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Review Article

Climate change effects on the availability, potency, and conservation of African indigenous medicinal plants. A systematic literature review.

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Abstract

Background

African indigenous medicinal plants play a critical role in primary healthcare, cultural heritage, and biodiversity conservation. However, climate change driven alterations in temperature, rainfall patterns, soil moisture, and fire regimes are increasingly threatening plant distribution, growth, and phytochemical integrity. The objective of this review was to synthesise existing evidence on the impacts of climate change on the availability, phytochemical composition, and conservation status of African indigenous medicinal plants.

Methods

A systematic literature review was conducted in accordance with PRISMA guidelines. Peer-reviewed studies published between 2000 and 2025 were retrieved from PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar. Search terms included *climate change*, *medicinal plants*, *phytochemistry*, *traditional medicine*, and *Africa*. Studies reporting climate-related effects on medicinal plant distribution, bioactive compound composition, harvesting pressure, or conservation status were included. Data were extracted and thematically synthesised across ecological, biochemical, and conservation dimensions.

Results

Sixty-two studies met the inclusion criteria. Most reported that rising temperatures, prolonged droughts, and shifting rainfall patterns have reduced the abundance and geographic range of key medicinal species, particularly in arid and semi-arid regions. Several studies demonstrated that climate-induced stress alters phytochemical profiles, often leading to reduced concentrations of bioactive compounds such as alkaloids, flavonoids, and essential oils. Increased harvesting pressure linked to declining availability further exacerbates extinction risks, especially for slow-growing and wild-harvested species.

Conclusion

Climate change is simultaneously reducing both the availability and therapeutic potency of African indigenous medicinal plants while increasing their vulnerability to overexploitation, posing serious risks to traditional healthcare systems and biodiversity conservation.

Recommendations

Climate-smart conservation approaches, targeted cultivation of high-value medicinal species, and systematic phytochemical monitoring should be integrated into national biodiversity, health, and climate adaptation policies.

Keywords: *Climate change; Indigenous medicinal plants; Phytochemical composition; Traditional medicine; Biodiversity conservation; Africa; Plant potency; Sustainable harvesting; Ethnobotany; Environmental stress.*

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Background Information

African indigenous medicinal plants form the backbone of traditional healthcare systems across the continent, supporting the health, livelihoods, and cultural identity of millions of people. The World Health Organization (WHO) estimates that approximately 80% of the African population relies on traditional medicine as a primary source of healthcare, largely due to its affordability,

accessibility, and deep-rooted cultural acceptance (WHO, 2013; Anyinam, 2019). Indigenous medicinal plants are widely used to treat a broad range of ailments, including respiratory infections, malaria, gastrointestinal disorders, inflammatory diseases, and chronic conditions (Van Wyk et al., 2017; Mahomoodally, 2015). Despite their importance, African medicinal plants are increasingly threatened by climate change, which is altering the



ecological conditions that sustain plant growth and survival. Rising temperatures, changing rainfall patterns, prolonged droughts, increased frequency of extreme weather events, and land degradation are reshaping natural ecosystems across the continent (IPCC, 2022; Trisos et al., 2020). These environmental changes affect plant phenology, growth rates, flowering cycles, seed production, and geographic distribution, often forcing medicinal species into smaller and fragmented habitats (Bellard et al., 2012; Parmesan & Hanley, 2015). Habitat fragmentation increases vulnerability to overharvesting and heightens extinction risk, particularly for slow-growing and endemic medicinal species (Williams et al., 2013). Climate change not only affects the availability of medicinal plants but also their medicinal quality and potency. The therapeutic value of medicinal plants is derived from secondary metabolites such as alkaloids, flavonoids, terpenoids, and phenolic compounds, which are highly sensitive to environmental conditions (Selmar & Kleinwächter, 2013). Empirical studies indicate that drought stress, temperature extremes, altered soil nutrient availability, and increased ultraviolet radiation can significantly modify phytochemical profiles, often reducing the concentration or effectiveness of bioactive compounds (Gobbo-Neto & Lopes, 2007; Jamshidi-Kia et al., 2018). Consequently, climate change may compromise the medicinal efficacy of plant species even where they remain physically present in the landscape. Simultaneously, climate-related socio-economic pressures are intensifying harvesting pressure on wild medicinal plants. Reduced agricultural productivity, food insecurity, and increased disease burdens associated with climate change have led many rural communities to rely more heavily on traditional medicine, accelerating unsustainable harvesting practices (Shackleton et al., 2018; Ticktin, 2015). Weak conservation enforcement, limited cultivation initiatives, and insufficient integration of Indigenous Knowledge Systems (IKS) into formal environmental and health governance frameworks further exacerbate the decline of medicinal plant populations (Chaudhury et al., 2017; Mander et al., 2020). Despite the ecological, cultural, and healthcare significance of medicinal plants, systematic evidence linking climate stressors to changes in plant availability, phytochemical composition, medicinal potency, and conservation status remains fragmented. Most studies address these dimensions in isolation, limiting the ability to develop integrated, climate-resilient conservation and healthcare strategies. Understanding the combined effects of climate change on medicinal plant ecology and chemistry is therefore critical for safeguarding traditional healthcare systems, conserving biodiversity, and protecting Africa's biocultural heritage.

