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Original Research

Remote Sensing and GIS-Based Spatial Analysis of Arid Sparse Forest Vegetation in the Turyanchay State Nature Reserve (within Azerbaijan)

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Abstract

The research was conducted in the territory of the Turyanchay State Nature Reserve, located in Ganja-Gazakh and Shirvan physiographic regions of the Republic of Azerbaijan. Here, arid, sparse forest vegetation was studied using phytocenological principles. The study analyzed the relief, altitudinal zones, and spatial distribution characteristics of the Turyanchay State Nature Reserve (SNR) using the Geographic Information Systems (GIS) approach. The analyses were conducted in the ArcGIS Pro software environment. Based on the digital elevation model (DEM) of the area, elevation intervals, slope, and exposure indicators were calculated, and the relationship of these indicators with the distribution of pistachio-juniper arid sparse forests was assessed. Studies were carried out based on generally accepted geobotanical principles, and species forming vegetation were determined; their life forms were clarified. It has been established that arid, sparse forest vegetation consists of 2 formations and 3 associations within the forest vegetation type. This type of vegetation was also found in the mountainous part of Lankaran (within the Yardimli region) and in the Nakhchivan Autonomous Republic. In the course of the study, a classification scheme of plant groupings was developed, and geobotanical descriptions were given. Phytocenological analysis revealed that the association Caraganetum-Pistaciae-Juniperosum was formed with participation of 25 species (20-50% of total cover), the association Astragaletum-Acantholimonae-Juniperosum with 18 species (45% of total cover), and the association Paliurusetum-Pistaciae-Juniperosum with 24 species (60% of total cover). In general, in these cenoses, *Pistacia*

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mutica Fisch. et C.A. Mey., *Juniperus oblonga* Bieb., *J. polycarpos* K. Koch, and *Paliurus spina-christi* Mill. are recorded as the dominant species.

Keywords: arid forest, classification and GIS mapping of vegetation, DEM, plant groupings, phytocenological analysis

Introduction

The degradation of the natural environment under conditions of intensive climate change, combined with increasing anthropogenic pressure on ecosystems, has significantly accelerated the process of aridization. These transformations negatively affect the structure, stability, and productivity of natural landscapes, particularly in arid and semi-arid regions. In this context, systematic monitoring of arid landscape vegetation is of particular importance. Studying the current condition of economically valuable, endemic, rare, and other ecologically significant plant species is essential for developing effective conservation strategies. Furthermore, the identification of sustainable species and the formation of stable plant communities are highly relevant from both scientific and practical perspectives, as they contribute to biodiversity conservation and the long-term sustainability of arid ecosystems [1, 2].

Within the territory of the Republic of Azerbaijan, xerophytic (arid) sparse forests are distributed at elevations ranging from 600 to 1200 m above sea level. These forests predominantly occur on mountain brown soils and are characteristic of foothill, low-mountain, and middle-mountain zones, as well as xerophytic forest and shrub mountain-steppe landscapes. Xerophytic forest vegetation represents the principal plant cover of arid regions and plays a crucial role in soil protection, water regulation, and the maintenance of ecological balance. The xerophytic forest type in Azerbaijan has been the subject of continuous scientific investigation since 1949. Significant contributions to its study have been made by numerous researchers, including Grossheim A.A. [3], Prilipko L.I. [4], Gadjiev V.D. [5], Mammadova Z.J. [6, 7], Gurbanov E.M. [8], Rzayeva A.A. [9, 10], and others, whose works have laid the foundation for understanding the composition, structure, and ecological significance of xerophytic forest ecosystems in the country.

Grossheim A.A. [3] classified the sparse arid forests of the South Caucasus as a distinct and independent type of vegetation. According to his interpretation, these forests are characterized by open, well-lit stands with discontinuous and unclosed tree canopies. The arboreal layer is formed mainly by xerophytic tree species adapted to arid and semi-arid climatic conditions, while the ground layer is dominated by steppe grasses and herbaceous plants. This combination of woody xerophytes and steppe vegetation reflects the ecotonal nature of these ecosystems and highlights their adaptation to limited moisture availability.

Building on this concept, Mammadov G.Sh. and Khalilov M.Y. [11] further interpreted arid forests as a transitional vegetation belt between treeless semi-deserts and the continuous forest zone, emphasizing their intermediate ecological and floristic characteristics. In their view, these communities represent a dynamic transition stage where forest elements gradually replace desert and steppe components under relatively favorable conditions while still retaining pronounced xerophytic and steppe features.

In the foothill regions of Azerbaijan, where xerophytic sparse forests are widely distributed, long-term human activity, particularly agriculture and cattle breeding, has significantly altered natural vegetation cover, leading to the formation of secondary and derived phytocenoses. Against this background, the Turyanchay State Nature Reserve represents one of the most important refugia of relatively well-preserved arid forest ecosystems. Established in 1958 and covering an area of 22,488 hectares across Agdash, Oguz, Yevlakh, and Gabala districts, the reserve plays a key role in the conservation of xerophytic sparse forests and associated rare and endemic plant species.

Within this context, the present study focuses on the species composition and structural organization of Pistachio–Juniper sparse forest vegetation in the Turyanchay State Nature Reserve, with particular emphasis on plant communities containing economically valuable, rare, and ecologically significant species. The study area, located in the Agdash region on the southern slopes of the Greater Caucasus and the northwestern part of the Shirvan Plain, represents a transitional geographical zone characterized by complex environmental conditions that support high habitat diversity and biodiversity value, as reflected in the Red Data Book of the Republic of Azerbaijan [12].

