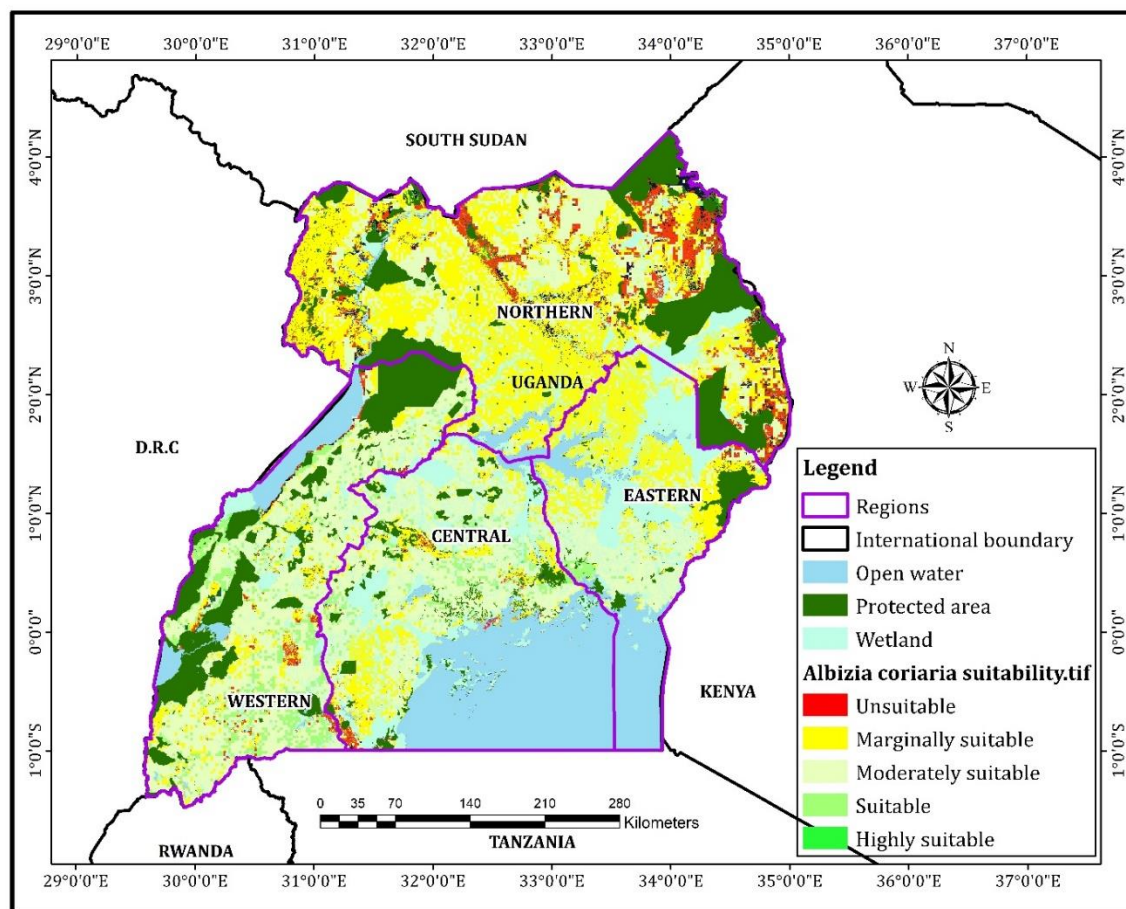
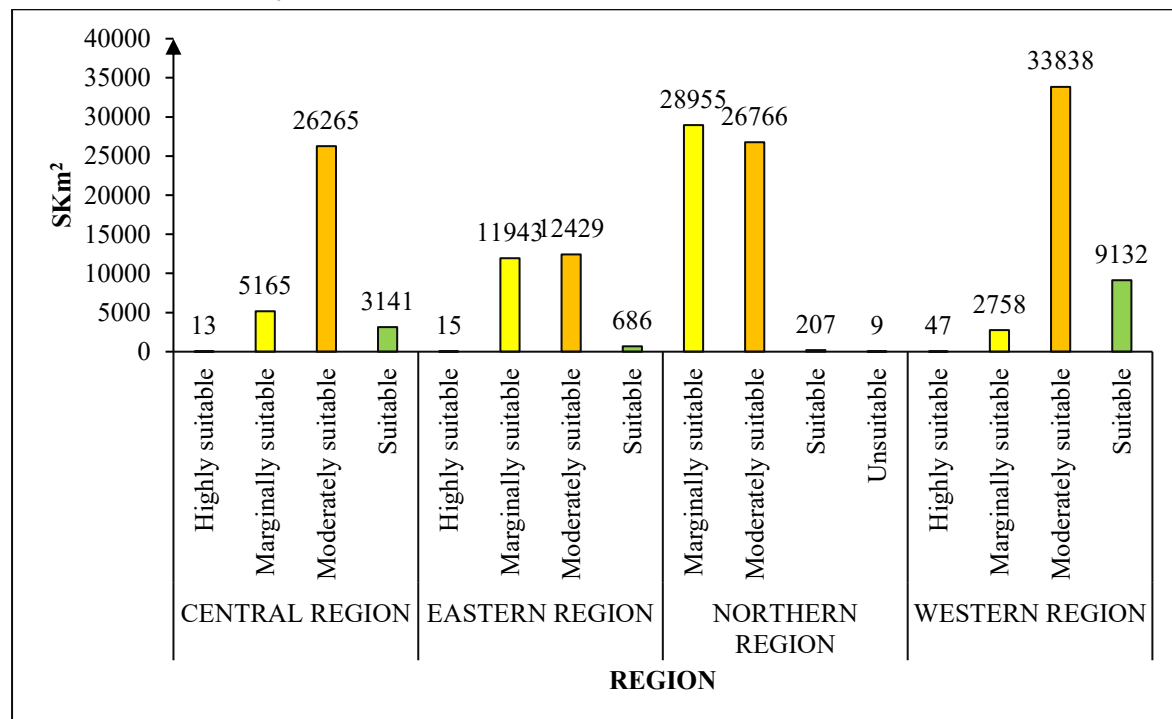


