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# Current State of Natural Resources of *Peganum harmala* L. in Navoi Region, Uzbekistan

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## Abstract

The study of medicinal plant resources holds considerable practical importance for the development of sustainable natural resource management systems and environmental monitoring frameworks. To evaluate the potential for harvesting medicinal raw materials, comprehensive field surveys were conducted across natural habitats in the Navoi Region of Uzbekistan. As a result of these investigations, natural stands suitable for the sustainable harvesting of *Peganum harmala* were identified. The study involved detailed mapping of the species distribution, assessment of plant raw material yield (expressed in air-dry weight), estimation of population abundance, and calculation of exploitable reserves. These parameters are critical for evaluating the ecological capacity of the region and for establishing sustainable use thresholds. The research provides essential data for the rational use of wild medicinal plant resources and supports the development of environmentally responsible harvesting practices. Moreover, the findings contribute to biodiversity conservation by identifying plant species and habitats that possess both ecological significance and economic potential. Field assessments enabled the quantification of the total area occupied by *Peganum harmala* populations and the estimation of the potential harvestable volume of raw materials. These evaluations offer a scientific basis for determining the sustainability of current and future harvesting activities, guiding resource regulation in line with ecological limits.

## Keywords

*Peganum harmala*, Medicinal Plants, Resource, Annual Volume, Correlation, Navai, Uzbekistan

## 1. Introduction

The development of modern industries and the rapid population growth over the next 50 years pose significant challenges for scientists in the search for new renewable resources: sources of food, biofuels, medicinal products, cosmetics, and hygiene products. This will undoubtedly lead to an increased interest in plant-based resources. In recent decades, the World Health Organization has highlighted the growing use of plant-derived medicines and the increasing share of medicinal plants consumed by the global population [1]. The development of a domestic pharmaceutical, medical, and food industry in Uzbekistan should be based on a sustainable raw material base, meaning it should not depend on imported raw materials. The study of medicinal plant resources plays an important role in the comprehensive assessment of the potential for practical use of raw materials in the production of phytomedicines. There are 500 - 600 medicinal plant species in Uzbekistan, and according to some sources, this number may reach up to 1000. Of these, 112 species are officially registered in the Pharmacopoeia of Uzbekistan as medicinal substances. Each year, applications are submitted to the Ministry of Ecology, Environmental Protection, and Climate Change for quotas related to 73 species of medicinal plants. It is necessary to obtain a permit for the wild harvesting, domestic use, or export of these plants [2]. To preserve natural reserves of medicinal plant raw materials, it is necessary to monitor the distribution areas and establish extraction norms for commercial harvesting.

*Peganum harmala* L., commonly known as Syrian rue or "*isiriq*, *adraspan*" in Central Asia, is a perennial herbaceous plant widely distributed across arid and semi-arid regions of Central Asia, the Middle East, and parts of North Africa. Its pharmacological properties and ecological resilience have made it an object of interest in both ethnobotanical and resource-based studies. Recent studies have documented the distribution and raw material potential of *Peganum harmala* in several regions. In the Batken and Osh provinces of the Kyrgyz Republic, natural populations of *Peganum harmala* were recorded in 10 different plant communities, covering an area of 92.8 hectares. The exploitable reserve was estimated at 40.37 tons, with a possible annual harvest of 10.09 tons [3]. In Kazakhstan, researchers have assessed thickets of *Peganum harmala* in the Atyrau region, identifying a coverage of 22.5 hectares and a raw material reserve totaling 116.95 tons [4]. These findings underscore the plant's significant potential as a medicinal resource across the Central Asian region. *Peganum harmala* has long been used in traditional medicine for a range of therapeutic purposes. It serves as an analgesic, anti-inflammatory, and abortifacient, and is commonly used to treat bronchial asthma. Phytochemical analyses have revealed a diverse profile of bioactive compounds in the plant, including alkaloids (such as harmine and harmaline), flavonoids, and amides [5]. These compounds are known for their antibacterial, antimicrobial, and cytotoxic properties, which have been the focus of many experimental pharmacological studies. The anatomical and morphological characteristics of *Peganum harmala* have been studied by Kazakhstan researchers including [6]. Their work provided detailed insights into the plant's vegetative and reproductive organs, vascular structures, and adaptive traits—vital for proper identification, classification, and assessment of its ecological value.

