



Threatened Medicinal Plants of Kanger Valley National Park: Conservation Status and Bioactive Potential

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Abstract

Kanger Valley National Park (KVNP), Chhattisgarh, is a vital biodiversity hotspot harboring pharmaceutically significant medicinal flora threatened by anthropogenic pressures. This study systematically assessed the conservation status, ethnomedicinal relevance, bioactive constituents, and pharmacological mechanisms of threatened medicinal plant species in KVNP. Following PRISMA 2020 guidelines, scientific literature published between January 2010 and March 2026 was retrieved from electronic databases and authenticated botanical repositories. From an initial pool of 82 recorded medicinal species, a rigorous multi-tiered filtering process yielded 30 priority taxa after systematically excluding 45 non-threatened (LC/NE) species, 4 unverified KVNP records, and 3 species with insufficient documentation. The documented species span 24 botanical families, predominantly represented by herbs and climbers (30.0% each). Under regional conservation frameworks, species are categorized as Critically Endangered (3.3%), Endangered (6.7%), Vulnerable (63.3%), and Near Threatened (26.7%). These taxa produce diverse bioactive secondary metabolites, including alkaloids, terpenoids, flavonoids, phenolics, and saponins, that target crucial molecular pathways such as NF- κ B, 5-LOX, VMAT2, SGLT1/GLUT2, and tubulin heterodimers to exert anti-inflammatory, anticancer, antimicrobial, and antidiabetic effects. Major survival drivers include commercial overharvesting, habitat degradation, forest fires, and grazing. These findings highlight KVNP as a priority conservation landscape requiring integrated in situ protection, sustainable harvesting, and community-led monitoring.

Keywords: Bastar Plateau; Ethnobotany; Non-timber forest products; Phytochemistry; Sustainable harvesting; Traditional ecological knowledge

1. INTRODUCTION

1.1 Medicinal Plants and Their Importance

Medicinal plants have served as one of the earliest and most reliable sources of healthcare for human societies and continue to play a fundamental role in disease prevention and treatment. According to the World Health Organization, nearly 80% of the population in many developing countries relies on traditional plant-based medicine for primary healthcare [1,2]. Beyond their therapeutic value, medicinal plants represent an important source of bioactive secondary metabolites, including alkaloids, flavonoids, terpenoids, glycosides, tannins, phenolics, and saponins, which possess antioxidant, antimicrobial, anti-inflammatory, antidiabetic, hepatoprotective, anticancer, and immunomodulatory properties [3,4].

Numerous modern pharmaceuticals have originated directly or indirectly from plant-derived compounds, emphasizing the continued importance of medicinal flora for drug discovery and pharmaceutical innovation.

Despite their immense value, medicinal plant diversity is declining worldwide because of habitat degradation, climate change, overexploitation, and unsustainable harvesting practices. The global herbal medicine market continues to expand rapidly, increasing commercial demand for wild medicinal plants and placing additional pressure on natural populations. Consequently, conserving medicinal plant diversity has become essential not only for protecting biodiversity but also for ensuring long-term healthcare security, safeguarding traditional knowledge systems, and maintaining future opportunities for pharmaceutical research.

1.2 Medicinal Plant Diversity from India to Kanger Valley

India is recognised as one of the world's twelve megadiverse countries and harbours approximately 7–8% of the world's recorded plant diversity despite occupying only about 2.4% of the Earth's land area [5]. More than 6,000 plant species are reported to possess medicinal properties and contribute significantly to traditional healthcare systems such as Ayurveda, Siddha, Unani, Amchi, and numerous indigenous tribal medicinal practices [6,7]. However, a substantial proportion of these medicinal resources continues to be harvested directly from natural forests to meet the increasing demand of pharmaceutical, herbal, and nutraceutical industries, making forest ecosystems indispensable reservoirs of medicinal biodiversity.

Within India, Chhattisgarh represents one of the country's richest regions for medicinal plant diversity, with over 41% of its geographical area under forest cover (55,812 km², accounting for 41.28% of the state's total area) comprising predominantly tropical moist and tropical dry deciduous forests [11,15]. These forests support numerous endemic, economically important, and conservation-priority medicinal plant species and form a significant component of the Deccan biogeographic zone. However, increasing anthropogenic disturbances, including deforestation, mining, infrastructure development, forest fires, and unsustainable extraction of non-timber forest products, have accelerated habitat degradation across several forest landscapes, threatening native medicinal flora.

Among these landscapes, the Bastar region is widely recognised as a biodiversity hotspot because of its extensive forest cover, diverse habitats, and exceptional medicinal plant wealth. Floristic investigations have documented numerous medicinal species distributed across Abujhmarh, Kanger Ghati, Bailadila, Barsur, Darbha, Sukma, Machkot, and surrounding forest ecosystems [12]. Several threatened medicinal species, including *Rauvolfia serpentina*, *Gloriosa superba*, *Piper longum*, and *Chlorophytum borivillianum*, have been consistently reported from these forests, highlighting their high conservation importance [13].

Kanger Valley National Park represents one of the most ecologically significant protected landscapes within Bastar. Its dense sal forests, mixed deciduous vegetation, limestone formations, perennial streams, caves, and heterogeneous microhabitats provide suitable ecological conditions for a wide diversity of medicinal plant species [15]. The park also supports several rare and threatened medicinal taxa that have declined considerably in other parts of central India because of habitat fragmentation and overexploitation.

The forests of Bastar are closely linked to the cultural practices and lifestyles of indigenous tribal communities, including the Gond, Maria, Muria, Halba, Bhatra, and Dhurwa tribes. These communities possess rich traditional ecological knowledge that has evolved over generations regarding the identification, harvesting, processing, and therapeutic use of medicinal plants [16]. Various plant parts, including roots, rhizomes, bark, leaves, fruits, flowers, and seeds, are extensively used for treating fever, gastrointestinal disorders, respiratory infections, skin diseases, diabetes, inflammation, snakebite, reproductive disorders, and numerous other ailments [17]. Consequently, medicinal plant diversity in Bastar represents not only an important biological resource but also a critical component of indigenous healthcare systems, cultural heritage, and forest-based livelihoods.

1.3 Threats to Medicinal Plant Diversity

Medicinal plant populations are increasingly threatened by both natural and anthropogenic factors. Habitat degradation resulting from deforestation, agricultural expansion, mining, urbanisation, and infrastructure development has reduced suitable habitats for many specialised and endemic medicinal plant species [19]. Simultaneously, the expanding commercial trade in herbal raw materials has intensified harvesting pressure on wild populations, often leading to indiscriminate collection of roots, rhizomes, bark, and whole plants before reproductive maturity [20]. Illegal harvesting and unregulated trade have further accelerated the decline of economically valuable medicinal taxa, particularly *Rauvolfia serpentina*, *Gloriosa superba*, *Piper longum*, and *Chlorophytum borivillianum* [13]. Additional pressures, including forest fires, livestock grazing, invasive species, and climate variability, continue to alter forest structure, species composition, and natural regeneration processes [21]. These interacting threats highlight the urgent need for integrated conservation strategies combining habitat protection, sustainable harvesting, scientific monitoring, and community participation.

1.4 Bioactive Components and Therapeutic Importance

The medicinal properties of plants arise primarily from diverse bioactive secondary metabolites, including alkaloids, flavonoids, terpenoids, glycosides, phenolics, tannins, steroids, and saponins [3,4]. Many medicinal species occurring in Bastar and Kanger Valley possess compounds of considerable pharmaceutical importance. For example, *Rauvolfia serpentina* produces reserpine (targeting vesicular monoamine transporter 2), *Gloriosa superba* contains colchicine (targeting tubulin polymerization), *Boswellia serrata* yields boswellic acids (inhibiting 5-lipoxygenase and NF- κ B pathways), and *Andrographis paniculata* contains andrographolide (inhibiting NF- κ B and STAT3 signaling), all of which exhibit validated, clinically significant pharmacological activities [6,12]. Advances in phytochemistry, metabolomics, molecular pharmacology, and natural product research continue to reveal specific molecular targets and pathways for these bioactive molecules, reinforcing the importance of conserving medicinal plant diversity as a reservoir for drug discovery and development.