Figure 13: Regional Areas that are Highly Suitable, Marginally Suitable, Moderately Suitable and Suitable for *Albizia coriaria*



The regional areas are categorised as highly suitable, marginally suitable, moderately suitable, and suitable for *Albizia coriaria* across four regions (Figure 13). In the Central Region, the highly suitable area was 13 km², the marginally suitable area was 5,165 km², the moderately suitable area was 26,265 km², and the suitable area was 3,141 km². In the Eastern Region, the highly suitable area measured 15 km², the marginally suitable area was 11,943 km², the moderately suitable area was 12,438 km², and the suitable area was 686 km².

In the Northern Region, the highly suitable area was 207 km², the marginally suitable area was 28,955 km², and the moderately suitable area was 26,766 km². In the Western Region, the highly suitable area was 47 km², the marginally suitable area was 2,758 km², the moderately suitable area was 33,838 km², and the suitable area was 9,132 km².

Land Suitability Mapping of *Arundinaria alpina*

The land suitability map depicted the spatial distribution of suitability classes for *Arundinaria*

alpina across Uganda, with a focus on the Rwenzori Mountains National Park and its surrounding landscapes. Uganda was subdivided into northern, eastern, central, and western regions.

Areas classified as highly suitable were mainly concentrated in the western region, particularly within and around protected areas associated with the Rwenzori Mountains. Moderately suitable areas were widely distributed across the western and central regions, forming continuous zones extending into parts of eastern Uganda. Unsuitable areas were extensive and dominated much of the northern and eastern regions, occurring as broad and fragmented patches across the country.

Wetlands and open water bodies were distinctly mapped and excluded from the suitability classes, while protected areas were prominently highlighted. Generally, the map showed marked spatial variation in habitat suitability for *Arundinaria alpina*, with suitability decreasing from the western highland areas toward the northern and eastern lowland regions.

