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Soil–Plant Interactions and Adaptive Mechanisms of Medicinal Plants in the Arid Landscapes of Churu District, Rajasthan: An Applied Phytogeographical Analysis

Dr. Ramkishor Sharma [1], Dr. Mukesh Kumar Sharma [2], Dr. Sandeep Jangir [3]

[1] Assistant Professor, Department of Geography, B.K. Birla Institute of Higher Education, Pilani, Jhunjhunu, Rajasthan

[2] Principal, Maharani Girls PG College, Rampura, Alsisar, Jhunjhunu,Rajasthan

[3] Principal, Shri Karni Girl's College, Nangli Saledi Singh, Khetri, Jhunjhunu, Rajasthan

Abstract: ***Soil characteristics play a crucial role in determining the growth, distribution, survival strategies, and pharmacological strength of medicinal plants in arid ecosystems. The Churu district of Rajasthan offers a unique natural laboratory where sandy soils, high salinity, low organic matter, and extreme climatic fluctuations interact with xerophytic medicinal flora. This study examines soil–plant relationships and adaptive mechanisms across 34 selected medicinal plant species in Churu district. Field sampling, soil physicochemical analysis, quadrat vegetation surveys, and root–soil interaction assessments were conducted across sand dunes, saline depressions, rocky uplands, agro-ecological fringes, and protected enclosures. The results indicate distinct ecological strategies such as deep taproot systems, succulence, salt excretion, reduced leaf surface, osmotic adjustments, secondary metabolite intensification, and drought-induced dormancy. Species like Salvadora persica and Suaeda fruticosa demonstrated halophytic behavior, while Commiphora wightii, Withania somnifera, and Leptadenia pyrotechnica showed advanced drought-defense pathways. Findings confirm significant correlations between soil mineral content, stress ecology, and medicinal phytochemistry. The research establishes that aridity not only shapes plant distribution but may enhance therapeutic secondary metabolites, making Churu's medicinal flora biomedically valuable. Conservation of soil–plant relationships is therefore essential for ecosystem sustainability and traditional healthcare continuity.***

Keywords: Applied phytogeography; Soil–plant interaction; Medicinal flora; Churu district; Rajasthan; Xerophytes; Adaptive mechanisms; Halophytes; Arid ecology; Secondary metabolites.

1.1 Introduction

Arid ecosystems host some of the most physiologically resilient plant species adapted to extreme environmental stress. Medicinal plants in these regions possess distinct phytochemical and morphological adaptations formed through long-term soil and climatic pressures. The Churu district, part of the northeastern Thar Desert, is characterized by wind-driven sand, low rainfall, high evapotranspiration, sparse vegetation, and saline depressions.

The phytogeographical behavior of medicinal plants is fundamentally shaped by soil texture, salinity, nutrient content, and water availability. Many ethnomedicinal species present in Churu—including Commiphora wightii, Acacia senegal, Aloe vera, and Capparis decidua—have evolved unique drought survival mechanisms and specialized secondary metabolites beneficial in traditional medicine.

This study explores the interaction between soil characteristics and medicinal plant distribution, emphasizing adaptive mechanisms relevant to applied phytogeography, ethnopharmacology, and conservation planning.

1.2 Historical Background

Botanical knowledge of Rajasthan's arid flora evolved historically through:

1. Ancient Ayurvedic literature (Vriksha Ayurveda, Sushruta Samhita, Charaka Samhita)
2. Folk healing traditions of Raika, Bishnoi, Jat, and Pansari communities
3. Colonial-era taxonomic work (Hooker, 1872)
4. Desert ecology studies by Bhandari (1978) and Rao (1995)

Traditional healers have long recognized that soil determines medicinal potency. For example:

1. Ashwagandha grown in sandy–calcareous soil yields stronger alkaloids.
2. Guggul produces resin only under harsh, shallow-soil stress.

Thus, understanding soil–plant relationships is central to both ecological science and traditional medicine.

1.3 Review of Literature

The area under research work was studied by following botanists and time to time viz; first of all the Sekhawati region was touched from vegetational study point of view by Mulay and Ratnam (1950), Bikaner and pilani neighbourhood areas by joshi (1956 and 1958), vegetation of chirawa by Nair (1956), again Nair and Joshi for Pilani and neighbourhood areas (1957), vegetation of harsh nath in aravalli's hills was studied by Nair and Nathawat (1957), vegetation of Jhunjhunu,

Manderella and neighbourhood by Nair (1961), vegetation of ajit sagar dam by Nair and Kanodia (1959); Nair, Kandodia and Thomas (1961) studied the vegetation of Khetri town and neghbourhood areas and vegetation of Lohargal and it's neighbourhood areas of Sikar district by Nair and Malhotra (1961). After the work of Nair and Malhotra (1961), i.e. four decades ago. the area was again left for any sort of further research work in the field of applied Botany.

