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Linden Plantations in the Volga Region and Azerbaijan: (Characteristics of Establishment, Morphology and Utilisation)

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Abstract

This article presents a comparative ecological and silvicultural analysis of linden stands (genus *Tilia L.*) in the Volga region and the mountain forest ecosystems of the Greater Caucasus (Azerbaijan). This paper summarises the characteristics of the spatial distribution, species composition, morphometric parameters, and ecological and biological properties of the small-leaved lime (*Tilia cordata Mill.*) and the Caucasian lime (*Tilia caucasica Rupr.*). This study analyses the multi-purpose resource potential, forestry significance, and environmental functions of the lime tree in lowland and mountain forests.

Keywords: Tilia cordata, Tilia caucasica, the Greater Caucasus, the Volga region, biodiversity, mountain forests, comparative analysis

1.Introduction

1.1. Distribution of linden plantations

The lime tree is one of the valuable broad-leaved tree species that are of great importance to forest ecosystems, forestry, landscaping, and various areas of commercial use. Species of the genus *Tilia* are characterised by their longevity, well-developed crowns, high ornamental value, and the valuable properties of their timber. Furthermore, the lime tree is an important honey plant and plays a significant role in maintaining the biodiversity of forest communities. (Mamadjanov et al., 2019).

Linden trees are widely found in the forests of Eastern Europe, including the Volga region. Here, the small-leaved lime (*Tilia cordata*) is a characteristic component of broad-leaved and mixed forests, particularly oak-lime stands. It is capable of forming a significant proportion of the tree stand and growing successfully alongside oak, maple, ash, elm, and other broad-leaved species (Zykov et al.,2022). (Figure 1)



Figure 1. *A lime tree growing in open countryside.*

In Azerbaijan, the distribution of lime trees is more localised. Natural populations are found predominantly in the mountain forest ecosystems of the Greater Caucasus. The most characteristic species found here is the Caucasian lime (*Tilia caucasica*). Studies carried out in the forests of the Greater Caucasus within Azerbaijan have revealed the presence of the Caucasian lime in the Ismayilli, Sheki and Zakatal districts, as well as its co-occurrence with the small-leaved lime in the Guba and Gusar districts (Efendieva & Novruzov, 2021; Efendieva & Novruzov, 2020).

It is clear from the above that the linden tree has different patterns of distribution in the two regions under consideration. In the Volga region, it is a common component of broad-leaved forests, whereas in Azerbaijan its natural range is predominantly confined to the mountain forests of the Greater Caucasus. At the same time, in both regions, the lime tree is of considerable interest as a forest-forming, ecologically valuable and multi-purpose tree species.

1.2. Characteristics of the establishment of lime tree plantations

The formation of lime tree stands is determined by a combination of climatic, soil, hydrological and topographical conditions. In the Volga region, the lime tree is a common component of broad-leaved forests. Oak-lime forests are particularly characteristic, with lime trees sometimes occupying a significant proportion of the upper or second tree layer. (Seidafarov, 2012; De Jaegere et al., 2016). The Middle Volga region is characterised by forest communities comprising oak, small-leaved lime, maple, ash and elm. The lime tree adapts well to the conditions of the forest community and is capable of surviving for long periods under the canopy of other tree species.

In Azerbaijan, the natural distribution of the lime tree is mainly associated with the forests of the Greater Caucasus. In the Ismailli, Zakatali and Sheki districts, the natural populations consist mainly of Caucasian lime trees. In the Gubinsky and Gusarsky districts, Caucasian lime and small-leaved lime are found growing together. The differences between regions are primarily due to natural conditions. The Volga region is characterised by a predominantly flat and gently undulating landscape and extensive areas of broad-leaved forests. In Azerbaijan, the distribution of lime trees is more closely linked to the mountainous terrain, altitudinal zonation, slope aspect, and the characteristics of the local microclimate. (Martynova et al., 2026; Afandiyeva & Novruzov, 2020).

1.3. Species composition of lime tree plantations

Species composition is of great importance in forestry, as different species of lime tree may differ in their morphological characteristics, ecological requirements, and distribution patterns. In this regard, the extent to which the species composition of lime plantations found in the Volga region and the Greater

Caucasus has been studied is of great importance in determining the current status of these populations (Zykov et al., 2022).

In the Volga region, the main species of the genus *Tilia* is the small-leaved lime (*Tilia cordata*). It is one of the region's characteristic broad-leaved tree species and plays a part in the formation of mixed and structurally complex forest stands.

In Azerbaijan, the main native species is the Caucasian lime (*Tilia caucasica*). It is widespread in the forest ecosystems of the Greater Caucasus and is particularly characteristic of mountainous areas. Small-leaved lime is also found in the northern part of Azerbaijan. (Radoglou et al., 2009; Eaton et al., 2016). In forestry, the lime tree is significant as a companion species in mixed forests. Its presence influences the structure of the forest stand, the formation of storeys and the ecological conditions within the forest community.

1.4. The use of linden resources and linden plantations

The lime tree has a long history of being used for practical purposes. Due to its softness, uniform texture, and ease of working, this wood has long been used to make household items, furniture, interior fittings, and decorative and applied art objects. Linden wood is characterised by its light colour, relatively low density, softness, and uniform texture. It can be easily worked with both hand tools and power tools, which is why it is widely used in situations where a smooth surface or a complex shape is required (Pigott & Huntley, 1978). Linden is used to make furniture and decorative items; artistic woodcarving holds a special place amongst these, as the soft and uniform grain of linden wood is particularly well-suited to this craft.

The bark and the bast of the tree are of particular importance. Traditionally, the bast was used to make ropes, bast fiber, wickerwork, and other items. This use was particularly widespread in traditional agriculture and reflected the versatile nature of the lime tree as a forest resource. The bark and bast also have practical uses. In the past, they were widely used to produce fibrous material. At present, this kind of use is predominantly of a traditional and historical-cultural nature.

The flowers of the lime tree are also of great significance. Thanks to its profuse flowering and the presence of nectar, the lime tree is considered a valuable honey-producing tree species. Its purpose therefore extends far beyond the production of timber. As well as timber, lime tree plantations are valuable for their non-timber resources. The best-known use is in beekeeping. During the flowering season, the lime tree becomes an important source of nectar and pollen for pollinating insects. It is therefore appropriate to regard the linden as a multi-purpose forest species, combining timber, non-timber, ecological and honey-producing functions.

2. Results and Discussion

2.1. The structure of lime trees and lime tree plantations

Linden trees are large deciduous trees with a well-developed trunk and a broad crown. Under favourable conditions, they are capable of reaching considerable sizes and persisting within forest communities for a long time. In the Volga region, the small-leaved lime typically reaches heights of around 25–30 metres, whilst under favourable conditions, individual trees may grow even taller. The Caucasian lime is also a large tree. In the forests of the Greater Caucasus studied, trees were observed to be around 30–35 m tall, with a trunk diameter of around 100–150 cm. The size of individual trees depends on their age, site conditions, their position within the stand, stand density, and the availability of water and nutrients (Rahman et al., 2017).

The trunk and the bark. The trunk of a lime tree is usually straight and well-formed. The bark of young trees is relatively smooth, but as they age, it becomes rougher and develops longitudinal cracks. In mature trees, the trunk can reach a considerable thickness. Particularly large specimens of the Caucasian lime tree

are found in the mature mountain forests of Azerbaijan. The shape and dimensions of the trunk are of silvicultural importance, as they determine the quality of the timber, the stability of the tree and its position within the stand structure.

Crown. The lime tree is characterised by a well-developed crown. In trees growing freely, it can be broad, dense and rounded. In the forest, the shape of the crown varies depending on the density of the stand and the position of the tree (Moser et al., 2015). With high canopy closure, trees tend to grow vertically, and the crown becomes narrower. If there is sufficient space, the lateral branches develop more vigorously, and the crown becomes wider. A well-developed crown provides a large leaf area and plays an important role in photosynthesis and the formation of the forest microclimate.

Leaves. Linden leaves have a distinctive heart-shaped form and long petioles. The small-leaved lime has relatively small leaf blades, usually around 3-8 cm long, with a pointed tip and a serrated margin (Zykov et al., 2022; Mamieva et al., 2022). (Figure 2)



Figure. 2*. The structure of a small-leaved lime leaf*

Leaves are one of the key diagnostic features used to identify a species. Their size and condition can also be used to assess the health of trees. The leaves of the Caucasian lime are also heart-shaped, although their specific dimensions and certain morphological characteristics differ from those of the small-leaved lime (Rahman et al., 2016.

Flowers. Linden flowers are small, yellowish-green, and arranged in inflorescences. Flowering is of great ecological importance, as trees attract large numbers of insects during this period (Martynova et al., 2026; Figure 3).



Figure 3. *The flowering of the small-leaved lime*

Linden flowers produce nectar and provide insects with a food source. The flowering period is therefore significant not only for the biology of the lime tree itself, but also for the functioning of the forest ecosystem (Mamieva et al., 2022).

Fruits and seeds. The fruit of the lime tree is a small nut attached to a distinctive bract. Once ripe, the fruits can be dispersed by the wind (Efendieva & Novruzov, 2020). Linden trees flower during the summer. At this time, the trees become one of the main sources of nectar and pollen for insects.

Fruit set is an important stage in natural reproduction. The presence of seed regeneration enables the lime tree to persist within forest communities, provided that suitable conditions exist for seed germination and the development of young trees.

Characteristics of the structure of lime trees in the study areas. The small-leaved lime and the Caucasian lime share a number of common morphological characteristics. Both are characterised by large trees, a well-developed crown, heart-shaped leaves, small flowers and distinctive fruits (Pigott & Huntley, 1978). At the same time, the Caucasian lime tree can grow to a very large size in the Greater Caucasus. This is particularly noticeable in mature trees growing in favourable conditions. Consequently, whilst they bear an external resemblance, members of the genus *Tilia* exhibit certain differences linked to their species and specific environmental conditions (De Jaegere et al., 2016).

3. The biology and ecology of lime tree plantations

Attitudes towards lighting. The lime tree is one of the tree species that can tolerate shade. This characteristic is of great importance for its survival in mixed forests. Young plants can grow for a while under the canopy of taller trees. In the forests of the Volga region, this characteristic enables the lime tree to persist as part of multi-layered oak-lime stands. In the mountain forests of Azerbaijan, its ability to tolerate shade also contributes to its survival within the complex structure of the forest community. As light levels increase, the growth of young trees may accelerate; however, the optimal conditions depend on the age of the plant and the nature of the forest cover (Mamadjanov et al., 2019).

Soil and moisture requirements. Linden trees thrive best in fairly fertile soils with favourable water and air conditions. It is important for the plant to have an adequate supply of moisture; however, prolonged waterlogging of the soil is detrimental (Saltan et al., 2019). In the Volga region, the lime tree grows in a variety of forest habitats, but the most resilient stands are found in areas with suitable soil and hydrological conditions (Moser et al., 2015). In Azerbaijan, environmental conditions change significantly with altitude. The mountainous terrain gives rise to a wide variety of soils, microclimates, and moisture conditions. Consequently, the condition of lime tree stands can vary considerably even within a single mountainous region.

Growth and development. Linden is one of the long-lived tree species. Under favourable conditions, individual trees may remain part of the stand for a long time. Growth rates depend on age, light levels, soil fertility, moisture availability and competition from neighbouring trees. At a young age, the ability of the root system and the crown to develop is of great importance (Afandiyeva & Novruzov, 2020). In mature forests, lime trees can occupy various positions within the vertical structure of the stand, including the upper and lower storeys.

Natural regeneration. The natural regeneration of lime trees depends on the presence of fruiting trees, seed quality, soil conditions, moisture levels, and light levels. Seed propagation is of great importance for the natural regeneration of lime tree stands. The success of the emergence and development of young trees also depends on the presence of fruiting trees and competition from other plants (Moser et al., 2015). In mixed forests, the light conditions beneath the canopy are particularly important. A forest canopy that is too dense may restrict the growth of young trees, whilst excessive light may increase competition from herbaceous vegetation and other tree species. Therefore, when carrying out a silvicultural assessment, it is

necessary to take into account not only the quantity of young growth, but also its viability, age structure and ability to progress to subsequent age stages (Radoglou et al., 2009).

One of the most important characteristics of the lime tree is its ability to thrive in mixed stands. Oak-lime forests are particularly common in the Volga region, where lime trees grow alongside oaks and other broad-leaved species. The following formulae may be used as illustrative examples of stand composition: 7L3O or 6L2O1B1M. They denote, respectively, 70% lime and 30% oak, or 60% lime, 20% oak, 10% birch and 10% maple. These formulae are provided solely to illustrate the principle of classifying stand composition and do not represent average figures for the entire Volga region. In Azerbaijan, the lime tree forms part of the complex mountain forest communities of the Greater Caucasus, where it coexists with other broad-leaved species. The mixed composition of such forests helps to increase biodiversity and create a variety of ecological niches (Zykov et al., 2022).

Environmental significance. Linden plantations fulfil important ecological functions. They play a part in shaping the forest microclimate, accumulating organic matter, protecting the soil and maintaining biodiversity (Pigott & Huntley, 1978). Linden flowers provide a food source for pollinating insects. The crown and foliage create conditions conducive to the survival of various organisms, whilst fallen leaves contribute to the formation of forest litter and the nutrient cycle. In the mountainous regions of Azerbaijan, forests containing lime trees play an additional role in protecting the soil from erosion and regulating surface runoff.

4. Resources and uses of the lime tree

Wood resources. The main resource of the lime tree is its timber. It is light in colour, relatively soft, uniform in texture, and easy to work with [6]. Compared with heavy and denser types of timber, lime wood is less strong; consequently, its range of applications is determined primarily by its technical properties.

The main advantage is that it is easy to work with. The timber is well suited to manual and machine working, carving and the manufacture of items that do not require high structural strength. Linden wood can be used to make interior fittings. Its light colour and uniform texture enable the creation of smooth and aesthetically pleasing surfaces.

Wood is particularly valued for its ability to be worked relatively easily and to take on various shapes. This broadens the range of ways in which it can be used in interior design. One of the well-known uses of lime wood is the manufacture of materials for baths and saunas. This is due to its relatively low density, low thermal conductivity and ease of processing (Mamieva et al., 2022; Efendieva & Novruzov, 2021). Linden wood can be used to make panelling, interior cladding, shelves and various small items. At the same time, the specific application of timber must take into account the operating conditions and the requirements for the material's strength and durability.

The ability to achieve a smooth surface after treatment is particularly valued. As a result, lime wood is suitable for products where surface quality and the ability to produce complex shapes are important. One of the most characteristic uses of lime wood is artistic carving. The soft, uniform grain of the wood makes it possible to create delicate features and intricate decorative shapes. For this reason, lime wood is traditionally used to make decorative panels, sculptural elements, small decorative items, and other objects.

Bark and bast. Linden bark has historical economic significance. The bast is particularly valuable, as it has traditionally been used to produce a fibrous material. Bast was used to make ropes, bass, wickerwork and other items. At present, this field is of primarily historical, traditional and cultural significance.

Flowers and other non-timber resources. Linden flowers are an important non-timber resource. They are used as a plant-based raw material and are of great importance to beekeeping. During the flowering season, lime tree plantations become a source of nectar and pollen. Therefore, the presence of lime trees in forests can increase their value not only as timber forests but also as honey-producing areas. The seeds and

other parts of the tree are also of biological interest; however, their economic importance is considerably less than that of the timber and floral raw materials.

Significance for honey production. The lime tree is one of the best-known honey-producing tree species. Its flowering is of great importance to bees and other pollinating insects. In the Volga region, the linden tree's importance as a honey plant stems from its widespread presence in broad-leaved and oak-linden forests. In Azerbaijan, this significance is evident locally in areas where the linden tree grows naturally, particularly in the mountain forests of the Greater Caucasus. The honey-producing function is a common characteristic of linden stands in both regions, although the extent to which it manifests itself is determined by the area and structure of the linden forests.