Against this ecological and biogeographical background, arid forest ecosystems of the South Caucasus remain among the least quantitatively resolved vegetation systems despite their high conservation importance. Addressing this gap, the present study moves beyond traditional descriptive phytocenological approaches by developing an integrated, spatially explicit ecological framework for Pistachio-Juniper sparse forests in the Turyanchay State Nature Reserve. By integrating fine-scale field-based phytosociological surveys with GIS-based terrain modelling derived from a 30 m digital elevation model, vegetation patterns were reconstructed along key environmental gradients, including elevation, slope, and aspect. This approach enables, for the first time in the region, a spatially explicit delineation of plant association boundaries based on georeferenced field data rather than solely expert interpretation.

Furthermore, the study integrates classical South Caucasian geobotanical traditions with contemporary landscape ecology by situating vegetation units within a multi-scale environmental framework. This allows for a clearer understanding of how topographic heterogeneity influences species assemblages and community differentiation in arid woodland ecosystems. The resulting analytical framework not only refines xerophytic forest classification but also provides a transferable methodological model for other dryland ecosystems where ecological complexity and field constraints limit conventional vegetation mapping. Overall, the study establishes a robust link between vegetation syntaxonomy and terrain-driven ecological processes, thereby contributing to improved biodiversity assessment and conservation planning in arid forest landscapes.

Materials and Methods

Physical-Geographical and Landscape Features of the Study Area

The research was carried out in the territory of the Turyanchay State Nature Reserve during 2021-2024. The reserve is located in the southeastern foothills of the Greater Caucasus, in the border zone of Ganja-Gazakh and Shirvan physiographic regions, and is considered a typical representative of arid and semi-arid landscapes [13-15]. The study area is mainly characterized by low mountain ranges and adjacent denudation surfaces, and the absolute heights vary from 50-100 m to 800-900 m. Analysis of the digital elevation model shows a high degree of fragmentation of slopes in the area, the development of deep valleys and an erosion network, which determines the formation of an arid denudation relief type [16]. The study area also corresponds to broader ecosystem classification units within the IUCN Global Ecosystem Typology framework. In terms of realm and biome classification, the system can be linked to the Terrestrial-Freshwater (TF) realm, particularly transitional ecological settings where terrestrial and freshwater interactions are significant. Within this framework, the surrounding landscape is associated with the Rivers and Streams biome (F1), reflecting the influence of fluvial processes on vegetation distribution and ecosystem dynamics.

The climate is influenced by the temperate-warm semi-desert and dry steppe climate types. The average annual temperature is about 14°C, the annual precipitation varies between 200-500 mm, and precipitation is recorded mainly in the spring and autumn seasons. High temperatures and intense evaporation in the summer months limit the soil-moisture balance, creating favorable conditions for the development of xerophytic vegetation [17].

The soil cover consists mainly of hilly brown, brown, light brown and gray-brown soils. These soils are characterized by carbonation, relatively low humus content and light mechanical composition, and are considered prone to water erosion due to the slope of the relief. The relief stratification and slope exposure determine the mosaic distribution of soil types and vegetation cover over space [18].

The landscape structure is dominated by the semi-desert landscape of the low mountains and the dry-steppe landscape of the plains. Within these landscapes, sparse pistachio-juniper forests, wormwood and other xerophytic thickets constitute the main phytocenoses and were selected as the main object of the study. The interaction of relief, climate and soil factors acts as the main natural factor determining the formation of arid ecosystems and their ecological characteristics in the Turyanchay State Nature Reserve [19].

Geobotanical Research and Vegetation Classification Methods

In the course of the study, when studying the species composition, structure of plant groupings, and their modern state, geobotanical descriptions were carried out, and at this time, the taxonomic structure of the flora, the vital forms of plants found in it [20], ecological groups [21], etc., were defined. Also, during the study, a classification scheme was developed based on the relevant literature and ecological and geobotanical studies conducted in xerophytic (arid) sparse forests in the territory of the Republic of Azerbaijan. Phytocoenoses created by plants occurring in the area were studied under semi-permanent conditions. Thus, in determining the type of vegetation, formations, and associations found in the territory, i.e. in field studies, plant identification and geobotanical descriptions were based on “Flora of Azerbaijan” [22], “Field Geobotany” [23], Gurbanov [8] and other geobotanical methods, and recent nomenclatural changes in species names were checked using “The World Flora Online” [24].

Biodiversity indices (Shannon and Simpson diversity indices) were calculated using species abundance scores (1-4) derived from relevé data, which were subsequently converted into relative proportions (pi). The calculations were performed in accordance with standard phytosociological and vegetation-ecological methods for semi-quantitative data analysis [25-27].

Geographic Information Systems (GIS) and ArcGIS Pro Methodology

All maps and spatial analyses were produced using ArcGIS Pro 3.6 software [28]. The boundary map of the Turyanchay State Nature Reserve was digitised and georeferenced within the software. Reserve boundaries were manually digitised as polygon features and attributed to the corresponding coordinate reference system.

