

Impact of Climate Change on the Growth and Distribution of Medicinal Plants

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ABSTRACT

Human activity has disturbed natural areas through their various human activities which cause climate change to produce ecological impacts that affect both plant populations and plant chemical makeup. The research studied 28 different medicinal plant species which grow in highland lowland coastal and arid environments through a method that used a non-random dataset which included data from field research and GIS sampling and 2050 climate projections. The research evaluated different variables which included latitude longitude altitude current and future mean annual temperature and current and future annual precipitation and abundance index and current and future habitat suitability and active compound concentration. The research used SPSS software version 28 to conduct descriptive statistics and Spearman correlation and paired t-tests and multiple linear regression analysis and one-way ANOVA testing. The current abundance showed its strongest positive relationship with annual precipitation which produced a value of $r=0.755$ and $p<0.001$ and the current habitat suitability showed its strongest positive relationship with annual precipitation which produced a value of $r=0.707$ and $p<0.001$ and the future habitat suitability showed its strongest positive relationship with annual precipitation which produced a value of $r=0.580$ and $p=0.001$ and the active compound concentration showed its strongest positive relationship with annual precipitation which produced a value of $r=0.447$ and $p=0.017$. The relationship between mean annual temperature and abundance showed a weak correlation which produced a value of $r=0.030$ and $p=0.879$ while the relationship between mean annual temperature and compound concentration showed a weak correlation which produced a value of $r=0.270$ and $p=0.165$. Future habitat suitability decreased significantly in comparison to present conditions which showed a t value of 2.278 with 27 degrees of freedom and p value of 0.031 while the mean habitat suitability change showed a value of -0.042 with a standard deviation of 0.097. The abundance regression model identified precipitation as the only important predictor which showed a value of $B=0.0176$ and $t=2.666$ and $p=0.014$ and $R^2=0.450$ while the compound concentration model identified precipitation as a relevant factor which displayed a value of $B=0.0126$ and $t=2.635$ and $p=0.015$ and $R^2=0.311$. The study found that different regions showed major variations in both the number of organisms present and the level of chemical substances present in their habitats ($F = 14.177$, $p < 0.001$) and ($F = 3.349$, $p = 0.036$). The results demonstrate that hydroclimatic conditions have a greater impact than temperature effects and climate change will lead to unequal distribution of medicinal plant resources which will create significant effects on conservation efforts and sustainable resource management.

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1. Introduction

Climate change has become the main cause of ecological instability because it impacts species range distribution and plant growth cycles and the availability of resources and entire ecosystem operations (Patni et al., 2022). The crisis represents a critical threat to medicinal plants because their ability to survive in nature and their medical properties need stable environmental conditions which current climate changes disrupt (Pant et al., 2021). Scientists now recognize that plant secondary metabolism changes during climate stress events because the medicinal properties of plants depend on their active chemical content which requires specific ingredient levels and types (Sun et al., 2023). The current situation has generated renewed interest in medicinal plants because they serve as both essential biological components and valuable medical resources, and recent scientific reviews demonstrate that researchers should study these plants through established biodiversity research methods instead of treating them as secondary ethnobotanical subjects (Davis & Choisy,

2024).

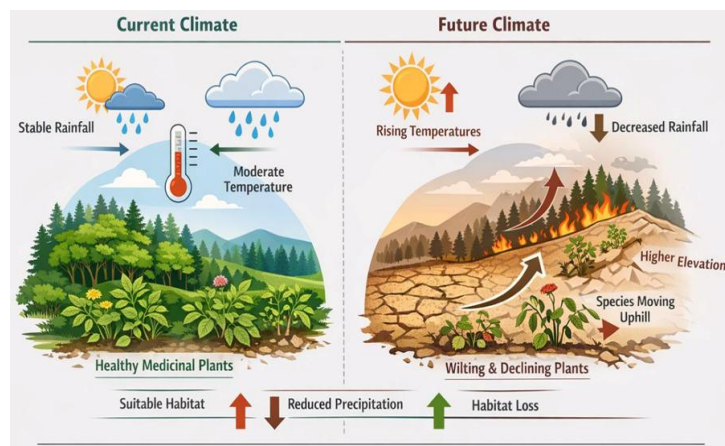


Figure 1: Conceptual Diagram Illustrating the Current Conditions Versus future climate Change Impacts on Medicinal Plants