5. A comparative analysis of lime trees and lime tree plantations

A comparison of linden stands in the Volga region and Azerbaijan shows that their current condition and distribution patterns are determined primarily by differences in natural conditions. Despite the general biological similarity among species of the genus *Tilia*, the establishment of stands in these regions takes place under varying forest-vegetation conditions (Mamadjanov et al., 2019; Saltan et al., 2019). In the Volga region, the small-leaved lime (*Tilia cordata*) is a characteristic component of broad-leaved and mixed forests. It is of particular importance in oak-lime tree communities, where it can account for a significant proportion of the tree stand. The flat nature of the terrain and the presence of extensive woodlands create conditions conducive to the wider distribution of lime trees (Mamieva et al., 2022; Seidafarov, 2012).

In Azerbaijan, the natural distribution of lime trees is considerably more localised. The main wild populations are found in the forest ecosystems of the Greater Caucasus. The Caucasian lime (*Tilia caucasica*) is of particular importance here, whilst the small-leaved lime is also found in certain areas of northern Azerbaijan. The distribution of these rock types is closely linked to altitude, topography, slope aspect, soil conditions, and moisture regime (Rahman et al., 2016).

A comparison of morphological characteristics reveals a significant similarity between the species under consideration. They are characterised by large trees, a well-developed crown, heart-shaped leaves, small flowers, and distinctive fruit. At the same time, the size of individual trees can vary considerably depending on the growing conditions. In the mountain forests of Azerbaijan, the Caucasian lime tree can grow to a considerable size, which highlights its role in the structure of mature forest communities.

From an environmental perspective, a common characteristic of linden species is their ability to thrive within mixed stands. The lime tree can tolerate shade, which enables it to thrive beneath the canopy of other tree species. In the Volga region, this contributes to its presence in multi-layered oak-lime forests, whilst in Azerbaijan it is found in complex mountainous broad-leaved communities. A key difference between regions relates to the spatial structure of forests. In the Volga region, the lime tree tends to form extensive forest communities and is a common component of tree stands. In Azerbaijan, its distribution is patchy and localised, and the status of individual populations depends more on the characteristics of the mountainous terrain and local growing conditions.

The linden tree is of multi-purpose value in both regions. Wood is used because of its softness, uniformity and ease of working. It is suitable for use in the manufacture of furniture, household goods, interior fittings and materials for baths and saunas. The lime tree is of particular importance in the field of artistic woodcarving. In addition to woody resources, flowers and other non-woody parts of the plant play an important role. Flowering provides a food source for pollinating insects and determines the value of lime tree plantations as a source of nectar. Historically, bark and bast have been used to produce fibrous materials, ropes and woven goods.

Thus, the main difference between the linden stands of the Volga region and those of Azerbaijan lies not so much in the biological characteristics of the trees themselves as in the extent of their distribution, the composition of the forest communities and the growing conditions. Forest stands in the Volga region are

characterised by a greater prevalence of lime trees in lowland broad-leaved forests, whilst Azerbaijani populations are predominantly mountainous and localised. From a silvicultural perspective, it is necessary in both regions to preserve the mixed composition of the tree stands, to support the natural regeneration of lime trees and to take account of their ecological functions. In this regard, it is particularly important for Azerbaijan to protect the natural populations of lime trees in the mountain forests of the Greater Caucasus, as their distribution is limited by specific natural conditions.

6. Conclusion

The study found that the lime tree stands in the Volga region and Azerbaijan are of high ecological and economic value, but have developed under significantly different natural conditions. In the Volga region, the lime tree is a characteristic component of broad-leaved forests, particularly oak-lime stands. In Azerbaijan, its natural range is predominantly associated with the mountain forests of the Greater Caucasus, where the Caucasian lime plays an important role.

Common to both regions are the linden tree's ability to form part of mixed stands, its ecological role, the value of its timber, and its importance as a source of nectar. At the same time, differences in topography, climate and forest growth conditions determine the varying distribution and structure of lime tree stands. The sustainable use of lime trees must go hand in hand with the conservation of natural populations, the promotion of their regeneration and the protection of valuable forest ecosystems. This is particularly important for the natural lime tree stands of the Greater Caucasus within Azerbaijan.

Overall, the lime tree should be regarded not only as a source of timber, but also as an important component of sustainable forest ecosystems, possessing ecological, protective, honey-producing and resource-related significance.

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The Economic Efficiency of Digital Technologies in Forest Management and Their Implications for Tourism Development

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Abstract

Digital technologies are changing the way forests are observed, considered, and watched for, but how useful these technologies are for organizations that hack forests is not clearly defined. The economic efficiency of forest management is attributed to the use of geographic information systems, satellite remote sensing, drones, and artificial intelligence, and to how these technologies influence financial, operational, and institutional factors. Through a critical evaluation of peer-reviewed studies and international reports published primarily from 2021 to 2026, the analysis correlates specific applications, such as satellite-based wildfire monitoring, drone-backed inventory, and digital restoration systems, to economic value mechanisms such as labor savings, better resource allocation, reduced losses, and lower restoration costs. Reported benefits are substantial but conditional. Asset scale, data infrastructure, workforce skills, and interoperable institutional arrangements are key factors in arbitrating returns, while cost-benefit evidence remains limited and sensitive to assumptions. According to the review, digitalization is a worthwhile investment for covering intensity, disturbance risk, and management assets, and it furnishes recommendations for managers, policymakers, and researchers. Good management of digital forestry also assists in observing the landscape in good condition, which is important for forest-based tourism.

Keywords: forest economics; digital forestry; remote sensing; cost-benefit analysis; precision forestry; forest inventory; tourism

1. Introduction

Forests are responsible for timber and non-wood products, conserving soils and water, storing carbon, and supporting tourism and recreation, but their management is typically defined by tight budgets, outdated inventories, and mounting disturbance risks. Economic efficiency in managing forests refers to exercising limited labor, money, and time in a way that observes the value of what the forests furnish at the lowest possible cost. Two pressures make this task harder. Climate-related wildfires, pestilence infestations, and severe storms have led to more frequent and intense disruptions that damage timber value and backwash in higher costs for suppression and restoration (Hope et al., 2024). The sector has been slow to update, as evidenced by the limited adoption of information and communication technologies by forest operators and the scarcity of automation and remote machinery control, according to the United Nations Economic Commission for Europe (UNECE, 2024). Digital technologies propose a way to reduce this limitation by reducing the cost of gathering information. Having accurate and up-to-date information about the condition of trees, any disturbances, and harvest activities assists managers design their work, entrust teams, and

determine where to steep resources more effectively. This reduces the need for frequent trips to the field and minimizes effort. The focus of this research is on how digital technologies can better the economic efficiency of forest management, and what are the financial, operational, and institutional factors that arbitrate whether they hold measurable benefits? The goal is to synthesize the latest information on how digital forestry tools influence the economy, identify when these tools are beneficial, and emphasize what this implies for real-world use and government policies, especially for countries like Azerbaijan that are creating their forest monitoring systems. Instead of presenting primary empirical research as a report, the article serves as a critical, evidence-based analytical review that separates findings from interpretation.

2. Digital Technologies in Forest Management

The main tools habituated in digital forestry contain geographic information systems (GIS), satellite remote sensing, manned aerial surveys, drones, laser scanning, and artificial intelligence (AI) techniques for breaking down data. GIS platforms are accustomed to containing spatial data on areas, roads, land use, and ownership, which aid in spatial planning and resource allocation (UNECE, 2024). A university-cherished forest enterprise in Slovakia developed a web-based GIS portal that evolved the collection, processing, and availability of forestry information and improved collaboration between research and management, showing that even small GIS investments can improve the information base for operational decisions (Zápotocký & Koreň, 2022). Satellite systems proposition regular, affordable observation of big areas. The mapping of defoliation, host species, and disturbance at scales unsuitable for field crews is predicated on free and open data gathered from missions like Sentinel-1 and Sentinel-2 (Bhattarai et al., 2021). AI techniques break down these data streams: a review of 79 studies showed that machine learning and deep learning models, such as convolutional neural networks, usually achieve over 90% accuracy in diagnosing pests and diseases, deforestation and illegal logging, and damage from wildfires (Amoah-Nuamah et al., 2025). The gap between satellites and ground plots is by drones, which furnish high-quality imagery at low prices while minimizing impact on sensitive habitats while also guaranteeing regulatory compliance, data security, and technical constraints (Wang et al., 2025). Beyond monitoring, digitalization extends into operations. Harvesting machines with sensors pack production data almost instantly, which assists in bracketing performance, identifying when equipment might need repair, and automatically marking how much has been reaped. Additionally, a virtual forest simulation permits you to evaluate the costs and types of wood that can be reaped before coinciding with a job (UNECE, 2024). Virtual twins that conjoin remote sensing, weather, and sensor data are being used to support the prevention, response, and post-fire recovery of wildfires (Li et al., 2024). The economics of information in forestry is influenced by these applications, acting as a shift in the marginal cost of assessing the state of a forest, which is the channel for all downstream savings.

3. The Economic Efficiency of Digital Technologies in Forest Management

The reason for exercising digital forestry in economics is predicated on four main benefits: saving money by displacing work that requires a lot of human effort; exercising resources more effectively because of better information; heading off losses by identifying problems earlier; and expending less on disposing of and planting trees. The evidence for each mechanism is more robust in certain scenarios than in others, and the described magnitudes contrast significantly, so the discussion below condenses solely on the figures reported in the mentioned studies. Labor and monitoring costs. Traditional field inventories are one of the biggest ongoing expenses in managing forests. The use of remote sensing is replacing airborne and ground observation for padding plots. In Maine, USA, researchers examined how useful different remote sensing methods are, like satellites and drones, for detecting spruce budworm defoliation, which is the most expensive problem affecting the region's forests (Foster et al., 2024). The substitution of habitual field and aerial survey campaigns with satellite-based observation improves consistency, as AI-backed interpretation typically achieves a classification accuracy of over 90% for pest detection and related tasks, thereby reducing the potential for harvests and mistimed treatments (Amoah-Nuamah et al., 2025). Avoided losses. The most valuable use of digital information is in the management of disturbances, as early detection holds

a disproportionate impact on outcomes. Monte Carlo simulation was used in a cost-benefit analysis of WildFireSat, a Canadian satellite mission for active-fire monitoring, to estimate suppression costs, timber losses, property losses, evacuation costs, and smoke-related health costs (Hope et al., 2024). When comparing the costs and benefits, if we exercise more cautious estimates, the costs were higher than the benefits.But if we exercise more hopeful estimates, the benefits were about 9 to 10 times greater than the costs.The main reason for this big difference was how effective the decision-support tools were, not how much we blinked future costs. This study is instructive in two ways: it papers potentially significant losses that may not have come due to satellite monitoring, and it emphasizes the sensitivity of evaluated estimates to assumptions about the use of information by managers. Restoration and establishment costs. The cost of reforestation can be reduced with the use of digital systems. According to Sasaki and Abe (Sasaki & Abe, 2025), the cost of enforcing traditional labor-predicated planting programs was evaluated at USD 2.00 to 3.75 per tree, while the cost of digital-twin-backed drone seeding systems was evaluated at USD 0.11 to 1.08 per tree. The comparison is predicated on what technology companies and real-world projects have exhibited, not on constrained experiments, so it's more of a general idea.However, the big difference in costs implies that automation can really modify how much money is essential for restoration work, especially in the right kinds of places. Allocation and operational efficiency. Precision forestry combines sensing with machines and planning systems. Harvesters qualified with sensors automatically record yields and assortments, permitting managers to bracket performance across contractors, and the simulation of a virtual forest to evaluate harvesting costs and volumes before disbursement betters negotiation and reduces planning errors. In silviculture, better information degrades the risk of maladaptation by exercising growth models and predictive analytics to halves species, thinning schedules, and harvesting intensity with actual site productivity rather than outdated inventory averages (Wang et al., 2025). Investment and maintenance costs. Along with these advantages, there are big expenses to count: sensors and drones, software licenses, cloud processing, connectivity, and especially highly skilled workers. High implementation costs, system interoperability issues, and digital skill shortages are the primary financial barriers cited in stakeholder surveys in the forestry sector (Damaševičius et al., 2024). The economic feasibility of AI- and LiDAR-predicated forest mapping services is dependent on scalable business models, partnerships, and cost optimization, rather than the complexity of algorithms, as shown by a study of Finnish forest mapping technology (Kordi & Salo, 2025). In actuality, the relevant unit of analysis for an investment decision is a data pipeline, which contains all of its lifecycle costs, rather than just a sensor. Conditions under which digitalization remunerates. When coming across at all the conned evidence, returns are most likely to episode when three specific conditions are caught. The value of the information is in line with the value of the asset, so monitoring that is not cost-effective for a small woodlot may be valuable for a large, high-risk, or high-value company. Second, the risk of disturbances excuses the level of monitoring, because the benefits of heading off losses are most important in areas where there chances actual pressure from wildfires, pests, or illegal logging (Hope et al., 2024; Amoah-Nuamah et al., 2025). The absence of staff capable of processing and construing outputs, connectivity, and compatible systems hinders the acquisition of picked up information, making it difficult for the organization to soak. When these conditions aren't present, options like incremental adoption, participatory services, and open data sources like Sentinel imagery can furnish more affordable ways to get started. Measurement limitations. The evidence base limits the use of indicators such as return on investment and cost-benefit analysis, despite their appropriateness. Avoided losses are not real and are hard to establish because benefit estimates depend on guesses about how well something is working, as exhibited in the WildFireSat analysis (Hope et al., 2024). Many of the cost figures printed are predicated on either technology vendors or single-case deployments (Sasaki & Abe,2025). The scarcity of independent economic analyses on digital forest investments is a result of the lack of technological advancements in the economic literature.

4. Implementation Challenges and Development Opportunities

The literature on implementation identifies a set of limitations that are consistent across different countries and income levels. Small enterprises are unable to prosper due to capital requirements and

uncertain payback; a stakeholder survey in Italy indicates that high investment costs, lack of interoperability, inadequate digital skills, and poor connectivity in rural and mountainous areas are persistent barriers, and training is the primary limiting factor (Corona et al., 2026). At the system level, there are similar constraints such as the absence of data standards, legislative hindrances, data privacy concerns, and stakeholders' reluctance to take action due to concerns about data exposure retarding adoption (Damaševičius et al., 2024). The UNECE has bustling structural reasons as the reason why a significant portion of forest land is cherished by the public and hacked conservatively, while commercial forests are institution in remote areas with poor infrastructure, and forest operations are pacified by small firms with limited investment potential (UNECE, 2024). The lack of data quality in organizations is due to their reliance on drone regulations, photogrammetric processing, and the integration of point clouds into GIS (Corona et al., 2026). The opportunities supervene directly. Due to organizational rather than technical constraints, policies like participating in national platforms, open satellite data, common standards, and training programs run to bring higher returns are tied to hardware subsidies (Kordi & Salo, 2025; Corona et al., 2026). For Azerbaijan, the progress is clear through international projects rather than national data: a project championed by the FAO and GEF, done in 2021 with a budget of about $1.48 million, a system to hack forest resources information, formed a national guide for forest inventory, housebroken planning teams, and helped recreate thousands of hectares of degraded forests and pastures. The project also reports that there was not much experience in inventory work and planning before (FAO, 2021). The National Forestry Programme for 2020-2030 holds a comparable focus on inventory, protection, and restoration (UNECE, 2019). The data show a cautious inference: exercising low-cost, open-data monitoring to build on the new information system chances likely to be a more effective approach than exercising large proprietary platforms, even though there are no published economic evaluations of Azerbaijan's forestry digitalization. Tourism enters as a secondary, downstream implication. Forest-predicated recreation is dependent on landscape quality, safe and accessible trails, and the absence of fire and pest damage; the ecosystem services delivered by sound management contain recreation explicitly (FAO, 2021). Using digital monitoring to rip down on disturbances and direct recreation facilities to stronger, more durable locations assists defended the natural area that brings about in money from tourism. A limited timber-only accounting would command an indirect benefit that strengthens the case for covering investments in forests with economic significance, despite the lack of quantified estimates of this tourism channel in the current literature.