The Digital Elevation Model (DEM) used in this study has a spatial resolution of 30 m (1 arc-second), obtained from the SRTM dataset via the OpenTopography portal [16]. The DEM was imported into ArcGIS Pro and clipped to the study area extent using the Extract by Mask tool. The extracted elevation data were subsequently reclassified into four altitudinal intervals to characterise the hypsometric zonation of the reserve. A hillshade layer was generated to enhance the visual representation of relief features in cartographic outputs.

Vegetation distribution maps were produced on the basis of field surveys conducted within the reserve. GPS-recorded locality data collected during field observations were used to delineate association group boundaries. Individual plant association groups were digitised as polygon features using the polygon mapping tool in ArcGIS Pro and attributed according to the dominant species composition recorded at each site. Vegetation boundaries were validated through field observations conducted during 2022-2024 and cross-checked with existing geobotanical descriptions. All cartographic outputs were prepared in Layout View in accordance with standard map design requirements, including scale bar, north arrow, legend, and coordinate grid.

Results and Discussion

In the territory of the Republic of Azerbaijan, forest vegetation is mainly distributed in mountainous and high-mountainous areas and is classified as broad-leaved, coniferous, and rare arid forests. Arid sparse forests by composition are gum tree, juniper, oak, pine, hackberry, almond, pear-hawthorn forests, etc. [13]. Brown mountain forest soils are predominantly developed in the lower altitudinal zones of xerophytic shrublands and forests, particularly in regions characterized by the extensive distribution of pistachio-juniper formations, including the Araz riverside areas, the middle and lower elevations of the Greater and Lesser Caucasus Mountains, and the Nakhchivan Autonomous Republic [28]. The distribution areas of sparse arid forests in the Lesser Caucasus are gradually shrinking, and juniper trees are seldom found in natural conditions on the Absheron Peninsula, except for a sparse distribution in the Duvanny area of the Gobustan region [6]. In the territory of the republic, the following types of formations are distinguished: pistachio sparse forests, pistachio-juniper sparse forests, juniper sparse forests, arid sparse forests formed by Georgian oak, pine-juniper sparse forests characterized by the dominance of Eldar pine, pear-hawthorn sparse forests, hackberry and maple-hackberry sparse forests, as well as almond and Araz oak-dominated sparse forest formation types [18]. Arid sparse forests of the Turyanchay State Nature Reserve are found in plain and foothill areas.

In the course of ecological-geobotanical research conducted based on phytocenological principles, a class of pistachio-juniper sparse forest formations occurs in xerophytic (arid) sparse forests with predominance of leguminous shrubs in the study area; 1 type of vegetation, 1 class of formations, 2 groups of formations, and 2 associations were determined. The classification scheme and GIS mapping of association groups were developed (Figs. 1 and 2).

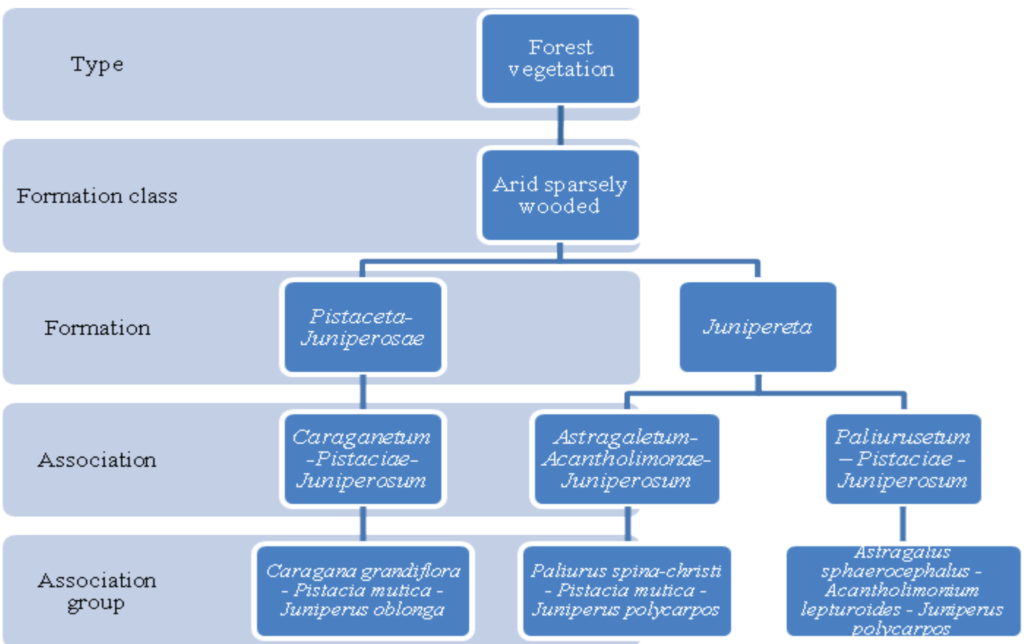

Fig. 1. Classification scheme of xerophytic sparse forest vegetation in the Turyanchay SNR.