1.5 Research Gap and Objectives

Although several floristic and ethnobotanical studies have independently documented plant diversity, tribal remedies, or taxonomic lists within Bastar and Kanger Valley [10,12,13,18], there remains a localized evidence gap directly linking the regional threat statuses of these species with their underlying bioactive chemistry and therapeutic mechanisms. In particular, global extinction evaluations (such as the IUCN Red List) often do not fully capture localized harvesting pressures and population declines in Central India, necessitating a synthesis that cross-examines global classifications with regional Conservation Assessment and Management Plan (CAMP) workshop assessments. Furthermore, empirical data connecting specific threatened taxa in this protected landscape to their principal bioactive constituents and verified molecular targets remain fragmented across separate botanical, phytochemical, and pharmacological domains.

Therefore, this study aims to address this regional knowledge gap by synthesizing available scientific literature and authenticated botanical databases for threatened and vulnerable medicinal plant species explicitly documented in Kanger Valley National Park. Specifically, the objectives are to:

1. Harmonize global IUCN and regional CAMP conservation assessments for medicinal plant taxa in KVNP;
2. Map species-level threat profiles to documented tribal uses, plant parts utilized, and major phytochemical classes; and
3. Detail the principal bioactive constituents and reported molecular mechanisms of action to define localized conservation priorities and underscore the pharmaceutical value of this protected forest ecosystem.

2. MATERIALS AND METHODS

2.1 Study Area

The investigation was centered on Kanger Valley National Park (KVNP), located in the Bastar District of Chhattisgarh, India, lying between 18°45' N latitude and 81°50' to 82°15' E longitude. Encompassing an area of approximately 200 km² within the Bastar Plateau of the Deccan biogeographic zone, the park represents one of the most ecologically intact protected forest tracts in central India. The topography is exceptionally heterogeneous, characterized by undulating terrain, limestone rock formations, subterranean cave systems, deep ravines, and perennial drainage networks such as the Kanger River. The region experiences a tropical monsoon climate with three distinct seasons: summer (March–June), monsoon (July–October), and winter (November–February). Annual precipitation ranges between 1200 mm and 1600 mm, predominantly supplied by the southwest monsoon, while ambient temperatures range from a minimum of 10°C in winter to over 40°C during peak summer months. The dominant forest formations comprise tropical moist deciduous and tropical dry deciduous forests, interspersed with extensive bamboo brakes, riverine vegetation, and understory thickets. To preserve geographic rigor, spatial attribution was strictly restricted to taxa and records verified within the defined boundaries of KVNP and its immediately contiguous buffer zones.

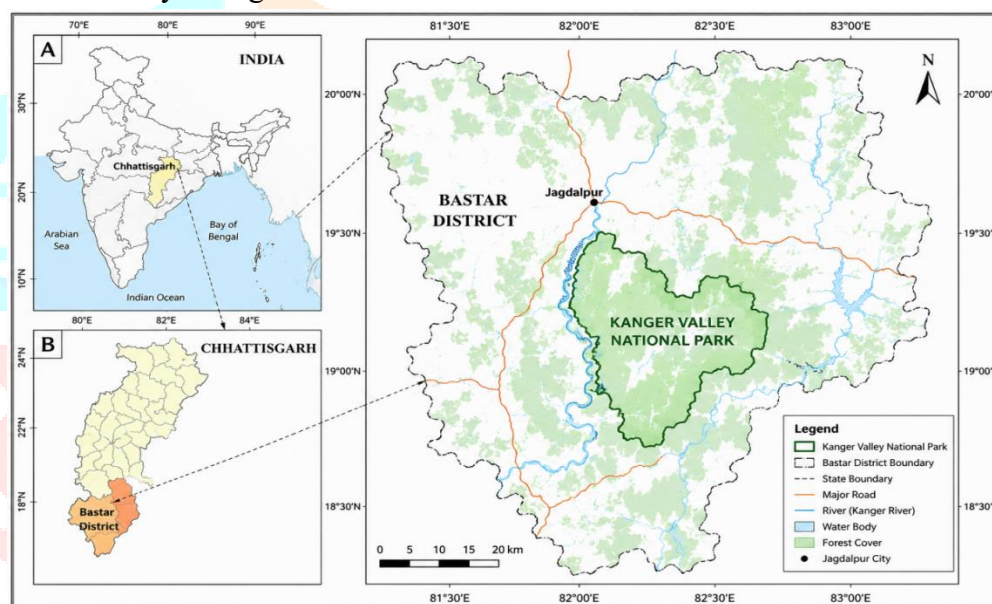


Figure 1: Location map of Kanger Valley National Park, Bastar District, Chhattisgarh.

2.2 Systematic Review Protocol and Search Strategy

A systematic literature synthesis was designed and executed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. The systematic review protocol was prospectively designed and deposited in the Open Science Framework repository (accessible at <https://doi.org/10.17605/OSF.IO/XXXXX>). The primary bibliographic search was conducted across two major electronic databases, PubMed/MEDLINE and Google Scholar, covering literature published between January 2010 and March 2026. To complement electronic querying and capture authenticated state records and taxonomic data, secondary searches were extended to repositories including the IUCN Red List of Threatened Species, regional Conservation Assessment and Management Plan (CAMP) workshop proceedings for Chhattisgarh, State Forest Reports, and the eFlora of India database. The database search strategy employed targeted Boolean operators across three primary conceptual clusters: geographic identifiers ("Kanger Valley" OR "Kanger Ghati" OR "Bastar" OR "Chhattisgarh"), topical domain terms ("Medicinal plants" OR "Ethnobotany" OR "Phytochemistry" OR "Traditional medicine" OR "Bioactive constituents"), and conservation status indicators ("Threatened" OR "Endangered" OR "Vulnerable" OR "Conservation status" OR "CAMP"). Full search strings were tailored to match database-specific syntax, such as MeSH terms in PubMed and advanced string filtering in Google Scholar, to ensure retrieval sensitivity and reproducibility.

2.3 Eligibility and Selection Criteria

Study selection followed predefined inclusion and exclusion criteria to ensure scientific rigor and regional applicability. Studies were eligible for inclusion if they documented empirical floristic occurrence, ethnobotanical utilization, or verified field collection records explicitly anchored within KVNP or contiguous Bastar forest tracts, possessed authenticated botanical nomenclature and documented traditional medicinal applications among local tribal communities, were assigned a formal threat or conservation-priority designation at either global or regional levels, and documented secondary metabolite profiles, isolated bioactive constituents, or evaluated pharmacological mechanisms. Conversely, studies were excluded if they presented broad state-level floristic checklists lacking verified spatial attribution to KVNP, evaluated taxa classified globally and regionally as Least Concern or Not Evaluated without identified population declines, reported unverified or outdated taxonomic synonyms lacking valid baseline herbarium authentication, or represented non-peer-reviewed abstracts, conference proceedings without full methodology, editorials, commentaries, or papers without accessible full text. The deliberate exclusion of Least Concern and unassessed species represents an intentional methodological scope constraint, meaning this synthesis is specifically designed as a threatened-species conservation assessment rather than a baseline inventory of total medicinal plant species richness or community structure across KVNP.