5. Conclusion and Recommendations

Digital technologies improve the economic efficiency of forest management by lowering the cost of information and converting it into better allocation, earlier disturbance detection, and cheaper restoration. The strongest evidence supports three conclusions. The cost of monitoring can be degraded by exercising remote sensing, especially for dogging disturbance across vast stretches (Foster et al., 2024). Another point is that the advantages of avoiding losses through satellite monitoring can be significant, but these benefits depend a lot on how managers choose to exercise the information (Hope et al., 2024). Third, the benefits are only available if certain conditions are met: the size of the assets, the risk of disruptions, the level of skills, the quality of connections, and the existence of compatible institutions (Damaševičius et al., 2024; Corona et al., 2026). For forestry managers, the advice is to commence by coming across at the main decision problem, not just the technology.Identify the monitoring and planning decisions that have the biggest impact on costs and profits. Start by using free satellite data and existing GIS tools. Only introduce drones, LiDAR, or AI services in areas where the risk of mislaid out on benefits is high. Implement these new tools in steps, with small test projects first. Also, plan for ongoing training and maintenance costs for the team over time. Public goods that private adopters do not invest in, such as open data infrastructure, interoperability standards, rural connectivity, and vocational training, are the primary concerns of policymakers. For researchers, the biggest missing piece is clear, habitual evidence about the costs and benefits in different kinds of forests and different-sized organizations; studies that show what actually changes, instead of just what is due, would make all the estimates here more accurate. The well-being of

forests contributes to the sustainability of forest tourism through its scenery, safety, and accessibility, making tourism revenues a part of the overall assessment of forest management performance, even though the economics of the forest detritus is the primary focus in digital investment decisions.

Author's contribution

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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Features of Establishing Oak Plantations in Azerbaijan

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Abstract

In Azerbaijan, oak forests play an essential role in preserving biodiversity, protecting soil and water resources, and ensuring the environmental sustainability of forest ecosystems. This article examines the main aspects of establishing oak plantations in Azerbaijan, the bio-ecological characteristics of oak species, reforestation methods, and agronomic measures for the management of these plantations. Particular attention is paid to the conservation and restoration of populations of the chestnut-leaved oak (*Quercus castaneifolia*) and the Araxian oak (*Quercus araxina*), both of which are listed in Azerbaijan's 'Red Book'. This analysis examines seed sowing, seedling planting and combined methods of establishing oak plantations, as well as the 'hill-drop drilling' and 'square-cluster planting' methods. The issue also examines matters relating to the supply and storage of seeds, soil preparation, determining planting density, protecting planting areas and caring for young plants. The advantages of direct sowing are highlighted in terms of promoting the development of the oak's taproot system and increasing its drought tolerance. Experience of establishing oak plantations in Azerbaijan shows that, for successful afforestation, it is necessary to take into account the soil and climatic conditions of the area in question, the topography of the terrain, and the potential for natural forest regeneration. The findings of the study highlight the importance of scientifically sound afforestation methods for the conservation of native oak species, the restoration of degraded forest areas, and the sustainable development of forest ecosystems.

Keywords: oak forests, oak plantations, Chestnut-leaved oak, Araxian oak, afforestation, seed sowing, afforestation methods, agronomic management, biodiversity conservation

1. Introduction

1.1. Distribution, bioecology and uses of the oak

There are nine known species of oak in Azerbaijan: Chestnut-leaved oak (*Quercus castaneifolia*), Caucasian oak (*Quercus macranthera*), Araxian oak (*Quercus araxina*), English oak (*Quercus longipes*), Georgian oak (*Quercus iberica*), Silver oak (*Quercus hypochrysa*), Downy oak (*Quercus crispata stev.*), and other varieties. Tree species such as Holm oak (*Quercus ilex*), Cork oak (*Quercus suber*), and the западный дуб have been introduced to various regions and are now being cultivated there (Əsədov et al., 2008; Safarov & Olisaev, 1991).

Oak forests in Azerbaijan are mainly found in foothill and mountainous areas (at altitudes of up to 2,000 metres) and account for a significant proportion of the country's forest cover – up to 23%. Georgian, chestnut-leaved, English, Oriental and Araxian oaks are widespread, forming dense stands, particularly on the southern slopes of the Talish Mountains and the Greater Caucasus. These forests are also of great ecological and economic importance. Of these species, the chestnut-leaved oak and the Araxian oak are

listed in Azerbaijan's 'Red Book'. The following section will now examine some of the characteristics of these types (Anuchin, 1982; Bandin, 1954).

1. The chestnut-leaved oak (*Quercus castaneifolia, C. A. Mey*) is a rare species of tree native to Azerbaijan, found predominantly in the Lankaran natural province (in the Talish Mountains). The chestnut-leaved oak is a tree that thrives in warm, sunny conditions. It is one of the relict plants of the Tertiary period and a representative of the Hircanian flora, characteristic of the ancient Arctic Tertiary epoch (the Turganian period) (Mamedova & Mamedova, 2019; Yakhyaev, 2023). (Figure. 1)



Figure 1. *Beech forest.*

It got its name because its leaves look very much like chestnut leaves. This majestic tree can reach a height of 30-35 metres, and its trunk can measure 1.0-1.5 metres in diameter. (Alekseev, 1989; Maleev, 1935; Seifullaev, 2017). The leaves are usually 10-15 cm long, lanceolate, oblong-elliptic or oblong-lanceolate, with a wedge-shaped, rounded or slightly heart-shaped base; the apex ends in a sharp triangular point, and the margin is coarsely toothed. (Figure. 2)



Figure 2. *A young chestnut-leaved oak tree.*

Fruits: The nuts are large, 2.5-3.5 cm long. Flowering takes place in April–May, whilst the nuts ripen in September–October. 1,000 seeds weigh 7 kg (Figure 3). It is a long-lived plant; it can live for 400-500 years, and sometimes even longer.



Figure 3. *Oak acorns.*

As oak is a hard and valuable timber, it is used in shipbuilding, joinery, furniture-making, and cooperage. Nuts are also a main source of food for animals. Ancient and giant specimens of this species can be found in the Hirkan National Park. It grows in Iran (Gilan, Mazandaran), in the Caucasus, including the Talysh Mountains in Azerbaijan (from the plains up to an altitude of 2,000 metres above sea level) (Badalov, 1969). Amongst oak species, it grows faster and produces a bountiful seed crop every year. Natural regeneration from seed occurs successfully in moist forest ecosystems. It adapts quickly to local conditions, so growing it in a variety of climatic and soil conditions presents no difficulties.

2. Araxian oak (*Quercus araxina A.Grossh.*). Araxian oak is a valuable timber species belonging to the genus Quercus in the family Fagaceae. A tree species characterised by its resilience and endemic features, it forms an integral part of forest ecosystems and is found predominantly in the Okchuchay area, the Aras River basin, and the Caucasus region. It is listed in the 'Red Book of Azerbaijan'.

As a species of oak, it is a deciduous tree with high environmental resilience. This is a tree that can grow up to 20 metres tall. The leaves are 6-8 cm long and 2-7 cm wide, oblong-ovate or elliptical. Bright green on top, pale green underneath, with sparse pubescence. The edges are serrated, resembling a blunt cut. It flowers in March–April, and the nuts ripen in August–September. The fruit is small, with a short stalk; its calyx, which is cap-shaped, is covered with felt-like hairs and densely scaly. (Amirov, 1997; Maleev, 1935).

This herb grows naturally in northern Iran and the Caucasus. In Azerbaijan, this plant grows in forests at altitudes of 500-1,100 metres in the Zengilan and Kubadli districts in the south of the Lesser Caucasus. In some cases, it also forms monocultural forests. Resistant to high temperatures and frost. It contributes to the formation of swamp forests in extremely arid conditions. It is of exceptional importance for afforestation on dry mountain slopes. A drought-tolerant species of tree that does not require any special care. It can be found in the landscaping of botanical gardens and in the Aran region.

A significant portion of the valuable Araz oak forest, situated in the Okchuchay Nature Reserve within the occupied Zengilan district, was subjected to environmental terrorism during the occupation. All the trees in the forest were felled and destroyed. In conclusion, it should be noted that the main species of oak found in Azerbaijan (Chestnut-leaved oak, Caucasian oak, Araxian oak, English oak, Georgian oak) are considered endemic to the Caucasus; that is, these trees grow naturally only in the Caucasus and neighbouring regions (Turkey, Iran). Two species – Chestnut-leaved oak and the Araxian oak – are already listed in Azerbaijan's 'Red Book', and it is now vital to take special measures to protect them, as they are important components of Azerbaijan's tree flora. Therefore, the establishment of plantations of these tree species is regarded as the most effective management measure aimed at restoring and expanding oak stands and natural forests, protecting the forest ecosystem, ensuring its sustainable development, and so on (Əsədov et al., 2008).

2. Results and Discussion

2.1. Experience of establishing oak plantations in Azerbaijan

Although the establishment of oak plantations in our country became more widespread from the second half of the last century, for a long time these plantations failed to produce the desired results. The reasons for this included, in particular, the difficulty of ensuring timely weeding in forest plantations, as well as – in the case of direct seeding – the lack of soil preparation, the difficulty of protecting the plants from adverse natural phenomena, and the poor adaptation of the species. (Figure. 4)



Figure 4. *Cultivation of Chestnut-leaved oak in the Ismayilli District.*

Oak forests are currently being restored in Azerbaijan as part of government programmes. For example, of the 45.7 tonnes of seeds collected for afforestation in 2021, 38.3 tonnes were acorns. Particular attention is paid to the artificial restoration of oak as one of the most valuable timber species, especially in reclaimed areas and in tugai forests (the Kura–Araks Lowlands), using methods designed to ensure the successful establishment of oak plantations (Figure 5).



Figure 5. *Chestnut-leaved oak.*

Types of oak plantations:

Continuous and Partial oak plantations is practised on arid land with unirrigated soils in foothill, lower and mid-mountain regions.

Continuous oak planting – On former arable land, clear-cut areas and glades, plots cleared of crops, and on mountain slopes, sampling is carried out using a 2×2-metre grid, employing one of two methods:

either furrows are ploughed using a tractor, or 1×1-metre plots are marked out by hand (Anuchin, 1982; Mammadov & Asadov, 2010).

With this type of planting, the sowing or planting sites are spaced out relatively evenly to ensure that the main (cultivated) species dominate the future stand. Continuous forest plantations are established using either full or partial soil preparation. Although the use of machinery to cross-cut furrows, where possible, helps to reduce manual labour and lower the costs of sowing crops, the presence of stump remnants in these areas, the steepness of the slopes, the lack of specialised machinery and the difficulty in operating it, and, finally, the fact that manual soil preparation is considered the best approach for preserving the soil and vegetation cover on these slopes.

Partial planting is carried out in cases where natural forest regeneration is taking place on the plantation site or is expected to occur. Consequently, the establishment of partial afforestation involves the use of a combined afforestation method that *combines natural and artificial forest regeneration*. Tree plantings established on reforestation sites, taking into account existing natural regeneration, will form mixed stands in the future. As a general rule, partial reforestation is carried out on felled areas where natural regeneration of the main tree species is taking place.

Partial planting, unlike continuous planting, is always carried out on partially tilled soil. At this stage, only the part of the field where economically valuable tree species are to be planted is ploughed. Seeding is usually carried out in plots measuring 1×1 metre (2,000-2,500 plots per hectare).

In forests established as continuous plantations, the forest stand develops without any natural regeneration taking place. Compared with partial forest plantations, continuous forest plantations vary considerably in terms of tree species composition, density, soil preparation methods, planting patterns and the mixing of tree species (Методический кабинет Гидрометцентра России. (n.d.).

In the case of *partial planting*, the land is prepared, and monocultures are established, whilst mixed forests sometimes develop as a result of natural regeneration. The advantage is that the crop is grown in a forest environment, which prevents the formation of natural grass cover and helps to reduce the amount of planting material required, as well as labour and resource costs.

2.2. Key aspects of establishing oak plantations

There are three ways to establish oak plantations: *by planting saplings, by sowing seeds, and by a combined method*.

Sowing method (direct sowing method) – Oak acorns (seeds) are sown directly onto the prepared plots. This method allows the oak's vertical root system (the taproot) to develop unhindered, which makes the tree more drought-resistant in the future (Figure 6).



Figure 6. *Planting of chestnut-leaved oak.*

Planting method (planting seedlings) – One- and two-year-old oak seedlings, grown in nurseries, are planted in reforestation areas. This method reduces the risk of the seeds being eaten by rodents and helps the plants get through the initial growth stage more quickly (Mamedov, 2004).

A combined method – Both planting and sowing take place in the same forest area. Furthermore, it is used to create protective strips featuring oak trees. On oak plantations, the sowing method should generally be used. This is because oak acorns develop powerful taproots, which penetrate to a depth of up to one metre in their very first year. When transplanted into the field, the seedling loses most of its root system, which has a very negative effect on its condition. The newly formed roots of cuttings penetrate the soil more slowly than the roots of newly emerged seedlings grown from seed. Only when soil moisture is at an optimal level can sowing and planting cuttings be equally successful.

The *sowing method* used in the establishment of oak plantations comprises the following *stages:*

Seed preparation: Oak acorns ripen in late October–early November. However, for use in afforestation schemes and orchards, it is necessary to wait until the seeds are fully ripe. This process can continue until as late as 15 November. Acorns are gathered by hand once the seeds have ripened and fallen to the ground. To check the quality of the seeds, they are placed in water; empty husks that float to the surface are discarded, whilst those that sink to the bottom are considered suitable for sowing. The harvested seeds should be sorted, removing any that are diseased or damaged.

In the mountainous and foothill regions of the Lesser Caucasus, the Greater Caucasus and the Talysh Mountains, it is more advisable to leave oak acorns in the forest until spring arrives. The area of woodland set aside for seed collection must first be cleared of small shrubs and undergrowth. However, when clearing the area, you must not disturb the dead ground cover or the leaves that have fallen to the ground. A layer of seeds 5-6 cm thick is spread over the leaves, followed by a layer of leaves 15-20 cm thick. If frosts are expected or likely, the thickness of the top layer of leaves is increased to 30 cm (Mustafayev, 2012; Safarov, 1967).

In the Aran regions, it is recommended to store acorns in cellars. Small batches of seeds for spring sowing can also be stored in running water. Oak acorns can be stored for up to two years in ice cellars, freezer cellars and deep trenches.

Soil preparation: Soil preparation is carried out taking into account the soil and climatic conditions of the area where sowing is to take place, its topography, altitude above sea level, the orientation and gradient of the slopes, as well as the feasibility of using machinery.

When carrying out continuous sowing on mountainous terrain – on old scree slopes, in clearings and forest aisles, on land freed up after the harvest of agricultural crops, and on exposed mountain slopes:

– Where mechanical tillage is possible, ploughing to a depth of 60–80 cm promotes good root system development. Once the field has been ploughed, furrows are dug at two-metre intervals for sowing the seeds. On mountain slopes, in order to reduce costs, prevent the complete destruction of the site's soil cover and improve its resistance to erosion, the land is often ploughed not across the slope but in furrows (50 per hectare);

– In areas where machinery cannot be used, the field is tilled in 1×1-metre plots arranged in a 2×2-metre grid, amounting to 2,500 squares per hectare.

In afforestation, partial planting is carried out in cases where natural regeneration is observed or expected. In such cases, 1,200-1,500 plots of various shapes and sizes are prepared in the open areas of the site. Establishing protective tree belts *on flat terrain*: *the combined method, the row-nest method, and the square-nest* method are used.

Seed sowing: sowing is carried out using the row-nest and square-nest methods.