Figure 14: Land Suitability Map for *Arundinaria alpina*

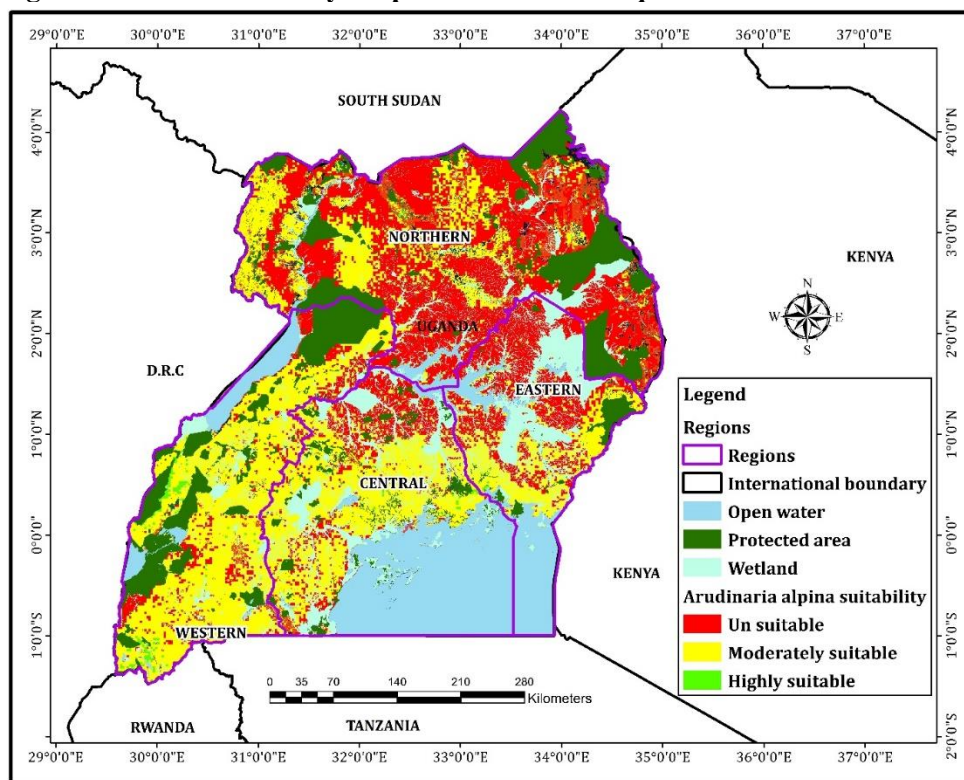
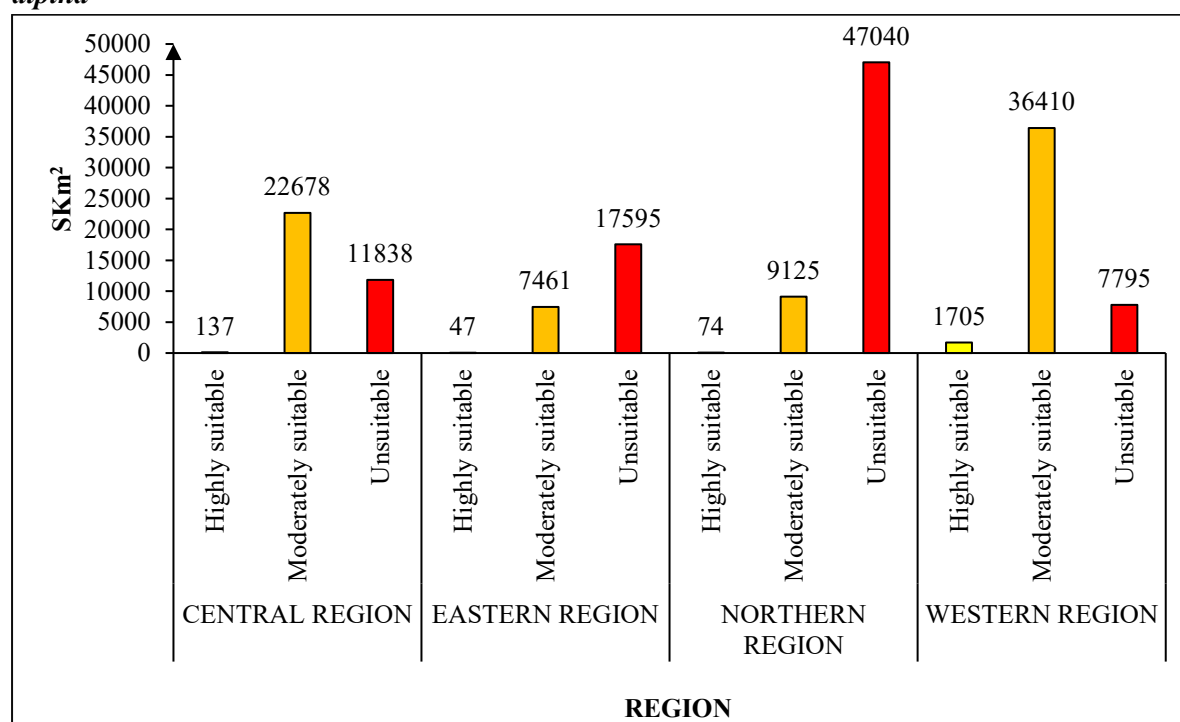


