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Application of Geoinformation Databases in the Digital Monitoring and Rational Use of Land Resources in Kazakhstan

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Abstract

In the context of the ongoing digital transformation of land administration systems in the Republic of Kazakhstan, geoinformation databases are becoming a key instrument for land monitoring and rational land resource management. The purpose of this study is to substantiate and evaluate the application of geoinformation databases as the core of land monitoring systems, as well as to develop a methodological approach for their use in spatial analysis and decision support. The study is based on the application of modern geoinformation technologies, including ArcGIS Pro, spatial analysis tools, and visual geoprocessing modeling using ModelBuilder. The research focuses on the development of a structured geoinformation database that ensures data consistency, integrity, and reproducibility of analytical results. An analytical land-use monitoring model was developed to automate spatial data processing, including spatial selection, overlay analysis, area calculation, and the generation of summary statistics. The proposed approach was practically tested using data stored in the geoinformation database, which made it possible to assess its applicability for analyzing land-use structure and identifying spatial changes in land resources. The results demonstrate that the integration of geoinformation databases with automated analytical models significantly improves the efficiency of land monitoring, enhances result comparability, and reduces the influence of subjective factors in spatial analysis. The findings of this study confirm that geoinformation databases, combined with spatial analysis and automated geoprocessing tools, provide a solid methodological and technological basis for the development of regional and national land monitoring systems. The proposed framework can be used to support rational land resource management and spatial planning in Kazakhstan.

Keywords: geographic information systems, geoinformation database, land resources, land monitoring, land use, spatial analysis, ArcGIS Pro, ModelBuilder

1. Introduction

In the context of the digital transformation of public administration and the development of spatially oriented information systems, geoinformation technologies are becoming a key tool for monitoring and the rational management of land resources. In many countries, geoinformation databases serve as the foundation for modern spatial analysis systems, ensuring the integration of diverse information, increased transparency in land use, and well-founded management decisions. For the Republic of Kazakhstan, which

possesses land resources that are vast in area and diverse in structure, the development of effective geoinformation solutions is relevant (D'Acunto et al., 2024).

In recent years, Kazakhstan has been implementing several programs aimed at introducing geographic information systems, Earth remote sensing technologies, and web-based platforms into the fields of land management and spatial planning. Cadastral information systems, regional geoportals, and land-use monitoring services are being established and developed. Numerous studies show that the use of GIS contributes to improving the accuracy of land valuation, identifying changes in land cover, and supporting management decision-making in the fields of agriculture, ecology, and land management. At the same time, a significant portion of existing solutions is focused primarily on the visualization of spatial data and its reference use (Blanche, M.F. et al., 2024).

International experience shows that geoinformation databases form the technological core of modern spatial data infrastructures, ensuring long-term storage, processing, and analysis of geographic information. Using databases as the foundation of GIS enables a systematic approach to land resource management, including spatial analysis, modeling, mapping, and decision support. The widespread adoption of open geoinformation solutions further expands the possibilities for creating scalable and replicable land monitoring systems (Asam, S. et al., 2025).

In this context, the development and application of geoinformation databases focused on the tasks of monitoring and rational management of Kazakhstan's land resources represent a pressing scientific and practical challenge. The object of the study is a land resource monitoring system based on geoinformation technologies. The subject of the study is the structure, principles of formation, and functional capabilities of geoinformation databases used for the analysis and management of land use (Shokparova D.K. et al., 2025).

The aim of this study is to develop and justify a geoinformation database as the foundation for monitoring and rational management of land resources in the Republic of Kazakhstan. To achieve this aim, the study will address the following objectives:

- analyze current approaches to the use of geoinformation databases in land resource management;
- develop the structure of a geoinformation database that integrates spatial and attribute data on land use;
- assess the potential applications of the developed database for analysis, monitoring, and supporting management decisions.

The structure of the article includes a theoretical review and analysis of existing approaches, a description of the source data and methodological solutions, a presentation of the developed geoinformation database, and a discussion of the results of its application in the tasks of monitoring and rational land resource management.

