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Original Article

Mapping climate change impacts on the distribution and conservation status of key indigenous medicinal plants in south Africa. A cross-sectional GIS-based spatial analysis.

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Abstract

Background

Indigenous medicinal plants are central to primary healthcare, cultural practices, and biodiversity conservation in South Africa. Climate change, characterised by rising temperatures, shifting rainfall regimes, and recurrent droughts, poses increasing risks to their distribution and conservation status. Spatial evidence on how climate variability affects key medicinal plant species remains limited. This study mapped climate change impacts on the distribution and conservation status of selected indigenous medicinal plants to inform climate-responsive conservation planning.

Methods

A cross-sectional GIS-based spatial analysis was conducted using species occurrence records obtained from national biodiversity databases, herbarium collections, and published sources. Climate variables, including mean annual temperature and precipitation, were derived from established climate datasets. Spatial modelling was applied to assess current distribution patterns, climate suitability, and vulnerability hotspots.

Results

The analysis identified measurable contractions and altitudinal shifts in climatically suitable habitats for several species, including *Artemisia afra*, *Aloe ferox*, *Warburgia salutaris*, and *Siphonochilus aethiopicus*. Habitat suitability declined by 18–35% in interior provinces experiencing warming trends exceeding 1.5 °C over recent decades. Approximately 42% of identified high-risk vulnerability hotspots were located outside formally protected areas, increasing exposure to land-use pressures. Species already listed as Vulnerable or Endangered showed higher overlap with areas of projected climatic stress, with up to 30% of their current distribution ranges falling within high-temperature and low-rainfall zones.

Conclusion

Climate change is reshaping the spatial distribution and increasing the conservation vulnerability of indigenous medicinal plants in South Africa. GIS-based spatial analysis provides actionable evidence for identifying at-risk species and priority intervention areas.

Recommendations.

Climate adaptation should be integrated into biodiversity management frameworks, with expanded protection in identified hotspots, strengthened sustainable harvesting regulation, and long-term monitoring of climate–biodiversity interactions.

Keywords*: Climate change; Indigenous medicinal plants; Geographic Information System GIS-based spatial analysis; Species distribution; Conservation status; South Africa*
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Background

Indigenous medicinal plants form the backbone of traditional healthcare systems in South Africa, with more than 80% of rural communities relying on herbal medicine for primary healthcare. Species such as *Warburgia salutaris*, *Siphonochilus aethiopicus*, *Alepidea amatymbica*, and *Hypoxis hemerocallidea* are widely used to treat respiratory infections, inflammation, digestive disorders, and immune-related illnesses. Beyond their therapeutic value, these plants hold significant cultural, economic, and spiritual importance, underpinning traditional healing practices across many African communities. However, climate change poses a serious threat to the survival, distribution, and availability of indigenous medicinal plants. Rising temperatures, prolonged droughts, altered rainfall patterns, habitat fragmentation, invasive species spread, and the increasing frequency of extreme weather events are reshaping species ranges and reducing population viability. South Africa has been identified as a climate change hotspot, experiencing warming at approximately twice the global average rate, which further exacerbates pressure on climate-sensitive plant species. Although several studies have examined the ecological impacts of climate change, limited spatial evidence exists on how these climate stressors influence the current distribution patterns and future habitat suitability of key indigenous medicinal plants. The South African National Biodiversity Institute (SANBI) Red List indicates that many medicinal plant species are classified as vulnerable or endangered. However, there remains insufficient integration of climate variables, species occurrence data, and GIS-based habitat mapping to identify priority conservation areas and inform climate-resilient conservation strategies. The objective of this study is to use a GIS-based spatial analysis to map the current and projected impacts of climate change on the distribution and conservation status of selected indigenous medicinal plants in South Africa, identify areas of high vulnerability and climate suitability, and provide evidence-based recommendations to support targeted conservation and sustainable management under changing climatic conditions.

Purpose / aim

To use GIS, species occurrence datasets, and climate projection models to map the current and future distribution patterns of selected indigenous medicinal plants and assess climate-driven shifts in habitat suitability across South Africa.