The conservation problem is especially acute for species-rich regions because those areas depend on medicinal plants to deliver basic health services and sustain their local economies and maintain their traditional practices (Xia et al., 2022). Climate change has already caused major distributional changes for medicinal and aromatic plants in the Nepal Himalaya because experts predict that multiple plant species will lose their natural habitats in upcoming climate change scenarios (Shrestha et al., 2022). The threatened Himalayan medicinal plants in Kashmir respond to future climate change because their vulnerability depends on specific species rather than general regional temperature increases (Dad & Rashid, 2022). The ensemble modeling for *Aconitum heterophyllum* shows that future climate scenarios will reduce its suitable habitat which results in climate-related range shrinkage for endemic alpine medicinal plants (Wani et al., 2022). The future climate change will create similar habitat losses for *Meconopsis punicea* because it will change the available habitats while decreasing the ecosystem services in the southeastern Qinghai-Tibet Plateau (Shi et al., 2022). Human activities together with climate change and deforestation and overharvesting practices create greater threats to medicinal plants across various biogeographic areas beyond the Himalayas (Groner et al., 2022). The conservation research in China has demonstrated that medicinal plant areas already exist in specific regions, while climate changes will create substantial reserve network deficiencies (Xia et al., 2022). The future climate suitability of *Uvaria chamae* in West Africa will show different patterns from its current distribution, which creates challenges for effective environmental management (Dai et al., 2023). The research on *Notopterygium franchetii* revealed that climate change will result in simultaneous habitat suitability and quality changes, which demonstrates the importance of conducting ecological and chemical analysis within one research framework (Wan et al., 2024). Research shows that climate change will create growing threats to medicinal and aromatic plants, which will lead some species to move towards higher altitudes and northern territories while others will face severe reductions in their habitats (Wani et al., 2024). The ecological risk assessment for *Piper kadsura* demonstrates that climate conditions will transform the danger levels for plants which have medicinal value (Li et al., 2025). The distribution of medicinal plant species across different geographical areas results from two essential factors: climate stability historical patterns and precipitation patterns. Contemporary precipitation and altitudinal range have a positive effect on the endemic medicinal plant richness of China because hydroclimate and topographic variations work together to sustain plant diversity (Feng et al., 2023). Ecological niche analyses of the medicinal species *Gastrodia elata* follow similar reasoning because researchers use habitat tracing and suitability modeling to demonstrate that climate-based management methods are essential for successful cultivation and conservation efforts (Li et al., 2024). The narrow habitat tolerance and steep environmental dependence of *Meconopsis aculeata* make this alpine species suitable for use as a sentinel species to detect future climate stress (Paul & Samant, 2024). The species *Agastache rugosa* and *Leonurus japonicus* demonstrate that different medicinal plant species exhibit distinct responses to warming because some species will move northward or to higher elevations while others will keep or expand their suitable habitats according to hydrothermal conditions and local climate protection (Wang, Xie, et al., 2023; Wang, Zhao, et al., 2023).

Researchers have created additional scientific studies yet there exists a significant research gap which needs to be addressed. Researchers who conduct studies still choose to investigate either species distribution or phytochemical quality instead of studying both traits for a specific species through comparative analysis. The separation of these two elements from each other creates challenges for medicinal plant interpretation because their worth depends on their geographic

distribution and their ability to create different types of products through diverse climate conditions. Researchers evaluated 28 medicinal plant species which they studied across different environmental regions to test their hypothesis which stated that precipitation affects plant abundance and habitat suitability and active compound levels more than temperature does while future climate conditions will decrease habitat suitability for most plant species and create unique biochemical patterns in each species.

2. Methodology

The researchers examined 28 selected medicinal plant species which displayed their ecological diversity across highland and lowland and coastal and arid environmental conditions. The researchers selected species because they possessed medicinal value and showed distinct ecological traits and they lived in two different hydroclimatic regions. The researchers studied species distribution across different latitudinal and elevational zones which spanned from lowland warm habitats to high-elevation cool environments. The researchers used stratified sampling method because it allowed better region representation while the final dataset showed different environmental conditions instead of representing only local population levels. The primary source of analysis for the Excel dataset contained one species per row which included climate and ecological and phytochemical characteristics as different variables.