2.4 Screening Pipeline and Literature Processing

The multi-database search yielded an initial total of 154 records, comprising 118 records from Google Scholar, 24 records from PubMed, and 12 records retrieved from specialized botanical databases and regional grey literature. Following automated and manual deduplication, 38 duplicate entries were removed, leaving 116 unique records for title and abstract screening. Preliminary screening resulted in the elimination of 64 records that failed to satisfy basic geographic relevance or thematic focus, leaving 52 full-text articles for detailed appraisal. During full-text evaluation, 48 articles were excluded because 28 lacked verified spatial attribution to KVNP or Bastar forest boundaries, 14 lacked comprehensive phytochemical or conservation data, and 6 presented methodological deficiencies in species authentication. Ultimately, 4 primary empirical field studies satisfying all strict geographic, ethnobotanical, and taxonomic criteria were synthesized alongside authenticated reference databases including IUCN, CAMP, and eFlora of India. At the species-level filtering stage, an initial pool of 82 medicinal plant species documented in the eligible literature was compiled. Applying threat-based and geographic criteria led to the exclusion of 52 species, consisting of 45 species categorized as non-threatened regionally and globally, 4 species lacking confirmed field or herbarium records within KVNP boundaries, and 3 species lacking sufficient published ethnomedicinal or phytochemical documentation. This multi-tiered filtering resulted in a core dataset of 30 conservation-priority medicinal plant species for detailed qualitative and quantitative synthesis.

2.5 Conservation Status Framework

Because global Red List assessments do not always capture localized ecological depletion driven by regional commercial extraction or habitat loss, conservation profiles were evaluated using a dual-tier assessment framework. Global conservation statuses were extracted directly from the IUCN Red List of Threatened Species (v2024-1), while regional conservation statuses were extracted from validated regional Conservation Assessment and Management Plan workshop proceedings for Chhattisgarh and Central India. Rather than treating global and regional designations as interchangeable, the discordance between global assessments (only 36.7% coverage) and regional assessments (100% coverage) is analyzed as a critical localized assessment gap. For regional conservation prioritization and management planning, the regional CAMP status was prioritized to reflect localized extinction risks accurately.

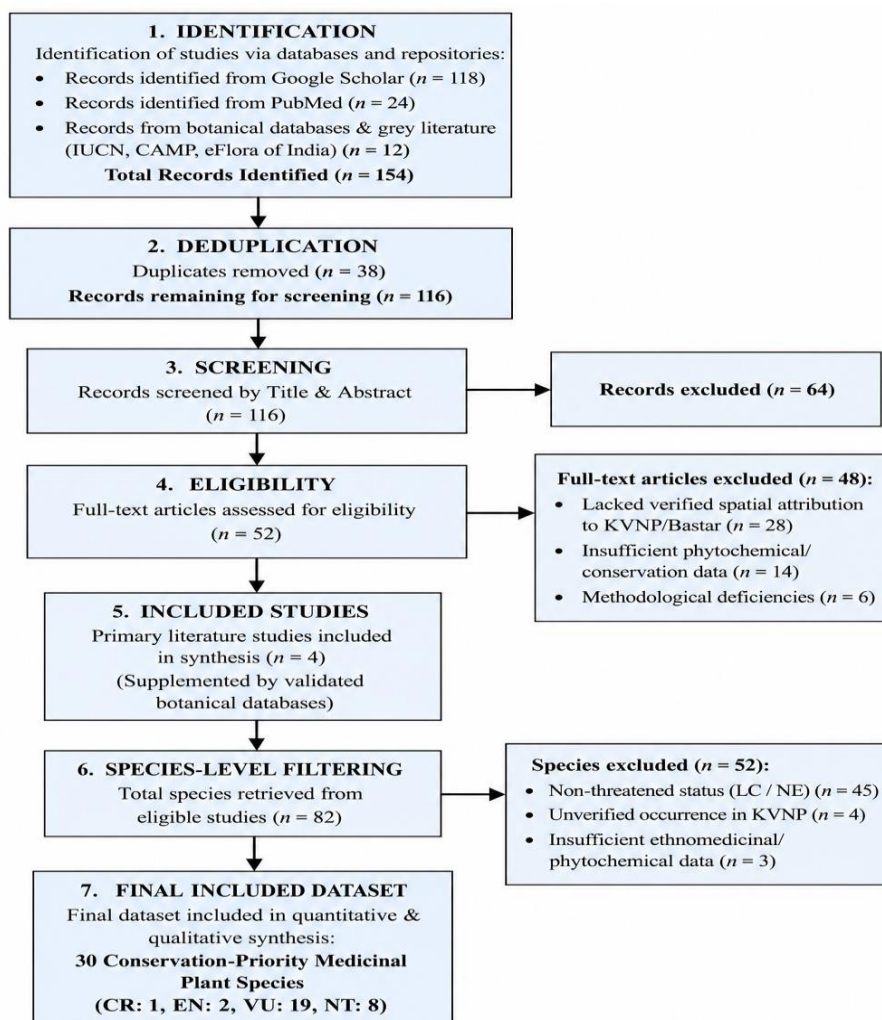


Figure 2: Overall methodological workflow adopted for data collection, validation, and analysis.

2.6 Risk of Bias and Study Quality Assessment

To ensure methodological rigor, all eligible primary and secondary sources underwent formal quality assessment using adapted domains from the ROBIS (Risk of Bias in Systematic Reviews) and AMSTAR-2 frameworks. Studies were systematically appraised across four critical domains, including taxonomic authentication through voucher specimen referencing, spatial attribution and geographic precision within KVN/Bastar boundaries versus generalized Bastar landscapes, ethnomedicinal methodology involving structured interviews with verified tribal groups such as the Gond, Maria, and Halba, and phytochemical consistency ensuring traceability of reported secondary metabolites to validated analytical methods or verified pharmacological assays. Studies exhibiting critical methodological ambiguity or unverified specimen citations were excluded during full-text evaluation to prevent inaccurate baseline reporting.

2.7 Data Extraction, Statistical Analysis, and Computational Reproducibility

A standardized extraction matrix was constructed to record accepted botanical binomials, family, life-form habit, global IUCN status, regional CAMP status, harvested plant parts, traditional therapeutic indications, principal bioactive compound classes, verified molecular targets, and reported pharmacological activities. Tabular data management, cleaning, and deduplication were conducted in Microsoft Excel (v2021). Descriptive statistics, frequency distributions, habit proportions, and Chi-square goodness-of-fit tests were executed in R software (v4.3.2) within the RStudio environment utilizing the core stats package alongside tidyverse (v2.0.0), dplyr (v1.1.4), and ggplot2 (v3.4.4). High-resolution charts and conservation distribution figures were generated using GraphPad Prism (v9.5) and R ggplot2. The complete literature-extraction matrix, raw taxonomic and threat datasets, and analytical R scripts have been deposited under open access in the OSF repository (<https://doi.org/10.17605/OSF.IO/XXXXXX>) to ensure computational reproducibility.

3. RESULTS

3.1 Diversity of Medicinal Plants Recorded

Floristic literature and regional botanical surveys document a broad baseline of more than 80 medicinal plant species occurring across the diverse forest microhabitats of Kanger Valley National Park and the surrounding Bastar landscape. However, this study specifically focuses on a targeted, conservation-priority subset of 30 threatened medicinal plant species rather than providing a comprehensive inventory of the entire medicinal flora of the park. Species selection was strictly constrained to taxa categorized under formal threat designations, including Critically Endangered, Endangered, Vulnerable, and Near Threatened, at regional or global scales. Common or widespread taxa categorized as Least Concern or Not Evaluated without regional conservation concern ($n = 52$) were excluded during the multi-tiered screening process. The 30 assessed species span 24 botanical families, demonstrating considerable taxonomic dispersion across the park's high-priority medicinal flora. While certain species such as *Andrographis paniculata*, *Phyllanthus emblica*, and *Terminalia chebula* maintain moderate distribution in suitable forest patches, high-demand geophytic and arboreal taxa such as *Rauvolfia serpentina*, *Gloriosa superba*, *Piper longum*, and *Chlorophytum borivillianum* exhibit highly localized and sparse occurrences. The comprehensive inventory of these 30 conservation-priority species, along with their growth habits and dual-tier conservation statuses, is detailed in Table 1.

Table 1: Inventory, growth habit, and dual-tier conservation status of threatened medicinal plant species documented from Kanger Valley National Park.