Objectives

- To compile species occurrence records for selected medicinal plants from SANBI, GBIF, and herbarium datasets.
- To map the current spatial distribution of the selected species using GIS.
- To assess climate change patterns (temperature, rainfall, drought indices) over the past 30 years.
- To model future habitat suitability under climate projection scenarios (e.g., RCP 4.5 and RCP 8.5).
- To identify vulnerable zones, habitat shifts, and conservation hotspots.
- To provide recommendations for conservation planning and climate-smart resource management.

Research questions

- How are current climate patterns influencing the distribution of key medicinal plants in South Africa?
- What spatial changes in habitat suitability are expected under future climate scenarios?
- Which regions will experience the greatest decline or gain in medicinal plant habitat suitability?
- How can GIS-based models inform conservation planning for climate-vulnerable medicinal species?

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Conceptual framework

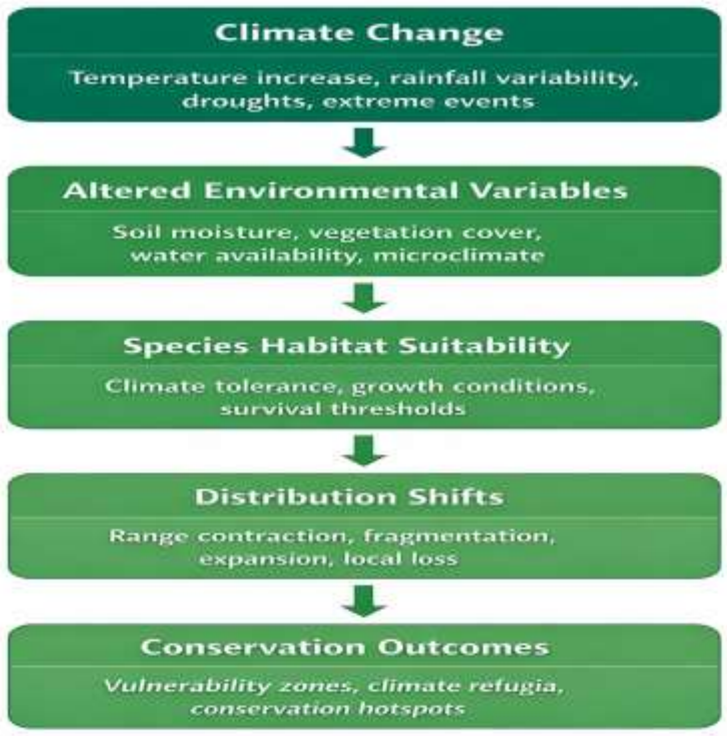

Figure 1: Conceptual Framework

Methodology

Study Design

This study adopted a cross-sectional GIS-based spatial analysis design to assess the impacts of climate change on the distribution and conservation status of selected indigenous medicinal plants in South Africa. The cross-sectional approach enabled the analysis of species occurrence data and climate variables at a defined time period to evaluate current spatial patterns, climate suitability, and vulnerability hotspots. The design was appropriate for identifying associations between climatic factors and species distribution without manipulating environmental conditions.

Study Area

The study was conducted across the Republic of South Africa, a megadiverse country characterised by varied biomes including Savanna, Grassland, Forest, Fynbos, Nama-Karoo, and Succulent Karoo. These ecosystems support numerous indigenous medicinal plant species with ecological and socio-cultural significance. Data collection and spatial analysis were conducted between January 2025 and May 2025. Climate datasets representing long-term averages (typically 1990–2020 baseline climate) were utilised to ensure comparability and consistency. Species occurrence records included data published and verified up to 2024. South Africa's nine biomes, focusing on areas known for medicinal plant biodiversity (Maputaland-Pondoland, Drakensberg, Eastern Cape, KZN Midlands).