Figure 15: Regional Areas that are Highly Suitable, Suitable, and Unsuitable for *Arundinaria alpina*

The regional areas are categorised as highly suitable, moderately suitable, and unsuitable for *Arundinaria alpina* (Figure 15). In the Central Region, 137 km² were highly suitable, 22,678 km² were moderately suitable, and 11,838 km² were unsuitable. In the Eastern Region, 47 km² were highly suitable, 7,461 km² were moderately suitable, and 17,595 km² were unsuitable. In the Northern Region, 74 km² were highly suitable, 9,125 km² were moderately suitable, and 47,040 km² were unsuitable. In the Western Region, 1,705 km² were highly suitable, 36,410 km² were moderately suitable, and 7,795 km² were unsuitable.

Land Suitability Mapping of *Albizia gummifera*

The land suitability map showed the spatial distribution of suitability classes for *Albizia gummifera* across Uganda, with emphasis on the Rwenzori Mountains National Park and surrounding regions. Uganda was divided into northern, eastern, central, and western regions.

Highly suitable areas were mainly concentrated in the western region, particularly within and adjacent to protected areas associated with the Rwenzori Mountains. Moderately suitable areas were widespread across the western and central regions and extended into parts of eastern Uganda, forming continuous and fragmented zones. Unsuitable areas were extensively distributed across the northern and eastern regions, occurring as dense and scattered patches throughout these areas.

Wetlands and open water bodies were distinctly mapped and excluded from suitability classifications, while protected areas were prominently highlighted. Finally, the map presented clear spatial variation in the suitability of *Albizia gummifera*, with higher suitability concentrated in the western highland areas and lower suitability dominating the northern and eastern regions.