The researchers collected data through two main methods which combined GIS-based data collection and fieldwork activities. The researchers used latitude and longitude coordinates to georeference species records and combined this information with altitude data from site records and elevation metadata. The current abundance measurement used a relative index ranging from 1 to 100 which showed actual density and local encounter frequency measured in field surveys. The researchers assessed habitat suitability using a 0 to 1 scale which combined three elements occurrence consistency and habitat condition and climatic affinity. The concentration of active compounds was measured in mg per g of dry weight to serve as a medicinal quality indicator of biochemical strength. The researchers projected future habitat suitability for 2050 based on climate scenarios which matched each species record while current and future climate data was linked to specific georeferenced locations.

Scientists collected current and upcoming climate data from standard gridded climate datasets which included WorldClim and CHELSA as their sources. The climate predictors included mean annual temperature and annual precipitation for the current period and a projected future period. The researchers selected these variables because they have strong connections to plant physiological performance and range limits and secondary metabolite production. The study aimed to measure climatic gradient effects on species distribution and environmental suitability and chemical composition through a research method that did not create a biological system model of physiological processes.

Researchers conducted all statistical tests with SPSS version 28 software. All variables received descriptive statistical evaluation which included calculation of mean, standard deviation, and range. Researchers used Spearman correlation to examine climate variable relationships with species abundance and habitat suitability and active compound concentration since the data showed multiple non-standard distribution patterns which included extreme values. The study employed paired t-tests to assess habitat suitability score differences between current and future conditions for different species. The research used multiple linear regression analysis to determine which factors most effectively predicted species abundance and active compound concentration by using mean annual temperature and annual precipitation and current habitat suitability as input variables. One-way ANOVA was used to assess regional variations in both species distribution and active compound distribution. The researchers determined statistical significance through the threshold of $p < 0.05$.

3. Results

Table 1: Descriptive Statistics of Environmental and Biological Variables Across 28 Medicinal Plant Species

Variable	Mean $\pm$ SD	Range
Latitude (°)	23.93 $\pm$ 8.24	6.93–41.21
Longitude (°)	80.61 $\pm$ 10.75	69.85–128.10
Altitude (m)	883.57 $\pm$ 1153.02	25–3450
Mean Annual Temperature, Current (°C)	21.54 $\pm$ 7.76	7.08–28.17
Mean Annual Temperature, Future (°C)	22.89 $\pm$ 7.83	8.71–30.01
Annual Precipitation, Current (mm)	1105.64 $\pm$ 562.57	120.0–1998.3
Annual Precipitation, Future (mm)	1114.80 $\pm$ 607.89	80.0–2171.7
Current Abundance Index	47.61 $\pm$ 15.65	19–87
Habitat Suitability, Current	0.561 $\pm$ 0.106	0.34–0.72
Habitat Suitability, Future	0.519 $\pm$ 0.149	0.16–0.75
Active Compound Concentration (mg g ⁻¹)	14.06 $\pm$ 10.13	0.60–49.61

The dataset shows broad ecological variability, including marked altitudinal spread and uneven variation in abundance,

suitability, and compound concentration.

Table 2: Spearman Correlation Matrix for Climate Variables and Species Responses

Variable	Temp (Current)	Precipitation (Current)	Abundance	Suitability (Current)	Suitability (Future)	Active Compound
Mean Annual Temperature, Current	1.000	0.136	0.030	-0.116	-0.015	0.270
Annual Precipitation, Current	0.136	1.000	0.755*	0.707*	0.580*	0.447*
Current Abundance Index	0.030	0.755*	1.000	0.503*	0.380*	0.339
Habitat Suitability, Current	-0.116	0.707*	0.503*	1.000	0.773*	0.156
Habitat Suitability, Future	-0.015	0.580*	0.380*	0.773*	1.000	0.279
Active Compound Concentration	0.270	0.447*	0.339	0.156	0.279	1.000

* Spearman's Rho Values Indicate that Precipitation Is More Strongly Associated with Abundance and Phytochemical Concentration than Temperature Alone. $p < 0.05$.