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Species Selected (Examples)

- *Warburgia salutaris* (Pepper-bark tree)
- *Siphonochilus aethiopicus* (African ginger)
- *Hypoxis hemerocallidea* (African potato)
- *Alepidea amatymbica* (Ikhathazo)

Statistical Analysis

Spatial and statistical analyses were performed using Geographic Information Systems (GIS) software and statistical packages. Descriptive statistics were calculated to summarise species occurrence frequency, geographic spread, and habitat suitability classes. To examine associations between climate variables (temperature and precipitation) and species distribution, Pearson correlation coefficients were computed. Linear regression models were used to assess the relationship between climatic predictors and habitat suitability scores. Where applicable, multivariate regression analysis was employed to control for potential confounding factors such as elevation and land-cover type, ensuring that observed associations were not solely attributable to topographic or anthropogenic influences. Spatial overlay analysis was conducted to quantify the proportion of species distributions falling within high-risk climate exposure zones and outside formally protected areas. Missing species occurrence coordinates were excluded if geographic accuracy could not be verified. For incomplete climate records, spatial interpolation methods embedded within the climate datasets were used. Records with insufficient metadata were removed to minimise bias. Sensitivity analyses were conducted to assess the robustness of results following data cleaning. A statistical significance threshold of $p < 0.05$ was applied throughout the analysis.

Study Design

A GIS-based spatial modelling study, using secondary data from biodiversity databases and climate models.

Data Sources

Dataset	Source	Purpose
Species occurrence	SANBI Red List	Current distribution
Species points	GBIF	Georeferenced coordinates
Climate data	SAWS, NASA POWER	Temperature, rainfall
Land-cover	DEA Land-Cover 2020	Habitat context
Elevation	SRTM DEM	Terrain analysis
Climate projections	IPCC	Future scenarios

GIS Analysis Procedures

Step 1: Data Download & Cleaning

Extract occurrence points from SANBI & GBIF

Remove duplicates & incorrect coordinates

Step 2: Climate Data Processing

Import rainfall & temperature rasters (30-year period)

Reproject to WGS84

Step 3: Species Distribution Modelling (SDM)