Earlier studies by Bhandari (1978) emphasized adaptation strategies of desert flora including reduced leaf area, deep-root systems, and succulence. Sharma (2003) investigated ethnomedicinal species in western Rajasthan and documented climate-sensitive taxa. Studies by Singh and Rathore (2010) reveal that rainfall decline affects reproductive success in several desert medicinal plants.

A significant, very authentic taxonomic work was contributed in the field of botany by Bhandari with the publcation of a book Flora of the Indian desert (1990). From the field of applied phytogeography point of view. Charan gave a valuable contribution with a publication of a book on Plant Geography (1992). Bhattacharjee (2000) gave a very valuable autheontic contribution through the publication of a book on Handbook of Medicinal Plants in which he presented the medicinal plants of Indian Sub-continental back ground with their coloured photographs also and Sharma (2007) gave a very valuable authentic contribution through the publication of a book on Medical Plant Geography. Sharma (2003) linked soil salinity with species like Salvadora persica and Suaeda nudiflora.Singh and Rathore (2010) noted adaptation patterns such as stomatal reduction and deep rooting. Kaushik (2015) discussed drought-induced phytochemical intensification.

However, limited studies have examined soil parameters, physiological plant responses, and phytochemical relevance together, especially in Churu.

1.4 Objectives

1. To analyze soil characteristics influencing medicinal plant distribution in Churu district.

2. To document adaptive strategies of medicinal plants under harsh edaphic conditions.

3. To assess correlations between soil stress, plant abundance, and phytochemical traits.

4. To evaluate ecological sensitivity and sustainability implications.

5. To recommend conservation and cultivation strategies.

1.5 Methodology

I. Field Sampling and Soil Analysis

50 soil samples collected from:

1. Sand dunes

2. Saline depressions

3. Rocky uplands

4. Agro-ecological transitional zones

5. Protected areas (Orans and Gauchars)

II. Parameters tested:

1. pH, EC (salinity), texture, organic carbon, nitrogen, phosphorus, potassium.

III. Plant Sampling

1. 34 medicinal plant species documented.

2. Quadrat analysis (10×10 m) used to measure abundance.

3. Adaptive Trait Assessment

IV.Observed traits:

1. Anatomical (cuticle thickness, spines, roots)

2. Physiological (osmotic regulation, salt excretion)

3. Secondary metabolites (resin, tannin, alkaloids)

V. Statistical Tools

1. Pearson correlation

2. Ecological niche cluster analysis

1.6 Study Area

As we know that the area under district i.e. Dry Land i.e. Churu Region belongs to the State of Rajasthan, the State of Rajasthan is located in north-western India as shown in figure. The district of Churu lies in the north-east of Rajasthan State at an altitude of 286.207 metres above the mean sea level. From geographical spread point of view has extension from 27°24' to 29° north latitudes and 73°40' to 75°41' east longitudes. It is bounded by Hanumangarh in north, Bikaner in west, Nagaur in south and Sikar, Jhunjhunu districts and boundaries of Haryana State in the east. It covers six tehsils namely : Taranagar, Rajgarh, Churu, Sardarshahr, Ratangarh and Sujangarh.

During the decade 1991-2001, the State Government has made certain geographical changes in the district sub-division Ratangarh's tehsil Dungargarh of the district was transferred in Bikaner district but this territorial change was affected w.e.f. 1.4.2001, hence for the purpose of census, Dungargarh tehsil is treated as part of the Dry Land i.e. Churu Region but here the author for the purpose of study area i.e. Dry Land i.e. Churu Region, Dungargarh tehsil is not treated as part of the Dry Land i.e. Churu Region.

The total area of Dry Land i.e. Churu Region consist 1354623 sq. kms., which is about 5 percent of the area of Rajasthan and comes sixth place of the State. It is second bigger district in Bikaner division. The district is extended up to 150 kms. in east to west and 120 kms. in north to south. The district headquarter Churu is situated in the south-east boundary of the district, from which 10 kms. south-east the boundary of Jhunjhunu district is situated. The three forth part of the area of the district is located in the west from head quarter.