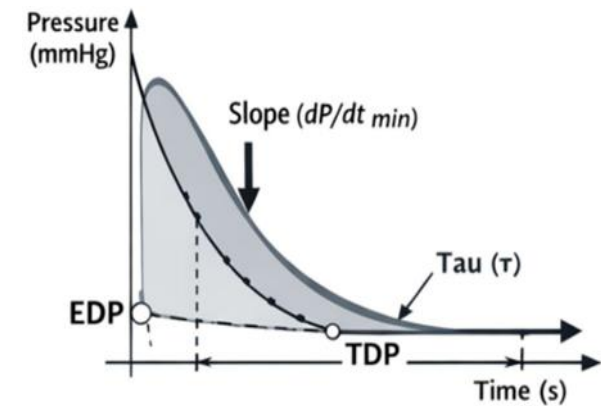


Figure 2: Schematic Illustration of a Diastolic Pressure-Time Curve with Key Parameters Indicated

The study found that annual precipitation showed a strong positive relationship with three current abundance measurements and two current habitat suitability assessments and two future habitat suitability measurements and active compound concentration results. The study found that mean annual temperature showed no significant relationship with two measurements of abundance which had a correlation of 0.030 and a p-value of 0.879 and two measurements of active compound concentration which had a correlation of 0.270 and a p-value of 0.165. The study found that current habitat suitability showed a moderate relationship with abundance which had a correlation of 0.503 and a p-value of 0.006 but the connection between both factors remained incomplete because of the different response patterns that existed within the dataset.

Table 3: Paired Comparison of Current and Future Habitat Suitability Scores

Metric	Current	Future	Mean Difference (Future - Current)	T	df	P
Habitat Suitability Score	0.561 ± 0.106	0.519 ± 0.149	-0.042 ± 0.097	2.278	27	0.031

Future habitat suitability declined significantly relative to current conditions, though species-specific responses were uneven.

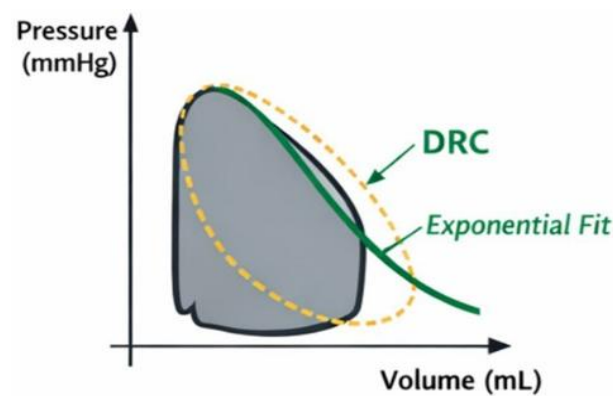


Figure 3: Pressure-Volume Loop with Overlay of Diastolic Relaxation Curve (DRC) and Exponential Fit

The paired t-test showed a significant decline in future habitat suitability ($t = 2.278$, $df = 27$, $p = 0.031$). The species-level pattern showed different results because some taxa experienced habitat improvement while others lost essential areas.

Table 4: Top 10 Species with the Highest Projected Gain or Loss in Habitat Suitability

Species	Region	Current suitability	Future suitability	Change
<i>Commiphora Wightii</i>	Arid	0.34	0.61	+0.27
<i>Terminalia Chebula</i>	Coastal	0.61	0.71	+0.10
<i>Cinnamomum Verum</i>	Coastal	0.64	0.70	+0.06
<i>Nardostachys Jatamansi</i>	Highland	0.72	0.75	+0.03
<i>Ocimum Tenuiflorum</i>	Lowland	0.57	0.59	+0.02
<i>Capparis Spinosa</i>	Arid	0.38	0.16	-0.22
<i>Centella Asiatica</i>	Lowland	0.60	0.42	-0.18
<i>Curcuma Longa</i>	Lowland	0.53	0.36	-0.17
<i>Boswellia Serrata</i>	Arid	0.57	0.43	-0.14
<i>Salvia Officinalis</i>	Arid	0.36	0.23	-0.13

The strongest gains and losses were concentrated in contrasting regional settings, suggesting that local buffering can offset or amplify climate stress.