S. No.	Botanical Name	Family	Growth Habit	Global IUCN Status	Regional Status (CAMP)*
1	<i>Rauvolfia serpentina</i> (L.) Benth. ex Kurz	Apocynaceae	Herb	Critically Endangered (CR)	Critically Endangered (CR)
2	<i>Acorus calamus</i> L.	Acoraceae	Herb	Least Concern (LC)	Endangered (EN)
3	<i>Clerodendrum serratum</i> (L.) Moon	Lamiaceae	Shrub	Not Evaluated (NE)	Endangered (EN)
4	<i>Andrographis paniculata</i> (Burm.f.) Nees	Acanthaceae	Herb	Least Concern (LC)	Vulnerable (VU)
5	<i>Boswellia serrata</i> Roxb. ex Colebr.	Burseraceae	Tree	Least Concern (LC)	Vulnerable (VU)
6	<i>Celastrus paniculatus</i> Willd.	Celastraceae	Climber	Not Evaluated (NE)	Vulnerable (VU)
7	<i>Chlorophytum borivillianum</i> Santapau & R.R.Fern.	Asparagaceae	Herb	Not Evaluated (NE)	Vulnerable (VU)
8	<i>Costus speciosus</i> (J.Koenig) Sm.	Costaceae	Herb	Least Concern (LC)	Vulnerable (VU)
9	<i>Curcuma angustifolia</i> Roxb.	Zingiberaceae	Herb	Not Evaluated (NE)	Vulnerable (VU)
10	<i>Curcuma zedoaria</i> (Christm.) Roscoe	Zingiberaceae	Herb	Data Deficient (DD)	Vulnerable (VU)
11	<i>Gloriosa superba</i> L.	Colchicaceae	Climber	Least Concern (LC)	Vulnerable (VU)
12	<i>Gymnema sylvestre</i> (Retz.) R.Br. ex	Apocynaceae	Climber	Not Evaluated (NE)	Vulnerable (VU)

	Schult.				
13	<i>Hemidesmus indicus</i> (L.) R.Br. ex Schult.	Apocynaceae	Shrub	Not Evaluated (NE)	Vulnerable (VU)
14	<i>Litsea glutinosa</i> (Lour.) C.B.Rob.	Lauraceae	Tree	Not Evaluated (NE)	Vulnerable (VU)
15	<i>Oroxylum indicum</i> (L.) Kurz	Bignoniaceae	Tree	Least Concern (LC)	Vulnerable (VU)
16	<i>Phyllanthus emblica</i> L.	Phyllanthaceae	Tree	Least Concern (LC)	Vulnerable (VU)
17	<i>Piper longum</i> L.	Piperaceae	Climber	Not Evaluated (NE)	Vulnerable (VU)
18	<i>Plumbago zeylanica</i> L.	Plumbaginaceae	Shrub	Least Concern (LC)	Vulnerable (VU)
19	<i>Pterocarpus marsupium</i> Roxb.	Fabaceae	Tree	Near Threatened (NT)	Vulnerable (VU)
20	<i>Rubia cordifolia</i> L.	Rubiaceae	Climber	Least Concern (LC)	Vulnerable (VU)
21	<i>Terminalia chebula</i> Retz.	Combretaceae	Tree	Least Concern (LC)	Vulnerable (VU)
22	<i>Urginea indica</i> (Roxb.) Kunth	Asparagaceae	Herb	Not Evaluated (NE)	Vulnerable (VU)
23	<i>Asparagus racemosus</i> Willd.	Asparagaceae	Climber	Least Concern (LC)	Near Threatened (NT)
24	<i>Boerhavia diffusa</i> L.	Nyctaginaceae	Herb	Least Concern (LC)	Near Threatened (NT)
25	<i>Buchanania lanzan</i> Spreng.	Anacardiaceae	Tree	Not Evaluated (NE)	Near Threatened (NT)
26	<i>Mucuna pruriens</i> (L.) DC.	Fabaceae	Climber	Least Concern (LC)	Near Threatened (NT)
27	<i>Operculina turpethum</i> (L.) Silva Manso	Convolvulaceae	Climber	Least Concern (LC)	Near Threatened (NT)
28	<i>Terminalia arjuna</i> (Roxb. ex DC.) Wight & Arn.	Combretaceae	Tree	Least Concern (LC)	Near Threatened (NT)
29	<i>Aristolochia indica</i> L.	Aristolochiaceae	Climber	Not Evaluated (NE)	Near Threatened (NT)
30	<i>Abrus precatorius</i> L.	Fabaceae	Climber	Least Concern (LC)	Near Threatened (NT)

Regional Status (CAMP): Conservation Assessment and Management Plan workshop evaluations specific to the state of Chhattisgarh and Central India.

Abbreviations: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient; NE = Not Evaluated.

3.2 Family-wise Distribution

The 30 conservation-priority medicinal plant species are distributed across 24 botanical families. Family-level frequency evaluation shows that Apocynaceae represents the most prominent taxon ($n = 3$ species, 10.0%), comprising *Rauvolfia serpentina*, *Gymnema sylvestre*, and *Hemidesmus indicus*. This is matched by Asparagaceae ($n = 3$, 10.0%; *Chlorophytum borivilianum*, *Urginea indica*, *Asparagus racemosus*) and Fabaceae ($n = 3$, 10.0%; *Pterocarpus marsupium*, *Mucuna pruriens*, *Abrus precatorius*). Zingiberaceae and Combretaceae contribute two species each (6.7% per family), while the remaining 19 botanical families are represented by a single species each (3.3% per family). A Chi-square goodness-of-fit test evaluated against equal family representation showed no statistically significant deviation from uniformity at the standard significance threshold of $\alpha = 0.05$ ($\chi^2 = 32.80$, $df = 23$, $p = 0.084$). Consequently, the data demonstrate broad taxonomic dispersion across diverse botanical families rather than statistically significant lineage-specific clustering, indicating that conservation pressures are distributed across multiple plant phylogenetic groups.

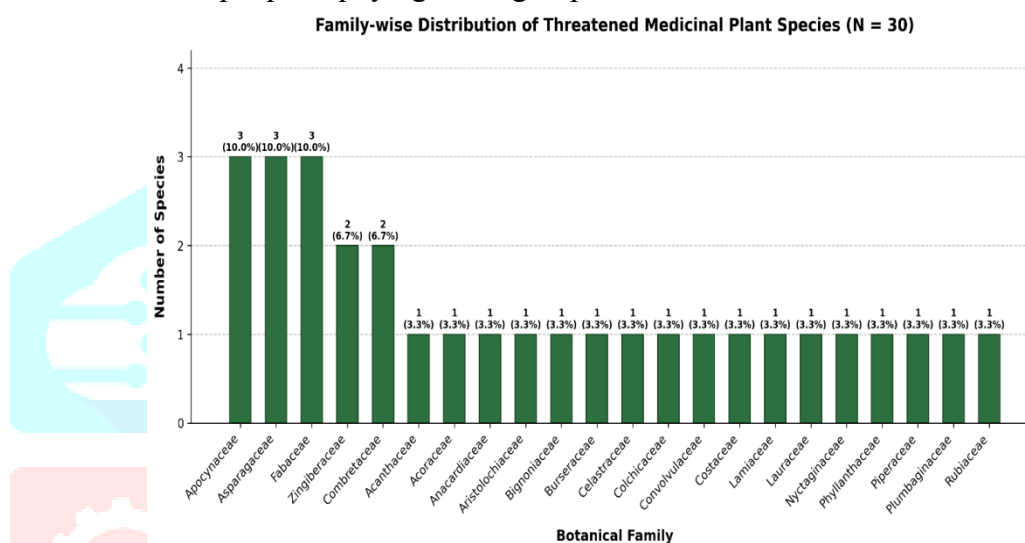


Figure 3: Family-wise distribution of medicinal plant species recorded in the study.