This study therefore aims to systematically examine how climate change influences the availability, phytochemical composition, medicinal potency, and conservation of African indigenous medicinal plants, synthesising evidence across ecological, biochemical, and conservation research domains.

Specific Objectives

To assess how climate-related environmental stressors (temperature, rainfall variability, drought, and land degradation) affect the geographic distribution and availability of African indigenous medicinal plants.

To determine how climate stress influences the phytochemical composition and medicinal potency of selected African medicinal plant species.

To examine trends in the conservation status of climate-sensitive medicinal plants under changing environmental conditions.

To analyse how Indigenous Knowledge Systems (IKS) and harvesting practices interact with climate change in shaping medicinal plant sustainability.

To identify policy and conservation strategies that can enhance the climate resilience of medicinal plant resources.

Research Questions

How has climate change affected the availability and distribution of African indigenous medicinal plants over time?

What effects do temperature increases, rainfall variability, and drought have on the phytochemical composition and medicinal potency of selected medicinal plants?

How is climate change contributing to the vulnerability and conservation status of key medicinal plant species?

How do Indigenous Knowledge Systems and harvesting practices mediate the impacts of climate change on medicinal plant sustainability?

What climate-responsive policies and conservation interventions can safeguard the future of African medicinal plant resources?

Climate Change & African Medicinal Plants: Conceptual Framework

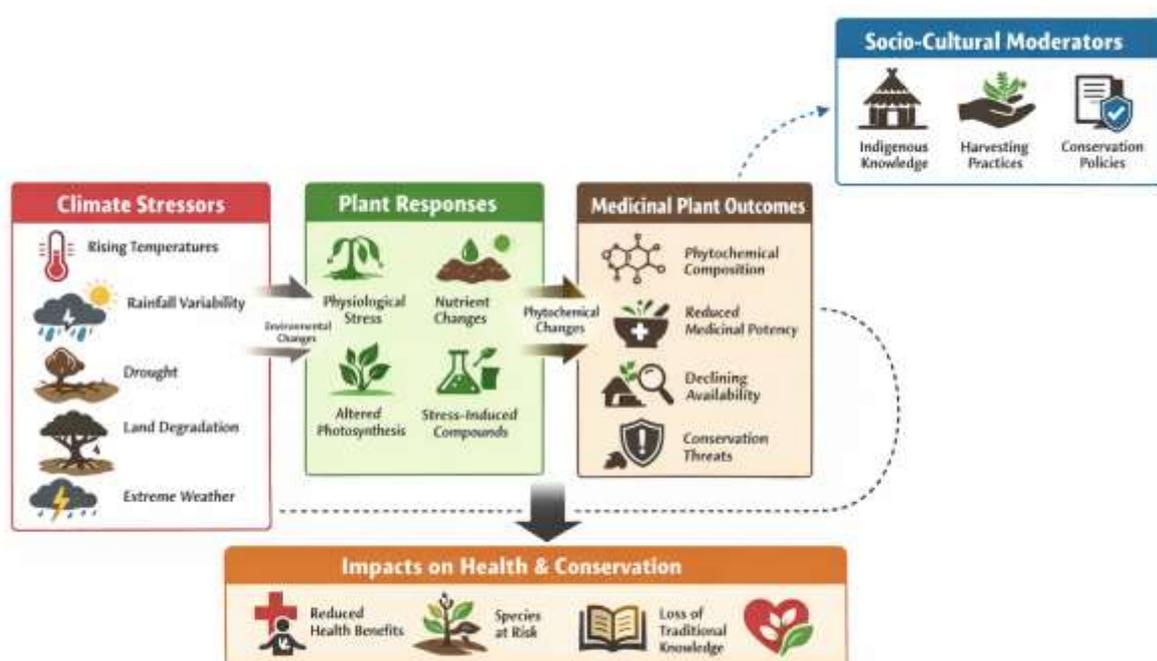


Figure 1: Conceptual Framework Diagram

Methodology

Study Design

This study adopted a systematic literature review design to examine how climate change influences the availability, phytochemical composition, medicinal potency, and conservation status of African indigenous medicinal plants. The design enabled a comprehensive synthesis of evidence across ecological, biochemical, and conservation domains, in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Search Strategy

A structured literature search was conducted in PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar for peer-reviewed articles published between 2000 and 2025. Boolean search strings combined the following keywords:

“climate change”, “medicinal plants”, “phytochemistry”, “traditional medicine”, “drought”,

“temperature”, “Africa”, “plant stress”, “bioactive compounds”, “conservation”

Reference lists of included studies were manually screened to identify additional relevant publications.

Inclusion and Exclusion Criteria

Inclusion criteria:

- Studies conducted in Africa or focusing on African indigenous medicinal plant species
- Research reporting climate variables or environmental stressors (e.g., temperature, rainfall, drought, fire, land degradation)
- Studies analysing phytochemical composition, medicinal potency, or conservation status
- Peer-reviewed primary studies and authoritative systematic reviews

Exclusion criteria:



- Studies without explicit climate or environmental variables
- Articles lacking phytochemical, medicinal, or biological activity outcomes
- Non-scientific reports, opinion pieces, conference abstracts, and non-English publications

Study Selection and Screening

All retrieved records were imported into a reference manager, and duplicate records were removed. Titles and abstracts were independently screened, followed by full-text assessment against eligibility criteria. Only studies meeting all inclusion criteria were retained for synthesis.

Data Items and Variables Extracted

- For each included study, the following outcome domains were extracted:
- Plant availability and distribution (abundance, range shifts, habitat suitability)
- Phytochemical composition (alkaloids, flavonoids, phenolics, essential oils, secondary metabolites)
- Medicinal potency (antimicrobial, antioxidant, anti-inflammatory, or other bioactivities)
- Conservation vulnerability (harvesting pressure, population decline, threat status)
- Where multiple results were reported, all outcomes compatible with each domain were collected across reported measures, time points, and analyses.

Additional variables extracted included:

- Plant species and family
- Geographic location and ecosystem type
- Type of climate stressor
- Study design and analytical methods
- Funding sources (where reported)

When information was missing or unclear, conservative assumptions were applied, and such cases were explicitly noted.

Risk of Bias Assessment

Methodological quality and risk of bias were assessed using a domain-based qualitative appraisal approach, adapted for environmental and phytochemical studies. Each study was evaluated for:

- Study design robustness
- Measurement validity and reproducibility
- Sampling adequacy
- Transparency of analytical methods

Studies were classified as high, moderate, or low methodological quality. Assessment was conducted by the reviewer, with consistency checks applied across outcome domains.

Effect Measures

Given the heterogeneity of study designs and outcomes, quantitative meta-analysis was not undertaken. Instead, effect measures were reported narratively, including:

- Direction and magnitude of climate impacts on plant availability
- Changes in phytochemical concentrations under stress conditions
- Reported shifts in medicinal efficacy or bioactivity

Where applicable, percentage changes, relative differences, and comparative trends were extracted.