With the *'row-nest' method*, seeds are sown into holes made along the sowing rows, with 3-5 seeds in each hole, and the resulting plants form *bio-groups*. When using the *'square-nest' method*, holes are made in

rows of seeds at intervals corresponding to the planting pattern; in plots measuring 1×1 m, squares are formed (creating a 'square' pattern), then four holes are placed within each of these squares, and 3-5 seeds are sown into each hole. The resulting plants, from both the holes and the squares, form a *combined bio-group* (Shevchenko & Tsilyurik, 1986).

Defence: Artificially restored areas must be fenced off to protect the young saplings from damage caused by wild animals and livestock. Erecting barriers, where possible in mountainous areas, 1.0 metre wide. This can be achieved by digging trenches 1.5 metres deep, piling up the excavated earth to form berms, and using local materials (such as poles, stakes and blackberry bushes obtained from pruning, etc.) to reinforce the tops of these berms. As this type of fencing is both cheaper and more effective, it is considered suitable for all arable land in mountainous areas.

2.3. The main sowing methods, mixing patterns and planting densities used in oak plantations

In mountainous areas:

– With *continuous planting* in furrows using the *'row-nest' method* (with a spacing of 2×1 m), 50 furrows are laid out per hectare, spaced 2 metres apart.

– The planting holes are prepared in furrows at intervals of 1 metre, and 3-5 acorns are sown in each hole. Given that the average weight of each seed (of the sessile oak) is 7 grams, the sowing rate per hectare can range from 105 to 175 kg, whilst the number of one-year-old seedlings can vary from 15,000 to 25,000.

In *continuous sowing* using the *'square-nest' method*, with planting spots arranged according to a 2×2 m scheme, 2,500 plots measuring 1×1 m are prepared per hectare. Four holes are made in each of these plots (squares) – one in each corner – and between three and five seeds are sown into each hole. This results in 10,000 sowing points per hectare (Yakhyaev, 2007; Yakhyaev et al., 2011).

Given that the average weight of a seed (of the sessile oak) is 7 grams, the seed yield per hectare can range from 210 to 350 kg, whilst the number of one-year-old seedlings can vary from 30,000 to 50,000. In reforestation under natural regeneration conditions, sowing is carried out in part on plots using the 'square-nest' method (on a 2×2 metre grid), with between 1,200 and 1,500 plots, each measuring 1 square metre, being prepared per hectare. Four holes are prepared in each plot (square), with 3-5 seeds sown into each. This results in 4,800-6,000 sowing points per hectare. With this sowing method, the number of radish seedlings per hectare can range from 14,400 to 30,000, and seed consumption from 100 to 240 kg.

The following methods are used when establishing protective tree belts on *flat terrain*:

From 1950–1951, work began in Azerbaijan under the leadership of Ibrahim Safarov to establish shelterbelts. When planting trees in the shelterbelts, preference was given to oak species (Chestnut-leaved oak, English oak). Oak seeds were sown using the '*square nest' method*, with the planting holes arranged in blocks across the plots. This method was mainly used in arid conditions.

In irrigated conditions, this arrangement of holes makes it difficult to water crops. With this in mind, it was proposed that acorns from the oak – used as the main tree species – be planted using the '*6-hole' method*, with three holes on either side of the irrigation furrow. When watered, these holes are well supplied with moisture. The optimum depth for the watering furrows has been found to be 35–40 cm, whilst the acorns are sown at a depth of 8–10 cm. In all cases, the planting area must be cleared of weeds, stones and shrubs (Yakhyaev et al., 2017).

The methods described above involve the establishment of monoculture plantations of the genus Quercus, and it appears that the number of sowing sites per hectare ranges from 4,800 to 10,000, whilst the number of seedlings produced varies from 14,000 to 50,000. This is a very high density and, according to the planting density scale, it falls into the category of the densest plantations.

The main purpose of creating such dense stands is to intensify competition for limited resources – light, water, nutrients and space – amongst individuals of the same species. This process stimulates natural selection, leading either to the survival of the fittest or to the displacement of species.

As a result, after 3–5 years, instead of 12–20, approximately 2–4 of the strongest and healthiest oak seedlings remain in each plot. The average annual height growth of the seedlings reaches 35–40 cm.

The results presented were obtained from sweet chestnut plantations established using the 'square nest' method at the Jalilabad Forestry Enterprise in the early 2000s. On these plantations, grown in arid conditions, the average height of the seedlings reached almost 2.0 metres after five years, whilst the actual survival rate exceeded 80%.

2. 4. Agronomic management of oak plantations

Agricultural practices aimed at improving the growing conditions for tree and shrub species cultivated in forestry; agronomic measures aimed at creating more favourable conditions and ensuring optimal conditions include a range of activities, such as regular soil cultivation, soil loosening and weed control. In pure oak stands, the main aim of these operations is to ensure that the plot remains weed-free through systematic soil cultivation or inter-row cultivation, thereby reducing competition for light and water.

In oak plantations with mixed stands, the primary management objective is, first and foremost, to remove undergrowth through timely thinning, as well as to clear the site of unwanted oak seedlings that hinder the successful growth of higher-quality trees, in order to prevent the oak stands from being displaced by faster-growing species at a young age. In arid, desert conditions, whether planting in holes or in furrows, two 3–5-year-old oak saplings should be left in each hole, and the rest should be removed (Yakhyaev, 2004; Yakhyaev, 2007).

3. Conclusion

This article provides a brief overview of oak trees and oak forests, which form part of Azerbaijan's forest resources. A review of the literature has shown that nine species of oak grow in our forests; of these, the chestnut-leaved oak and the Arax oak are threatened with extinction; consequently, these oak species have been included in the Republic's 'Red List'. In light of this, we investigated issues relating to the restoration and sustainable development of these oak species, including the establishment of oak plantations in previously studied areas.

It has been established that oak plantations are created in two ways:

In mountainous areas

– *For continuous planting*, when sowing in furrows using *the 'row-nest' method* (in a 2×1 m pattern), 50 furrows are laid out per hectare at 2-metre intervals. Nests are prepared in the furrows at one-metre intervals, with 3–5 acorn seeds sown into each nest. Given that the average weight of a single seed (for the sessile oak) is 7 grams, the sowing rate per hectare is 105–175 kg, and the number of one-year-old seedlings can vary from 15,000 to 25,000.

– During *continuous sowing* in plots (following a 2×2 m grid) using the '*square nest' method*, 2,500 plots measuring 1×1 metre are prepared per hectare. Four planting holes are formed in each of these plots (squares) – one in each corner – and 3–5 seeds are sown into each hole. In this way, 10,000 sowing points are created per hectare.

The following methods are used when establishing protective tree belts on *flat terrain*:

From 1950–1951, work began on the creation of shelterbelts in Azerbaijan under the leadership of Ibrahim Safarov. When establishing shelterbelts, preference was given to oak species (chestnut-leaved oak, English oak). Oak seeds were sown using the '*square nest' method*, with the planting holes arranged in blocks across the plots. This method was mainly used in arid conditions.

Author's contribution

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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A Spatio-Temporal Analysis of Changes in Vegetation Cover on The Absheron Peninsula

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Abstract

Rapid urbanisation and industrial activity on the Absheron Peninsula, oil and gas extraction, the expansion of transport infrastructure, and climate change have led to significant environmental changes in the landscape and vegetation cover. The primary objective of the research in this area is to identify the spatial and temporal patterns of vegetation cover change, to assess the magnitude of these changes and their spatial variation, and to investigate the relationship between these processes and natural and human-induced factors. As part of the study, an assessment was carried out of changes in vegetation cover over various years using Landsat 5 TM, Landsat 8 OLI/TIRS and Landsat 8 LC08_L2SP satellite data, the Normalised Difference Vegetation Index (NDVI) and spatial analysis methods. It has been established that, over the period 2006–2025, significant changes in the spatio-temporal dynamics of vegetation cover were recorded, as determined on the basis of NDVI indices. In 2006, the total area of land without vegetation cover was 167,961 hectares, of which 26,280 hectares had sparse vegetation, 2,200 hectares had moderate vegetation, and 186 hectares had dense vegetation. In 2016, the total area of land devoid of vegetation cover was 196,424 hectares, of which 53,595 hectares had sparse vegetation cover, 3,702 hectares had moderate vegetation cover, and 619 hectares had dense vegetation cover, In 2025, the total area of land without vegetation cover was 203,369 hectares, of which 77,443 hectares had sparse vegetation cover, 7,277 hectares had moderate vegetation cover, and 880 hectares had dense vegetation cover. These changes indicate that the condition and spatial distribution of vegetation in this area vary from year to year.

Keywords: Absheron Peninsula, vegetation cover, transformation, spatio-temporal analysis, geographic information systems (GIS), remote sensing, NDVI, anthropogenic impact, land degradation

1.Introduction

The Absheron Peninsula enjoys a favourable economic and geographical location. Economic and geographical location is an important factor influencing the development and formation of an economic region (figure. 1). This factor has influenced the development of the region to varying degrees at different stages in history. Consequently, this is where the most important rail, road, water, and air transport hubs converge, linking the republic with other countries. This region's border with the Caspian Sea highlights the unique nature of its transport links. Access to Russian territory via the Caspian-Volga Canal provided a link to the northern seas, transforming the city of Baku into a port of international importance. The natural conditions, combined with the favourable geographical location of the Absheron Peninsula, play an important role in its future development as an economic region (Bədəlov, 2016).



Figure 1. *Satellite image of the Absheron Peninsula.*

Owing to its geographical, economic, and social characteristics, the Absheron Peninsula has been subject to significant human impact over many years, which has led to a complex environmental situation. In a region where two-thirds of the republic's industrial capacity and one-third of its population are concentrated, the land is more heavily affected by human activity. The improper operation of local oil fields, oil extraction carried out without complying with basic environmental protection requirements, and other breaches have led to the pollution of various landscape areas on the Absheron Peninsula (Ağayev & Əfkərov, 2007; Aslanov & Səfərli, 2008; Həsənov, 1997).

The modern flora of the Absheron Peninsula has developed since the Quaternary period under the influence of natural and historical conditions. Across the entire peninsula, the structure and composition of plant communities depend on the terrain, soil conditions, climate, and other natural factors. Most plant communities are widespread on saline, grey, grey-brown, meadow-marsh and alluvial-meadow soils, which are characteristic mainly of the semi-arid, arid and arid subtropical zones of the peninsula. The peninsula has its own distinctive phytogeographical boundary, which marks the outermost limit of the ranges of certain endemic species. This once again confirms the uniqueness of this area. Consequently, the relevance and timeliness of conducting a comprehensive inventory survey of the flora stem from the fact that, over the past seventy years, the territory of the Absheron Peninsula has undergone significant anthropogenic changes, and no detailed monitoring of this area has ever been carried out. This is due to the large-scale man-made transformation of ecosystems resulting from the development of oil fields and the intensive construction of residential areas, as well as technical and social infrastructure. Such factors threaten the survival of many local stenotopic species. At the same time, they create new habitats and conditions for invasive and expansive species (Mirzəyeva, 2025; Sadigova, 2023; Zernov & Mirzayeva, 2021).

Years of oil extraction, industrial activity, traffic congestion, and urbanisation on the peninsula have altered the chemical and physical properties of the soil, leading to the degradation of vegetation cover and a decline in crop yields. In particular, petroleum products, industrial and domestic wastewater seeped into the soil, causing environmental stress and becoming one of the main causes of soil erosion and damage to vegetation.

On the Absheron Peninsula, soil pollution and degradation are primarily caused by oil extraction, oil waste, and other forms of extractive activity. The discharge of petroleum products and large volumes of well water into surface waters also leads to a rise in the groundwater level and the re-salinisation of the soil. The improper operation of oil fields in Absheron, where oil extraction took place for decades without compliance with even the most basic environmental protection standards, and the discharge of oil, gas, chemicals, and highly mineralised and radioactively contaminated water onto the ground have led to the contamination and degradation of certain natural and man-made landscape areas (Xəlilova & Zeynalova, 2022; Qurbanov, 2016; Mirzəyev & Şıxəliyev, 2012).

The vegetation of the Absheron Peninsula, particularly along its Caspian Sea coastline, is characterised by its diversity and has been subject to various forms of salinisation. Here, salinisation is classified into chloride-sulphate, sulphate-chloride, and chloride-sulphate-carbonate types. Most of the peninsula's territory consists of sandy soils, and in rare cases, light sandy loam soils. The pH of such saline soil types ranges from 6.0 to 7.5, and there is virtually no humus layer in these soils. Natural vegetation on such soils is sparse and, in early spring, consists of short-lived ephemerals and hemiphytes (Ağayev & Əfkərov, 2007).

The storage of crude oil and well water produced during the initial phase of operation of the Absheron oil fields in above-ground earthen reservoirs, as well as the lack of technologies that met the economic requirements of that period, had a negative impact on the environment, including high levels of oil contamination of land. Soils contaminated with oil are light grey-brown, loose, medium loam, and moderately saline. 33,000 hectares of the peninsula's territory are covered by wasteland. The area of land contaminated by oil is 10.6 thousand hectares. Bituminous (pyritisised) soils are a type of asphaltic soil that has undergone fundamental changes over time (Ağayev & Əfkərov, 2007; Aslanov & Səfərli, 2008; Qurbanov, 2016).

In addition, the peninsula also has deposits of salt, sand, limestone, and clay. Cement, gypsum and lime in Garadagh; brick clay in Sumqait and Zykh; building sand in the vicinity of Shykhlar, Balakhani and Hokmali; paving stones in the vicinity of the settlements of Garadagh, Gyuzdek, Mashtagha, Nardaran and Korgoz; Nardaran, Shuvelen, Mashtagha, Zira and Zykh – near limestone deposits; Karadag, Gyuzdek, Zykh and Korgoz – near villages where facing stone is quarried. The aforementioned building materials are widely used. The total area of the five domestic waste landfill sites on the peninsula is 232.5 hectares. The area covered by unauthorised rubbish dumps totals 448.6 hectares, and there are 128 of them in total. The officially operating landfill sites in Baku do not comply with environmental regulations and standards. Hazardous waste generated during the production of caustic soda and chlorine using the mercury process is one of the factors causing serious environmental problems in the city of Sumgait and on the Absheron Peninsula as a whole (Xəlilova & Zeynalova, 2022; Qurbanov, 2016).

According to the findings of an assessment of the environmental situation in the region, the following four instances of landscape degradation were identified on the Absheron Peninsula:

- Satisfactory – the soil and vegetation cover are undamaged;
- Moderate – the soil cover is slightly damaged;
- Critical – the soil cover has been destroyed, and the relief has changed;
- Catastrophic – all elements of the landscape have been altered, and all internal landscape connections have been disrupted.

The exploitation of natural resources, industrial activities, and human-induced activities are leading to excessive pollution and land degradation. Another environmental problem is the poor condition of the sewerage systems on the peninsula. Overall, around 560 million cubic metres of wastewater are generated in the Baku district over the course of a year. A sharp rise in the groundwater level on the peninsula, the dilapidated state of the town's water supply and sewerage networks, and the inefficiency of the municipal services have led to a sharp deterioration in the environmental situation, posing a serious threat to public health. The main causes of the high level of environmental pressure in urban areas are: the concentration here of 70% of the country's economic potential, without due regard for natural conditions and environmental carrying capacity; the use of outdated technologies by industrial enterprises; the dilapidated state of the water supply network and sewerage system; vehicles that do not meet environmental standards; vast areas occupied by landfill sites; insufficient funding allocated to environmental protection; and a lack of attention to this area on the part of the city administration and environmental protection bodies and organisations (Həsənov, 1997; Xəlilova & Zeynalova, 2022).

Along the Absheron coastline in the north, east and south, landforms of abrasive-accumulative origin and sand dunes are widespread. Due to the large number of windy days (300-350), shifting sands are

constantly blown into the air, leading to an increase in the amount of dust in the air. This, in turn, causes enormous damage to the economy and the population (Google, n.d.).