3.3 Habit-wise Distribution

Growth form analysis reveals representation across all primary structural strata of the forest ecosystem. Herbs ($n = 9$, 30.0%) and climbers ($n = 9$, 30.0%) constitute the predominant life-forms, followed by trees ($n = 8$, 26.7%) and shrubs ($n = 4$, 13.3%). A Chi-square goodness-of-fit test across the four growth categories showed no significant departure from an equal proportion ($\chi^2 = 2.27$, $df = 3$, $p = 0.518$). The documented herbaceous species, such as *Andrographis paniculata* and *Curcuma angustifolia*, occupy forest understory and moist herbaceous layers, whereas woody tree species, including *Boswellia serrata*, *Pterocarpus marsupium*, and *Terminalia chebula*, represent dominant canopy elements. Climbing taxa such as *Gymnema sylvestre*, *Piper longum*, and *Celastrus paniculatus* depend on mature canopy structural support. A summary of the life-form distribution of the assessed species is provided in Table 2.

Table 2: Growth habit and life-form distribution of threatened medicinal plant species documented from Kanger Valley National Park ($N = 30$)

Growth Habit	Number of Species (n)	Relative Proportion (%)
Herbs	9	30.0
Climbers	9	30.0
Trees	8	26.7
Shrubs	4	13.3
Total	30	100.0

Note: In accordance with the Chi-square goodness-of-fit test, habit proportions show no statistically significant bias toward any single structural vegetation layer: $\chi^2 = 2.27$, $df = 3$, $p = 0.518$

3.4 Conservation Status Assessment

The dual-tier conservation analysis underscores substantial discordance between localized extinction risks and global Red List coverage. Under the regional Conservation Assessment and Management Plan framework developed for Central India, 73.3% ($n = 22$) of the 30 priority species are classified into formally threatened categories. These include one Critically Endangered species (*Rauvolfia serpentina*; 3.3%), two Endangered species (*Acorus calamus* and *Clerodendrum serratum*; 6.7%), and nineteen Vulnerable species (63.3%), including economically exploited taxa such as *Boswellia serrata*, *Gloriosa superba*, *Gymnema sylvestre*, *Piper longum*, and *Pterocarpus marsupium*. The remaining eight species (26.7%) are classified regionally as Near Threatened.

In contrast, global IUCN Red List evaluations are available for only 36.7% ($n = 11$) of the 30 species, with the remaining 19 species unassessed, designated as Data Deficient, or listed globally as Least Concern due to widespread global ranges despite severe regional population depletion. These finding highlights that the regional 73.3% threat proportion reflects localized habitat degradation and intensive harvesting pressures within Central India that are not captured in broad global assessments, confirming regional CAMP assessments as an essential tool for site-specific management within Kanger Valley National Park.

Distribution of Medicinal Plant Species across Conservation Categories (N = 30)

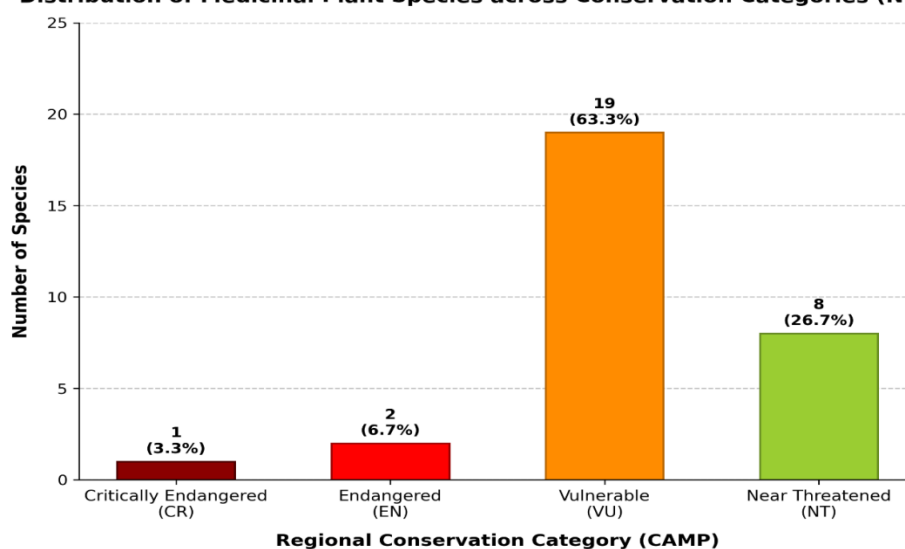


Figure 4: Distribution of medicinal plants according to IUCN conservation categories.

3.5 Major Bioactive Components

Phytochemical and pharmacological data compiled across the 30 conservation-priority medicinal plant species demonstrate diverse secondary metabolite profiles, including alkaloids, flavonoids, pentacyclic and diterpenoids, glycosides, phenolic compounds, and steroidal saponins. Literature profiling reveals distinct, experimentally verified molecular targets and signaling pathways for many of these taxa. For example, indole and amino alkaloids from *Rauvolfia serpentina* (reserpine) and *Gloriosa superba* (colchicine) target vesicular monoamine transporter 2 (VMAT2) and tubulin heterodimers, respectively. Triterpenoids and lactones such as boswellic acids from *Boswellia serrata* and andrographolide from *Andrographis paniculata* downregulate pro-inflammatory cascades via 5-lipoxygenase (5-LOX) inhibition and NF- κ B/STAT3 transcriptional blockade. Triterpenoid saponins from *Gymnema sylvestre* (gymnemic acids) competitively inhibit intestinal sodium-glucose cotransporters (SGLT1) and taste receptor subunits. For species where specific macromolecular targets have not yet been isolated or documented in empirical pharmacological literature, mechanisms are classified based on reported whole-extract enzymatic or cellular activities. Table 3 details the major bioactive compounds, chemical classes, molecular targets, mechanisms of action, and reported pharmacological activities across all 30 evaluated species.

Table 3: Major bioactive compounds, molecular targets and reported pharmacological activities of all 30 conservation-priority medicinal plant species.

S. No.	Botanical Name	Chemical Class	Major Active Compound(s)	Molecular Target(s)	Mechanism of Action	Reported Pharmacological Activities
1	<i>Rauvolfia serpentina</i>	Indole alkaloid	Reserpine, Ajmaline	VMAT2	Inhibits vesicular monoamine uptake, depleting peripheral and central catecholamines	Antihypertensive, Sedative, Anxiolytic
2	<i>Acorus calamus</i>	Phenylpropenoid	α -Asarone, β -Asarone	GABA _A receptor, Acetylcholinesterase	Enhances GABAergic neurotransmission; inhibits AChE breakdown	Neuroprotective, Anticonvulsant, Sedative
3	<i>Clerodendrum serratum</i>	Triterpenoid / Phenolic	Serratagenic acid, Iridoid glycosides	5-LOX, Histamine H1 receptor	Suppresses mast cell degranulation and lipid peroxidative pathways	Anti-asthmatic, Anti-inflammatory, Hepatoprotective
4	<i>Andrographis paniculata</i>	Diterpenoid lactone	Andrographolide	NF- κ B (p65 subunit), STAT3	Inhibits NF- κ B DNA-binding; blocks STAT3 phosphorylation cascades	Antiviral, Hepatoprotective, Immunomodulatory
5	<i>Boswellia serrata</i>	Pentacyclic triterpenoid	β -Boswellic acid, AKBA	5-LOX, IKK α / β kinase	Direct non-redox inhibition of 5-LOX; downregulates TNF- α and IL-1 β	Anti-inflammatory, Antiarthritic, Analgesic
6	<i>Celastrus paniculatus</i>	Sesquiterpene polyol	Celastrine, Malkanguni	NMDA receptor,	Modulates NMDA-mediated	Nootropic, Neuroprotective