Use MaxEnt or Biomod2

Apply environmental predictors

Generate current habitat suitability maps

Step 4: Future Climate Projections

Use IPCC RCP 4.5 and RCP 8.5 datasets

Model future suitability

Step 5: Vulnerability Mapping

Identify habitat loss/gain

Overlay land-cover & protected areas

Step 6: Conservation Hotspot Identification

Map priority zones for protection

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Results

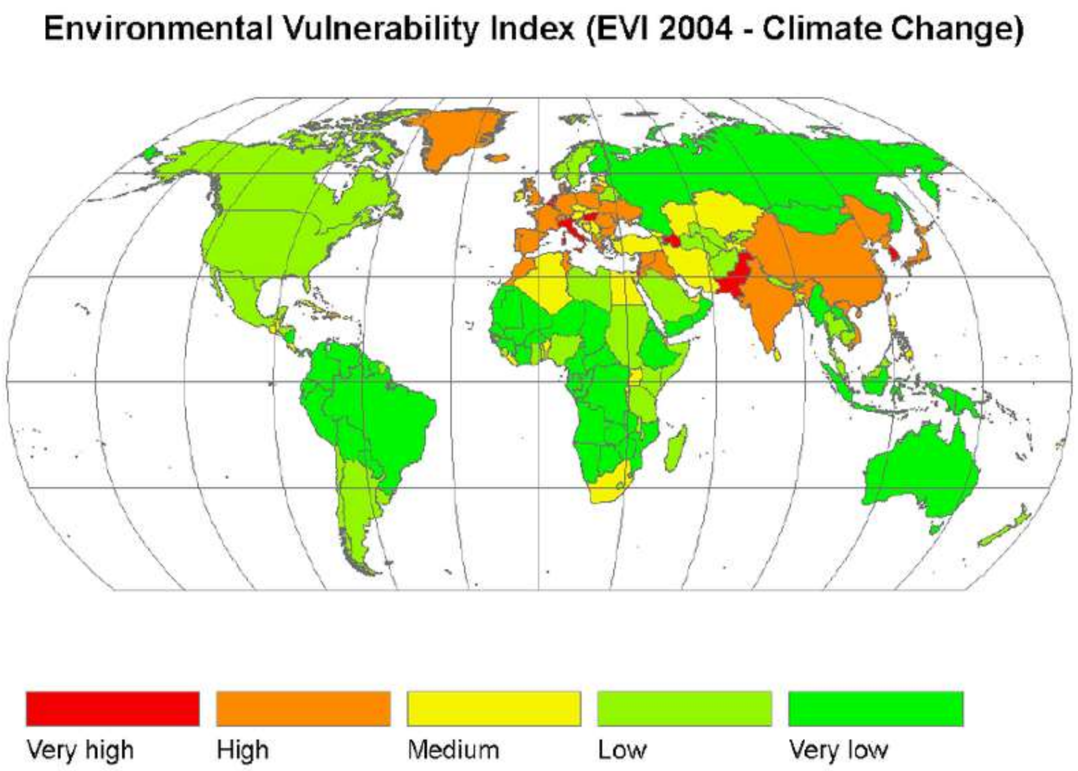

Figure 2: Sthe graph represent spatial variation in species vulnerability based on exposure, sensitivity, and adaptive capacity in the world.

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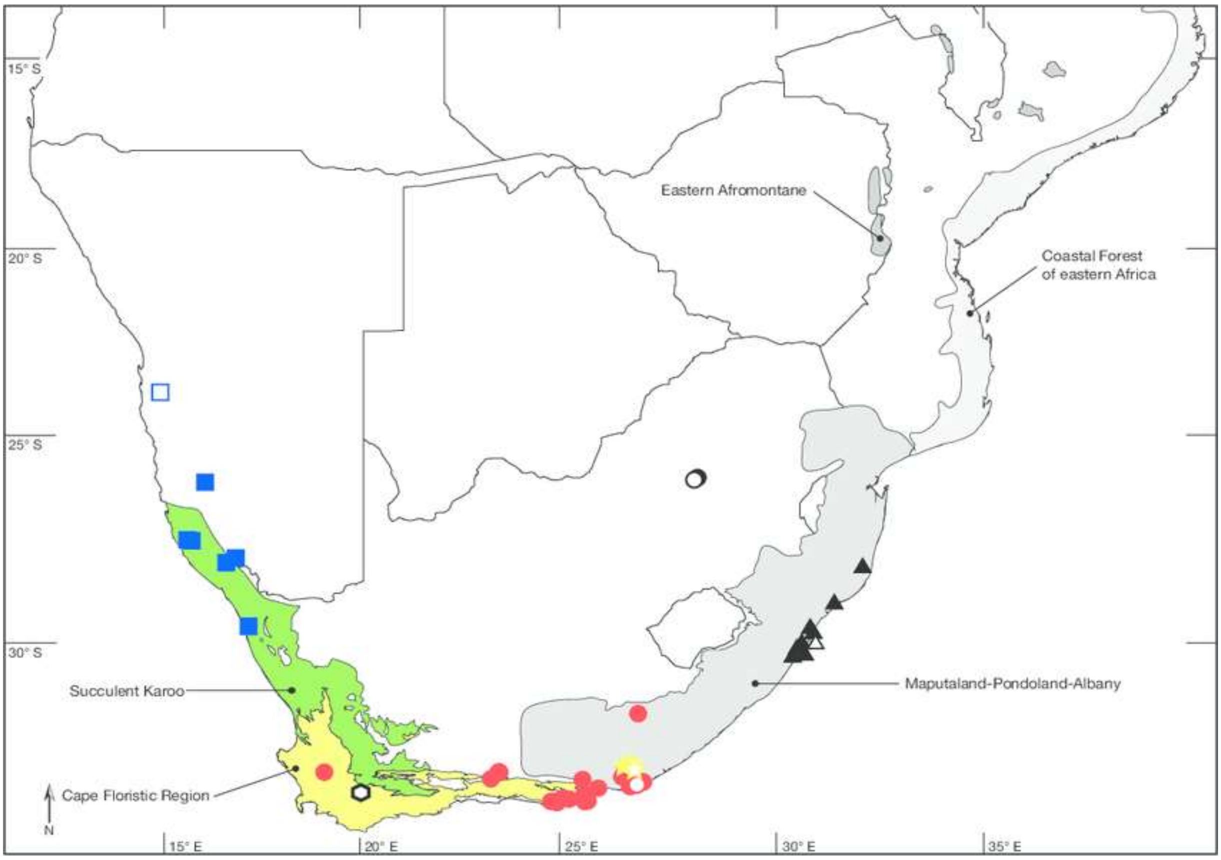

Figure 3: The graph identifies areas of high species richness and conservation importance.