The Absheron Peninsula is the main region in Azerbaijan and even in the whole world where mud volcanoes are active. Frequent surges in their activity cause damage to the landscape, leading to natural changes in the soil and vegetation cover. Azerbaijan ranks first in the world in terms of the number and variety of mud volcanoes. Of the 800 known mud volcanoes in the world, 400 are located in the southern Caspian oil and gas basin, including more than 300 on the mainland of Azerbaijan and in the Caspian Sea. Therapeutic mud is found on the Absheron Peninsula, in Lake Masazir, in the Gobustan and Lower Kurin depressions, and also in areas where mud volcanoes erupt (Bədəlov, 2016).

The arid climate of the peninsula creates favourable conditions for the development of gully and ravine erosion, as well as arid denudation processes. The annual number of hours of sunshine here reaches 2,450-2,500. Annual rainfall is 250-300 mm, whilst in the south-west (in the Buty area) it is 130-150 mm, which is low for the Absheron Peninsula. A significant difference between precipitation and evaporation (950-1,000 mm) leads to the development of physical erosion and the degradation of vegetation cover.

2. Materials and methods

This research is primarily devoted to assessing the long-term spatial and temporal characteristics of vegetation cover change on the Absheron Peninsula. The main scientific objective of this study is to identify changes in vegetation cover between 2006 and 2016 and in 2025, and to analyse the intensity of anthropogenic impacts using GIS.

Landsat satellite images obtained from the archives of the United States Geological Survey (USGS) were used to analyse the terrain. To ensure seasonal comparability of the study and the accuracy of the results based on satellite imagery from three satellites, a suitable season was selected, and for the months marking the transition from summer to autumn 'Level 2 Surface Reflectance' (L2SP) products characterised by the lowest cloud cover were selected:

For 2006, a satellite image acquired by the TM sensor on Landsat 5 (LT05_L2SP) on 10 August 2006 was used. At this stage, Band 4 channels, corresponding to the near-infrared (NIR) spectrum, and Band 3 channels, corresponding to the red (Red) spectrum, were used to determine the spectral reflectance of vegetation.

For 2016, images obtained using the OLI/TIRS sensor on the Landsat 8 satellite (LC08_L2SP), taken on 21 August 2016, were used. In the case of the Landsat 8 satellite, the near-infrared channel is designated as Band 5, and the red channel as Band 4.

For 2025: to provide an up-to-date assessment of the current situation, satellite imagery from Landsat 8 (LC08_L2SP) taken on 30 August 2025 and 3 September 2025 (bands 5 and 4) was used.

During the processing of the satellite images, all data were transformed into a single coordinate system (UTM, Zone 39N, WGS 84). The standard normalised difference vegetation index (NDVI) has been used for many years to calculate the density of vegetation cover, its health status and variations in its spatial distribution. Taking into account the characteristics of the sensors, the indicator was calculated using the following mathematical formulae. As different satellites were used in the study, the calculations were carried out using two different formulae:

For Landsat 5 (2006):

$$\mathrm{NDVI} = \frac{\mathrm{Band\ 4} - \mathrm{Band\ 3}}{\mathrm{Band\ 4} + \mathrm{Band\ 3}}$$

For Landsat 8 (2016, 2025):

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4}$$

Here, B5 (or B4 for Landsat 5) refers to the near-infrared spectral band, whilst B4 (or B3 for Landsat 5) refers to the red light band. NDVI values, which range from -1 to +1, also enable the accurate classification of bodies of water, bare soil, building sites, and areas with dense vegetation.

At the same time, the images were classified using supervised classification methods in order to assess overall changes to the landscape in this area. Based on the large-scale maps and statistical indicators obtained, a comparative analysis of environmental and geographical trends on the Absheron Peninsula was carried out.

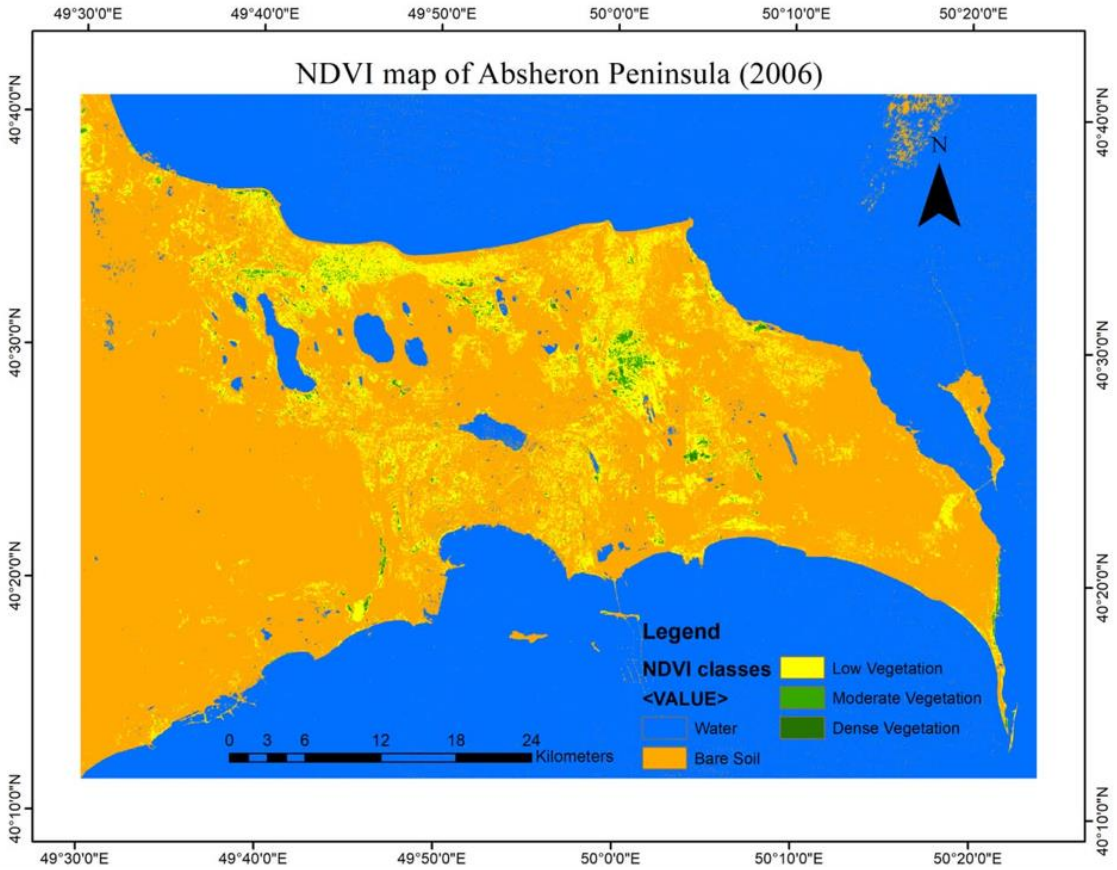


Figure 2. *NDVI map of the Absheron Peninsula, 2006.*

Table 1. *Analysis of the NDVI index for the Absheron Peninsula – 2006.*

NDVI classes (2006)	Area (ha)
Bare Soil	167961
Low Vegetation	26280
Moderate Vegetation	2200
Dense Vegetation	186

As can be seen from Figure 2 and Table 1, in 2006, bare soil and sparse vegetation predominated across vast areas of the Absheron Peninsula. Vegetation occurs in limited areas. It would appear that this landscape reflects conditions associated with the peninsula's arid climate, low rainfall, high evaporation rates, and a lack of moisture in the soil. On the map, the vegetation is fragmented and distributed unevenly. Long-term

human-induced impacts also play a role in this process. Oil production, industrial activity, and the development of transport infrastructure are contributing to changes in the natural composition of the soil and vegetation cover. It should be borne in mind that low NDVI values cannot be regarded solely as a consequence of anthropogenic degradation, as natural vegetation in semi-arid landscapes is also sparse. The main purpose of the 2006 map is to establish a baseline for assessing subsequent changes.

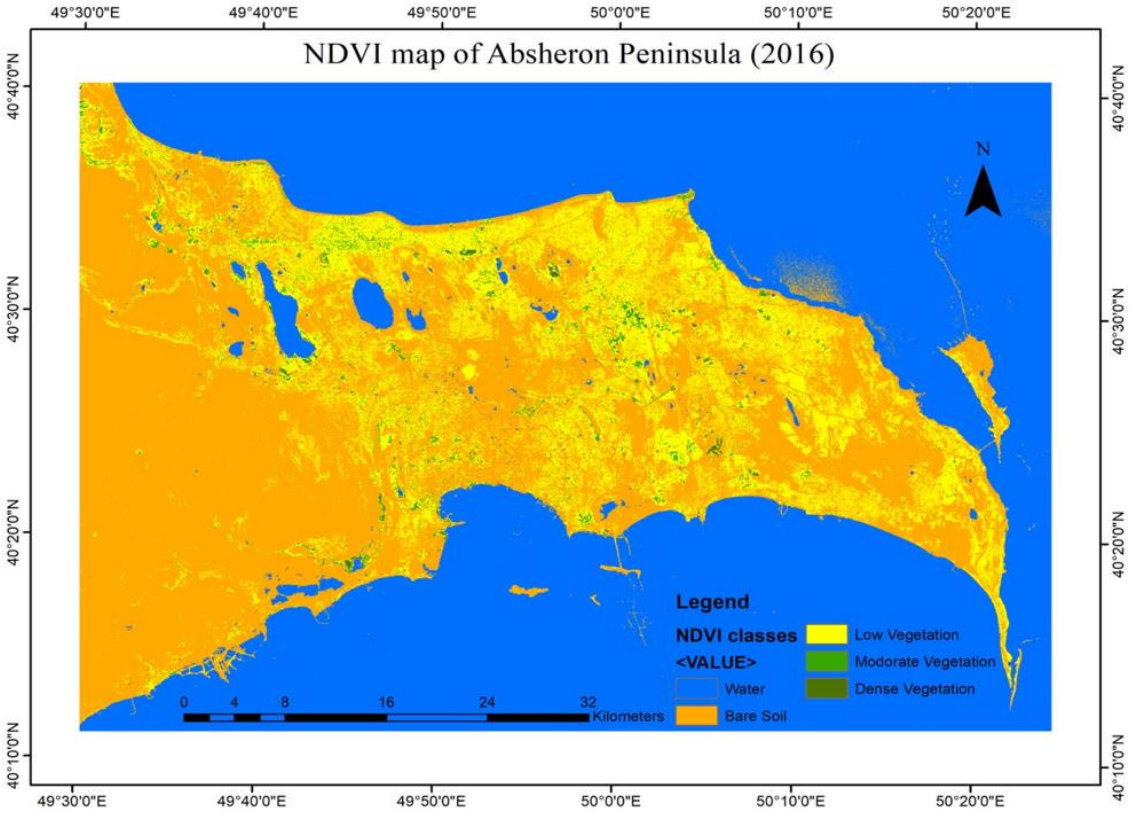


Figure 3. *NDVI map of the Absheron Peninsula, 2016.*

Table 2. NDVI analysis of the Absheron Peninsula-2006.

NDVI classes 2016	Area (ha)
Bare Soil	196424
Low Vegetation	53595
Moderate Vegetation	3702
Dense Vegetation	619

As can be seen from Figure 3 and Table 2, certain changes are observed in the spatial description of vegetation in 2016 compared to 2006. Alongside this, an expansion of medium and high NDVI values is noticeable in various areas. These changes are associated with greening measures carried out under conditions of intensive urbanisation, the creation of park and garden areas, the planting of ornamental trees and shrubs, as well as reclamation measures undertaken to eliminate the consequences of anthropogenic impacts. Although at first glance the changes towards a positive result on the map may be understood as an improvement in the peninsula's ecological condition, it would be more accurate to regard them as aesthetic changes in the spatial structure of the vegetation cover. This is because the restoration of oil-contaminated and salinised soils to their original state is not possible, and compared to 2006, the area of areas without observed vegetation cover has increased by 28,463 ha.

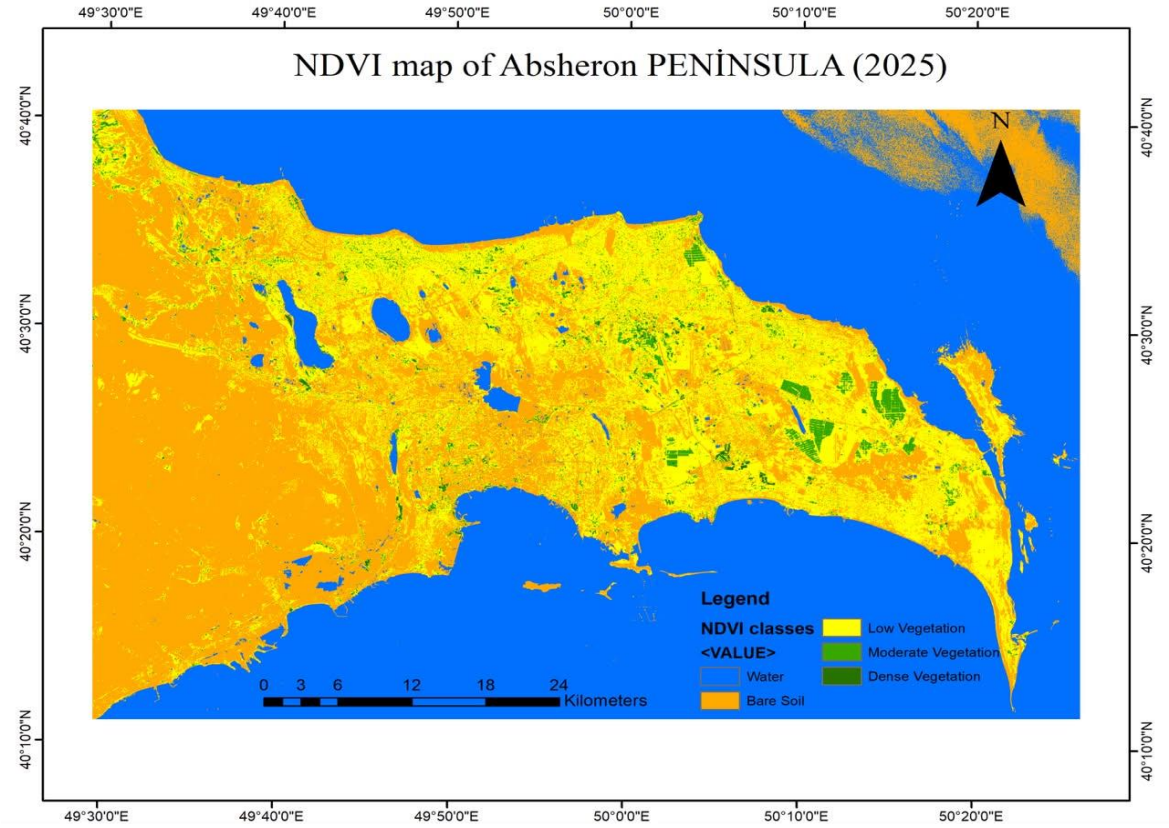


***Figure 4**. NDVI map of the Absheron Peninsula, 2025.*

***Table 3.** NDVI analysis of the Absheron Peninsula-2025.*

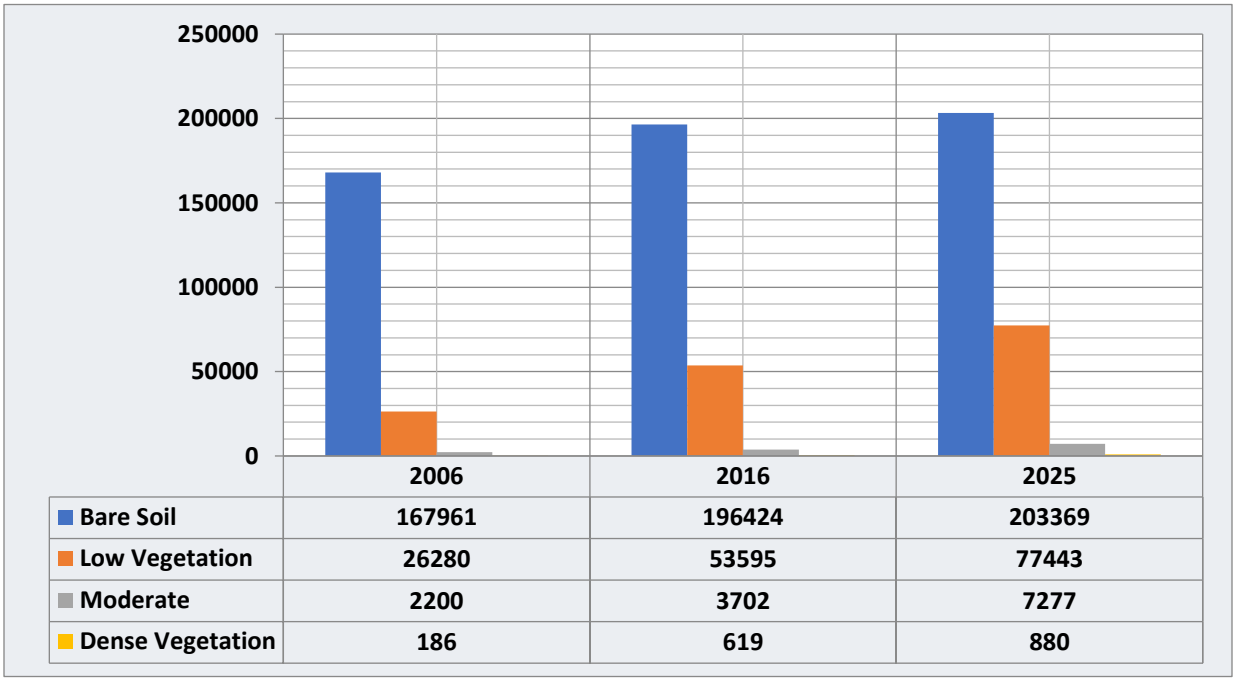
NDVI classes 2025	Area (ha)
Bare Soil	**203369**
Low Vegetation	**77443**
Moderate Vegetation	**7277**
Dense Vegetation	**880**