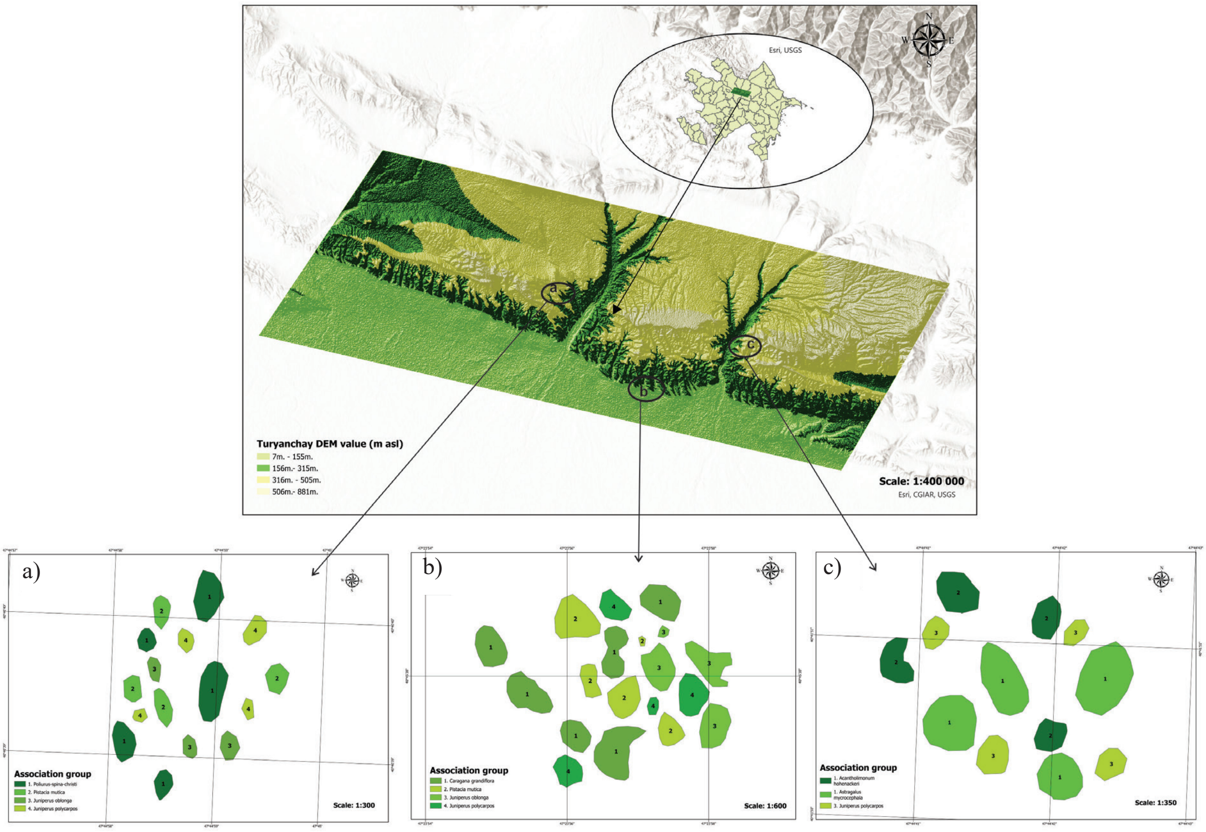

Fig. 2. Vegetation mapping based on association groups of the study area. a) Paliurusetum-Pistaciae-Juniperosum association; b) Caraganetum-Pistaciae-Juniperosum association; c) Astragalus sphaerocephalus-Acantholimonium lepturoides-Juniperus polycarpos association).

According to the IUCN Red List of Ecosystems Global Ecosystem Typology, these vegetation formations are related to temperate xeric woodlands and shrublands occurring within the dryland ecosystem complexes of the Caucasus region. This classification highlights the ecological and conservation significance of the arid woodland ecosystems identified within the Turyanchay State Nature Reserve [29].

The class of formations of arid sparse forests identified on the territory is represented by pistachio-juniper (Pistaceta-Juniperosae) sparse forests dominated by leguminous shrubs and juniper formations (Junipereta) dominated by juniper species. The pistachio-juniper formation (Pistaceta-Juniperosae) is represented by the caragana-pistachio-juniper (Caraganetum-Pistaciae-Juniperosum) association; and juniper formation (Junipereta) is represented by 2 associations: milkvetch-prickly thrift-juniper (Astragaletum-Acantholimonae-Juniperosum) and garland thorn-pistachio-juniper (Paliurusetum-Pistaciae-Juniperosum).

1. Caragana-pistachio-juniper association: During the research, it was found that this phytocenosis is represented by an associative group of caragana large-flowered - pistachio blunt-leaved - juniper common (*Caragana grandiflora* - *Pistacia mutica* - *Juniperus oblonga*). The species composition and structure of this grouping, with predominance of the common juniper, was recorded in June 2021-2024, 5 km from the Turyanchay River, in the territory of the Gabala district, located on the southern slope of the Greater Caucasus Range, within the Turyanchay SNR, in the territory of Bayramkokhala municipality (Table 1).

During this research, it became clear that 25 species occur within the Caragana-pistachio-juniper association (Caraganetum-Pistaciae-Juniperosum). This conclusion was based on systematic phytocenological field surveys conducted using standard releve sampling methods. Within each representative plot, all vascular plant species were recorded, and species presence was verified across multiple sampling sites within the association. The total number of species (25) represents the cumulative species pool identified across all sampled releves within this community type. According to their vital forms, 4 species (16.0%) are trees, 8 species (32.0%) are shrubs, 1 species (4.0%) is a semi-shrub, and 12 species (48.0%) are perennial grasses. Of these species, by ecological groups, 14 species (56.0%) were categorized as xerophytes, 4 species (16.0%) as mesoxerophytes, and 7 species (28.0%) as mesophytes.