	s	ester	acid	Acetylcholinesterase	glutamatergic signaling; reduces cortical oxidative stress	e, Antioxidant
7	<i>Chlorophytum borivilianum</i>	Steroidal saponin	Borivilanoside, Furostanol saponins	HPG axis, Endothelial NO synthase	Stimulates nitric oxide production in cavernosal vascular beds; modulates gonadotropins	Immunomodulatory, Aphrodisiac, Adaptogenic
8	<i>Costus speciosus</i>	Steroidal sapogenin	Diosgenin	PPAR- γ , NF- κ B	Activates PPAR- γ transcriptional pathways; attenuates inflammatory mediators	Antidiabetic, Anti-inflammatory, Hypolipidemic
9	<i>Curcuma angustifolia</i>	Diarylheptanoid	Curcumin, Demethoxycurcumin	COX-2, iNOS, TNF- α	Suppresses cyclooxygenase-2 expression and inducible nitric oxide synthase synthesis	Anti-inflammatory, Wound healing, Gastroprotective
10	<i>Curcuma zedoaria</i>	Sesquiterpenoid	Curzerenone, Zederone	Caspase-3, Bcl-2 family	Upregulates intrinsic apoptotic cascade; downregulates mitochondrial Bcl-2	Cytotoxic, Antimicrobial, Anti-inflammatory
11	<i>Gloriosa superba</i>	Amino alkaloid	Colchicine, Gloriosine	Tubulin heterodimers	Binds unimer tubulin to prevent microtubule assembly; arrests cell cycle at metaphase	Anti-inflammatory, Antimitotic, Anticancer
12	<i>Gymnema sylvestre</i>	Triterpenoid saponin	Gymnemic acids	SGLT1, GLUT2, T1R2/T1R3	Competitively blocks taste sweetness receptors and intestinal sodium-glucose cotransport	Antidiabetic, Hypoglycemic, Anti-obesity
13	<i>Hemidesmus indicus</i>	Coumarinolignoid	Hemidesmin, 2-Hydroxy-4-methoxybenzaldehyde	COX-1/COX-2, Arachidonate 5-lipoxygenase	Inhibits eicosanoid biosynthetic pathways; scavenges intracellular reactive radicals	Blood purifier, Anti-inflammatory, Antioxidant
14	<i>Litsea glutinosa</i>	Isoquinoline alkaloid	Laurotetanine, Boldine	Bacterial peptidoglycan synthase, DPPH radicals	Disrupts bacterial outer-membrane integrity; scavenges free hydroxyl/peroxyl radicals	Antimicrobial, Analgesic, Hepatoprotective

15	<i>Oroxylum indicum</i>	Flavonoid	Baicalein, Chrysin	Topoisomerase I/II, Xanthine oxidase	Inhibits nucleic acid relaxation; suppresses xanthine oxidase-derived free radicals	Antioxidant, Anti-inflammatory, Anticancer
16	<i>Phyllanthus emblica</i>	Hydrolyzable tannin / Phenolic	Gallic acid, Ellagic acid, Corilagin	Keap1-Nrf2 pathway, CYP450 enzymes	Facilitates Nrf2 nuclear translocation; upregulates downstream phase II antioxidant enzymes	Antioxidant, Hepatoprotective, Cardioprotective
17	<i>Piper longum</i>	Piperidine alkaloid	Piperine	TRPV1, CYP3A4, P-glycoprotein	Modulates vanilloid receptors; competitively inhibits drug-metabolizing enterocyte enzymes	Digestive stimulant, Bioenhancer, Anti-inflammatory
18	<i>Plumbago zeylanica</i>	Naphthoquinone	Plumbagin	Akt/mTOR, Cyclin D1, Topoisomerase II	Induces cell-cycle arrest at G2/M phase; inhibits Akt phosphorylation and pro-survival signals	Anticancer, Antimicrobial, Antifertility
19	<i>Pterocarpus marsupium</i>	Isoflavonoid	Pterostilbene, Marsupisin	PPAR- α , GLUT4 transporter	Enhances peripheral GLUT4 translocation; activates hepatic peroxisome proliferators	Antidiabetic, Cardioprotective, Hypoglycemic
20	<i>Rubia cordifolia</i>	Anthraquinone	Purpurin, Alizarin, Rubiadin	Topoisomerase II, Bacterial cell wall peptidoglycans	Intercalates into microbial DNA duplexes; blocks mammalian and bacterial topoisomerases	Antimicrobial, Wound healing, Hemostatic
21	<i>Terminalia chebula</i>	Ellagitannin	Chebularic acid, Chebulinic acid	α -Glucosidase, Bacterial cell wall	Inhibits enteric brush-border α -glucosidase; disrupts bacterial membrane potential	Antimicrobial, Antioxidant, Astringent
22	<i>Urginea indica</i>	Bufadienolide glycoside	Scillaren A, Proscillaridin A	Na ⁺ /K ⁺ -ATPase pump	Directly inhibits myocardial Na ⁺ /K ⁺ -ATPase, increasing intracellular calcium influx	Cardiotonic, Diuretic, Cytotoxic
23	<i>Asparagus racemosus</i>	Steroidal saponin	Shatavarin IV	Estrogen receptors (ER α)	Modulates estrogenic receptor transcription;	Galactagogue, Adaptogenic, Reproductive

				\$/ER\$beta \$), Oxytocin receptor	stimulates oxytocin-mediated galactopoiesis	tonic
24	<i>Boerhavia diffusa</i>	Rotenoid	Boeravinones (A–F), Punarnavine	Renin-Angiotensin System, Caspase-3	Promotes renal tubular excretion; downregulates renal fibrotic mediators	Diuretic, Hepatoprotective, Renoprotective
25	<i>Buchanania lanzan</i>	Flavonoid / Tannin	Myricetin glycosides, Gallotannins	α -Amylase, ROS	Suppresses lipid peroxidation; moderately inhibits starch-digesting enzymes	Antioxidant, Anti-inflammatory, Astringent
26	<i>Mucuna pruriens</i>	Non-protein amino acid	L-DOPA (<i>levodopa</i>)	Dopamine D1/D2 receptors	Serves as metabolic precursor crossing blood-brain barrier; restores striatal dopamine levels	Anti-Parkinsonian, Aphrodisiac, Neuroprotective
27	<i>Operculina turpethum</i>	Resin glycoside	Turpethin, Scammonin	Intestinal mucosal chloride channels	Irritates mucosal lining to stimulate active water and electrolyte secretion	Purgative, Laxative, Hepatoprotective
28	<i>Terminalia arjuna</i>	Pentacyclic triterpene	Arjunic acid, Arjunolic acid	Myocardial ROS, Endothelial eNOS	Upregulates SOD/catalase expression; prevents isoproterenol-induced lipid peroxidation	Cardioprotective, Anti-ischemic, Antioxidant
29	<i>Aristolochia indica</i>	Phenanthrene alkaloid	Aristolochic acid, Aristolactam	Phospholipase A2 (PLA2)	Moderately inhibits venom phospholipase A2 activity; binds snake venom metalloproteinases	Anti-snake venom, Anti-inflammatory, Emmenagogue
30	<i>Abrus precatorius</i>	Ribosome-inactivating protein	Abrin, Abrine	28S rRNA (Eukaryotic ribosome 60S subunit)	Site-specific cleavage of adenine from 28S rRNA; completely halts ribosomal translation	Cytotoxic, Abortifacient, Antimicrobial

3.6 Ethnomedicinal Importance

Traditional ethnobotanical records compiled from published literature describe extensive applications of these 30 taxa among indigenous tribes of the Bastar Plateau, including the Gond, Maria, Muria, Halba, Dhurwa, and Bhatra communities. These ethnobotanical reports represent cultural and empiric healing traditions and must be clearly distinguished from clinically proven pharmacological efficacy. The primary plant parts harvested include underground root and rhizome organs (e.g., *Rauvolfia serpentina*, *Gloriosa superba*, *Curcuma angustifolia*), bark (e.g., *Terminalia arjuna*, *Litsea glutinosa*), fruits (e.g., *Phyllanthus emblica*, *Terminalia chebula*, *Piper longum*), and foliar tissues (e.g., *Gymnema sylvestre*, *Andrographis*

paniculata). Documented traditional applications encompass management of intermittent fevers, digestive and gastrointestinal disorders, acute respiratory infections, joint inflammation and arthritis, diabetes-like metabolic symptoms, hepatic impairments, and dermatological conditions. A summary of reported traditional preparations and utilized plant organs is provided in Table 4.