As can be seen from Figure 4 and Table 3, the more pronounced presence of areas with medium and high NDVI values in 2025 compared with other years (2006, 2016) indicates an increase in vegetation cover. This trend can be explained by the creation of parks on the peninsula as part of urban planning and improvement measures; significant contributing factors include green belts along riverbanks, ornamental plantings, irrigated landscape areas, and cultivated landscapes created for aesthetic purposes. Nowadays, the ongoing expansion of industrial activity and oil and gas extraction, soil pollution, salinisation and the fragmentation of natural habitats represent constant environmental pressures, whilst the area of vegetation cover is increasing rapidly. Therefore, an increase in NDVI values should not be regarded as direct evidence of the natural recovery of ecosystems, an increase in species diversity, or improved soil fertility. Accordingly, the changes shown on the 2025 map highlight the importance of studying the relationship between the increase in green space in Absheron and improvements in environmental quality.

3. Conclusion

In the course of our study, which focused on a spatio-temporal analysis of changes in vegetation cover on the Absheron Peninsula, it was established that, according to NDVI indices, the total area of land devoid

of vegetation in 2006 amounted to 167,961 hectares, with 26,280 hectares of land having sparse vegetation, 2,200 hectares having moderate vegetation cover, and 186 hectares having dense vegetation cover; in 2016, the total area of land devoid of vegetation was 196,424 hectares, with sparse vegetation cover covering 53,595 hectares, moderate vegetation cover covering 3,702 hectares, and dense vegetation cover covering 619 hectares; in 2025, the total area of land without vegetation cover was 203,369 hectares, of which 77,443 hectares had sparse vegetation cover, 7,277 hectares had moderate vegetation cover and 880 hectares had dense vegetation cover.



	2006	2016	2025
Bare Soil	167961	196424	203369
Low Vegetation	26280	53595	77443
Moderate	2200	3702	7277
Dense Vegetation	186	619	880

***Figure 5**. Vegetation dynamics from 2006 to 2025.*

As can be seen from Figure 5, although there has been an increase in the area of parks and green spaces in the study area in recent years, the area of land where vegetation cover has undergone radical changes or disappeared entirely is growing at a faster rate. Consequently, compared with 2006, the area of land devoid of vegetation had increased by 35,408 hectares by 2025.

The results obtained are of great significance for tracking the positive changes taking place in the peninsula's ecosystem, as well as for planning future environmental monitoring.

Author's contribution

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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Principles for Assessing Anthropogenic Impacts on Azerbaijan's Freshwater Resources

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Abstract

Nowadays, the protection and conservation of freshwater resources are among the most pressing environmental issues. The rapid development of agriculture and industry, rising population density, increasing volumes of household waste, and urbanisation are having a negative impact on the quality and quantity of water resources. This article examines the anthropogenic factors affecting freshwater resources and analyses the ecological status of the Kura and Aras rivers, which are regarded as two of Azerbaijan's major rivers. When assessing water quality, factors such as pH, dissolved oxygen (DO, mg/l), biochemical oxygen demand (BOD, mg/l), and nitrate and phosphate levels are taken into account. In addition, an assessment is being carried out of the impact of climate change on river hydrology, the availability of water resources, and the resilience of aquatic ecosystems. The findings of the study highlight the importance of effective water resource management, pollution prevention, and regular environmental monitoring.

Keywords: freshwater resources, human impact, the Kura River, the Aras River, water quality, climate change, environmental monitoring, water resources management

1.Introduction

Water resources are vital for meeting the population's drinking water needs, for the development of agriculture and industrial production, and for the functioning of natural ecosystems. However, population growth, expanding economic activity, and climate change are placing increasing pressure on freshwater resources. Excessive water consumption, the discharge of untreated wastewater into natural water bodies, and the intensive use of chemicals in agriculture are among the main factors leading to a deterioration in water quality (UN-Water. (n.d.).

The Kura and Aras rivers hold a special place in Azerbaijan's water resources system. These rivers serve an important role in providing irrigation water for agriculture, supplying water to the population, and protecting aquatic ecosystems. At the same time, as these are transboundary rivers, the condition of their water resources depends not only on internal factors, but also on processes taking place in other parts of the catchment area [5; 6].

The aim of this article is to identify the main human-induced factors affecting the Kura and Aras rivers. To analyse the indicators used to assess water quality. To summarise the data on the impact of climate change on the hydrological and ecological conditions of these rivers.

2. Main areas of human impact on freshwater resources

Anthropogenic impact encompasses changes to the natural state of water resources caused by human economic activity. These consequences manifest themselves both in changes to the chemical and biological properties of the water and in disruptions to river flow patterns. The primary factors affecting freshwater reserves are industrial activity, agriculture, domestic waste, urbanisation, and the inefficient use of water resources (Singh & Mishra, 2014; UNWWAP, 2021).

2.1. Industrial activity

Wastewater from industrial plants and the chemicals used in manufacturing processes lead to the pollution of water resources. Furthermore, heavy metals, petroleum products, and other toxic compounds have a negative effect on the chemical composition of the water, the life processes of aquatic organisms, and the overall health of the ecosystem.

The extent of industrial pollution depends on the treatment technologies used at industrial sites, the wastewater management system, and the effectiveness of ecological monitoring. Therefore, reducing the volume of industrial waste at source, modernising treatment plants, and regularly monitoring pollutants are regarded as key priorities in the protection of water resources [4; 7].

2.2. Agricultural activities

Agriculture is not only one of the main sectors that consume freshwater resources, but it can also contribute to water pollution. When mineral fertilisers and pesticides are applied in excess, some of them end up in rivers and lakes via surface runoff, whilst others enter the groundwater as a result of leaching.

Excessive accumulation of nitrogen and phosphorus compounds in water bodies accelerates the process of eutrophication. This process can lead to rapid growth of aquatic plants and algae, an increase in oxygen consumption during the decomposition of organic matter and, as a result, a reduction in the dissolved oxygen content of the water. It is necessary to analyse the composition of runoff from irrigated land in the Kura and Aras river basins, to conduct monitoring of fertiliser and pesticide use, and to expand the use of water-saving irrigation methods, as significant changes are causing a deterioration in the habitats of fish and other aquatic organisms (Singh & Mishra, 2014; UNWWAP, 2021).

2.3. Household waste and urbanization

Urban expansion, population density, and the strain on public utility infrastructure increase the risk of pollution from residential sources. When poorly treated or completely untreated wastewater enters water bodies, the levels of organic compounds, nutrients, and pathogenic microorganisms in them increase (National Geographic, n.d;Azərbaycan Respublikası Ekologiya və Təbii Sərvətlər Nazirliyi, n.d.).

All of this has a negative effect on water quality. Furthermore, it leads to a reduction in dissolved oxygen levels and the degradation of aquatic ecosystems. Plastic and other solid waste also contribute to water pollution and the destruction of aquatic habitats. To tackle this problem, it is necessary to modernise the sewerage networks, improve the standard of wastewater treatment and strengthen controls over the management of household waste (Seymur, 2025; Bünyadzadə, 2023).

2.4. Inefficient use of water resources

The overexploitation of water resources affects river flow, water levels and the natural hydrological regime. Rising demand for water, particularly during the irrigation season, losses in irrigation channels, and the uneven distribution of water can reduce the efficiency of water use.

Changes in the hydrological regime of rivers also affect the ecological condition of riparian zones, the habitats of aquatic organisms, and the water's ability to purify itself. Therefore, when managing water resources, it is essential to take into account not only the volume of water abstracted, but also the needs of ecosystems and the need to preserve the river's natural flow (UN-Water, n.d.).

3. Anthropogenic impact on the ecological condition of the Kura and Aras rivers

The Kura and Aras rivers play an important role in the formation and utilisation of Azerbaijan's water resources. The water from both rivers is of great importance to agriculture, public utilities and other economic activities. Furthermore, the ecological status of rivers may be affected by issues relating to population settlement, irrigation, industrial activity and wastewater management within river basins (Allan & Castillo, 2007; Gleick, 2018).

3.1. Key factors affecting the Kura River

When assessing the environmental condition of the Kura River, the main focus is on industrial and domestic waste, agricultural runoff, and the intensive use of water resources. Industrial pollutants can cause changes to the chemical composition of water. In this regard, it is particularly important to determine the concentrations of heavy metals, petroleum products, and other potentially hazardous substances. However, in order to confirm the areas and levels in which specific pollutants are present, relevant monitoring and laboratory analysis results are required. [4; 6]

Agricultural activity in the Kura River basin is also one of the factors affecting water quality. Runoff from irrigated areas may lead to increased levels of nitrates and phosphates. Nevertheless, an excessive accumulation of nutrients increases the risk of eutrophication.

Furthermore, the abstraction of water for irrigation and other agricultural purposes may lead to changes in the flow and water levels at various points along the river. These changes may lead to more serious environmental and socio-economic problems during periods of drought (Gleick, 2018).

3.2. Key factors affecting the Aras River

The environmental condition of the Aras River is affected by agriculture, domestic waste, industrial activity, and water abstraction for irrigation. The composition of runoff from irrigated areas is of particular importance in terms of the accumulation of nutrients and other pollutants in the river and its associated water systems.

The use of water for agricultural purposes in the Aras River basin could lead to an increase in seasonal demand for water and changes to the hydrological regime. Uneven rainfall distribution and arid conditions create additional challenges for irrigation and water supply, as they exacerbate these effects.

In order to objectively assess the ecological status of the river, it is necessary to carry out a comparative analysis of the chemical and biological parameters of the water at various points along its course. In addition, given that this is a transboundary river, the exchange of information and joint monitoring activities within the catchment area are of paramount importance [5; 6].

4. Assessment of river water quality

Physical, chemical, and biological parameters are used to evaluate the ecological status of rivers. These indicators make it easier to determine the level of water contamination. The state of the ecosystem and the possible consequences of human activity are determined using the same indicators (UNWWAP, 2022).

Physical parameters include water temperature, colour, turbidity and the amount of suspended particles. These indicators characterise the physical condition of the water and can be used for an initial assessment of precipitation, surface runoff and other impact factors.

Chemical indicators enable us to assess the concentration of substances in water and environmental processes. Among these parameters, pH, dissolved oxygen (DO) content, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and nitrate and phosphate concentrations are of particular importance (IPCC, 2021).

Biological indicators cover the condition of phytoplankton, zooplankton, bioindicator organisms, and pathogenic microorganisms. Biological indicators play an important role in determining the response of an aquatic ecosystem and the impact of pollution on living organisms.

4.1. The environmental significance of key chemical parameters

pH indicates the degree of acidity and alkalinity of water. This indicator affects the living conditions of aquatic organisms and the form in which certain chemicals are present in the water. When assessing pH values, it is also necessary to take into account natural geochemical characteristics and seasonal variations.

Dissolved oxygen (DO) is one of the key indicators used to characterise the condition of aquatic ecosystems. A reduction in the oxygen content of water may be due to the decomposition of organic matter, high temperatures, and other factors. A lack of oxygen creates unfavourable conditions for fish and other aquatic organisms (Gleeson et al., 2020).

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen required to break down organic matter in water through the action of microorganisms. An increase in the BOD value may indicate contamination by organic substances. To interpret the results correctly, however, it is necessary to specify the duration and method of measurement, the sampling site, and other laboratory conditions.

Chemical oxygen demand (COD) is used to estimate the quantity of substances in water that are susceptible to chemical oxidation. This indicator is useful for determining the level of organic pollution; however, it is not as significant as BOD.

Nitrates and phosphates can enter water bodies via agricultural runoff, domestic wastewater, and other sources. Their excessive accumulation may exacerbate the process of eutrophication, leading to a deterioration in the ecological status of water bodies (National Geographic, n.d.).

4.2. Comparison of data for the Kura and Aras rivers

The source material presented the following ranges of data for the Kura and Aras rivers. Since the years, sampling points, and laboratory methods used to obtain these figures are not specified, however, they should be regarded not as confirmed monitoring results but as preliminary data requiring further verification (Table 1).

Table 1. *Water quality parameters for the Kura and Aras rivers, as stated in the source data.*

Parameter	The Kura River	The Araz River
pH	7,2-8,1	7,0-7,8
Dissolved oxygen (DO, mg/l)	5,5-7,0	5,8-7,2
Biochemical oxygen demand (BOD, mg/l)	3-6	2-5
Nitrates (mg/l)	8-25	6-18
Phosphates (mg/l)	0,2-0,8	0,1-0,5

Note: The figures in the table are based on data from the source text. As the data source, the date on which the measurements were taken, and the methodology are not specified, these results should not be regarded as definitive indicators of the current state of the rivers.

Considering the figures in the table as preliminary data only, it becomes clear that the BOD value for the Kyur River lies within the range of 3-6 mg/l, and for the Aras River, within the range of 2-5 mg/l. These indicators can play an important role in assessing the extent of organic pollution. However, it would be incorrect to state categorically that one river is more polluted than another, based solely on individual figures. This requires analyses carried out during the same period, using the same methodology and at comparable locations (UNECE, 2018).

The same approach applies to nitrate and phosphate levels. High concentrations of these substances may be linked to runoff from agricultural land and domestic wastewater; however, to determine their specific source, it is necessary to carry out a comprehensive analysis of land-use patterns within the catchment area, the sources of runoff and the results of laboratory tests. Consequently, in order to assess

water quality reliably, it is necessary not only to provide individual parameters, but also to specify the time and location of the measurements, the methodology used, and the conditions under which the results were compared (Azərbaycan Respublikası Ekologiya və Təbii Sərvətlər Nazirliyi, n.d.).