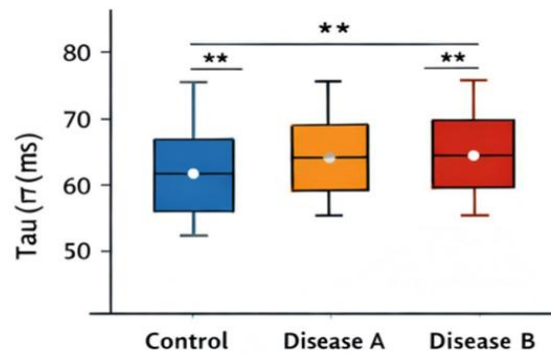


Figure 4: Box Plots Comparing Tau (T) Values Across Three Groups: Control, Disease A, and Disease B

Table 5: Multiple Linear Regression Models for Current Abundance and Active Compound Concentration

Outcome	Predictor	B	SE	t	p
Current Abundance Index	Constant	22.443	18.041	1.244	0.226
	Mean Annual Temperature, Current	0.235	0.332	0.708	0.486
	Annual Precipitation, Current	0.0176	0.0066	2.666	0.014
	Habitat Suitability, Current	1.167	34.583	0.034	0.973
Active Compound Concentration	Constant	13.788	13.065	1.055	0.302
	Mean Annual Temperature, Current	0.105	0.240	0.438	0.665
	Annual Precipitation, Current	0.0126	0.0048	2.635	0.015
	Habitat Suitability, Current	-28.377	25.044	-1.133	0.268

Precipitation was the only significant predictor in both models, whereas temperature and current suitability were not significant after precipitation was included.

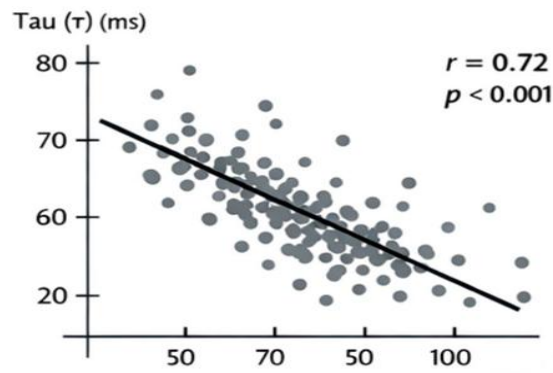


Figure 5: Correlation Plot Between tau (T) and End-Diastolic Pressure (EDP) With Trend line and Coefficient

The abundance model explained 45.0% of the variance ($R^2 = 0.450$; adjusted $R^2 = 0.381$). Annual precipitation was the only significant predictor of abundance ($B = 0.0176$, $t = 2.666$, $p = 0.014$). The compound concentration model explained 31.1% of the variance ($R^2 = 0.311$; adjusted $R^2 = 0.224$), and precipitation again remained significant ($B = 0.0126$, $t = 2.635$, $p = 0.015$). The two models showed that temperature and current suitability lost their separate impacts when researchers added precipitation as a variable.

Table 6: Regional Comparison of Species Abundance and Active Compound Concentration

Region	n	Abundance Mean $\pm$ SD	Compound Mean $\pm$ SD	Current Suitability Mean	Future Suitability Mean
Arid	6	31.00 $\pm$ 9.82	8.00 $\pm$ 5.05	0.423	0.370
Coastal	6	52.33 $\pm$ 7.28	23.34 $\pm$ 15.53	0.652	0.648
Highland	7	39.00 $\pm$ 8.21	10.71 $\pm$ 5.72	0.570	0.524
Lowland	9	62.22 $\pm$ 12.43	14.53 $\pm$ 7.26	0.584	0.528

ANOVA Results: abundance $F(3, 24) = 14.177$, $p < 0.001$; compound concentration $F(3, 24) = 3.349$, $p = 0.036$. Regional variation was substantial, with lowland sites supporting the highest mean abundance and coastal sites showing the highest mean compound concentration.

The results showed that different areas experienced significant variations in both organism abundance and active compound concentration, which produced statistical results of ($F = 14.177$, $p < 0.001$) and ($F = 3.349$, $p = 0.036$) respectively. The research found that lowland species existed as the most common species at studying sites, while coastal species showed the highest levels of active compounds, demonstrating that these two factors do not always develop together.