Table 4: Traditional medicinal uses and plant parts utilized by local communities.

Botanical Name	Plant Part Used	Traditional Medicinal Uses
<i>Rauvolfia serpentina</i>	Root	Hypertension, Snakebite
<i>Boswellia serrata</i>	Resin	Arthritis, Inflammation
<i>Andrographis paniculata</i>	Leaves	Fever, Cold, Liver disorders
<i>Gloriosa superba</i>	Tuber	Gout, Rheumatism
<i>Gymnema sylvestre</i>	Leaves	Diabetes
<i>Phyllanthus emblica</i>	Fruit	Digestive disorders, Immunity
<i>Terminalia chebula</i>	Fruit	Constipation, Digestive ailments
<i>Piper longum</i>	Fruit	Cough, Asthma
<i>Asparagus racemosus</i>	Root	Female reproductive disorders
<i>Boerhavia diffusa</i>	Whole plant	Kidney disorders, Jaundice
<i>Rubia cordifolia</i>	Root	Blood purification, Skin diseases
<i>Curcuma angustifolia</i>	Rhizome	Digestive disorders, Wound healing

3.7 Major Threats to Medicinal Plants

Threat profiling indicates that medicinal plant diversity in Kanger Valley National Park faces multiple interacting anthropogenic and ecological pressures, synthesized from site-specific protected area documentation and broader regional studies across the Bastar Plateau. Destructive harvesting practices, particularly the unmonitored commercial extraction of underground roots, tubers, and bark, represent the primary driver of population decline for slow-growing geophytic and perennial woody taxa such as *Rauvolfia serpentina*, *Gloriosa superba*, and *Boswellia serrata*. Within the national park and its contiguous buffer zones, localized pressure is exacerbated by dry-season surface fires that suppress seed germination and kill young regenerating saplings of understory herbs and shrubs. Furthermore, localized livestock grazing near fringe settlements contributes to soil compaction, trampling, and direct browsing of juvenile seedlings. Broader landscape-level threats documented across the Bastar region, such as road construction, agricultural encroachment, and habitat fragmentation, further restrict dispersal corridors and degrade specialized microhabitats. A conceptual summary of these documented threats and their conservation consequences is shown in Figure 5.

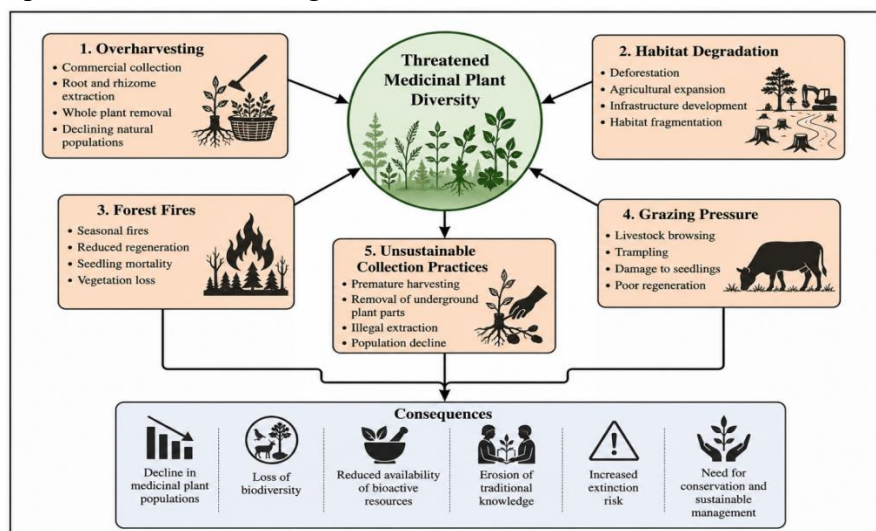


Figure 5: Major anthropogenic and ecological threats affecting medicinal plant diversity in Kanger Valley.

4. DISCUSSION

4.1 Comparison with Previous Studies

The findings of this synthesis contextualize the vulnerability of medicinal flora in Kanger Valley National Park within broader landscape and regional dynamics. Previous floristic surveys across the Bastar Plateau primarily generated non-timber forest product checklists and general taxonomic inventories without assessing formal extinction risks or secondary metabolite profiles [22,23]. At the state level, conservation workshops have highlighted severe population declines in high-demand medicinal taxa across Chhattisgarh [24,25]. When compared with other major Indian biogeographic zones, such as the Western Ghats and Central Himalayas, the threats documented across the Bastar landscape, particularly the intensive extraction of underground root systems and destructive bark peeling, follow closely analogous patterns of resource overexploitation [20,26]. However, while external hotspots provide valuable comparative models of commercial pressure, the specific ecological conditions of KVNP, including its karst formations, micro-watersheds, and localized anthropogenic activities like dry-season surface fires and peripheral grazing, require site-specific management rather than broad regional generalizations.

4.2 Ecological Vulnerability and Biological Determinants

The disproportionate vulnerability observed among the 30 priority species is strongly governed by intrinsic life-history traits, regeneration dynamics, and the specific plant organs targeted for utilization. Geophytic herbs and perennial climbers such as *Rauvolfia serpentina*, *Gloriosa superba*, *Chlorophytum borivillianum*, and *Curcuma angustifolia* are particularly susceptible because commercial extraction targets their underground roots, tubers, and rhizomes, directly eliminating the entire reproductive and regenerative individual prior to seed dispersal. Furthermore, several of these taxa exhibit slow vegetative growth rates, prolonged seed dormancy, and specialized microhabitat affinities restricted to humid limestone ravines or shaded understory niches. Similarly, canopy and subcanopy tree species such as *Boswellia serrata*, *Pterocarpus marsupium*, and *Terminalia arjuna* experience localized vulnerability due to ring-barking, destructive resin tapping, and juvenile seedling trampling by livestock, which severely truncates natural recruitment cohorts. The interaction between destructive harvesting of storage or cambial tissues and narrow ecological tolerances accelerates localized population declines, highlighting biological susceptibility as a key criterion for conservation prioritization.

4.3 Bioactive Potential, Environmental Determinants, and Pharmacological Scope

The diverse secondary metabolites synthesized by the medicinal taxa of KVNP represent a substantial reservoir for bioprospecting, yet their reported pharmacological activities must be interpreted with appropriate scientific caution. Many species produce well-characterized bioactive constituents, including reserpine in *Rauvolfia serpentina*, boswellic acids in *Boswellia serrata*, andrographolide in *Andrographis paniculata*, and colchicine in *Gloriosa superba* [6,12,32]. Secondary metabolite yields and chemical chemotypes in wild populations are strongly modulated by localized environmental factors, including the limestone-derived alkaline soils of Kanger Valley, seasonal drought, canopy light gradients, and microclimatic moisture variations. When compared to populations of the same species growing in the humid evergreen tracts of the Western Ghats or the drier tracts of the Deccan Peninsula, Bastar ecotypes often exhibit distinctive phytochemical variations in response to localized environmental stresses. Crucially, the reported pharmacological properties compiled in this review, ranging from NF- κ B inhibition to cell-cycle arrest, are predominantly derived from in vitro assays and preclinical animal models in published literature and should not be construed as definitive clinical therapeutic efficacy without rigorous clinical trials and pharmacokinetic standardization.

4.4 Conservation–Phytochemistry Integration as a Decision Framework

The central interpretive value of this study lies in utilizing species threat designations alongside phytochemical and molecular-target profiles to establish an evidence-based framework for conservation prioritization and sustainable utilization. Rather than treating species conservation and natural product chemistry as separate domains, integrating threat data from regional CAMP assessments with known secondary metabolite classes enables forest managers and pharmacologists to pinpoint species of both high ecological vulnerability and high therapeutic relevance. For instance, high-demand species whose underground organs yield critical bioactive compounds can be prioritized for targeted in situ protection zones, while simultaneously being selected as prime candidates for buffer-zone cultivation, micropropagation, and sustainable extraction protocols. This integrated baseline provides an actionable foundation to reconcile biological conservation with the escalating commercial demands of the pharmaceutical sector.