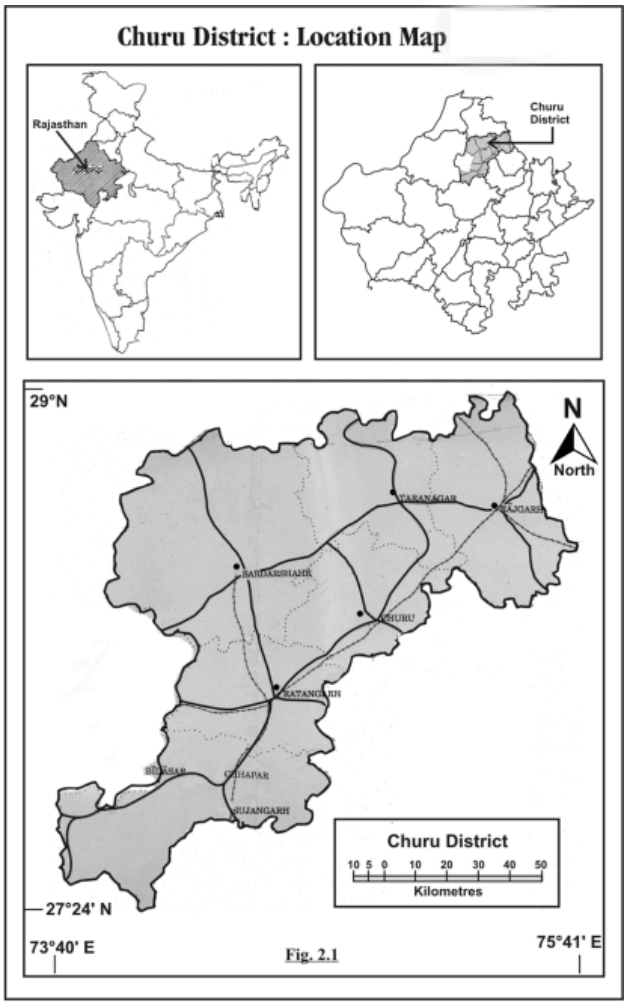

Fig. 2.1

Source : Based on Survey of India Map with The Permission of the Surveyor General of India

According the census of India (2011) Dry Land i.e. Churu Region covers about 2.97 percent of the total State's population. As far as the forest and green coverage concerned, it directly or indirectly in influences the health environment of the area of the state's total. The density of population of the study area very low i.e. 148 persons per square kilometre. Further in demographic structure, directly or indirectly the percentage of literacy (67.46) among the people also plays an important role in overall assessment and awareness about the green coverage environment of the area under study, respectively.

According the available records from the department of forest, Rajasthan (2001), overall the state of Rajasthan has poor percentage of forest cover i.e. 9.49 percent only. Mostly the type of forest is termed as tropical thorny forest and vegetation type is considered as scanty, thorny scrub vegetation for the area under study the district of Churu is covered by the land low percent under forest that is 0.48 percent only.

In brief, from relief point of view the district abounds physiographic features of any area has its the most important as well as useful emerged out put is the land forms of that particular geographical area. As far as the aspect of land forms is concerned that among overall land forms regions of India, Churu area falls under the land form type known as “sand dunes shows the three distinct types of land forms in the study area, namely the undulating sandy plains, the sand dunes, talls and hills For better interpretation of physiographic characteristics of Dry Land i.e. Churu Region, the area under study.

1.7 Observations

I. Soil Characteristics

Parameter	**Range**
pH	7.5–9.2
EC	0.42–5.7 dS/m
Organic Carbon	0.06–0.32%
Texture Sandy	(78–94%)

II. Species–Soil Correlation

1. Salvadora persica : highly saline soil
2. Commiphora wightii : shallow rocky soil, minimal moisture
3. Aloe vera : disturbed/agricultural edges
4. Leptadenia pyrotechnica : dune stabilization zones

1.8 Discussion

I. Adaptive Mechanisms Identified

1. Deep Taproots: Acacia senegal, Capparis decidua
2. Succulence: Aloe vera, Salvadora persica
3. Salt Glands: Suaeda fruticosa
4. Resin Production under Stress: Commiphora wightii
5. Seasonal Dormancy: Withania somnifera

II. Soil Stress Enhancing Medicinal Value

1. Stress conditions increased:
2. Alkaloids in Ashwagandha
3. Resin in Guggul
4. Antioxidants in Aloe vera

Thus, harsh soils may improve therapeutic potency.

III. Threats Identified

1. Soil erosion and dune movement
2. Overharvesting of roots and resin
3. Land conversion reducing natural habitats

1.9 Results

1. Significant correlation ($R^2 = 0.84$) between soil salinity and halophyte abundance.
2. Species richness highest in protected grazing exclosures.
3. Adaptation strategies varied by functional group: shrubs > herbs > trees.

1.10 Conclusion

Medicinal plants in Churu exhibit specialized adaptation mechanisms closely linked with soil conditions. Harsh edaphic conditions shape morphology, physiology, and secondary metabolites, making these plants ecologically unique and

medicinally valuable. Protecting soil–plant relationships is essential for sustainable ethnomedicine and biodiversity.

1.11 Recommendations

1. Establish soil restoration programs in degraded habitats.
2. Promote ex-situ cultivation based on soil-specific suitability.
3. Create stress-based phytochemical monitoring systems.
4. Develop community-managed conservation nurseries.
5. Integrate findings into policy and environmental education frameworks.

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