## 2. Research Methods

The resource survey was conducted using the route method [7]. Raw material reserves were assessed in specific thickets using the method of accounting plots or model specimens. The number of exploitable reserves and the volume of possible annual harvesting were calculated, taking into account the recovery period of thickets for each species [8]. When describing plant communities involving the studied species, geobotanical methods were used [9]. A small-scale (1:1,000,000) administrative map of the Navai region was used in the study. It served for planning harvesting activities across the regions as well as for the specialization of districts in the harvesting of specific types of medicinal plant raw materials. At the surveyed points along the route where the study objects were identified, we recorded the coordinates on-site using a GPS device and described the main plant communities involving the studied species. The species affiliation of accompanying wild-growing plants was determined using the Flora of Uzbekistan and the Illustrated Plant Identifier of Uzbekistan [10].

The research aimed at identifying the distribution areas of the species, as well as determining the biological and exploitable reserves of resource-valuable species, was conducted in accordance with the latest advanced methodological guidelines applied in modern resource science. These methodologies reflect current best practices in the field, incorporating geospatial analysis, ecological surveying, and quantitative resource assessment. Emphasis was placed on ensuring scientific accuracy and reproducibility, which involved systematic data collection across various habitats and the integration of field observations with geoinformation technologies. By using contemporary approaches such as GIS mapping, statistical modeling, and ecological resource evaluation standards, the study provides a reliable foundation for sustainable use, conservation planning, and future monitoring of plant resource potential [11]-[13]. According to this, for tree and shrub species whose raw material consists of generative organs, the exploitable volume was considered to be 25% of the biological reserve. In calculating the indicators of the sample plots, strict adherence was maintained to ensure that the average error did not exceed 15%. The sample plots were established with a size of $100 \times 100$ m$^2$, and up to $n = 10$ repeated plots were designated.

Within these plots, the following indicators were recorded: the total number of productive plants (units), collection norm per model plant (wet mass, kg), and collection norm per model plant (dry mass, kg). Statistical analysis of the obtained results was carried out using Past and Origin Pro software, and maps of areas containing reserve values for the species were created using ArcGIS Map software.

In recent years, extensive scientific research has been conducted across the Republic to assess the current status, bioecological characteristics, distribution range, and both economic and ecological significance of rare and economically valuable plant species [14]-[18]. Particular attention has been given to the conservation of these species, the anthropogenic and natural factors influencing their survival, and the preservation of biodiversity. Based on the outcomes of these studies, a number of scientific recommendations and practical proposals have been developed to protect endangered species, preserve their gene pools, and restore natural populations [17] [19]-[23].

In addition, comprehensive research initiatives have been launched to evaluate the genetic resources of wild relatives of cultivated plants that hold high economic, pharmaceutical, and agricultural importance. These studies provide a strong scientific and practical foundation for further applications in agriculture, plant breeding, pharmacology, and environmental science [24]-[27].

## Study Area

Our research was conducted in the Nurata mountain range and adjacent areas within the Navoi Region of Uzbekistan. Located in the central part of the Republic of Uzbekistan, the Navoi Region has long attracted the interest of botanists due to its rich floristic composition and ecological heterogeneity. Historical records indicate that botanical investigations in this area have been ongoing for more than 150 years, underscoring its importance as a center of plant diversity and endemism.

The region encompasses a broad spectrum of ecological zones, including arid deserts, semi-arid foothills, montane habitats, and steppe pastures. This environmental heterogeneity contributes significantly to the region's high level of biological diversity, supporting a wide array of vascular plant species adapted to varying climatic and edaphic conditions.

From a botanical-geographical perspective, the Navoi Region includes portions of seven distinct botanical-geographical districts. These fall within two major floristic provinces:

**1) Mountainous Central Asian Province**

- *Nurata* and *Aktau* districts of the Nurata region.
- *Ziyoddin-Zirabuloq* district of the Kuhistan region.

**2) Turan Province**

- *Kyzylkum* and *Kyzylkum Relict Mountains* districts of the Kyzylkum region.
- *Lower Zarafshan* and *Karshi-Karnabchul* districts of the Bukhara region.

These districts represent a complex mosaic of phytogeographical units, each characterized by specific climatic regimes, soil types, and endemic plant assemblages.

The Navoi Region holds not only botanical significance but also plays a strategic role in the conservation of genetic resources and natural ecosystems. This is particularly critical in light of accelerating anthropogenic pressures and climate change, which threaten the stability and resilience of native plant communities.

In recent years, the global demand for natural, plant-based raw materials has increased markedly, driven by shifts in human health preferences, pharmacological research, and sustainable resource utilization. Within this context, species of the genus *Peganum* L. have garnered special attention. Known for their wide ethnomedicinal use and adaptive ecological traits, *Peganum* species exhibit significant pharmaceutical potential due to their rich phytochemical profile, including alkaloids, flavonoids, and other bioactive compounds with antimicrobial, antioxidant, and neuroprotective properties.