2. Materials and Methods

The methodological framework of the study is based on the comprehensive use of geographic information systems, spatial databases, and Earth remote sensing methods, aimed at creating a unified geographic information database for monitoring and the rational management of land resources in the Republic of Kazakhstan. A systematic approach was applied in this work, ensuring the integration of heterogeneous spatial and attribute data within a unified logical structure oriented toward analytical support for management decisions (Sabljčić, L. et al., 2024; Dubovyk, O., 2017).

The source materials used included digital spatial data from various sources, such as information on the boundaries of administrative-territorial units, land-use patterns, natural features, and infrastructure elements, as well as medium-resolution Earth remote sensing data. All source datasets underwent mandatory preprocessing, including transformation to a unified coordinate system, correction of geometric

and topological errors, unification of attribute fields, and verification of the spatial consistency of layers. This ensured data comparability and improved the reliability of subsequent spatial analysis (FAO, Land resources planning for sustainable land management).

The methodology placed particular emphasis on the creation of vector datasets as a key component of the geodatabase. The process of selecting, refining, and vectorizing spatial information was carried out based on an analysis of available sources, the interpretation of satellite imagery, and comparison with existing cartographic materials (Figure 1). This stage facilitated the transition from disparate spatial sources to structured vector layers suitable for storage and analysis in a geodatabase.

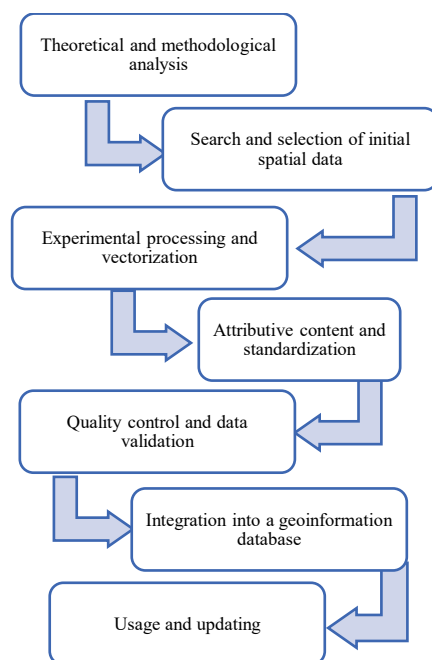


Figure 1. The process of selecting vector data for the development of a geodatabase

**Compiled by the author*

The geodatabase was designed in accordance with the principles of relational-spatial organization, ensuring data integrity, scalability, and the ability to update data. The structure of the geodatabase included interconnected thematic layers reflecting administrative divisions, land categories, land use types, natural conditions, and infrastructure elements. Logical relationships between objects made it possible to account for the spatial and temporal dynamics of land use, as well as to perform a comprehensive analysis of changes in land resources.

Methods of spatial analysis and cartographic modeling were used for analytical data processing, with the aim of identifying the structure and dynamics of land use. The analysis of remote sensing data included preliminary image correction and the calculation of spectral indices characterizing the condition of the land cover. The results obtained were integrated into a geographic information database, ensuring their compatibility with cadastral and thematic layers and expanding the system's analytical capabilities (Zhumataeva J. et al., 2024).

The developed geoinformation database was tested using typical usage scenarios characteristic of land resource monitoring and management tasks. The ability to update data in real time, execute spatial queries, and generate thematic maps necessary to support management decisions was evaluated. The results of the testing confirmed the feasibility of using geoinformation databases as a functional foundation for the monitoring and rational management of land resources.

3. Results and Discussion

During the study, a geographic information database was developed and tested, designed to address the tasks of monitoring and rational management of land resources in the Republic of Kazakhstan. The results confirm that using a structured geodatabase as the core of a geographic information system allows for a transition from fragmented storage of spatial data to a comprehensive, logically connected model of spatial analysis and management decision support (G. Kabzhanova et al., 2023; Reynolds, J. F., 2023).

Based on the developed structure of the geoinformation database, logical models of its practical use were formed, reflecting the main scenarios of user interaction with spatial information. These models are implemented as functional diagrams (“builder models”) demonstrating the sequence of data acquisition, processing, storage, and analysis within a unified geoinformation environment. This approach made it possible to formalize the processes of working with the geodatabase and ensure the reproducibility of analytical operations when solving land monitoring tasks (Zhu, Z., Woodcock, C. E., 2014).