As indicated in the classification scheme and in the geobotanical description, the dominant of this association is the juniper common (Caucasian) (*Juniperus oblonga* Bieb.), its abundance is 3-4 points;

Table 1. Species composition and structure of the Caraganetum-Pistaciae-Juniperosum association.

No.	Name of biomorphic species	Ecological groups	Abundance (in points)	Average height (in cm)	Phenological phases
Trees					
1.	*Pistacia mutica* Fisch. et C.A. Mey.	Xerophyte	2-3	I (600)	Vegetation
2.	*Acer ibericum* Bieb.	Mesoxerophyte	2	I (500)	Flowering
3.	*Pyrus georgica* Kuth.	Xerophyte	1-2	I (400)	Fruit ripening
4.	*Celtis caucasica* Willd.	Xerophyte	1-2	I (300)	Fruit ripening
Shrubs					
5.	*Juniperus oblon*ga Bieb.	Xerophyte	3-4	I (400)	Vegetation
6.	*Caragana grandiflora* (Bieb.) DC.	Xerophyte	2	I (100)	Flowering
7.	*Crataegus eriantha* Pojark.	Xerophyte	1-2	I (450)	Fruiting
8.	*Rhamnus spathulifolia* Fİsch. et C.A.Mey	Mesoxerophyte	1-2	I (250)	Flowering
9.	*Ephedra procera* Fisch. et C.A.Mey.	Xerophyte	1-2	I (150)	Vegetation
10.	*Viburnum opulus* L.	Xerophyte	1-2	I (120)	Flowering
11.	*Spiraea crenata* L.	Xerophyte	1-2	I (100)	Fruiting
12.	*Astragalus denudata* (Stev.) Podlech	Xerophyte	1-2	III (30)	Flowering
Semi-shrubs					
13.	*Thymus hadzhievii* Grossh.	Xerophyte	1-2	III (15)	Flowering
Perennial grasses					
14.	*Astragalus glycyphyllos* L.	Mesophyte	2	II (70)	Bean ripening
15.	*Nepeta cataria* L.	Mesophyte	1-2	II (65)	Flowering
16.	*Festuca alexeenkoi* E. Alexeev	Mesophyte	1-2	II (55)	Flowering
17.	*Bothriochloa ischaemum* (L.) Keng	Xerophyte	1-2	II (50)	Flowering
18.	*Hordeum europaeum* (L.) All.	Mesophyte	1-2	II (40)	Flowering
19.	*Stipa pulcherrima* C.Koch	Xerophyte	1-2	I (100)	Flowering
20.	*Medicago glutinosa* Bieb.	Mesophyte	1	II (80)	Flowering
21.	*Artemisia caucasica* Willd.	Mesoxerophyte	1	II (40)	Vegetation
22.	*Onobrychis bobrovii* Grossh.	Mesophyte	1	III (30)	Flowering
23.	*Poa iberica* Fisch et C.A.Mey.	Mesophyte	1	III (20)	Flowering
24.	*Vicia crocea* (Dsf.) Fritsch	Mesoxerophyte	1	III (15)	Bean ripening
25.	*Gagea chlorantha* (Bieb.) Schult. et Schult.	Xerophyte	1	III (10)	Seed ripening
Total projective coverage is 20-50%.					

Note: Abundance scores (1-4) indicate species frequency, where 1 - rare, 2 - occasional, 3 - frequent, and 4 - abundant. Roman numerals (I-III) represent the cover-dominance scale, where I - low cover (<10%), II - moderate cover (10-25%), and III - high cover (>25%).

subdominants are pistachio blunt-leaved (*Pistacia mutica* Fisch. et C.A.Mey.) (Fig. 3d)) and caragana large-flowered (*Caragana grandiflora* (Bieb.) DC.). The abundance of both subdominant species was estimated at 2-3 and 2 points, respectively.

The formation structure was found to consist of three tiers of vegetation (trees, shrubs, and grasses). Thus, the 1st tier is represented by such trees as *Pistacia mutica*, *Acer ibericum*, *Pyrus georgica*, *Celtis caucasia* (height 300-600 cm); the 2nd tier is represented by shrubs *Crataegus eriantha*, *Juniperus oblonga*, *Rhamnus spathulifolia*, *Caragana grandiflora* and others (height 450-100 cm); the 3rd tier consists of perennial grasses such as *Stipa pulcherrima*, *Astragalus glycyphyllos* and others (height 70-40 cm), *Astragalus microcephalus*, *Onobrychis bobrovii*, *Thymus hadzhievii* and others (height 30-15 cm). Total projective coverage varies between 20-50%.

Table 2. Species composition and structure of the Astragaletum-Acantholimonae-Juniperosum association.