Figure 16: Land Suitability Map for *Albizia gummifera*

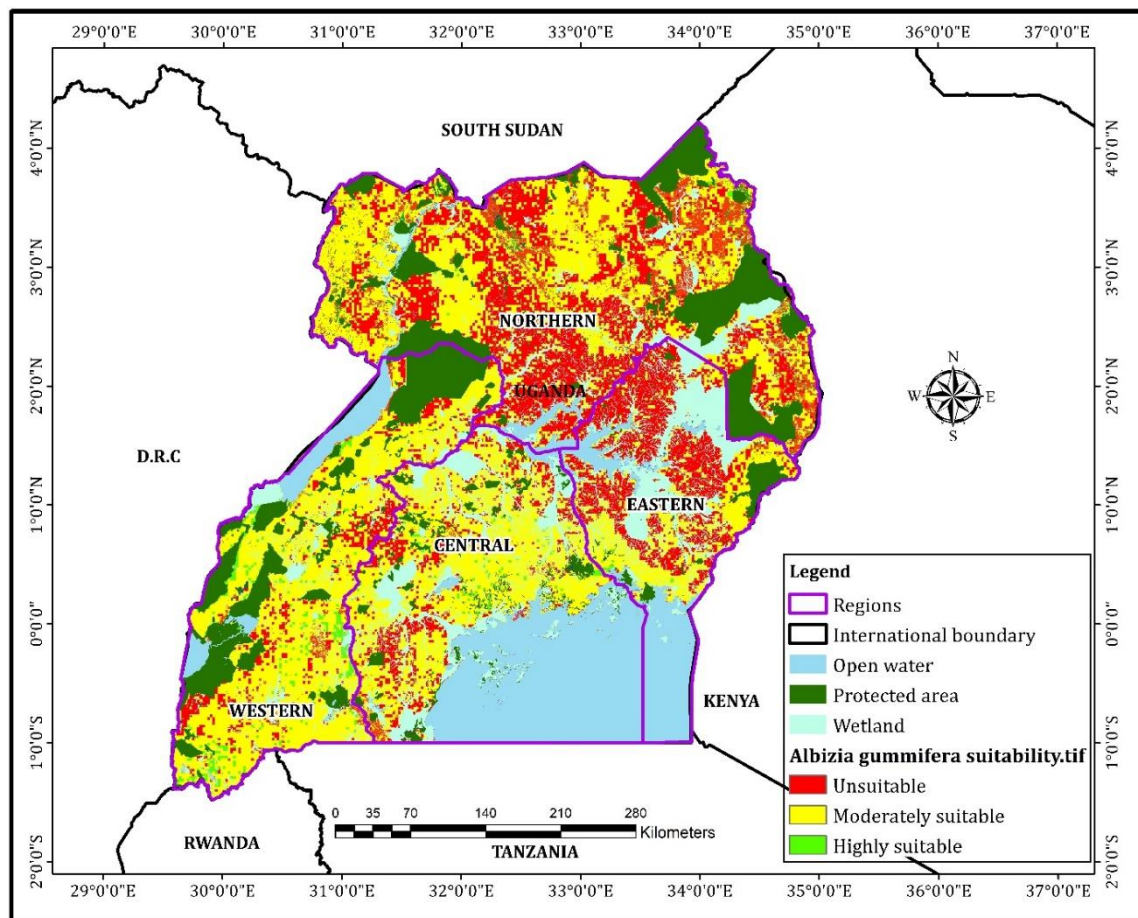
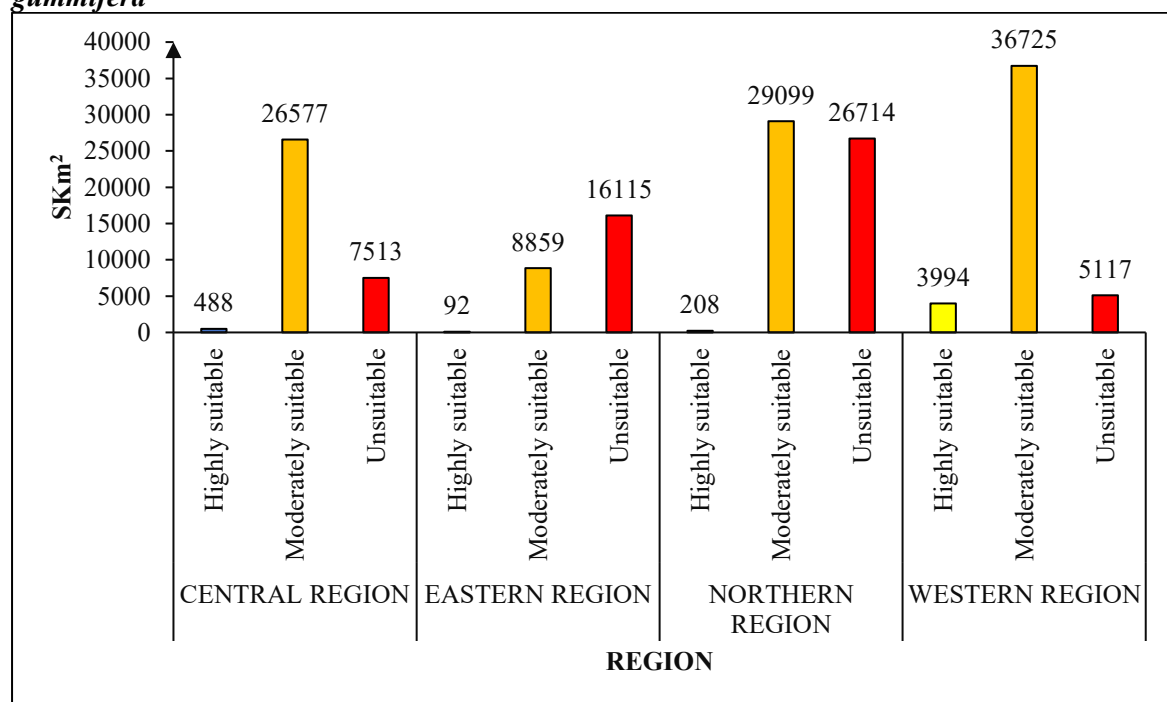