Table 2. *A comparative analysis of the Kura and Aras rivers.*

Indicator	The Kura River	The Aras River
Decrease in runoff	15-30 %	10-20 %
Consequences of drought	Severe	Medium
Risk of flooding	High	Medium
Eutrophication	More severe	Medium level
Water quality	Deterioration	Medium level

Table 2 presents a comparative analysis of the Kura and Aras rivers. In the Kura River basin, the effects of climate change are evident, first and foremost, in a reduction in water supplies. Research carried out in recent decades shows that the rise in the region's average annual temperature has led to increased evaporation, which, in turn, has caused a 15-25% reduction in river flow, particularly during the summer months. In dry years, this reduction can reach 30%, which creates serious problems in terms of the supply of water for irrigation and drinking. Changes are being observed in the seasonal distribution of precipitation. Increased precipitation in the winter and spring months raises the risk of flooding in the lower reaches of the Kura River, whereas reduced precipitation in the summer months exacerbates the problem of water scarcity even further. This comparison shows that the Kura River is more susceptible to human and climatic influences, whilst the Aras River is relatively stable, although the effects of drought and irrigation are more pronounced there.

5. The impact of climate change on the water resources of the Kura and Aras rivers

Climate change is a significant factor that can affect both the quantity and quality of water resources. Rising temperatures, changes in the spatial and temporal distribution of precipitation, changes in snow cover characteristics, and extreme weather events may affect the hydrological regime of rivers. These processes are of particular importance in regions where irrigation and drinking water supplies depend on river flow (World Wide Fund for Nature, n.d.).

5.1. Declining water reserves and changes to the hydrological regime

A rise in temperature may lead to increased evaporation. This process is exacerbated by a reduction in rainfall or its uneven distribution across the seasons, which increases the risk of a decline in water reserves in river basins. Furthermore, the intensity of rainfall may lead to more frequent flash floods and an increase in surface runoff.

Changes in water reserves in the Kura River basin are of great importance for irrigation, public water supply, and the sustainability of ecosystems. During the summer months, difficulties may arise with the allocation of water supplies when a reduction in water availability coincides with a period of increased demand for water. On the other hand, heavy rain and intense surface runoff may increase the risk of flooding in areas further downstream.

In the Aras River basin, climate change may also affect the seasonal distribution of water resources and irrigation potential. When changes in snow cover conditions and the timing of snowmelt affect spring runoff, uncertainty regarding the availability of water resources during the summer season may increase. In this regard, it is important to carry out long-term monitoring of precipitation, temperature, snow cover, and river flow in the catchment (WHO, 2017; UNEP, n.d).

The source data contained figures indicating a reduction in the flow of the Kura River by 15-30% and that of the Araks River by 10-20%. However, as it is not known which period, which regions, and which calculation method these percentage figures cover, they cannot be presented as a generalised scientific

conclusion. To use this data in an article, you must cite the relevant source of hydrological research or monitoring.

5.2. The impact of climate change on water quality

Climate change can affect water quality through several mechanisms. A rise in temperature reduces the solubility of oxygen in water. At the same time, a rise in water temperature may affect the rate of biological processes. As the river's flow rate decreases, the dilution of pollutants may become less effective, whilst the concentration of certain substances may increase.

High concentrations of nutrients and favourable temperature conditions can exacerbate the process of eutrophication. However, the extent of eutrophication depends not only on temperature, but also on the nitrogen and phosphorus content of the water body, current patterns, light levels and other environmental factors (Durán-Sánchez et al., 2018).

During periods of drought, a reduction in water levels can make the effects of pollution more noticeable. Floods and heavy rainfall can accelerate the entry of soil particles, fertiliser residues and other substances into rivers. Therefore, when assessing the impact of climate change on water quality, consideration should be given to hydrological, chemical and biological indicators alike (WHO, 2017).

5.3. Socio-economic outcomes

A decline in water volume and a deterioration in water quality could affect the water supply to the population, agricultural productivity and the sustainability of ecosystems. A shortage of water for irrigation increases the risks associated with agricultural production. However, contamination of drinking water sources may lead to increased water treatment costs and pose additional challenges in ensuring public health and safety.

Disturbances to oxygen levels and changes to habitat conditions in aquatic ecosystems can have a negative impact on fish stocks and biodiversity. These changes may also affect livelihoods in sectors dependent on rivers and the well-being of local communities (UNWWAP, 2021; WWFN, n.d).

Consequently, the effects of climate change are not limited solely to changes in the total volume of water. The seasonal distribution of water resources, water quality indicators, and ecosystem stability may also change in complex ways.

6. Improving the protection and sustainable use of water resources

Improving the environmental condition of the Kura and Aras rivers requires a reduction in human impact, the sustainable use of water resources and the implementation of measures to adapt to climate change. In this regard, the following measures are of particular importance.

Firstly, efforts to treat wastewater must be stepped up. Improving the treatment of urban and industrial wastewater, modernising treatment plants, and reducing pollutant emissions at source can help to reduce the pressure on rivers.

Secondly, environmentally friendly methods should be used in agriculture. The rational use of fertilisers and pesticides, regular soil and water analysis, the reduction of irrigation losses, and the use of modern irrigation technologies all help to conserve water resources (UNEP, 2021; UN-Water, n.d.).

Thirdly, water quality monitoring needs to be improved. Measurements of pH, DO, BOD, COD, nitrates, phosphates, and biological parameters should be carried out regularly at various points along the Kura and Aras rivers. To ensure that results are comparable, it is necessary to specify the sampling points, dates, laboratory methods, and units of measurement precisely (UNWWAP. 2022; National Geographic. n.d.).

Fourthly, measures to adapt to climate change need to be developed. Long-term analysis of hydrological observations, assessment of drought and flood risks, improving the efficiency of irrigation systems, and the planned allocation of water resources amongst different users can help to strengthen water security (WHO, 2017; UN-Water, n.d.).

Fifthly, we need to expand cross-border cooperation. The exchange of information, the application of agreed monitoring methods, and the joint assessment of pollution sources in the Kura and Aras river basins are of great importance for integrated water resources management (UNEP. n.d).

Sixthly, it is necessary to raise public awareness. Awareness-raising initiatives on the rational use of water resources, the proper management of household waste and the prevention of water body pollution can help to foster environmental responsibility amongst the public (WWFN, n.d).

7. Conclusion

The analysis carried out shows that the protection of freshwater resources is of great environmental and socio-economic importance in today's world. Industrial activity, agriculture, household waste, urbanisation and the unsustainable use of water resources are the main human-induced factors affecting water quality and the hydrological regime of rivers.

A comprehensive study of these factors is crucial for assessing the ecological status of the Kura and Aras rivers, which are among Azerbaijan's main waterways. Industrial and domestic pollution, runoff from agricultural land, and water abstraction for irrigation can pose a serious threat to both river basins. However, in order to confirm as a definitive conclusion the generalisation contained in the available preliminary materials that the Kura River is subject to greater anthropogenic impact than the Aras River, comparative monitoring data collected using the same methodology are required.

pH, dissolved oxygen content, biochemical and chemical oxygen demand, as well as nitrate and phosphate levels, play an important role in assessing water quality. Regular monitoring of these indicators makes it possible to identify pollution risks and track changes in the environmental situation. Furthermore, in order to interpret the results correctly, it is necessary to specify the sampling locations, the dates on which the measurements were taken, and the laboratory methods used.

Climate change may place additional pressure on river water supplies as a result of rising temperatures, uneven rainfall distribution, droughts and extreme hydrological events. These changes affect both the quantity and quality of water, increasing the risks associated with the sustainability of agriculture, water supply and aquatic ecosystems.

In this regard, in order to protect the Kura and Aras rivers, it is necessary to implement, in a coordinated manner, measures relating to wastewater treatment, the rational use of water and chemicals in agriculture, regular environmental monitoring, adaptation to climate change, and cross-border cooperation. These measures can contribute to the sustainable management of water resources, reduce the risks of pollution, and ensure water security for future generations.

Author's contribution

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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Absheron's Greening Schemes and Their Environmental Assessment

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Abstract

This article examines issues relating to the sustainability of the vegetation cover on the Absheron Peninsula. This research examined the climatic conditions of the region, including its arid climate, strong winds, and the level of human impact. The region's green spaces have a direct positive impact on reducing dust levels and air pollution, regulating the microclimate and mitigating the 'urban heat island' effect. The report found that, despite the afforestation measures being taken, industrialisation, urbanisation, land degradation and water scarcity are having a negative impact on the development of vegetation cover on the peninsula. To tackle these problems, it is of the utmost importance to expand green spaces, reclaim land contaminated by oil, treat wastewater, and reduce atmospheric emissions. Consequently, the protection and scientifically sound management of green systems are regarded as a priority for ensuring the environmental safety of the Absheron Peninsula, mitigating the effects of climate change and promoting sustainable urban planning.

Keywords: Absheron Peninsula, green systems, environmental assessment, environmental sustainability, urbanisation, land degradation, greening, environmental protection, biodiversity, sustainable urban development.

1.Introduction

The Absheron Peninsula is situated in eastern Azerbaijan and is considered one of the country's most densely populated and industrially developed regions. The peninsula is characterised by a dry subtropical climate, low rainfall, high evaporation, strong winds and limited water resources. Annual rainfall of just 200-400 mm, whilst potential evapotranspiration exceeds 1,000 mm, is one of the main factors limiting the natural development of vegetation. Furthermore, as a result of many years of intensive development in oil production, oil refining, and other industrial sectors, the peninsula's natural landscapes have undergone significant anthropogenic changes, and a considerable proportion of the soil and vegetation cover has been degraded (Eyyubov, 1993).

For this reason, the creation and development of green spaces in Absheron is not only an element of landscape architecture, but is also of immense importance for maintaining ecological balance, improving air quality, reducing dust and air pollution, regulating the microclimate, and creating healthy living conditions for the population. In contemporary urban planning concepts, green systems are regarded as a key component of a city's ecological infrastructure, and their sustainable development is seen as one of the main means of mitigating the negative consequences of urbanisation (Agayev & Efkerov, 2007).

The scientific foundations for afforestation work on the Absheron Peninsula began to take shape in the middle of the last century. Research has shown that selecting species of trees and shrubs suited to the peninsula's soil and climate conditions, as well as assessing the adaptability of introduced plants, establishing protective tree belts, and creating park and landscape complexes significantly improve the effectiveness of afforestation. In this regard, the research carried out by T.S. Mammadov, U.M. Agamirov, and other Azerbaijani scientists played an important role in establishing the scientific basis for the afforestation of the Absheron Peninsula (Aslanov, 1992).

The development of green spaces in the Baku–Absheron conurbation is currently regarded as one of the key priorities for ensuring environmental safety, adapting to climate change, enhancing the sustainability of the urban environment, and meeting the population's recreational needs. Parks, gardens, boulevards, woodland parks, protective green belts along major roads, and specially protected natural areas contribute to the formation of a unified green infrastructure and play a crucial role in enhancing the resilience of the urban ecosystem (Aslanov, 2004).

2. Existing green spaces in the Absheron district

The existing green spaces in the Absheron District consist of landscape features shaped by the peninsula's complex natural and climatic conditions and are, first and foremost, the result of human activity. As the Absheron Peninsula is characterised by a dry, windy and semi-arid climate, natural forests and dense vegetation rarely thrive here. Soil salinisation, limited water resources and strong northerly winds hinder the natural spread of vegetation. Nevertheless, thanks in particular to the urban improvement measures carried out since the second half of the 20th century, extensive and varied green spaces have been created in the region.

There is virtually no natural forest cover on the Absheron Peninsula; however, to compensate for this, artificial tree belts and protective green belts have been created. The Absheron National Park and other green spaces play an important role in this regard. These areas were established primarily to prevent wind erosion, preserve soil fertility, and maintain biodiversity at a certain level. At the same time, the protective green belts created around industrial areas and major roads help to reduce air pollution and trap dust.

3. Structural and functional characteristics of existing green spaces in the Absheron District

In the Absheron District, green spaces are divided into three categories depending on their intended use, size, and location: public use, restricted use, and private use. The first group comprises the improvement of cultural and recreational parks, public gardens, boulevards and street landscaping within the town of Absheron, as well as the areas adjacent to public gardens and public buildings, and the landscaping of residential areas with two-storey and multi-storey blocks of flats. The second group comprises green spaces on the grounds of schools, hospitals, cultural and residential buildings, unique structures, private and residential properties, as well as industrial complexes in Absheron. The third group comprises other types of protective green areas (wind and snowbreaks, flood defences, protective and land-improvement areas, nurseries, etc.).

Absheron's green spaces form part of a comprehensive green network – a unified system of interconnected landscape features covering the entire city and its surrounding areas. The functions of this area include: ensuring a comprehensive approach to development and restoration; environmental protection; recreational use; and improving working and living conditions. The integrated green space comprises an inner zone (the urban development zone) and an outer zone. The inner zone comprises: neighbourhoods and districts; green spaces for various purposes; the improvement of streets, roads and squares; and the development of industrial estates. The outer zone comprises: suburban developments and industrial estates; holiday resorts and recreational areas (beaches, holiday villages, leisure facilities); green spaces (forest parks), gardens and nurseries; undeveloped (agricultural) land; and bodies of water.

Absheron is surrounded by ‘green belts’ – suburban forests. Green spaces can therefore either have an independent significance (such as forest parks) or be integrated into the urban fabric as an organic component.

In these new areas, the vegetation cover is extremely poor in terms of its composition and mesostructure, and fulfils virtually no ecological or ecosystem functions.

Microstructure refers to the arrangement of individual elements of landscape design: lawns, flowerbeds, shrubs and trees. The significance of individual microstructural elements is not consistent with economic, environmental and aesthetic considerations. The environmental value of costly and aesthetically pleasing elements of landscape design, such as flowerbeds and lawns, is low. The dense hedgerows, ponds teeming with vegetation and thick thickets make a truly impressive sight.

4. Criteria and methods for environmental assessment

As the Absheron Peninsula is home to approximately 40% of the country’s population and accounts for 70% of its industrial capacity, the majority of the country’s environmental problems requiring a solution are concentrated in this region. The main causes of environmental problems are soil contamination by oil and associated waters resulting from many years of oil and gas production and drilling operations, the formation of oil-contaminated artificial lakes and reservoirs due to ineffective management of associated waters, and the accumulation of oil refining waste. Wastewater is discharged into water bodies containing petroleum products, suspended solids, sulphate compounds, chloride salts, surfactants, phenols, and various heavy metals (Babayev, 2001).

Soil pollution is one of the main problems facing the Absheron Peninsula. On the Absheron Peninsula, which covers an area of 222,000 hectares, the total area of unused land is 33,300 hectares, of which up to 10,000 hectares are oil-contaminated.

The State Oil Company of the Republic of Azerbaijan owns 7,500 hectares of land contaminated with oil and petroleum products, as well as a further approximately 2,800 hectares of contaminated land. The degree of soil contamination ranges from 12% to 30–40% at a depth of 23 metres or more. The Absheron economic region, situated in the east of the country, comprises the Absheron, Khizi and Sumgait districts and enjoys a highly favourable economic and geographical position. The total area of the economic zone is 381,776 hectares, which accounts for 4.4% of the country’s total area. It is one of the most economically developed regions in the republic. The Absheron Economic Region borders the Kuba-Khachmaz Economic Region to the northwest, the Dagestan-Shirvan Economic Region to the west, and the Aran Economic Region to the southwest. To the north, east, and south, it is bordered by the waters of the Caspian Sea, which helps to expand transport links (Həsənov, 1966).

One of the worst environmental problems facing Baku and the Absheron Peninsula relates to solid waste management. Air pollution is one of the main environmental problems facing Baku. In recent years, there has been an increase in the number of vehicles, a shortage of gas scrubbers and dust collectors designed to capture harmful substances emitted into the air, and a rise in the amount of harmful substances released into the atmosphere as a result of waste incineration. This poses a serious threat to the environment and human health, as it leads to atmospheric pollution. The Absheron Peninsula is home to more than 200 lakes with a total area of 3,325 hectares. Every year, 41.5 million cubic metres of wastewater are discharged into these lakes. These lakes have a negative impact on the environment, causing soil degradation and salinisation, the flooding of additional areas due to rising water levels, the release of hydrocarbons and other harmful substances into the atmosphere as a result of evaporation, and damage to settlements, businesses, roads and other infrastructure.