Given their ecological specificity and economic relevance, scientific efforts must prioritize the study of *Peganum* species. This includes detailed assessments of their phytochemical composition, population ecology, biogeographical distribution, and *in situ* and *ex situ* conservation strategies. Such research not only contributes to the sustainable utilization of medicinal plants but also supports broader goals of biodiversity conservation and ecosystem health in Central Asia (Figure 1).

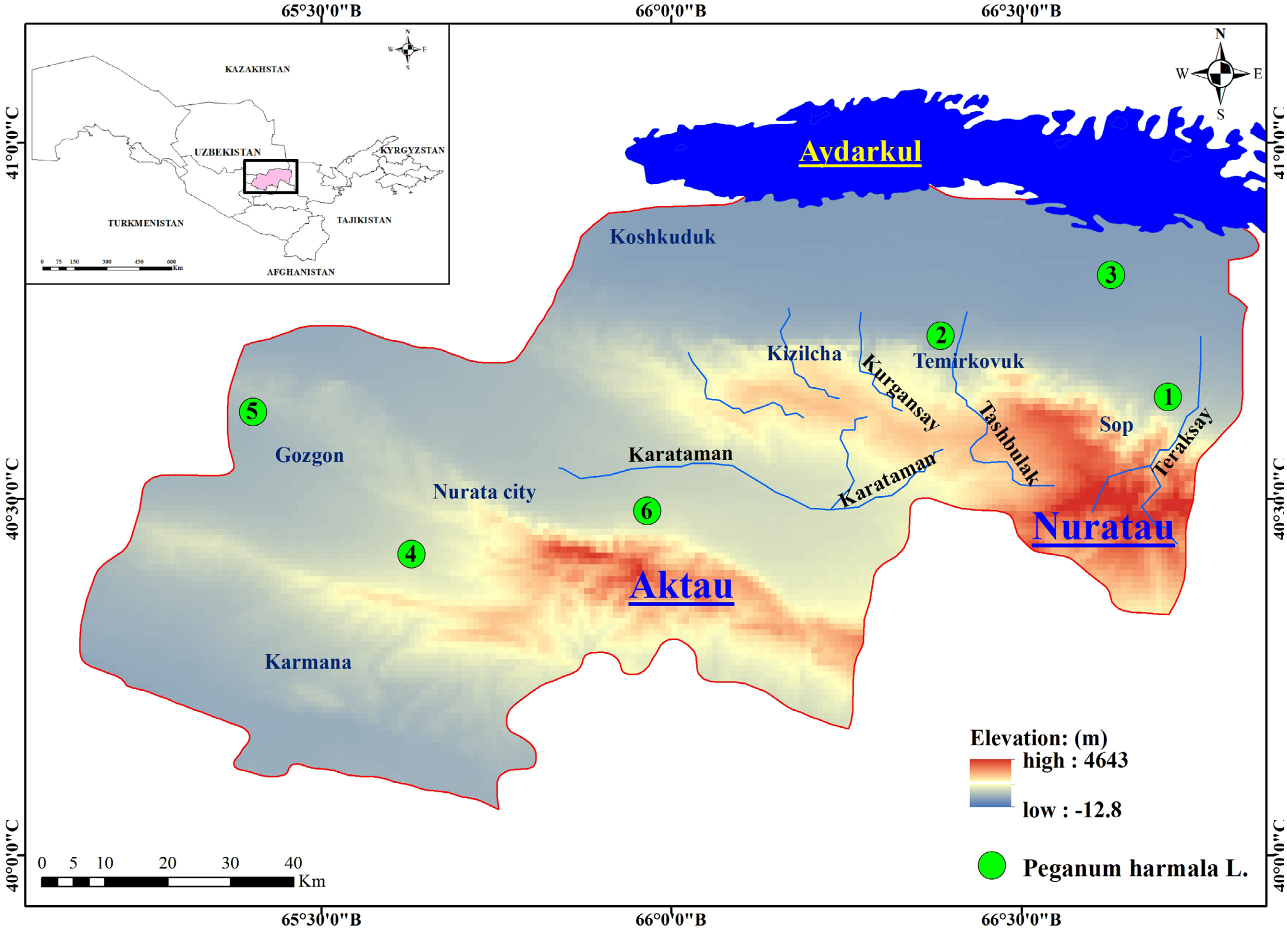


Figure 1. Study area.