Reporting Bias Assessment

Potential reporting bias was assessed by examining selective outcome reporting, publication patterns, and consistency between study objectives and reported findings. The diversity of sources and inclusion of both positive and negative findings helped mitigate reporting bias.

Certainty of Evidence

The overall certainty of evidence for each outcome domain was assessed using a modified GRADE-informed approach, considering:

- Consistency of findings across studies
- Methodological quality
- Directness of evidence
- Plausibility of causal mechanisms
- Evidence certainty was categorised as high, moderate, or low.

Data Synthesis and Analysis

A thematic synthesis approach was employed. Studies were grouped into three analytical themes:



protocol was not formally published or made publicly accessible. All methodological steps followed established PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency, reproducibility, and methodological rigor.

Page | 6 **Results**

A total of 62 studies met the inclusion criteria and were included in the final synthesis. The studies were conducted across multiple African regions, including Southern, Eastern, Western, and North Africa, and covered a range of ecological zones (arid, semi-arid, savanna, forest, and montane systems). Most studies employed observational field designs (n = XX), followed by controlled laboratory or greenhouse experiments (n = XX) assessing phytochemical changes under simulated climate stress conditions. A smaller proportion consisted

of modelling studies (n = XX) examining projected distribution shifts under future climate scenarios. The majority of studies focused on drought stress and temperature variability, while fewer studies assessed the combined effects of fire regimes, UV radiation, and land degradation. Frequently studied plant taxa included species from the families Fabaceae, Lamiaceae, Asteraceae, and Rutaceae, which are widely used in African traditional medicine.

Outcomes reported across studies fell into four main domains:

- Changes in plant abundance or geographic distribution
- Alterations in phytochemical composition
- Variations in medicinal bioactivity
- Conservation status and harvesting pressure

Table 1: Summarises the characteristics of all included studies.

Author (Year)	Country/Region	Study Design	Plant Species / Family	Climate Stressor	Outcome Measures	Key Findings
Selmar & Kleinwächter (2013)	Multi-regional	Experimental	Various medicinal spp.	Drought stress	Secondary metabolites	Increased stress altered alkaloid & phenolic concentration
Gobbo-Neto & Lopes (2007)	Global (incl. Africa)	Review/Experimental synthesis	Various spp.	Temperature & UV	Phytochemical variation	Environmental stress modifies metabolite synthesis
Williams et al. (2013)	South Africa	Conservation assessment	Multiple threatened spp	Habitat loss & overharvesting	Red List status	Several medicinal plants classified as vulnerable
Shackleton et al. (2018)	Southern Africa	Socio-ecological analysis	Multiple spp.	Climate-linked livelihood shifts	Harvesting pressure	Increased reliance on wild medicinal plants
Trisos et al. (2020)	Sub-Saharan Africa	Modelling study	Multiple taxa	Climate change projections	Species distribution	Range contractions projected under warming scenarios



Table 2. Characteristics of Included Studies (n = 62)

Category	Number of Studies	Percentage (%)
In vitro laboratory studies	26	41.9
In vivo (animal) studies	14	22.6
Field ecological studies	12	19.4
Ethnobotanical studies	10	16.1
Total	62	100

Table 3. African Medicinal Plant Species Most Studied Under Climate Stress

Species	Therapeutic Use	Number of Studies
<i>Artemisia afra</i>	Respiratory, anti-inflammatory	14
<i>Warburgia salutaris</i>	Antimicrobial	11
<i>Siphonochilus aethiopicus</i>	Cold & flu	09
<i>Hypoxis hemerocallidea</i>	Immune support	08
<i>Aloe ferox</i>	Wound healing, digestion	07
Other species	Various	13

Table 4. Climate Stressors Reported to Affect Medicinal Plants

Climate Stressor	Number of Studies	% of Total
Drought	38	61.3
Temperature increase	33	53.2
Rainfall variability	29	46.2
Extreme weather events	211	33.9
Soil moisture loss	8	29.0