No.	Name of biomorphic species	Ecological groups	Abundance (in points)	Average height (in cm)	Phenological phases
Trees					
1.	*Juniperus polycarpos* K.Koch	Xerophyte	2	I (600)	Fruiting
2.	*Diospyros lotus* L.	Mesoxerophyte	1	I (900)	Flowering
3.	*Celtis caucasica* Willd.	Xerophyte	1-2	I (300)	Fruit ripening
Shrubs					
4.	*Juniperus oblonga* Bieb.	Xerophyte	1-2	I (500)	Fruiting
5.	*Punica granatum* L.	Xerophyte	1	II (160)	Flowering
6.	*Crataegus pentagyna* Waldst. & Kit. ex Willd.	Xerophyte	1	I (560)	Fruiting
7.	*Paliurus spina-christi* Mill.	Xerophyte	1-2	II (200)	Fruiting
8.	*Chrysojasminum fruticans* (L.) Banfi (=*Jasminum fruticans* L.)	Mesoxerophyte	1-2	II (130)	Fruiting
9.	*Acantholimon lepturoides* Boiss.	Xerophyte	2	III (15)	Fruit ripening
Perennial grasses					
10.	*Astragalus brachycarpus* M.Bieb.	Xerophyte	1	III (10)	Fruiting
11.	*Astragalus sphaerocephalus* (Steven) Trautv. (=*Astragalus macrocephalus* subsp. finitimus (Bunge) D.F.Chamb.)	Xerophyte	2	III (60)	Fruiting
12.	*Convolvulus cantabrica* L.	Xerophyte	1-2	III (40)	Flowering
13.	*Stipa pontica* P.A.Smirn.	Xerophyte	2	III (60)	Fruit ripening
14.	*Poa nemoralis* L.	Xerophyte	1-2	III (45)	Fruiting
Annual grasses					
15.	*Avena fatua* L.	Xerophyte	2	III (50)	Ripening
16.	*Cuscuta europaea* L.	Xerophyte	1-2	III (25)	Flowering
17.	*Euphorbia falcata* L.	Xeromesophyte	1	III (30)	Flowering
18.	*Heliotropium ellipticum* Ledeb.	Xerophyte	1-2	III (25)	Flowering
Total projective coverage is 45%					

Note: Abundance scores (1-4) indicate species frequency, where 1 - rare, 2 - occasional, 3 - frequent, and 4 - abundant. Roman numerals (I-III) represent the cover-dominance scale, where I - low cover (<10%), II - moderate cover (10-25%), and III - high cover (>25%).

2. Milkvetch-prickly thrift-juniper association: The studied milkvetch-prickly thrift-juniper association consists of the milkvetch spherical-slender-tailed prickly thrift-multi-fruited juniper associative group (*Astragalus sphaerocephalus-Acantholimon lepturoides-Juniperus polycarpos*). The abundance of the dominant species in this association, multi-fruited juniper (*Juniperus polycarpos* K.Koch), was estimated at 3 points (Fig. 3a)). The abundance of the subdominant species, slender-tailed prickly thrift (*Acantholimon lepturoides* Boiss.) and spherical milkvetch (*Astragalus sphaerocephalus* (Steven) Trautv.), was estimated at 2 points each (Table 2).

In the western region of Azerbaijan, within the ecosystems distributed across the Jeyranchol–Ajinohur area, *Juniperus polycarpos* has been recorded in communities dominated by bulbous blue grass and feather grass. According to the conducted assessment, the distribution degree of the species was evaluated as 4 points on the Drude scale in the first community, while in the community dominated by feather grass, it was assessed as 1 point [30, 31]. Milkvetch-prickly thrift-juniper formation, formed with the predominance of multi-fruited junipers, was recorded in the territory of the Shahbuz district of Nakhchivan AR on stony areas around Turkesh and Ayryj villages [10, 32]. It should be noted that the plant grouping milkvetch-prickly thrift-juniper is also found on dry stony slopes of the lower mountainous part of Lankaran (Zuvand) [6].

3. Garland thorn-pistachio-juniper association: The studied garland thorn-pistachio-juniper association (Paliurusetum-Pistaciae-Juniperosum) was formed