## 3. Results

Our research was conducted in the Nurota mountain range and adjacent territories within the Navoi Region of Uzbekistan. The study focused specifically on plant communities in which *Peganum harmala* L. was identified as a dominant or co-dominant species. This perennial xerophytic plant, known for its ethnopharmacological significance, was found to form characteristic communities in several ecologically distinct locations across the study area. Field observations indicated the presence of substantial natural populations, suggesting that these territories possess considerable resource potential for *P. harmala*.

As part of the investigation, six key areas exhibiting significant populations of *P. harmala* were delineated for detailed study. A comprehensive phytocenotic (vegetation) description was conducted for each site, focusing on species composition, abundance, ecological characteristics, and disturbance regimes.

Coenopopulations 1 and 2 were located near the villages of Sentob and Temirkovuq in the Nurata District. These areas are subjected to continuous, year-round livestock grazing. This anthropogenic pressure has visibly influenced the structure and floristic composition of the plant communities, resulting in signs of degradation and a simplified vegetation profile.

Coenopopulation 3 was identified in the vicinity of Chuqurkuduk, near Lake Aydarkul. The environmental conditions here are characterized by semi-desert features, with moderately disturbed habitats supporting relatively stable populations of *P. harmala*.

Coenopopulation 4 was recorded along the Dehibaland-Ajrim road corridor. This area is partially affected by road development and transit-related disturbances, yet retains patches of semi-natural vegetation.

Coenopopulation 5 originated from habitats adjacent to the Central Kyzylkum Desert, representing typical desert-steppe vegetation under minimal anthropogenic influence.

Coenopopulation 6 was observed near the village of Chuya, at the foothills of the Aktau Mountains. This site combines montane and semi-arid ecological features, offering favorable conditions for the development of *P. harmala*-dominated communities.

Quantitative analysis of the six coenopopulations revealed considerable variability in the relative abundance of *P. harmala*, ranging from 5% to 25% of total vegetation cover. The highest species representation was recorded in less disturbed areas with limited grazing pressure, suggesting that the species thrives under conditions of minimal anthropogenic disturbance. In contrast, areas experiencing intensive and prolonged grazing exhibited lower densities of *P. harmala*, highlighting the plant's sensitivity to overgrazing and habitat degradation.

Floristic assessments indicated that the overall species richness within these coenopopulations was relatively low, ranging from 12 to 22 vascular plant species per site. This moderate level of diversity is consistent with the arid and semi-arid climatic conditions of the region, as well as the influence of land-use practices such as grazing. The limited species richness is likely a consequence of both environmental constraints (e.g. low soil moisture, high-temperature variability) and human-induced pressures, particularly overgrazing and habitat fragmentation.

These findings underscore the ecological vulnerability of *P. harmala* populations and their associated plant communities. They also highlight the importance of developing targeted conservation and sustainable management strategies to protect these valuable phytogenetic resources. Future research should focus on population dynamics, seed regeneration potential, and long-term monitoring to support *in situ* conservation and possible cultivation initiatives for medicinal use (Table 1).

**Table 1.** Botanical description of plant communities.

| N˚ | The name of the plant | Life form | Species coverage, (CP) % | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | *Crataegus songarica* C. Koch. | Tree | – | – | – | – | – | 2 |
| 2 | *Pistacia vera* L. | Tree | 1 | – | – | – | – | – |
| 3 | *Prunus bucharica* (Korsh.) Hand.-Mazz. | Tree | – | – | + | 8 | 3 | 2 |
| 4 | *Astragalus* sp. | Shrub | 1 | – | – | – | – | – |
| 5 | *Salvia karelinii* J.B. Walker | Semi-shrub | – | – | + | – | – | – |
| 6 | *Artemisia ferganensis* Krasch ex \|Poljak | Semi-shrub | 2 | – | – | – | – | – |
| 7 | *Artemisia* sp. | Perennial | + | – | – | – | – | – |
| 8 | *Allium barsczewskii* Lipsky | Perennial | – | – | – | + | – | – |
| 9 | *Allium caesium* Schrenk | Perennial | – | – | – | – | – | + |
| 10 | *Achillea wilhelmsii* K. Koch. | Perennial | – | – | – | – | + | – |
| 11 | *Agropyron badamense* Drobow | Perennial | – | – | + | – | – | – |
| 12 | *Astragalus turkestanus* Bunge ex Boiss | Perennial | – | – | – | – | + | – |
| 13 | *Artemisia eremophila* Krasch. & Butkov ex Poljakov | Perennial | – | – | + | – | – | – |
| 14 | *Artemisia oliveriana* J. Gay ex Besser | Perennial | – | – | – | 2 | – | – |
| 15 | *Bromus lanceolatus* Roth | Perennial | – | + | – | – | – | – |
| 16 | *Carex pachystachya* Cham. ex Steud | Perennial | 2 | + | + | + | – | – |
| 17 | *Carex diluta* M. Bieb. | Perennial | + | – | – | – | – | – |
| 18 | *Carex turkestanica* Regel | Perennial | – | – | – | – | – | + |
| 19 | *Dianthus crinitus* Sm. | Perennial | – | – | + | – | – | – |
| 20 | *Dianthus helenae* Vved. | Perennial | + | – | – | – | – | – |
| 21 | *Dodartia orientalis* L. | Perennial | – | – | – | – | – | + |
| 22 | *Elwendia* sp. | Perennial | – | – | – | – | + | – |
| 23 | *Ephedra* sp. | Perennial | + | – | 1 | – | 1 | – |
| 24 | *Eremurus soogdianus* (Regel) Benth. & Hook. f. | Perennial | + | 5 | – | – | – | – |
| 25 | *Eremurus olgae* Regel | Perennial | – | – | + | + | – | – |
| 26 | *Eremopyrum orientale* (L.) Jaub. & Spach. | Perennial | + | – | – | – | – | – |
| 27 | *Ferula nuratavica* Pimenov | Perennial | + | – | – | – | – | – |
| 28 | *Gagea capusii* A. Terracc. | Perennial | – | – | – | + | – | – |