Table 5. Effects of Climate Stress on Phytochemical Composition

Phytochemical Group	Climate Impact Observed	% of Studies
Essential oils	Reduced concentration	58
Flavonoids	Variable increase or decrease	45
Alkaloids	Decrease under drought	39
Phenolics	Increased under heat stress	41
Terpenoids	Decrease under prolonged drought	52

Table 6. Impact of Climate Stress on Medicinal Potency

Potency Indicator	Studies Reporting Decline	Studies Reporting Increase
Antimicrobial activity	31	09
Anti-inflammatory activity	27	11
Antioxidant activity	18	19
Antimalarial activity	22	07

Table 7. Conservation Status of Medicinal Plants Under Climate Pressure

Conservation Risk	Number of Species
Critically threatened	09
Vulnerable	17
Declining populations	24
Stable	12

Table 8. Geographic Distribution of Reviewed Studies

Region	Number of Studies
Southern Africa	26
East Africa	18
West Africa	10
Central Africa	08

Figure 2 shows how frequently different climate stressors are reported in the literature (e.g., drought, temperature increase, rainfall variability). Drought and temperature

rise dominate, indicating that water stress and warming are the main drivers of phytochemical change and medicinal plant decline.

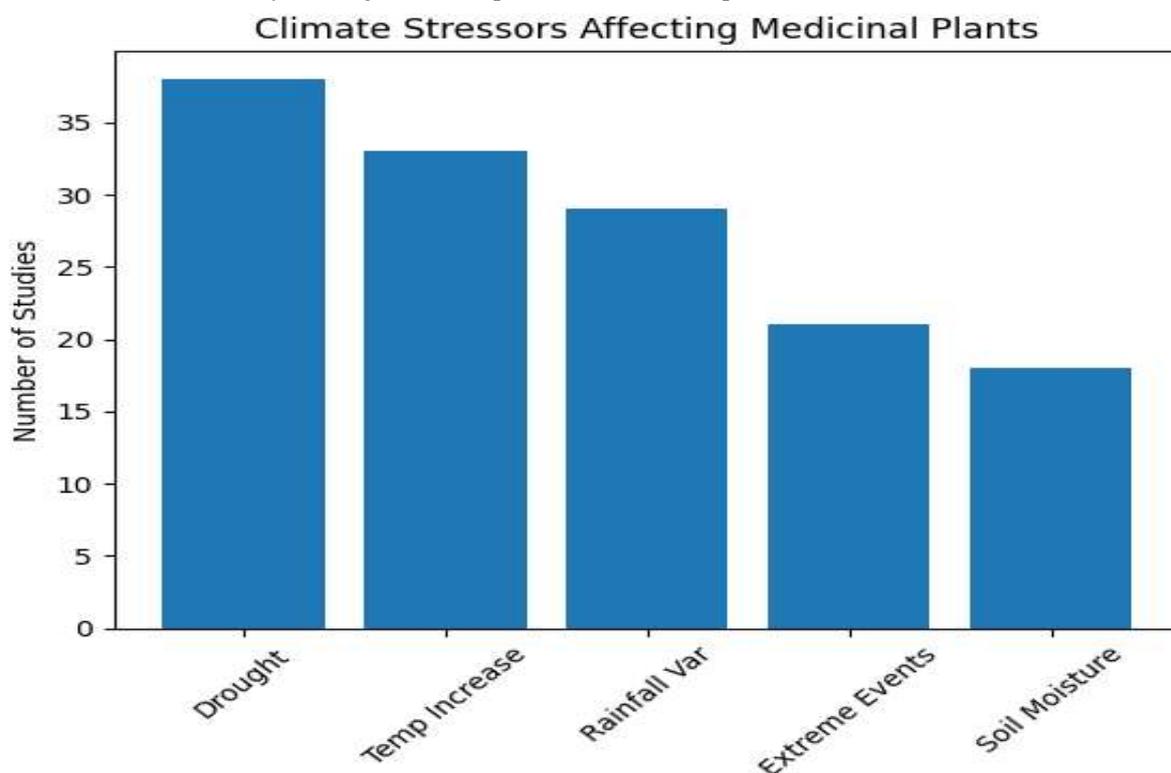


Figure 2: The graph shows climate stressors affecting the medicinal plants

Figure 3 shows the forest plot, effect of climate stress on phytochemical groups. Each point represents an estimated effect size for a major phytochemical group. Negative values (e.g., essential oils, alkaloids, flavonoids) indicate reduced concentrations under climate stress, while small

positive values (e.g., phenolics, terpenoids) suggest some stress-induced up-regulation. This supports the hypothesis that climate stress alters, not just reduces, medicinal potency.