As part of the modeling process, scenarios for integrating vector and raster data were implemented, in which spatial information from various sources is sequentially converted and stored in a geographic information database. The geodatabase serves as the central element of the system, ensuring the accumulation, updating, and logical linking of information on land resources. The use of a unified attribute structure and standardized spatial relationships ensured data comparability and minimized information duplication (Tucker, C. J., 1979).

Figure 2 presents a generalized diagram of the application of a geoinformation database in a land resource monitoring system, illustrating the key stages of working with spatial information—from the creation of vector layers to their use in analytical and management tasks.

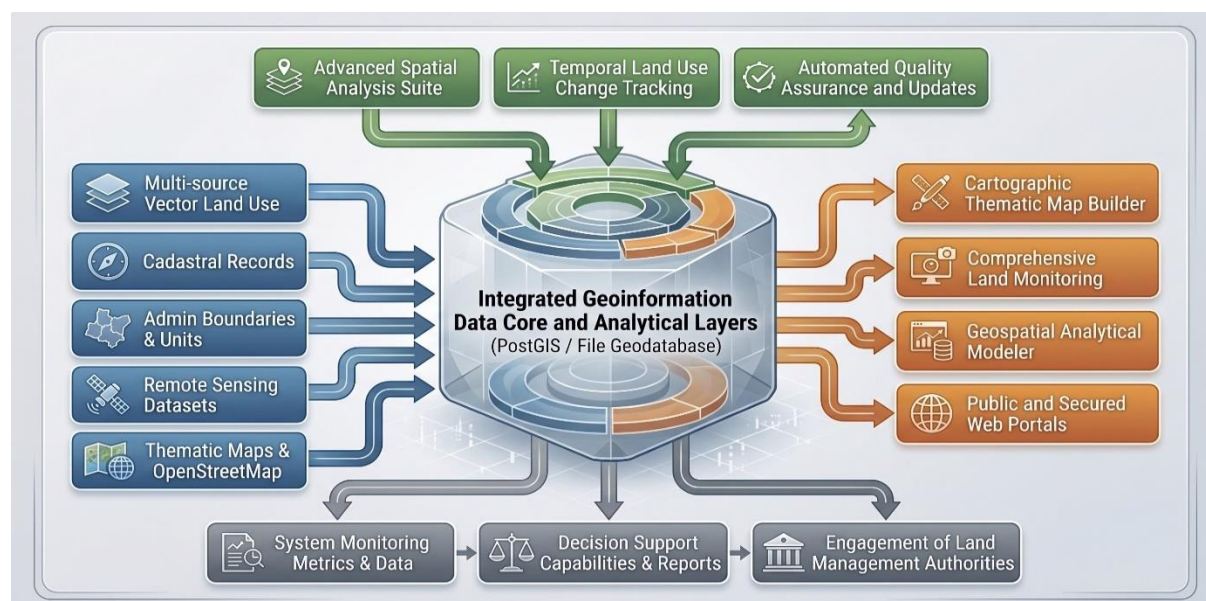


Figure 2. Model of the use of a geographic information database in a land resource monitoring system (G. Kabzhanova et al., 2023)

The model of geoinformation database usage presented in Figure 2 reflects the systematic and comprehensive nature of land resource monitoring. Within this model, the geoinformation database serves as a central integrating element, ensuring the consolidation of diverse spatial and attribute data, their consistency, and analytical processing. The model clearly demonstrates the interrelationship between the main sources of spatial information, analytical procedures, and application modules, the interaction of which results in cartographic and analytical products used to support management decision-making in the field of rational land use.

The structure shown illustrates that the geoinformation database is not limited to the function of storing information but serves as an active element of the monitoring system, ensuring the implementation of spatial analysis, assessment of land-use changes, and data quality control. Integrating the geodatabase with analytical and cartographic modules enables the creation of reproducible analysis scenarios designed to address both operational and strategic land resource management tasks.