**Continued**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 29 | *Gentiana olivieri* Griseb. | Perennial | + | + | − | + | − | + |
| 30 | *Haplophyllum acutifolium* (DC.) G. Don | Perennial | − | − | − | + | − | − |
| 31 | *Ixiolirion tataricum* (Pall.) Schult & Schult. f. | Perennial | − | + | + | − | + | + |
| 32 | *Jurinea lasiopoda* Trautv. | Perennial | − | − | + | − | − | − |
| 33 | *Mediasia macrophylla* (Regel *Nepeta olgae* Schmalh.) Pimenov | Perennial | 1 | + | − | − | − | − |
| 34 | *Muscari neglectum* Guss. ex Ten. | Perennial | − | − | − | − | − | + |
| 35 | *Nepeta olgae* Regel | Perennial | − | + | − | − | − | − |
| 36 | *Onosma dichroantha* Boiss | Perennial | − | − | − | + | − | − |
| 37 | *Oxytropis macrocarpa* Kar. & Kir. | Perennial | − | − | + | − | − | − |
| 38 | *Oxytropis capusii* Franch. | Perennial | − | − | − | − | + | − |
| 39 | *Origanum vulgare* subsp. *gracile* (K/Koch) letsw. | Perennial | − | − | − | − | − | + |
| **40** | ***Peganum harmala*** | **Perennial** | **15** | **20** | **25** | **8** | **7** | **5** |
| 42 | *Phlomis linearifolia* Zakirov | Perennial | − | + | − | 1 | − | − |
| 43 | *Phlomis thapsoides* Bunge | Perennial | − | − | − | + | − | − |
| 44 | *Phlomoides* sp. | Perennial | − | + | − | − | − | − |
| 45 | *Poa bulbosa* L. | Perennial | 1 | 1 | − | 1 | − | − |
| 46 | *Poa fragilis* Ovcz. | Perennial | − | − | + | − | + | + |
| 47 | *Polygonatum sewerzowii* Regel | Perennial | − | − | − | − | − | + |
| | *Rheum maximowiczii* Losinsk. | Perennial | + | 1 | + | + | − | − |
| 48 | *Salvia sclarea* L. | Perennial | 1 | − | + | − | − | + |
| 49 | *Scutellaria comosa* Juz. | Perennial | − | + | − | − | − | − |
| 50 | *Stipa caucasica* Schmalh. | Perennial | − | − | + | − | − | − |
| 51 | *Tulipa korolkowii* Regel | Perennial | + | + | − | + | − | − |
| 52 | *Tulipa turkestanica* (Regel) Regel | Perennial | 1 | − | − | + | + | − |
| 53 | *Artemisia annua* L. | Annual | + | + | − | 2 | − | − |
| 54 | *Astragalus camptoceras* Bunge | Annual | + | − | − | − | − | − |
| 55 | *Galium pamiroalaicum* Pobed. | Annual | − | − | − | − | − | + |
| 56 | *Papaver dubium* L. | Annual | + | − | − | − | − | − |
| 57 | *Papaver pavoninum* Schrenk | Annual | − | + | + | − | + | − |
| 58 | *Pedicularis olgae* Regel | Annual | − | + | − | − | − | − |
| 59 | *Spiraea hypericifolia* L. | Annual | − | − | − | − | − | 1 |
| 60 | *Ziziphora clinopodioides* subsp. *pamiroalaica* (Juz.) *Sennikov* & *Lazkov* | Annual | − | − | − | − | − | + |
| 61 | *Ziziphora tenuior* L. | Annual | + | + | − | − | − | − |