Figure 17: Regional Areas that are Highly Suitable, Suitable, and Unsuitable for *Albizia gummifera*



Regional areas are categorised as highly suitable, moderately suitable, and unsuitable for *Albizia gummifera*. In the Central Region, 488 km² were highly suitable, 26,577 km² were moderately suitable, and 7,513 km² were unsuitable. In the Eastern Region, 92 km² were highly suitable, 8,859 km² were moderately suitable, and 16,115 km² were unsuitable. In the Northern Region, 208 km² were highly suitable, 29,099 km² were moderately suitable, and 26,714 km² were unsuitable. In the Western Region, 3,994 km² were highly suitable, 36,725 km² were moderately suitable, and 5,117 km² were unsuitable.

DISCUSSION

The land suitability maps for *Warburgia ugandensis*, *Prunus africana*, *Maesa lanceolata*, *Albizia coriaria*, *Arundinaria alpina*, and *Albizia gummifera* reveal clear spatial patterns in habitat suitability across Uganda, with a consistent concentration of highly suitable areas in the western and southwestern regions, particularly within and around the Rwenzori Mountains National Park. This pattern highlights the ecological importance of montane and sub-montane forest ecosystems in supporting indigenous tree and bamboo species that are strongly associated with cool, moist, and relatively undisturbed environments.

Western Uganda and the Rwenzori Mountains as Biodiversity Hotspots

Across all modelled species, the western region, especially the Rwenzori Mountains, emerged as a core zone of high suitability. This finding is consistent with the region's complex topography, high rainfall, moderate temperatures, and extensive forest cover, all of which are critical determinants of species distribution in tropical montane systems (Hijmans et al., 2005; Plumptre et al., 2007). The Rwenzori Mountains are recognised as one of Africa's most important centres of plant endemism and diversity, providing a wide range of microclimates and ecological niches over short elevational gradients (Burgess et al., 2007).

For *Warburgia ugandensis* and *Prunus africana*, the concentration of highly suitable areas in montane forest zones reflects their strong dependence on humid, high-altitude environments. Both species are known to be sensitive to temperature increases and prolonged dry conditions, which limit their occurrence in lowland and heavily modified landscapes (Cunningham et al., 2016; Kindt et al., 2011). The suitability patterns, therefore, align well with documented ecological requirements and observed field distributions. The observed spatial pattern for *Warburgia ugandensis* reflected a strong association with ecologically favourable zones, particularly those characterised by higher rainfall, well-drained soils, and relatively intact forest systems. The dominance of optimal conditions in the western landscapes suggested that montane and sub-humid environments provide critical ecological requirements for the species. In contrast, areas with expanding agriculture and increasing human pressure appeared to constrain its optimal distribution, resulting in a shift toward moderately suitable habitats. This pattern underscores the species' sensitivity to land-use change and habitat fragmentation, which have been widely reported as key drivers of its declining populations in East Africa (Omondi et al., 2021; Kigen et al., 2023).