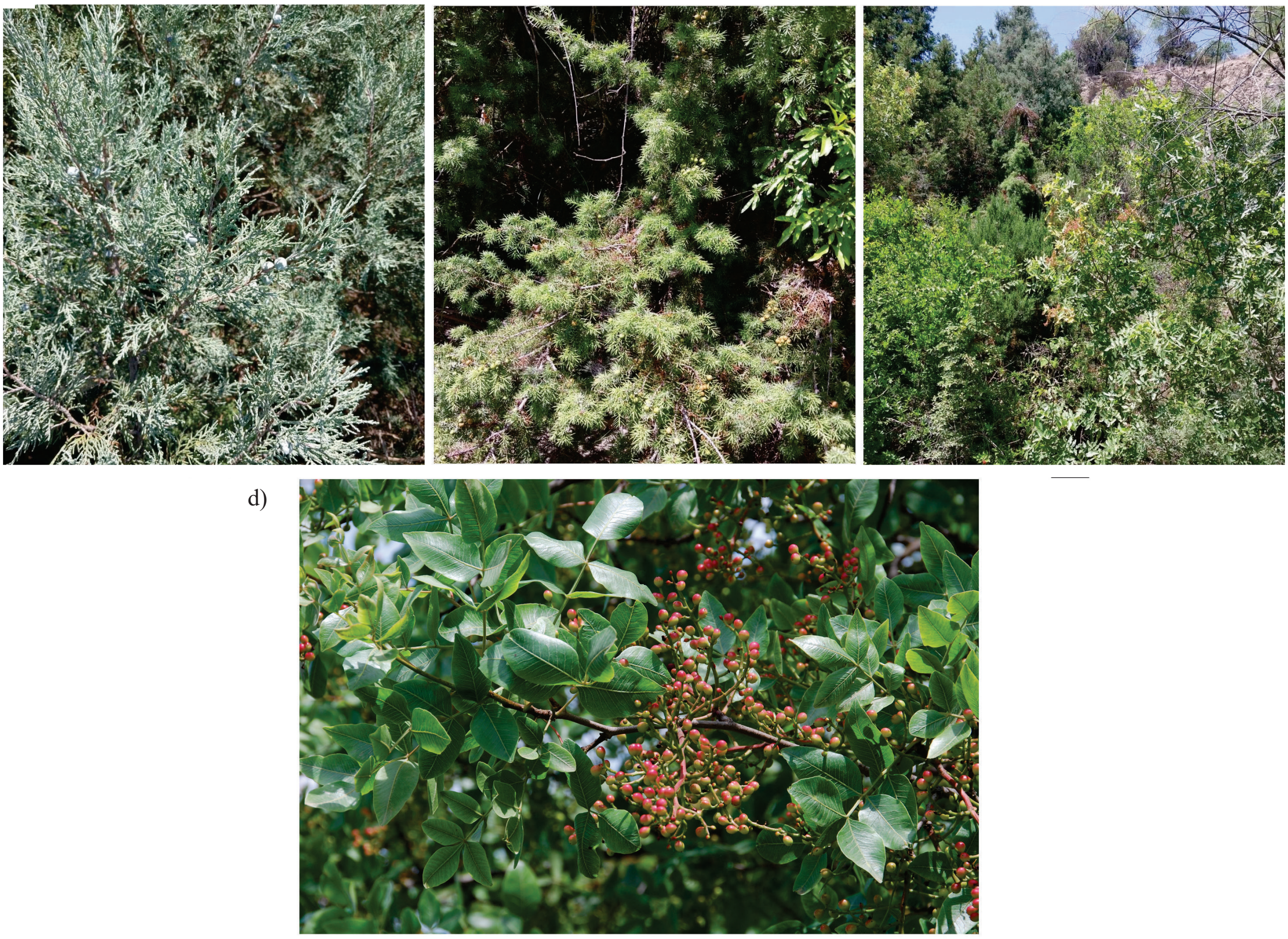

Fig. 3. a) *Juniperus polycarpos* K.Koch; b) *Juniperus oblonga* Bieb.; c) Paliurusetum-Pistaciae-Juniperosum association; d) *Pistacia mutica* Fisch. et C.A.Mey.

from the group of associations of garland thorn-blunt-leaved pistachio-juniper multi-fruited (*Paliurus spina-christi-Pistacia mutica-Juniperus polycarpos*) (Fig. 3b) and c)).

The abundance of the dominant species of the association, Pistacia mutica and Juniperus polycarpos, was estimated as 2-3 points; the abundance of the subdominant species, *Paliurus spina-christi* Mill., was estimated as 2 points. During phytocenological studies, it was found that the main part of the grouping is made up of trees and shrubs [33]. Unlike other groups, the total projective coverage is higher here (60%). Despite the formation of open cenoses, being a sparse forest, it has denser vegetation as a cover (Table 3).

To complement the phytocenological classification, biodiversity indices were calculated based on species

Table 3. Species composition and structure of the Paliurusetum-Pistaciae-Juniperosum association.

No.	Name of biomorphic species	Ecological groups	Abundance (in points)	Average height (in cm)	Phenological phases
Trees					
1.	*Juniperus polycarpos* K.Koch	Xerophyte	2-3	I (700)	Fruiting
2.	*Juniperus foetidissima* Willd.	Xerophyte	1	I (1200)	Fruiting
3.	*Pistacia mutica* Fisch. et C.A. Mey.	Xerophyte	2-3	I (600)	Fruiting
4.	*Celtis caucasica* Willd.	Xerophyte	1-2	I (500)	Fruit ripening
Shrubs					
5.	*Juniperus oblonga* Bieb.	Xerophyte	1-2	I (700)	Fruiting

6.	*Punica granatum* L.	Xerophyte	1-2	II (190)	Flowering-Fruiting
7.	*Prunus spinosa* L.	Xerophyte	1-2	II (240)	Fruiting
8.	*Crataegus pentagyna* Waldst. & Kit. ex Willd.	Xerophyte	1	I (500)	Fruiting
9.	*Rubus sanguineus* Friv. (= *Rubus sanctus* Schreb.)	Mesoxerophyte	1-2	II (150)	Flowering-Fruiting
10.	*Paliurus spina-christi* Mill.	Xerophyte	2	II (200)	Fruiting
11.	*Tamarix hohenackeri* Bunge (= *Tamarix smyrnensis* Bunge)	Mesoxerophyte	1-2	II (350-400)	Flowering-Fruiting
12.	*Rhus coriaria* L.	Xerophyte	1	II (250)	Flowering
Semi-shrubs					
13.	*Capparis spinosa* L.	Mesoxerophyte	1	III (150)	Flowering-Fruiting
Perennial grasses					
14.	*Alhagi pseudalhagi* (M.Bieb.) Desv. ex Shap.	Xerophyte	1-2	II (200)	Fruiting
15.	*Eryngium biebersteinianum* Nevski	Xerophyte	1	I (40)	Flowering
16.	*Achillea filipendulina* Lam.	Xerophyte	1	III (80)	Flowering
17.	*Allium rubellum* M.Bieb.	Xerophyte	1-2	III (120)	Flowering
18.	*Glycyrrhiza glabra* L.	Mesoxerophyte	1	III (100)	Vegetation
19.	*Stipa pontica* P.A.Smirn.	Xerophyte	1-2	III (80)	Seed formation
20.	*Poa nemoralis* L.	Xerophyte	1-2	III (35)	Seed formation
21.	*Artemisia vulgaris* L.	Xerophyte	1	III (90)	Flowering
Annual grasses					
22.	*Aegilops cylindrica* Host	Xerophyte	1-2	III (40)	Ripening
23.	*Euphorbia falcata* L.	Xeromesophyte	1	III (50)	Flowering
24.	*Hypericum acutum* Moench (= *Hypericum tetrapterum* Fr.)	Xerophyte	1	III (70)	Flowering
Total projective coverage is 60%					