During the course of the study, regular and often unmanaged livestock grazing was observed across the majority of sites where *Peganum harmala* populations occur. Although the species is generally considered unpalatable to most domestic herbivores and is rarely consumed directly, grazing still exerts a significant indirect impact on its populations through mechanical disturbance.

Uncontrolled grazing pressure frequently leads to trampling of vegetative structures, including stems, leaves, and basal shoots. This physical damage compromises the plant's ability to regenerate vegetatively and may negatively affect its overall vigor and competitive capacity within the plant community. Repeated mechanical injury can also reduce photosynthetic capacity, weaken plant resilience to environmental stressors, and impair clonal propagation mechanisms—an essential component of persistence for many xerophytic perennials in arid ecosystems.

Moreover, grazing-related disturbance often results in the premature dispersal or destruction of diaspores (seeds and fruits), interrupting the reproductive cycle of the species. In *P. harmala*, successful generative reproduction is contingent upon full seed maturation, which typically occurs over a specific phenological window. When this process is disrupted—either through direct trampling or early detachment of immature diaspores—the quality and viability of reproductive output are significantly reduced. This, in turn, limits the natural recruitment of seedlings and poses a long-term threat to population stability, especially in habitats already subject to climatic extremes and limited soil fertility.

These findings emphasize the need for adaptive grazing management practices in regions where *P. harmala* and other ecologically or pharmacologically significant species occur. Strategies such as rotational grazing, seasonal grazing exclusion, and community-based rangeland stewardship could mitigate the adverse impacts of overgrazing, thereby enhancing the sustainability of both natural plant communities and the ecosystem services they provide (**Figure 2**).

## 4. Discussion

In the Nurota mountain range and adjacent areas, the distribution of *Peganum harmala* is notably denser compared to other regions of Uzbekistan. However, its spatial distribution remains markedly uneven across different ecological zones, reflecting the species' sensitivity to local environmental conditions.

To evaluate the resource potential of *P. harmala*, detailed phytocenological studies were conducted within natural plant communities where the species occurs. These assessments included analyses of total occupied area, reserve-eligible sites, permanent monitoring plots, population density (measured as the number of individuals per 10 × 10 m quadrats), biological and exploitable biomass reserves, average biomass per individual plant, and the estimated annual harvestable yield.

Field investigations revealed that the species' natural habitat spans an area ranging from 20 to 70 hectares at surveyed sites, while zones with exploitable biomass reserves comprise between 13 and 47 hectares. Population density varied between 24 and 55 individuals per 100 m$^2$, indicating a moderate to high level of