To provide a more detailed explanation of the practical aspects of implementing the proposed model, we will now examine the architecture of the analytical and cartographic modules that operate based on a geoinformation database. Attention is paid to issues related to the organization of the geodatabase structure, the interaction of individual thematic datasets, and the mechanisms for their use in the process of spatial analysis and mapping. It is shown how the structured data of the geodatabase are applied in a desktop GIS environment to automate geoprocesses, generate thematic layers, and prepare analytical materials used in the land resource monitoring system.

The interface fragment presented below clearly illustrates the organization of the geodatabase and the principles of interaction between analytical and cartographic modules within a single software environment. This allows one to trace the logical connection between the conceptual model of using the geoinformation database and its practical implementation, as well as to emphasize the applied focus of the developed approach.

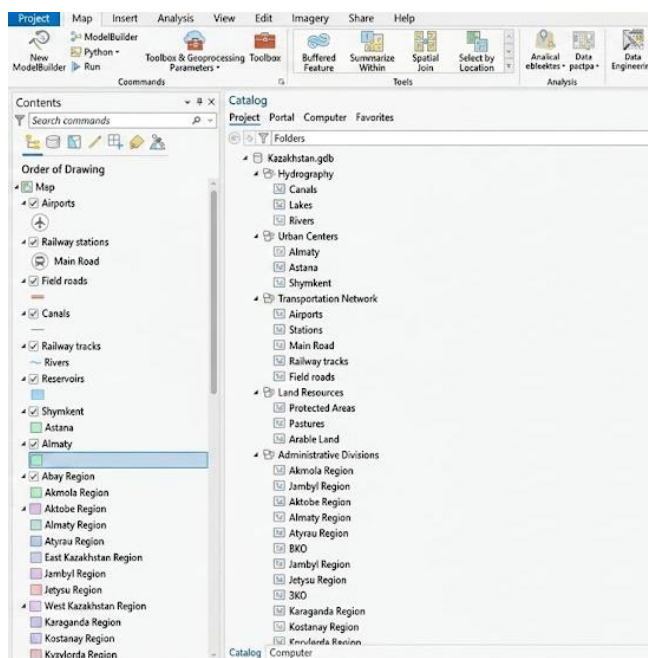


Figure 3. Architecture of analytical and mapping modules based on a geoinformation database
*Compiled by the author

The results of modeling and field testing have shown that the developed geographic information database can be effectively used as a core for implementing various analytical and cartographic scenarios. In particular, its application enables the analysis of land-use patterns, the identification of spatial changes in agricultural land, and the comparison of cadastral data with remote sensing results. These scenarios are implemented through the modular architecture of the geodatabase, which supports the reuse of spatial layers and analytical procedures across various application modules without altering the underlying data structure.

To systematize the results of the design and practical application of the geoinformation database, Table 1 summarizes the main functional components of the system and their role in the process of monitoring and rational management of land resources.

Table 1. Functional components of a geographic information database and their purposes

System component	Main content	Functional purpose
Vector layers	Administrative boundaries, land parcels, land use categories	Пространственная основа мониторинга и анализа
Raster data	Satellite images, land cover indices	Assessment of Land Dynamics and Condition
Attribute database	Cadastral and descriptive characteristics of land	Analytical support for management decisions
Analytical modules	Spatial queries, overlay, classification	Identifying changes and patterns
Cartographic billboards	Thematic maps, visualization of results	Data Presentation and Decision Support

The functional components presented in the table form a comprehensive system in which the geographic information database serves not only as a repository for spatial information but also as a key element of the analytical infrastructure for land resource monitoring. The integration of structured spatial data with analytical and cartographic modules enables comprehensive land-use analysis, the identification of spatial patterns, and the formulation of informed management decisions regarding the rational use of land.

The practical implementation of these functions is based on the use of tools for the visual modeling of geoprocesses, which allow for the formalization of a sequence of analytical operations and ensure their automated execution. The use of the ModelBuilder environment enables the construction of reproducible analytical chains based on data from the geoinformation database, including stages of spatial selection, overlay, classification, and calculation of quantitative indicators. This approach ensures the standardization of data processing procedures and improves the comparability of monitoring results when calculations are performed repeatedly.