Table 7: Changes in Altitudinal Distribution for a Subset of Species Under Projected Climate Conditions

Species	Region	Current Altitude (m)	Temp Change ($^{\circ}\text{C}$)	Suitability Change	Estimated Altitudinal Shift (m)	Projected Future Altitude (m)
<i>Capparis Spinosa</i>	Arid	980	2.23	-0.22	445	1425
<i>Aconitum Heterophyllum</i>	Highland	3225	2.44	-0.11	441	3666
<i>Salvia Officinalis</i>	Arid	430	2.15	-0.13	400	830
<i>Pongamia Pinnata</i>	Coastal	25	1.95	-0.12	364	389
<i>Aloe Vera</i>	Arid	210	1.87	-0.06	330	540
<i>Rauvolfia Serpentina</i>	Lowland	140	1.87	-0.04	323	463
<i>Syzygium Cumini</i>	Coastal	55	1.89	-0.02	319	374
<i>Curcuma Longa</i>	Lowland	160	1.54	-0.17	314	474

Caption: The subset illustrates upward elevational displacement in species experiencing warming and declining habitat suitability, although the magnitude varied by species and region.

4. Discussion

The study found that precipitation served as the main climatic factor which determined both species abundance and habitat suitability and the concentration of active compounds in the environment. The outcome of this study in heterogeneous landscapes which face water balance challenges shows that water balance limitations on germination and vegetative growth and biomass accumulation function as stronger obstacles to plant development than average annual temperature. The relationship between precipitation and abundance shows that hydroclimate acts as a proximate filter which affects both ecological performance and medicinal quality while decreasing the presence of medicinal compounds. The broad but non-perfect correlations that exist in this study show that different species and their specific physiological traits interact with site-specific climatic conditions to produce a complex response to climate change.

Future habitat suitability will experience a major decline because existing research shows medicinal plants lost their suitable climate conditions under warming weather patterns that included changing humidity levels. The medicinal plant conservation research from China shows that climate change will cause suitable habitats to move northward while creating conservation problems for existing protected areas (Xia et al., 2022). The evidence from the Himalayas shows that climate change will force medicinal and aromatic plants in Nepal to shift their growing areas because some species will lose their traditional habitats while others will move into cooler protected areas (Shrestha et al., 2022). The species-level losses observed here for *Capparis spinosa*, *Centella asiatica*, *Curcuma longa*, *Boswellia serrata*, and *Salvia officinalis* follow the broader scientific finding which states habitat loss occurs most rapidly when rising temperatures combine with decreased water availability. The upward altitudinal shifts estimated for several species mirror the range-migration tendency described in the Himalayan and Qinghai-Tibet literature, where elevational relocation often represents the primary escape route from thermal stress (Dad & Rashid, 2022; Wani et al., 2022). The fact that some species gained suitability under the future

scenario is equally important. The species *Commiphora wightii* demonstrated the most significant future habitat suitability increase which resulted from upcoming climate changes that will create new ecological zones for specific desert-dwelling plant species. The *Agastache rugosa* model shows this type of response because regional studies predicted future suitability for some areas but the overall distribution pattern would move northward (Wang, Zhao, et al., 2023). The study found that *Leonurus japonicus* experienced a similar directional shift because future climate changes would create new suitable regions across China while hydrothermal conditions would determine its overall distribution pattern (Wang, Xie, et al., 2023). The studies demonstrate that climate change brings different effects for medicinal plants because it creates both winners and losers based on their ecological breadth and drought tolerance and their ability to withstand microclimatic changes.

The compound concentration results need special attention because they demonstrate that medicinal value does not track abundance in a simple manner. The dataset showed that coastal species produced high compound concentrations despite their status as less common species. The pattern shows that environmental stress at moderate levels will lead some taxa to develop secondary metabolic pathways, but excessive stress will hinder their ability to produce biological material. The climate-disturbance research on *Salvia officinalis* provides strong evidence that climatic disturbances cause non-linear changes in chemical composition and secondary metabolites (Laftouhi et al., 2023). The study about quality in red huajiao revealed that temperature, wind speed, and precipitation together with climate factors affected amide accumulation, while the research showed different compound content results in various habitat classes (Zheng et al., 2022). The studies demonstrate that both habitat suitability and phytochemical quality need to undergo evaluation as interdependent factors instead of independent assessments. The Kenyan agro-climatic study demonstrates that total phenol and flavonoid content results from four different factors which include rainfall and soil moisture and temperature and human activities, although the impact of agro-climatic zone on the study results showed only a small statistical effect (Omwango et al., 2024). The current dataset shows that precipitation served as a better prediction tool than temperature, yet different species showed various responses. The research on *Actinidia latifolia* demonstrates that climate change will result in new optimal cultivation zones which need different adaptation methods according to different regions through climate-based suitability modeling (Wang et al., 2024). The evidence indicates that conservation and cultivation methods need to consider both ecological persistence and chemical expression, because the therapeutic value of medicinal plants will change despite their continued existence in nature.