Note: Abundance scores (1-4) indicate species frequency, where 1 - rare, 2 - occasional, 3 - frequent, and 4 - abundant. Roman numerals (I-III) represent the cover-dominance scale, where I - low cover (<10%), II - moderate cover (10-25%), and III - high cover (>25%).

abundance data derived from relevé sampling (Table 4). The Caraganetum–Pistaciae–Juniperosum association demonstrated a Shannon diversity index (H′) of 2.61, indicating a moderately high level of species diversity within the community. The Simpson diversity index ($1 - D = 0.90$) further confirms a low dominance structure and relatively balanced species distribution. Pielou's evenness index (J = 0.81) reflects a high degree of uniformity among species abundances, suggesting a well-structured and ecologically stable plant community.

Table 4. Biodiversity indices of plant associations in the Turyanchay State Nature Reserve

Plant association	Species richness (S)	Shannon index (H′)	Simpson index (1-D)	Simpson dominance (D)	Pielou evenness (J)
Caraganetum–Pistaciae–Juniperosum	25	2.61	0.90	0.10	0.81
Astragaletum–Acantholimonae–Juniperosum	18	2.34	0.87	0.13	0.78
Paliurusetum–Pistaciae–Juniperosum	24	2.58	0.89	0.11	0.80

Note: Diversity metrics of xerophytic sparse forest associations in the Turyanchay State Nature Reserve based on species abundance data derived from phytocenological relevés. Shannon diversity (H′), Simpson diversity (1-D), Simpson dominance (D), and Pielou's evenness (J) were calculated using semi-quantitative abundance scores (1-4).

These results quantitatively support the phytocenological observations and highlight the heterogeneity of xerophytic forest vegetation in the study area.

The results of field observations suggest that the protected vegetation within the reserve provides conditions that are likely to support natural regeneration and ecological restoration processes. This inference is based on the presence of well-structured plant communities, relatively high species diversity, and low levels of anthropogenic disturbance observed in the study plots. However, the realization of this regenerative potential is influenced by several limiting factors. Adverse climatic conditions, atmospheric pollution, and continuous soil erosion caused by river dynamics may significantly constrain ecosystem recovery and reduce the stability of vegetation development. Consequently, it is essential to ensure the protection of valuable woody, shrubby, semi-shrub, and perennial grass species within these plant communities. In addition, a more detailed geobotanical assessment should be conducted, and urgent conservation measures should be implemented, particularly focusing on vulnerable and ecologically significant species.

Conclusions

This research was carried out based on classical phytocenological principles within the Turyanchay State Nature Reserve, located in the Gabala and Agdash districts of Azerbaijan. The study area represents a distinctive type of arid forest vegetation, shaped by dry climatic conditions, complex relief, and specific edaphic factors. The forest communities are mainly composed of sparse xerophytic woodlands and include two main formations: Pistaceta-Juniperosae and Junipereta. Within these formations, three associations were identified: Caraganetum-Pistaciae-Juniperosum, Astragaletum-Acantholimonae-Juniperosum, and Paliurusetum-Pistaciae-Juniperosum, each reflecting variations in species composition, dominance structure, and ecological conditions.

A detailed phytocenological analysis was conducted for each cenosis, during which all included plant species were recorded. The total cenological cover, species abundance, and phenological phases were systematically evaluated to determine the structural and functional characteristics of the vegetation. The results indicate that trees and shrubs form the dominant life forms in these communities, playing a key role in stabilizing the ecosystem and shaping the overall physiognomy of the landscape. Among the most widespread and ecologically significant species are *Pistacia mutica* Fisch. et C.A. Mey., *Juniperus oblonga* Bieb., *Juniperus polycarpos* K. Koch, and *Paliurus spina-christi* Mill., which occupy extensive areas and serve as the main edificators of the arid forest ecosystems within the reserve.

In conclusion, the biodiversity indices indicate that the Caraganetum-Pistaciae-Juniperosum association is floristically diverse, ecologically stable, and characterized by a balanced species distribution.

AI Usage Disclosure Statement

During the preparation of this manuscript, the authors used OpenAI ChatGPT (GPT-5.5) solely to improve the English language, grammar, and readability of the text. The AI tool was not used for data collection, data analysis, interpretation of results, preparation of figures or tables, or generation of scientific conclusions. All AI-assisted content was carefully reviewed, verified, and edited by the authors, who take full responsibility for the final version of the manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

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