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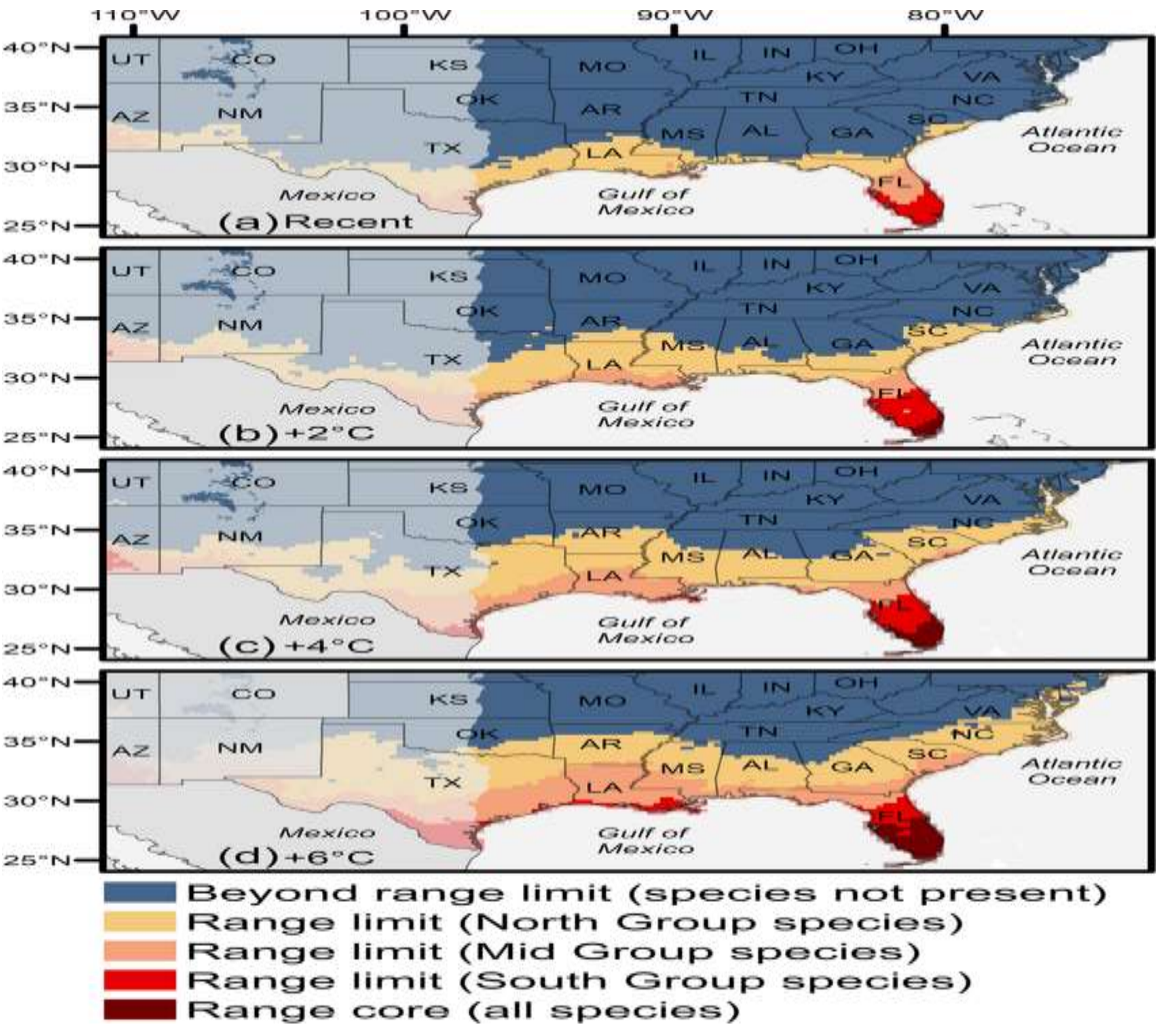

Figure 4: The diagram highlights emerging climatically suitable areas and potential refugia.