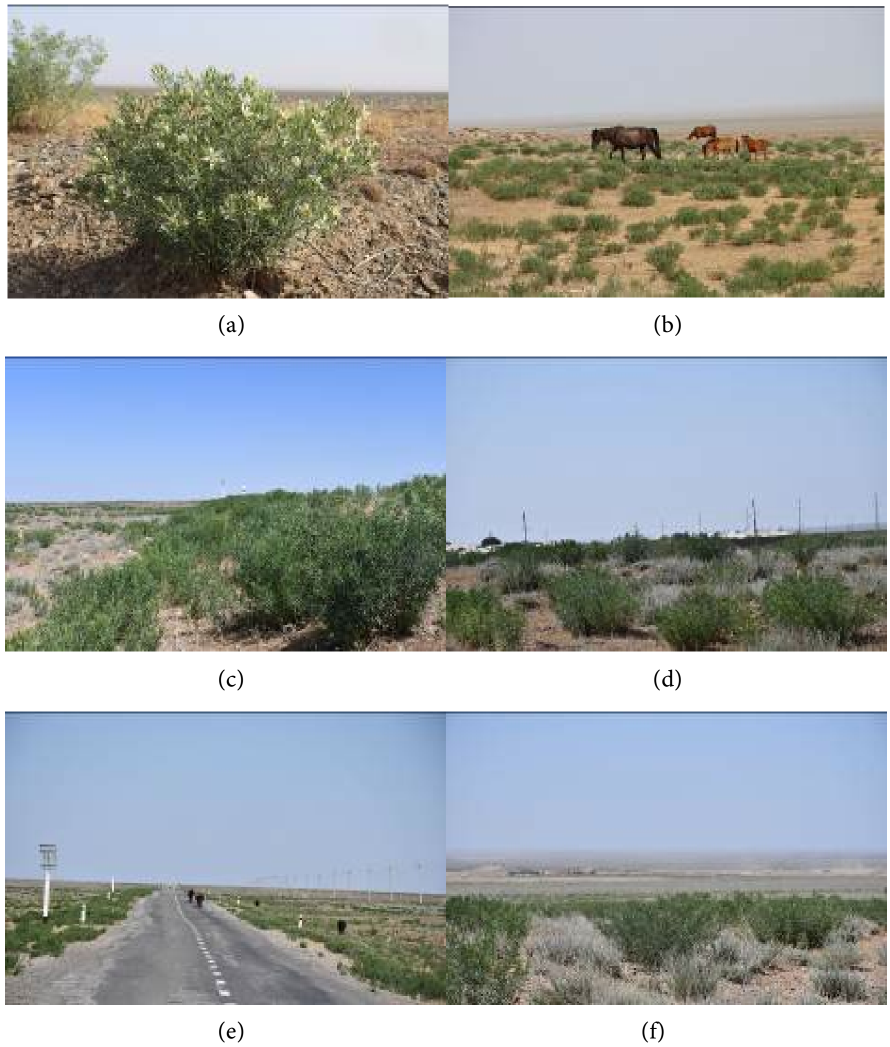


**Figure 2.** Areas where *Peganum harmala* is widespread.

abundance, influenced by local soil, moisture availability, and grazing intensity.

Biomass analysis demonstrated that total biological reserves of *P. harmala* ranged from 1.80 to 16.2 tonnes across study sites. The exploitable portion of these reserves—defined as the biomass that can be harvested without compromising population sustainability—ranged from 1.08 to 9.72 tonnes. These values align with ecological thresholds for sustainable harvesting in arid and semi-arid ecosystems, particularly for xerophytic and halophytic species. In such environments, it is generally accepted that up to 60% of exploitable biomass may be harvested without significant detriment to the species' long-term viability. This is based on the high ecological plasticity and regenerative capacity observed in *P. harmala* under natural stress conditions such as salinity, drought, and anthropogenic disturbance.

Estimates of potential annual harvestable biomass ranged from 0.54 to 4.86 tonnes across the studied areas. The most resource-abundant populations were found near the Lake Aydarkul region, where favorable edaphic (soil-related) and hydrological conditions were positively correlated with increased plant productivity. These results underscore the significance of microhabitat factors in determining resource potential.

Pharmacologically valuable biomass is primarily sourced from the aerial vegetative organs—namely stems, leaves, and inflorescences—which contain a range of bioactive compounds of medicinal interest. Depending on environmental factors and individual plant vigor, the average fresh biomass per individual ranged from 336 to 630 grams.

In conclusion, the study provides a comprehensive, scientifically grounded assessment of *P. harmala*'s resource potential in the Nurota region and surrounding landscapes. The estimated annual harvestable biomass yield of 0.54 to 4.86 tonnes highlights the species' economic and pharmacological value. These findings serve as a foundation for the formulation of sustainable harvesting protocols and evidence-based conservation management plans aimed at preserving wild medicinal plant resources in arid and semi-arid ecosystems of Central Asia (**Table 2**).

**Table 2.** Resource indicators of the *Peganum harmala.*

| CP | SDA (ha) | RVF | NF (pcs.) | 100 м$^2$ | BR | ER | BW, gr. | ACV, t. |
|---|---|---|---|---|---|---|---|---|
| 1 | 40 | 23 | 20 | 39 | 2.99 | 1.79 | 335 | 0.89 |
| 2 | 55 | 38 | 28 | 48 | 6.56 | 3.93 | 360 | 1.96 |
| 3 | 70 | 47 | 35 | 55 | 16.2 | 9.72 | 630 | 4.86 |
| 4 | 35 | 19 | 16 | 32 | 2.49 | 1.49 | 410 | 0.74 |
| 5 | 30 | 15 | 14 | 28 | 1.99 | 1.19 | 475 | 0.59 |
| 6 | 20 | 13 | 11 | 24 | 1.80 | 1.08 | 580 | 0.54 |

Note: Species distributed area (SDA); Reserve-valued field (RVF); number fields (NF), 10 × 10 (100 м$^2$); Biological reserve (BR); Expansion Reserve (ER); Bush weight (BW); Annual Collection Volume (ACV).