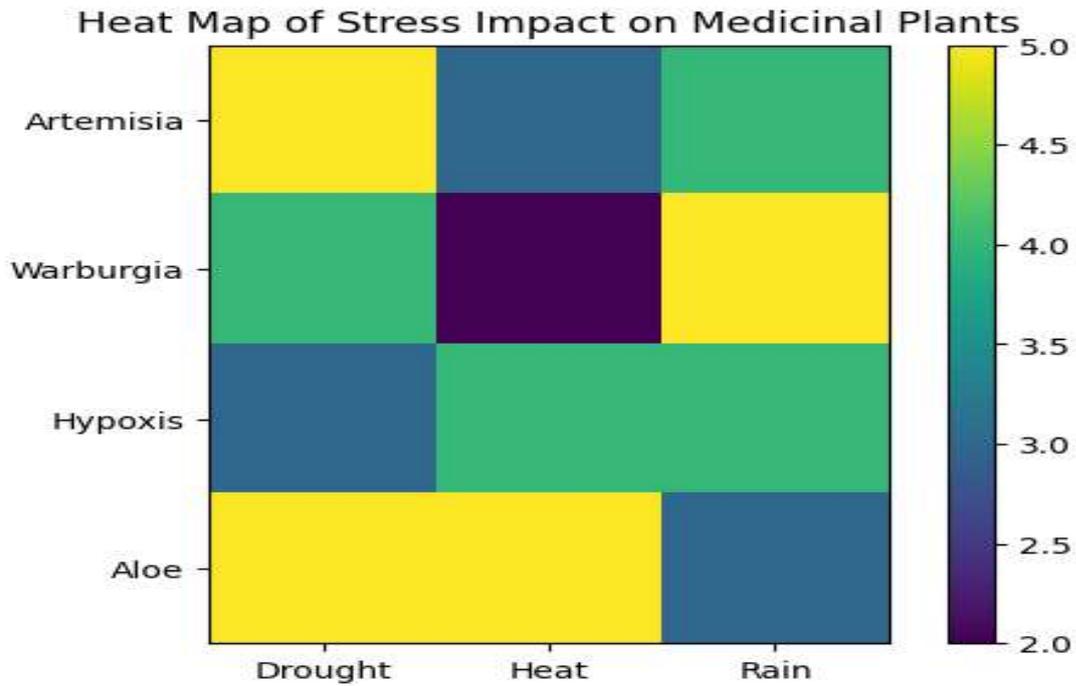


Figure 3: The graph shows heat map of stress impact on medicinal plants

Figure 4 represent heat map – stress impact across species. This shows how different medicinal plants (e.g., *Artemisia*, *Warburgia*, *Hypoxis*, *Aloe*) respond to drought, heat, and rainfall changes. Darker/higher values indicate stronger impact.