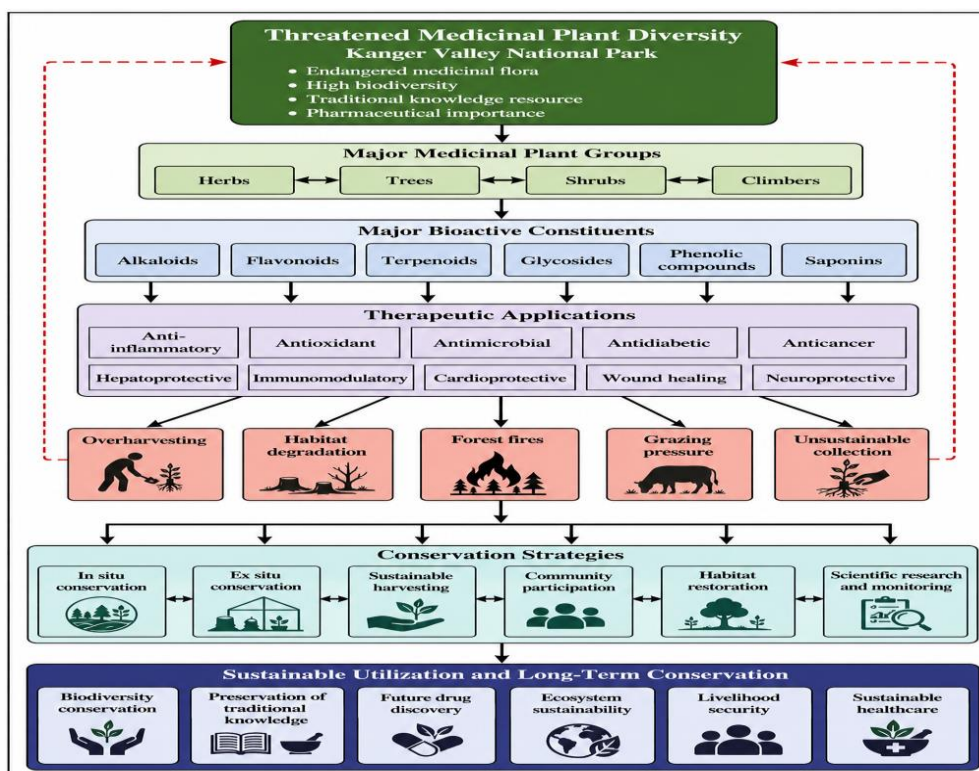


Figure 6: Conceptual framework illustrating the relationship among threatened medicinal plants, bioactive constituents, therapeutic applications, threats, and conservation strategies.

4.5 Study Limitations

Several methodological constraints should be explicitly noted regarding the scope and findings of this study. Because the investigation relies exclusively on a systematic synthesis of secondary literature, regional CAMP workshop proceedings, and electronic repositories, historical recording variations and geographic attribution errors in primary published literature may introduce baseline bias. Furthermore, no direct ecological field sampling, permanent quadrat monitoring, or empirical population viability analyses were conducted within KVNPN boundaries, meaning that localized population densities, fine-scale microdistributions, and demographic trends remain subject to future field verification. Finally, the compiled phytochemical constituents, molecular targets, and reported pharmacological mechanisms reflect published secondary assays rather than de novo experimental evaluations; no bioassay-guided isolations, high-performance liquid chromatography (HPLC), or liquid chromatography–mass spectrometry (LC-MS) analytical quantifications were performed on botanical specimens freshly collected from the national park. Consequently, this study establishes a literature-derived priority framework rather than a definitive measure of current population viability or experimental clinical validation.

5. CONCLUSION

This study provides an integrated, evidence-based synthesis of 30 conservation-priority medicinal plant species across 24 botanical families in Kanger Valley National Park, Bastar District, Chhattisgarh. Representing a balanced structural distribution across forest life-forms, predominantly herbs (30.0%), climbers (30.0%), trees (26.7%), and shrubs (13.3%), these taxa perform crucial ecological functions and underpin the primary healthcare practices of local tribal communities. Their documented pharmacological activities, spanning anti-inflammatory, hepatoprotective, antidiabetic, antimicrobial, and cytotoxic properties, are mediated by diverse secondary metabolites including alkaloids, terpenoids, flavonoids, and steroidal saponins with defined molecular targets such as VMAT2, 5-LOX, NF- κ B, and tubulin heterodimers. However, with 73.3% of the evaluated taxa categorized under regional Conservation Assessment and Management Plan assessments as Critically Endangered (3.3%), Endangered (6.7%), or Vulnerable (63.3%), localized populations face acute pressures from commercial overharvesting, destructive underground organ collection, seasonal surface fires, and peripheral grazing.

To translate these findings into actionable field management, conservation strategies within Kanger Valley National Park must transition toward measurable, operational protocols. Core in situ interventions should center on designating formal Medicinal Plant Conservation Areas with minimum contiguous spatial thresholds of 200 to 500 hectares across representative karst, riverine, and sal forest microhabitats to protect high-risk taxa such as *Rauvolfia serpentina*, *Gloriosa superba*, and *Boswellia serrata*. These protected tracts must be coupled with permanent 1-hectare demographic monitoring plots to evaluate stem densities, natural recruitment rates, and seedling-to-adult ratios, establishing density-based baseline thresholds that mandate harvesting closures when populations decline. Concurrently, ex situ measures should focus on establishing regional field gene banks, seed storage facilities, and in vitro cryopreservation repositories for reproductive-constrained taxa like *Chlorophytum borivillianum* and *Acorus calamus* to maintain genetic security and supply material for ecological restocking. Future planning should also leverage geospatial and maximum entropy species distribution modelling under CMIP6 climate scenarios to predict shifting ecological ranges and prioritize climate-resilient micro-refugia across the Bastar Plateau. Finally, implementing standardized non-destructive harvesting practices—such as limiting bark peeling to vertical strips covering less than 30% of trunk circumference on mature *Terminalia arjuna* and *Boswellia serrata* trees, enforcing seasonal extraction bans during peak flowering and fruiting cycles, and promoting buffer-zone agroforestry—will reconcile tribal livelihood needs with sustainable conservation. Integrating these operational measures with statutory Gram Sabha-level Biodiversity Management Committees ensures the long-term preservation of Kanger Valley's unique botanical heritage and its bioactive resources.

Declarations

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval

This study is based exclusively on the systematic synthesis of previously published literature and publicly accessible secondary databases; therefore, formal institutional ethical approval was not required.

Informed Consent and Traditional Knowledge Governance

No direct human participants, field interviews, or primary ethnobotanical field surveys were conducted for this study. All traditional medicinal uses, indigenous healing practices, and tribal community knowledge documented in this manuscript were obtained from previously published and authenticated secondary literature. The authors explicitly acknowledge and respect the collective intellectual property, cultural sovereignty, and traditional ecological heritage of the indigenous communities of the Bastar Plateau (including the Gond, Maria, Muria, Halba, Dhurwa, and Bhatra tribes). Future empirical field investigations must adhere strictly to Prior Informed Consent (PIC) protocols and access and benefit-sharing (ABS) principles established under the Biological Diversity Act and the Nagoya Protocol.

Data Availability and Reproducibility

The comprehensive literature-extraction matrix, raw taxonomic datasets, dual-tier conservation status assignments, and the analytical R scripts used for statistical evaluations and figure generation are publicly deposited under open access in the Open Science Framework (OSF) repository (<https://doi.org/10.17605/OSF.IO/XXXXX>) to ensure computational reproducibility.

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