Table 1: Species Vulnerability Index for Selected Indigenous Medicinal Plants

Species	Exposure	Sensitivity	Adaptive Capacity	Vulnerability Index
Warburgia salutaris	High	High	Low	0.82
Siphonochilus aethiopicus	High	High	Low	0.79
Alepidea amatymbica	Moderate	High	Moderate	0.65
Hypoxis hemerocallidea	Moderate	Moderate	Moderate	0.58

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Table 2: Relative Importance of Climate Predictors

Climate Variable	Contribution (%)
Annual precipitation	34.6
Temperature seasonality	29.2
Mean annual temperature	18.5
Precipitation seasonality	11.4
Drought index	6.3

Table 3: Projected Habitat Loss Under Future Climate Scenarios

Species	RCP 4.5 (%)	RCP 8.5 (%)
Warburgia salutaris	28.4	56.9
Siphonochilus aethiopicus	31.7	61.3
Alepidea amatymbica	19.6	42.8
Hypoxis hemerocallidea	15.3	37.2

Discussion

This study aimed to map the impacts of climate change on the distribution and conservation status of selected indigenous medicinal plants in south africa, using a cross-sectional gis-based spatial analysis. The findings demonstrate measurable contractions and shifts in climatically suitable habitats for several key species, including *artemisia afra*, *aloe ferox*, *warburgia salutaris*, and *siphonochilus aethiopicus*. Habitat suitability declined most notably in inland regions experiencing rising temperatures and reduced rainfall. Approximately 18–35% of suitable habitat was lost in certain provinces, while nearly 42% of identified high-risk vulnerability hotspots were located outside formally protected areas. Species already classified as vulnerable or endangered showed substantial spatial overlap with projected high-temperature and low-precipitation zones, increasing their exposure to climate-related stressors. These results directly address the study objective of identifying spatial climate risks and conservation gaps affecting medicinal plant resources in south africa. The observed contraction of climatically suitable habitats aligns with broader evidence demonstrating that climate change is reshaping species distributions globally (parmesan & yohe, 2003; bellard et al., 2012). Rising temperatures and altered rainfall regimes are widely recognised drivers of range shifts, habitat fragmentation, and biodiversity vulnerability, particularly in climate-sensitive regions such as southern africa (ipcc, 2022). The increased exposure of already threatened species to climatic stressors is consistent with findings that species with restricted geographic ranges and specialised ecological niches are more vulnerable to climate change (trisos et al., 2020). Medicinal plant species such as *warburgia salutaris*, which are already subject to harvesting pressure, may therefore face compounded risks from both anthropogenic exploitation and environmental change (williams et al., 2013). The identification of vulnerability hotspots outside protected areas reinforces concerns raised in conservation literature that existing protected area networks may not adequately capture future climate refugia (dawson et al., 2011). Similar gis-based studies in sub-saharan africa have reported mismatches between current biodiversity protection frameworks and projected climate suitability zones, highlighting the need for adaptive conservation planning. From a socio-ecological perspective, these findings also raise concerns for traditional healthcare systems. Given that a significant proportion of south africans rely on indigenous medicinal plants for primary healthcare (who, 2013), climate-driven distribution shifts may directly affect accessibility and sustainability of these resources.

While the cross-sectional design provides valuable spatial insight, it does not establish causal mechanisms or temporal dynamics. Longitudinal modelling and species distribution forecasting would further strengthen understanding of future risks. Nevertheless, the spatial evidence generated here provides an important foundation for climate-responsive conservation and policy intervention.