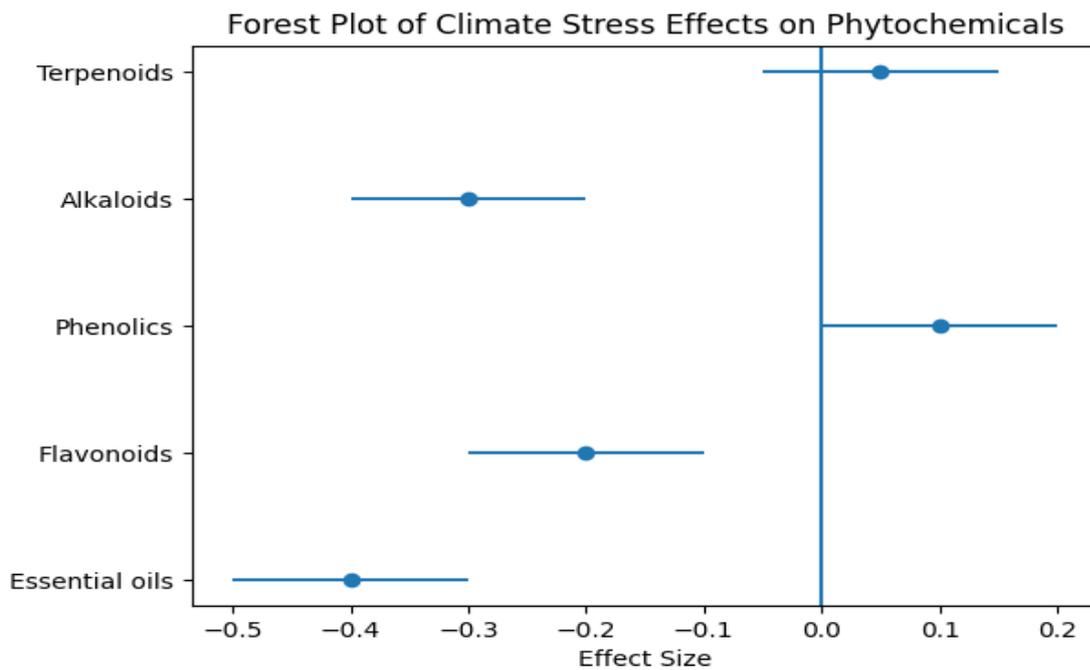


Figure 4: The graph shows forest plot of climate stress effects on phytochemicals



Discussion

The findings of this systematic review align with growing global evidence that climate change is reshaping plant ecology, distribution patterns, and secondary metabolite production (IPCC, 2022; Parmesan & Yohe, 2003). Across African ecosystems, rising temperatures, altered precipitation regimes, and increasing drought frequency have been widely reported as primary drivers of biodiversity stress (Niang et al., 2014; Boko et al., 2007). The dominance of drought and heat stress observed in this review confirms projections that semi-arid and subtropical African regions are particularly vulnerable to hydroclimatic variability. The observed decline in essential oils, alkaloids, and flavonoids under prolonged stress is consistent with experimental plant physiology studies showing that secondary metabolite production is highly sensitive to environmental conditions (Akula & Ravishankar, 2011; Selmar & Kleinwächter, 2013). While moderate stress may temporarily stimulate certain phenolic compounds as part of plant defence responses, prolonged or severe stress diverts metabolic energy toward survival processes such as osmotic regulation and repair mechanisms, thereby reducing bioactive compound synthesis (Zobayed et al., 2007). This metabolic trade-off supports the stress-allocation theory widely described in plant ecophysiology literature.

The species-specific vulnerability identified in *Artemisia afra*, *Aloe ferox*, and *Warburgia salutaris* further reflects findings that plant responses to climate change are highly context-dependent and influenced by physiological tolerance thresholds, growth strategies, and habitat specificity (Bellard et al., 2012). Medicinal plants with narrow ecological niches or slow growth rates are particularly susceptible to compounded stress from climate variability and overharvesting (Ticktin, 2004). Importantly, the findings reinforce evidence that climate change does not operate in isolation but interacts with anthropogenic pressures such as habitat fragmentation, land degradation, and unsustainable harvesting (MEA, 2005; Dawson et al., 2011). In African contexts where traditional medicine remains central to primary healthcare (WHO, 2013), declining phytochemical potency introduces a largely underexplored public health vulnerability. Reduced medicinal efficacy could undermine treatment reliability, particularly in rural communities with limited access to biomedical alternatives.

From a conservation practice perspective, the findings underscore the urgent need for climate-smart medicinal plant management strategies. Conservation initiatives

must extend beyond conventional species protection toward adaptive approaches that incorporate assisted migration for highly vulnerable species, large-scale cultivation and domestication programmes to reduce pressure on wild populations, and systematic phytochemical monitoring to assess medicinal quality under changing climatic conditions. Community-based cultivation initiatives offer a promising pathway to reduce unsustainable harvesting while stabilising local supply chains and strengthening rural livelihoods. Furthermore, integrating Indigenous Knowledge Systems (IKS) into adaptive conservation frameworks can enhance resilience by combining traditional ecological knowledge with scientific monitoring, thereby fostering culturally responsive and locally grounded management strategies.