For *Maesa lanceolata*, the distribution pattern suggested ecological flexibility, with the species thriving across a broad range of intermediate environmental conditions rather than being restricted to narrowly defined optimal habitats. This adaptability is often associated with species that tolerate variations in soil moisture, light availability, and disturbance regimes. However, the limited extent of optimal conditions implied that while the species is widespread, its peak performance may be constrained by specific ecological thresholds. Such behavior is consistent with recent findings that classify *Maesa lanceolata* as a generalist species, capable of persisting in disturbed and secondary habitats but still influenced by climatic and edaphic factors (Mwangi et al., 2022; Tadesse et al., 2024).

The suitability trends for *Albizia coriaria* highlighted its broad ecological amplitude but also pointed to prevailing suboptimal conditions across much of the landscape. The prominence of marginal and moderate suitability categories suggested that the species is tolerant of environmental stressors such as seasonal drought and soil variability, yet rarely encounters conditions that maximise its growth potential. This distribution pattern is typical of savanna and woodland species that are adapted to fluctuating environmental conditions but remain vulnerable to intensified land degradation and overexploitation. Recent studies emphasise that although *Albizia coriaria* is resilient, its regeneration and productivity decline significantly under increased anthropogenic pressure (Nabanoga et al., 2021; Mugasha et al., 2023).

The spatial configuration of *Arundinaria alpina* suitability demonstrated a clear dependence on specific ecological niches, particularly high-altitude and high-moisture environments. This specialisation explains its concentration in montane zones and its limited presence in lowland or drier regions. The species' narrow ecological requirements make it highly sensitive to climatic variability, especially changes in temperature and precipitation patterns. As a result, shifts in climate or land cover could significantly alter its distribution. Recent research confirms that montane bamboo ecosystems are among the most climate-sensitive vegetation types, with distribution closely tied to elevation gradients and moisture regimes (Weldegebriel et al., 2022; Mekonnen et al., 2024).

For *Albizia gummifera*, the pattern indicated a relatively wide ecological tolerance, allowing it to occupy diverse environmental conditions ranging from moderately favourable to optimal habitats. This adaptability is often linked to its ability to thrive in both natural forests and disturbed landscapes, making it less restricted compared to more specialised species. Nevertheless, the presence of unsuitable areas suggested that extreme environmental conditions and intensive land-use practices still limit its distribution. The

species' resilience does not entirely shield it from the impacts of deforestation and climate change, which continue to shape its spatial dynamics. This observation is supported by recent studies identifying *Albizia gummifera* as a moderately resilient species with distribution influenced by both climatic gradients and anthropogenic disturbances (Kebede et al., 2022; Okullo et al., 2023).

Species-Specific Suitability Patterns

Although a general west-east and highland–lowland gradient was evident, notable differences occurred among species. *Prunus africana* exhibited a more refined suitability gradient with five classes, indicating a narrower ecological amplitude compared to other species. The dominance of less suitable and unsuitable areas in northern and northeastern Uganda likely reflects warmer temperatures, lower rainfall, and extensive savanna landscapes, which are suboptimal for this montane forest species (Hall et al., 2000).

In contrast, *Maesa lanceolata* showed broader moderate suitability across central and parts of eastern and northern Uganda. This wider distribution may be attributed to the species' ecological flexibility and ability to persist in secondary forests and forest edges, although optimal conditions remain concentrated in moist montane zones (Friis et al., 2010).

Albizia coriaria and *Albizia gummifera* demonstrated relatively wider suitability ranges compared to the strictly montane species. Their moderately suitable and marginally suitable zones extended across much of the country, reflecting their tolerance of a broader range of climatic and edaphic conditions, including disturbed and agroforestry landscapes (Orwa et al., 2009). However, the highest suitability remained associated with western and central Uganda, suggesting that optimal growth conditions still coincide with higher rainfall and relatively intact ecosystems.