The lack of sewerage systems in some settlements means that domestic wastewater is discharged into the lake and surrounding areas, which further exacerbates the environmental situation. The areas of Absheron most heavily polluted by oil and petroleum products are Qaradag, Binegadi, Sabunchu,

Surakhany, Azizbeyov and Sabael. In addition, 142,300 tonnes of oil-contaminated sludge, generated at oil and gas production and processing facilities, are stored at industrial sites. The remaining areas of Absheron are considered environmentally safe. 12 August marks Caspian Sea Day. This date marks the entry into force of the Tehran Convention on the Protection of the Marine Environment of the Caspian Sea, signed by the five Caspian littoral states: Azerbaijan, Russia, Kazakhstan, Turkmenistan and Iran. The main aim of 'Caspian Day' is to protect the marine environment of the Caspian Sea from pollution, to conserve, restore and ensure the rational and sustainable use of the sea's biological resources, and to raise public awareness of these issues (İmanov & Ələkbərov, 2017).

More than 130 years of oil production on the Absheron Peninsula have left a distinct mark on its landscapes. As a result of prolonged, intensive, and excessive pollution by oil and petroleum products, the ecosystem of the Absheron Peninsula has been depleted, leading to the degradation of pastures and the formation of barren areas overgrown with withered shrubs and ephemeral plants. These oil-contaminated soils have long since been transformed into abiogenic landscapes, including oil-saturated bituminous soils.

The region's landscape has been almost entirely altered by human activity. The area of degraded and contaminated soil in this region is approximately 25,000 hectares. A significant proportion of the area is covered in hydrocarbons and bitumen, whilst vast tracts are contaminated with drilling mud. More than 18,000 hectares of land are contaminated with oil and petroleum products, and 1,300 hectares have become unusable solely as a result of waste from the chemical industry. It is known that 7,400 hectares of land have been contaminated by oil, of which 2,800 hectares require urgent clean-up. Pollutants penetrate the soil to a depth of 2–3 metres. Long-term soil contamination by oil and petroleum products, as well as its environmental consequences, indicate that this places an 'excessive burden' on arid ecosystems. Self-regulatory processes have long since proved insufficient to ensure the self-recovery of degraded ecosystems. As a result, the ecological balance in these ecosystems is being disrupted by ever-increasing anthropogenic factors (IOM, 2024).

Soil has the ability to accumulate these mutagenic substances. Polycyclic aromatic compounds with confirmed mutagenic activity accumulate in oil-contaminated soils and become concentrated in significant quantities within their microzones. Consequently, it is reasonable to expect the soil itself, as a natural substrate, to exhibit mutagenic activity. The available data (Ismailov, 2006) show that oil-contaminated soils in Absheron contain polycyclic aromatic compounds, including naphthalene, phenanthrene, dibenzothiophene, fluoranthene/pyrene, benzo(a)anthracene/benzo[a]pyrene, and PAHs, and their concentrations exceed the MPC (calculated as benzo[a]pyrene) by a factor of thousands.

Soil pollution goes hand in hand with the pollution of surface and groundwater. There are over 200 natural and artificial water bodies on the peninsula, many of which are contaminated with oil and petroleum products. The area of water bodies contaminated by petroleum products exceeds 2,000 hectares. These include, in particular, Lake Zigh, Lake Boyukshor and many others.

The concentration of polycyclic aromatic compounds in the coastal waters and sediments of the Caspian Sea, which exceeds the maximum permissible concentration by a factor of a thousand, indicates their potential carcinogenic and mutagenic effects on aquatic biota. In the oil-contaminated soils and water bodies of this region, self-regulating processes have long since been disrupted, which prevents the natural recovery of these ecosystems through natural processes (Kərimov, 2004).

According to calculations, in terms of forest area per capita, which is the main source of oxygen in the atmosphere, the Absheron District lags behind the national average. Azerbaijan (0.006–0.1 hectares in the region compared with 0.14 hectares nationally). The area of woodland per capita on the Absheron Peninsula (mostly planted) is several times lower than in other regions of the country and the former USSR, at 3 hectares (Bukhtinov, A.D. et al., 1981).

The area of coniferous woodland in this region (Eldarica pine and others) does not exceed 20,000 hectares; 10,000 hectares are taken up by orchards, villages, settlements, etc. At the same time, 1 hectare of

coniferous forest releases 30 tonnes of oxygen into the atmosphere per year, deciduous forests release approximately 16 tonnes, and agricultural land and meadows release 3–10 tonnes per year. In this regard, an assessment of the environmental situation reveals extremely low indicators of the region's reproductive potential: a mere 0.8 million tonnes of oxygen produced per year, with an index of 0.04; as for water resources – 10.5 million m³, which corresponds to a reproductive potential index of 54.0 for water resources (the lowest figure in the republic). The region's low reproductive potential stands in stark contrast to the very significant anthropogenic (accounting for around 70 per cent of industrial capacity and over 40% of the population, with the region's population standing at around 2.8-3.0 million) and technogenic impacts, which are exacerbating environmental problems. The population density averages between 1,200 and 1,400 people, which is 13-15 times higher than the national average. The annual growth rate of 1.6% corresponds to a population doubling time of 40 years.

Calculations show that on the Absheron Peninsula, carbon emissions into the atmosphere exceed the amount absorbed by natural ecosystems by approximately 1.8 million tonnes per year. On the other hand, only 3-4% of the peninsula's oxygen requirements for industrial purposes and natural processes are met (Ilkin, 2002).

Table 1. *Natural factors determining the self-purification capacity of the environment on the Absheron Peninsula.*

Favourable natural factors	Negative factors of natural origin
Wind. The average number of days on which wind speeds exceed 15 m/s is 50–114 m/s. High rate of organic matter turnover	Climatic drought (which has an extremely negative impact on the rate at which microorganisms break down pollutants, and results in low vegetation biomass) Small ecosystem size Low levels of natural biodiversity lead to high vulnerability to pollution Low oxygen sequestration capacity – just 0.8 million tonnes per year Sparse vegetation cover (in spring and autumn, only 20–30 % of the area is covered by natural ephemeroid vegetation); Rise in the groundwater level (by 5–15 metres over the last 20 years) Absence of a general groundwater level, poorly developed hydrography, high mineralisation Low bioclimatic potential Hydrothermal regime Absence of surface water and watercourses Highly mineralised, polluted and eutrophicated water bodies Characteristic unstable interrelationships between individual landscape components, with no mutual compensation between them

According to Table 1, carbon dioxide emissions in the country totalled 27.94 million tonnes, whilst carbon sequestration by the country's entire forest sector did not exceed 0.8 million tonnes, which represents just 3.2%. This means that the oxygen from the atmosphere consumed in this region as a result of industrial and natural processes is literally 'drawn' from neighbouring geographical areas – the Caspian Sea (through the photosynthetic activity of phytoplankton) and the foothills of the Greater and Lesser Caucasus.

An analysis of the natural, climatic and biological factors in the Absheron region shows that, overall, the number of adverse natural factors hindering self-purification significantly exceeds the number of natural factors promoting the self-purification of the environment (Table 2).

Low natural biodiversity, resulting in high sensitivity to pollution, and sparse vegetation cover (only 20–30% coverage by natural ephemerals in spring and autumn), a rise in the water table (by 5–15 metres over the last 20 years), high groundwater salinity, low bioclimatic potential, the absence of surface runoff, and other indicators are factors hindering the self-purification of landscapes under conditions of ever-increasing anthropogenic and technogenic pressure.

In accordance with the classification proposed by M.A. Glazovskaya (1988), we analysed the factors characterising the detoxification potential of man-made products in the natural environment and soils of Azerbaijan (Mammadov, Ismailov, 2006).

Furthermore, for the first time, we have taken into account the microbiological factor in determining the 'resilience' and 'quality' of soils, which determines their ability to self-purify in the event of contamination by organic substances. We carried out an analysis of the resource potential that ensures landscape stability in Azerbaijan, including biogenic (microbial and phytocenotic) reserves. It was found that the relative role of microorganisms and plant biomass in landscape self-purification processes in the Absheron district is comparable to that observed under other soil and climatic conditions.

The biogenicity indices of the grey-brown soils of the Absheron Peninsula averaged 50, whilst those of dark loamy soils (100), loamy (90), and grey soils (80), as well as for the grey soils of the Absheron region. It suffices to note that the amount of carbohydrates absorbed by desert plants during the growing season on the grey-brown saline-alkali soils of the Absheron district was 8.2–41.4 and 613–2,192 g/ha, respectively, compared with other districts of the republic.

As a result, anthropogenic pressure on natural habitats from various pollutants (hydrocarbons, atmospheric emissions, soil pollution, surface and groundwater pollution, etc.) remains at a relatively high level, close to the critical threshold. The reproductive potential of this area does not allow it to effectively 'offset' anthropogenic pressures compared with other regions of the country.

Although Azerbaijan's climatic and soil conditions generally create favourable conditions for the retention of organic pollutants in soils and water systems, the Absheron region, the Absheron region, along with the Kura-Araz Plain, is characterised by relatively unfavourable hydrothermal parameters due to a lack of natural moisture and low biogenicity. It is both possible and necessary to use modern technologies to regulate physico-chemical parameters with a view to optimising the hydrothermal regime, which will improve the biogenic capacity of the soil cover and, consequently, enhance self-purification processes. For example, the use of modern biotechnologies for the remediation of oil-contaminated soils in the Absheron district requires artificial irrigation, which, in turn, creates favourable conditions for an increase in the population and activity of certain groups of microorganisms capable of breaking down petroleum hydrocarbons (Mammadov et al.,2022).

All other things being equal, the most favourable conditions for the landscape to clean itself – including from oil pollution – in this region are observed in spring and autumn, when there is a favourable combination of temperature and humidity. Furthermore, in the Absheron District, conditions for the landscape's self-purification are more favourable in its eastern part, where the soils are less clayey and less alkaline, have higher nutrient content and a more favourable combination of heat and moisture, whilst the northern part is further away from the negative impact of oil production facilities.

An environmental assessment is the process of identifying, examining, describing and analysing the potential significant direct and indirect effects on the environment that may result from a planned or ongoing activity, or from a document being drafted. The purpose of an environmental impact assessment is to prepare the materials required for decision-making regarding the implementation of the planned activity or draft document, in line with the aims and objectives of the Republic of Azerbaijan's environmental legislation.

Environmental impact assessments, depending on their type, are organised and carried out in accordance with the Environmental Code and the methodological guidelines approved by the competent environmental protection authority.

Table 2. *Assessment of the area based on environmental indicators.*

Indicator	**Environmental assessment categories for sites**			
	Normal (N)	Risk (R)	Crisis (K)	Disaster (B)

The state of natural ecosystems	Satisfactory	Unsatisfactory	Loss of stability	Complete loss of stability
Ecosystem productivity	No reduction	Significant decline	Steep descent	Complete loss
Direct indicators	Below the maximum permissible concentration	Slight exceedance of maximum permissible concentrations	Significant exceedance of MAC	Exceeds the MAC by 20–50 times.
Soil degradation	5 %	5–20 %	20–50%	>50 %
Mental health of the population	Satisfactory	Partial deterioration	Serious health risk	Significant deterioration

Depending on the subject of the assessment, the environmental assessment is carried out in the following forms, as shown in Table 2.

- Strategic environmental assessment;
- Environmental impact assessment;
- Transboundary impact assessment;
- Environmental assessment under a simplified procedure.

The condition of this area is assessed on the basis of criteria and indicators used to evaluate the ecological condition of natural ecosystems.

In this case, indicators such as crop yields, soil fertility (humus content), soil acidity (pH), and so on are used (Museyibov, 2003). Parameters are the boundaries of the intervals corresponding to the values of the indicators. The criteria are defined as a set of indicators characterising the deterioration of the environment and public health.

The state of the natural environment and the quality of human living conditions are characterised by the following criteria:

– air, water and soil pollution;

– depletion of natural resources;

– degradation of ecosystems.

The quality of the natural environment is assessed in general terms in the light of general environmental and health and hygiene requirements. The Baku Master Plan up to 2040 was recently presented to the public; it covers a wide range of issues relating to the development of green spaces on the Absheron Peninsula. The plan places particular emphasis on green spaces as a key component of the city's well-being.

A sufficient amount of greenery helps to create a favourable microclimate. After all, in large towns and cities, when dust levels fall, it becomes easier to breathe, and the overall environmental situation improves. Furthermore, green spaces help city dwellers to reduce their stress levels.

Having a sufficient number of green spaces is particularly important in densely populated cities such as Baku. Population growth naturally leads to an increase in the number of vehicles, which is one of the main causes of air pollution. All available plots are being built on, with the result that there is less and less space left for green spaces.

The lack of green spaces in Baku has always been a pressing issue, caused by several factors: the dry and windy climate, water shortages, and the construction of numerous high-rise buildings in recent decades, which has been accompanied by the illegal felling of trees and a disregard for urban planning regulations. At the end of last year, Azerbaijan's State Agency for Environmental Assessment once again warned

construction companies that fail to comply with regulatory requirements would not be granted permits. However, local environmentalists note that the condition of the city's green spaces is improving, pointing out that more and more trees are appearing along roads, in parks and in squares, and that tree-planting campaigns are held regularly. Most importantly, the trees being planted are suited to our climate, which significantly improves their chances of survival in challenging conditions. The capital's flora has also become more diverse. Nevertheless, there are not enough green spaces, so it is hardly surprising that the proposed Baku Master Plan for 2040 places particular emphasis on them. According to the document, the plan is to allocate 8 square metres of green space per resident in the capital. This number seems reasonable and achievable. According to international standards, the recommended amount of green space is between 5 and 15 square metres per person. This is in accordance with the 'Standards for the Greening of Residential Areas', approved by the Cabinet of Ministers of Azerbaijan by Resolution No. 1 of 5 January 2018.

5. Conclusion

The results of the study show that, on the Absheron Peninsula, green infrastructure plays an important role in improving the ecological condition of the environment and ensuring the sustainability of ecosystems. Given the region's arid climate, strong winds, and high level of human impact, green spaces are regarded as one of the key environmental factors in protecting the soil, water resources, and the atmosphere. It has been established that vegetation helps to protect the soil from erosion, improve its structure and maintain its fertility. At the same time, vegetation plays an important role in regulating the water balance, helping to increase the infiltration of precipitation into the soil, reduce surface runoff and replenish groundwater reserves. For the Absheron Peninsula, where water resources are limited, these characteristics are of particular ecological significance.

Research findings show that green spaces also make a significant contribution to improving air quality. Plants absorb carbon dioxide and release oxygen, trap dust particles and other atmospheric pollutants, reduce noise levels, regulate the microclimate, and help mitigate the 'urban heat island' effect.

An environmental assessment has shown that, despite the afforestation measures implemented in recent years, the current state of green spaces in some areas of the Absheron Peninsula is insufficient to ensure environmental sustainability. Industrialisation, urbanisation, land degradation and limited water resources continue to be the main factors hindering the development of green spaces and causing adverse changes to the structure of ecosystems. Furthermore, the expansion of greening programmes in the region, the remediation of oil-contaminated land, improvements to wastewater treatment technologies, the reduction of atmospheric emissions and the adoption of more environmentally sustainable approaches to urban planning are regarded as important measures for improving the state of the environment.

Consequently, the protection, expansion and scientifically sound management of green spaces on the Absheron Peninsula can be regarded as one of the key priorities for ensuring the region's environmental security, mitigating the effects of climate change and implementing the principles of sustainable urbanisation.

Author's contribution

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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