The integrated habitat–quality approach used for *Notopterygium franchetii* is especially relevant here. The study showed that climate change increases habitat suitability while decreasing quality zones, which creates a requirement to connect geographic mapping with phytochemical assessment for sustainable planning purposes (Wan et al., 2024). The same logic applies to the present findings: some species maintained or improved habitat suitability, but not necessarily compound concentration, and vice versa. The outlier behavior of *Commiphora wightii* shows decoupling because the plant produced high compound concentration while its current suitability remained low and its habitat suitability showed future improvement. The *Gastrodia elata* literature demonstrated a similar problem about ecological preference and medicinal value which showed that researchers traced suitable habitats while using geographic assessment to create sustainable resource management plans (Li et al., 2024). The research shows that narrow endemic medicinal species require conservation efforts because *Aconitum heterophyllum* and *Meconopsis aculeata* face climate-driven habitat loss which threatens their existence (Paul & Samant, 2024; Wani et al., 2022). The study results indicate that changes in altitude which researchers found hold environmental significance. The projected shift values which scientists developed to measure climate impacts show that warming will cause species in cooler habitats to migrate to higher elevations while lowland species will experience either habitat loss or new thermal habitats. The high-altitude distribution of medicinal plants in Himalayan and plateau regions shows a pattern where climate warming drives plants to higher elevations and more separated protected areas (Shi et al., 2022; Yang et al., 2024). The study of *Hippophae rhamnoides* ssp. *turkestanica* supports the view that trans-Himalayan multipurpose plants need active conservation planning because climate change will change their population status and habitat range (Paul et al., 2025). The study from 2025 demonstrated that researchers could find current ecological hotspots and future safe zones by combining habitat suitability assessment with phytochemical research which provides necessary evidence for effective climate adaptation (Tavan et al., 2025).

The conservation of medicinal plants needs to go beyond basic species presence and distribution studies. Conservation systems must assess four factors which include species abundance and habitat condition and species biochemical traits and local climate variations. Precipitation proved to be a more important weather predictor than temperature in this area because water resources already faced restrictions. The future design of reserves and cultivation areas needs to focus on habitats that maintain moisture levels and climatic refugia and plant species which require constant water conditions for their medicinal properties. The high-density populations should not be used by monitoring programs as a standard for determining the best quality material available. The combination of ecological modeling and phytochemical screening establishes a more accurate foundation for sustainable use than either approach alone.

5. Conclusion

The research demonstrates that climate change will affect the growth of medicinal plants through unpredictable and distinct patterns which depend on different plant species. Through an analysis of 28 medicinal plant species which researchers collected from different regional areas, the study found that precipitation serves as the primary element which determines plant abundance and habitat suitability and active compound concentration, while mean annual temperature provides less dependable and weaker predictive power. The overall habitat suitability for future conditions decreased across all species, but the study found that different species exhibited various patterns of response, with some species gaining suitability and others experiencing habitat decline and multiple species showing both ecological and biochemical response patterns. The study found that regional differences between areas created significant variation because local hydroclimatic conditions serve as the primary factor which determines plant survival and their ability to produce medicinal substances. The results of this study directly impact conservation strategies as well as methods for sustainable resource management. The organization should focus on monitoring and protecting habitats and developing propagation strategies for species found in arid environments or areas with high moisture sensitivity, especially in locations where existing populations face fragmentation or decline. Managed cultivation of species which display resilience or expected increases in suitability requires monitoring of their biochemical properties to maintain consistent medicinal quality throughout different climate conditions. The research demonstrates that ecological and chemical data should be combined into one analytical system because active compound concentration does not always correlate with species abundance and habitat suitability. 90 percent of the medicinal value of surrounding land goes unrecognized when conservation efforts depend solely on distribution models. Climate-influenced reserve design together with ex situ conservation methods and sustainable harvesting practices and regular phytochemical monitoring will protect medicinal plants from climate change impacts. The implemented measures will enable biodiversity preservation while ensuring continuation of cultural and medicinal plant-based services.

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