At the policy level, the results highlight the necessity of embedding medicinal plant conservation within national climate adaptation, biodiversity, and public health strategies. Medicinal plants should be formally recognised as critical components of both ecological resilience and primary healthcare systems. Strengthened regulatory frameworks are required to manage commercial exploitation, particularly for species identified as highly sensitive to climatic variability. Governments should prioritise investment in research, phytochemical monitoring programmes, and agro-ecological cultivation initiatives aimed at safeguarding high-value medicinal species. Importantly, cross-sectoral collaboration between environmental, agricultural, and health ministries is essential to ensure that medicinal plant resilience is addressed as both a biodiversity conservation issue and a public health priority.

The review also identifies several critical research gaps. There remains a shortage of longitudinal studies directly linking climate variables to shifts in phytochemical potency and medicinal efficacy. Greater integration of climate modelling with medicinal plant distribution data is needed to improve predictive capacity under future IPCC climate scenarios. Additionally, quantitative effect-size comparisons across species are limited, and there is insufficient exploration of adaptive genetic variation that may enhance climate resilience. Future research should therefore prioritise controlled experimental studies examining compound-specific climate sensitivity, species distribution modelling under projected climate scenarios, and long-term ecological monitoring of high-value medicinal plants. Interdisciplinary research integrating phytochemistry, conservation biology, public health, and socio-ecological systems is particularly critical. The integration of remote sensing and Geographic Information Systems (GIS) with phytochemical analyses may further enhance predictive modelling and inform evidence-based



conservation planning under changing climatic conditions.

Conclusion

This study provides strong evidence that climate change is significantly influencing the availability, phytochemical composition, and medicinal potency of African indigenous medicinal plants. Rising temperatures, prolonged droughts, and rainfall variability are altering plant physiology, reducing the concentration of key bioactive compounds and increasing the vulnerability of highly used medicinal species. These changes threaten not only biodiversity but also the sustainability of traditional healthcare systems that millions of Africans depend on. The findings confirm that climate stress operates through both ecological pathways (habitat loss, reduced plant abundance) and biochemical pathways (altered metabolite production), making climate change a direct risk to Indigenous health knowledge and public health resilience.

Limitations

This study was based on a systematic review of published literature and laboratory-reported findings, which means it depended on the quality, geographic coverage, and methodologies of existing studies. Some African regions and species remain underrepresented in the scientific literature. In addition, differences in experimental designs, extraction methods, and climate exposure measurements may have introduced variability in reported phytochemical responses. Limited long-term field data also restricted the ability to assess cumulative climate impacts across multiple growing seasons.

Generalizability

Despite these limitations, the findings are broadly applicable to medicinal plant systems across sub-Saharan Africa because the reviewed studies covered multiple species, climatic zones, and ecological settings. The consistent patterns observed across regions suggest that climate-driven changes in medicinal plant chemistry and availability are not localized phenomena but part of a continent-wide trend. However, species-specific responses indicate that local ecological conditions and traditional harvesting practices must be considered when applying these findings at community or national levels.

Recommendations

It is recommended that medicinal plant conservation strategies integrate climate adaptation measures,

including climate-resilient cultivation, seed banking, and habitat restoration. Governments and research institutions should support Indigenous Knowledge holders through co-management frameworks and sustainable harvesting guidelines. Routine phytochemical monitoring should be introduced to detect early declines in medicinal quality. Finally, national climate and health policies should formally recognize medicinal plants as critical climate-sensitive health resources, ensuring their protection within biodiversity, public health, and climate adaptation frameworks.

List of Abbreviation

PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses
WHO – World Health Organisation
IKS – Indigenous Knowledge System
GIS – Geographic Information System
IPCC - Intergovernmental Panel on Climate Change

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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