Arundinaria alpina displayed the most pronounced restriction to western highland areas,

with suitability declining sharply toward northern and eastern Uganda. This pattern strongly reflects the species' dependence on cool temperatures and high moisture availability, as well as its confinement to montane bamboo zones typically above 2,000 m above sea level (Kigomo, 1988). The extensive unsuitable areas in lowland regions further emphasise the species' vulnerability to climate warming and land-use change.

Influence of Land Use, Wetlands, and Protected Areas

The exclusion of wetlands and open water bodies from suitability classifications improved ecological realism, as these land-cover types do not provide viable habitat for the studied species. The prominent overlap between highly suitable areas and protected areas, particularly within the Rwenzori Mountains National Park, shows the critical role of protected landscapes in conserving suitable habitats for indigenous and economically important plant species (Naughton-Treves et al., 2005).

Conversely, the scattered and fragmented unsuitable areas observed across lowland and heavily modified landscapes likely reflect the combined effects of deforestation, agricultural expansion, and settlement development. Such land-use pressures are well-documented drivers of habitat loss and fragmentation in Uganda, particularly outside protected areas (Mwavu & Witkowski, 2008).

CONCLUSION

This study successfully applied a GIS-based multi-criteria evaluation approach to assess land suitability for selected illegally harvested plant species associated with Rwenzori Mountains National Park (RMNP), namely *Warburgia ugandensis*, *Prunus africana*, *Maesa lanceolata*, *Albizia coriaria*, *Arundinaria alpina*, and *Albizia gummifera*. The findings demonstrate clear spatial variation in habitat suitability across Uganda, with highly suitable areas predominantly concentrated in the western and south-western highland regions, particularly within and around RMNP and other montane ecosystems. These patterns

reflect the strong influence of altitude, climate, soil characteristics, and land use on species distribution and growth potential.

The results confirm that RMNP and its surrounding landscapes provide optimal ecological conditions for most of the studied species, explaining both their natural abundance and the high pressure from illegal harvesting. Importantly, the study identified additional suitable areas outside the park boundaries that could support ex-situ conservation initiatives. This provides a viable pathway for reducing pressure on in-situ populations while sustaining access to important plant resources for local communities.

In general, the study demonstrates that land suitability mapping is a valuable decision-support tool for conservation planning, offering spatially explicit evidence to guide species restoration, ex-situ cultivation, and targeted management interventions. Therefore, integrating ecological data with spatial analysis, the research contributes to sustainable plant resource management and supports broader biodiversity conservation efforts in the Albertine Rift region.

Recommendations

Uganda Wildlife Authority (UWA), in collaboration with the National Forestry Authority (NFA), research institutions, and local governments, should prioritise the establishment of ex-situ conservation sites in areas identified as highly and moderately suitable. Botanical gardens, community nurseries, and enrichment planting schemes should focus on heavily exploited species such as *Prunus africana* and *Warburgia ugandensis*.

The land suitability maps generated by this study should be integrated into RMNP management plans and national conservation strategies. These maps can guide restoration efforts, buffer zone management, and species-specific conservation actions, ensuring that interventions are ecologically appropriate and cost-effective.

Local communities surrounding RMNP should be supported to cultivate suitable species in identified areas outside the park. This can be achieved through the provision of seedlings, technical training, and market linkages, thereby reducing dependence on illegal harvesting while enhancing household incomes.

While ex-situ solutions are promoted, enforcement within RMNP should be strengthened to curb ongoing illegal harvesting. Suitability hotspots identified within the park can be used to prioritise patrols, monitoring, and ecological restoration activities.

Periodic updating of land suitability models is recommended to account for climate change, land use dynamics, and population pressure. Continuous field validation and monitoring will improve model accuracy and ensure adaptive conservation planning.

Future studies should expand the suitability analysis to include additional illegally harvested and threatened plant species. Integrating socio-economic drivers of illegal harvesting with ecological suitability analysis would also enhance understanding and improve intervention design.

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