The widespread distribution and ecological persistence of *Peganum harmala* across arid and semi-arid regions of Central Asia, including Uzbekistan, Kazakhstan, Turkmenistan, and surrounding areas, reflect its exceptional adaptability to harsh environmental conditions. In many parts of the region, particularly in the foothills, semi-desert zones, and degraded rangelands, *P. harmala* is often observed as a dominant or subdominant species within plant communities.

Several ecological and biological traits contribute to its success. First, its high seed production and efficient dispersal mechanisms enable rapid colonization of disturbed or marginal habitats. The seeds of *P. harmala* are well adapted to abiotic dispersal by wind and water, and may also be spread through animal activity, including livestock movements, which are common in Central Asian grazing systems.

Second, its drought tolerance and ability to withstand temperature extremes are critical for survival in the continental climate of Central Asia, where precipitation is scarce and unevenly distributed. The deep taproot system of *P. harmala* facilitates water absorption from deeper soil layers, providing it with a competitive advantage over shallow-rooted species, especially during prolonged dry periods. Moreover, the allelopathic properties of *P. harmala*, through the release of bioactive secondary metabolites, may inhibit the germination and growth of neighboring plant species. This capacity allows *P. harmala* to reduce interspecific competition and maintain dominance in areas with limited biodiversity, a common feature in overgrazed or degraded landscapes throughout the region.

In addition, *Peganum harmala* exhibits notable ecological resilience to a variety of anthropogenic pressures, including intensive grazing, trampling, and soil compaction. These disturbances—common across many rangeland and pastoral landscapes of Central Asia—frequently result in the decline or local extinction of more sensitive plant species. In contrast, *P. harmala* not only persists under such stressors but may also increase in abundance, often forming dense, monospecific or co-dominant stands. This ecological behavior positions *P. harmala* as a potential bioindicator of land degradation and ecosystem imbalance, particularly in arid and semi-arid steppe environments.

From an ethnobotanical perspective, the long-standing cultural and medicinal use of *P. harmala* across Central Asia may further influence its spatial distribution. The seeds are widely harvested for traditional medicine, ritualistic purposes, and cultural practices, especially among rural and nomadic populations. Human-mediated dispersal—either intentional or unintentional—through seed collection, trade, or ritual use may facilitate the spread of the species across anthropogenically altered landscapes.

The ecological success of *Peganum harmala* in Central Asia can thus be attributed to a combination of biological traits and external factors. These include its high environmental plasticity, tolerance to abiotic and biotic stressors, allelopathic properties, and compatibility with disturbed habitats. Its prevalence in overgrazed or degraded areas suggests an opportunistic strategy that allows it to occupy ecological niches left vacant by more sensitive competitors.

Furthermore, its role in shaping plant community dynamics and successional processes in disturbed ecosystems warrants closer scientific scrutiny. On one hand, *P. harmala* may contribute to soil stabilization and early successional vegetation recovery. On the other, its competitive dominance and potential allelopathic interactions could suppress the regeneration of less resilient native flora, thereby influencing biodiversity patterns and ecosystem functionality.

In summary, the ecological prominence of *Peganum harmala* in Central Asia is the result of its intrinsic adaptive mechanisms and its ability to exploit disturbance regimes, both natural and anthropogenic. Its dual role as a culturally significant medicinal plant and an ecological indicator species highlights the importance of integrated research approaches that consider its impacts on biodiversity, rangeland health, and sustainable land management practices.

## 5. Conclusions

*Peganum harmala*, commonly known as Syrian rue, is widely utilized both globally and in the modern pharmaceutical industry as a medicinal plant due to its rich content of bioactive alkaloids. Compounds such as harmaline, harmine, and harmalol exhibit antimicrobial, antioxidant, and neuroprotective properties. In Uzbekistan, particularly in regions such as the Navai province, the local population has traditionally used this plant for medicinal purposes for several centuries, reflecting its enduring ethnobotanical significance.

Furthermore, it was observed that plant specimens were collected in a disorganized manner, without considering their phenological development stages. This practice adversely affects their potential generative productivity. In particular, some seeds were harvested before completing the full embryogenesis stage, resulting in incomplete maturation.

The effective utilization of the potential of this plant species, which is widespread in the Navai region, and the comprehensive assessment of its natural reserves are of significant scientific and practical importance. Due to its high resistance to various ecological and climatic stress factors, this species can be cultivated even under unfavorable environmental conditions. Therefore, a thorough investigation into the possibilities for its optimal and sustainable use is essential.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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