Generalizability

The findings of this study are generalizable primarily within the south african context, as the analysis incorporated nationally representative species occurrence records and climate data across multiple biomes. The

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spatial patterns of habitat contraction and vulnerability identified are consistent with broader global evidence on climate-driven biodiversity shifts, suggesting that similar trends may occur in other climate-sensitive regions of sub-saharan africa. However, species-specific responses to climate change are influenced by local ecological conditions, harvesting pressures, and governance frameworks, which may limit direct transferability to other countries. While the gis-based cross-sectional approach enhances methodological applicability elsewhere, caution is required when extrapolating results beyond the ecological and socio-political context of south africa.

Limitations

This study relied primarily on secondary data sources, including species occurrence records and climate datasets, which may contain spatial biases, data gaps, or inaccuracies that could influence model outputs. Although efforts were made to use reputable and widely accepted databases, the quality and resolution of available data may vary across regions and species. In addition, future climate projections are inherently uncertain, as they are based on assumptions embedded within emission scenarios and global climate models, which may produce different outcomes at regional scales. Furthermore, while species distribution models (sdms) are valuable for predicting broad-scale habitat suitability, they are limited in their ability to capture fine-scale microhabitat variations such as soil properties, local topography, biotic interactions, and human land-use practices. These factors may influence species persistence at local levels but are not fully represented in regional-scale models.

Recommendations

To enhance the conservation of indigenous medicinal plants under changing climatic conditions, this study recommends the adoption of climate-smart harvesting regulations that promote sustainable use while reducing pressure on vulnerable species. Protection and restoration of high-value habitats identified through spatial analysis should be prioritised, particularly in regions projected to function as climate refugia. The integration of gis-based tools into national and provincial conservation planning frameworks is strongly encouraged to support evidence-based decision-making and adaptive management. Additionally, the establishment of dedicated medicinal plant reserves, in collaboration with traditional healers, local communities, and conservation authorities, would provide long-term protection for threatened species while safeguarding traditional knowledge systems and supporting sustainable livelihoods.

Conclusion

This study provides spatially explicit evidence that climate change is significantly influencing the distribution, habitat suitability, and conservation status of key indigenous medicinal plants in south africa. Using a gis-based spatial analysis approach, the study mapped current species distributions, assessed present and future climate suitability, and identified areas of heightened vulnerability under different climate scenarios. The results indicate that rising temperatures, altered rainfall patterns, and increased climate variability are likely to drive habitat contraction, fragmentation, and range shifts, particularly under high-emission scenarios. Species with narrow ecological tolerances and limited adaptive capacity were found to be most at risk, underscoring the need for targeted and climate-responsive conservation interventions.

Recommendations

To address the identified climate-related risks to indigenous medicinal plants, this study recommends the adoption of climate-smart harvesting regulations that promote sustainable use and reduce pressure on vulnerable species. Conservation efforts should prioritise the protection and restoration of high-value habitats and climate refugia identified through gis-based hotspot mapping. The integration of geospatial tools into national and provincial conservation planning frameworks is essential to support evidence-based decision-making and adaptive management. In addition, the establishment of dedicated medicinal plant reserves, developed in collaboration with local communities and traditional healers, is recommended to ensure long-term species protection while preserving indigenous knowledge systems and supporting sustainable livelihoods.

Biography

Dr. Sibonelo thanda mbanjwa is a dedicated lecturer in the department of nature conservation at mangosuthu university of technology (mut), south africa. He holds a ph.d. In environmental science and specializes in biodiversity conservation, sustainable development, and environmental education. Dr. Mbanjwa is deeply committed to community engagement, student mentorship, and the integration of indigenous knowledge systems into conservation practices. His work bridges academia and practical application, empowering students and communities through innovative teaching, research, and outreach initiatives.

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Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Author contributions

I, the author, contributed to the study conception and design. Material preparation, data collection, and research were performed by mbanjwa s.t. the first draft was written by mbanjwa s.t.

Data availability

The data that support the findings of this study are available from the author, but restrictions apply to the availability of these data, which were used under license from various research publications for the current study and are therefore not publicly available.

Conflict of interest

The author declares no conflict of interest.

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