In this study, ModelBuilder was used as a tool for integrating geospatial data with applied land resource monitoring tasks, enabling a shift from one-off analytical operations to formalized analysis scenarios. The implemented models provide automated processing of spatial information, the generation of final cartographic materials, and the derivation of analytical indicators necessary for assessing the structure and dynamics of land use.

The developed geoprocessing workflow based on ModelBuilder clearly illustrates the architecture for using a geodatabase in a land resource monitoring system and demonstrates the relationship between source data, analytical procedures, and the results of spatial analysis. The concept and logic behind the construction of this model are presented in Figure 4.

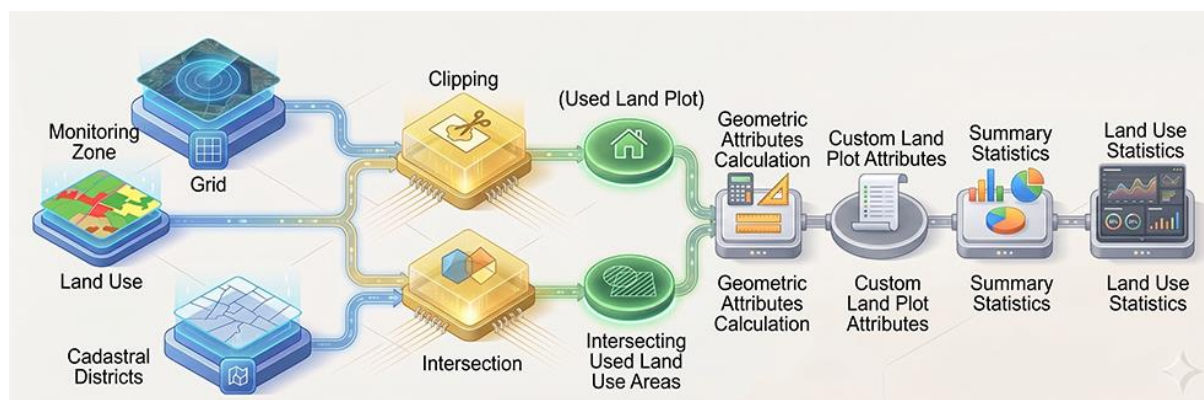


Figure 4. An analytical model for land-use monitoring based on a geoinformation database, implemented in the ModelBuilder environment (created with ArcGIS Pro)

The analytical model presented here clearly demonstrates the practical application of a geoinformation database in a land resource monitoring system. The formalization of the sequence of geoprocesses in the ModelBuilder environment enables the automation of spatial analysis operations, including data selection for the monitoring area, analysis of intersections with cadastral units, and calculation of quantitative land-use indicators. This allows for reproducible and comparable results, eliminating the influence of subjective factors during analytical operations.

The implementation of monitoring based on the developed model confirms that a geoinformation database can be effectively used not only as a repository of spatial information but also as a foundation for building applied analytical tools. The use of visual modeling of geoprocesses ensures the standardization of data processing procedures and creates conditions for their repeated application within the framework of various territorial and thematic tasks.

The results obtained indicate that integrating a geoinformation database with analytical modules improves the effectiveness of land-use monitoring and enhances the capacity to support management decisions. This, in turn, forms the methodological basis for the further development of the land monitoring system and its scaling up to the regional and national levels, which determines the main conclusions and prospects for further research.

4. Conclusion

In accordance with the research objectives and tasks outlined in the introduction, this study confirms the effectiveness of using geographic information databases as a foundation for monitoring and rational management of land resources in the Republic of Kazakhstan. The study showed that a structured geoinformation database ensures the integrity, comparability, and timeliness of the spatial information necessary for land use analysis and to support management decisions.

The primary objective of the study-the development and testing of a geoinformation database designed for land resource monitoring-has been achieved. The structure of the geodatabase ensures the integration of vector and raster data, accounts for the spatio-temporal characteristics of land use and allows for multiple analytical uses of the data without altering its underlying architecture.

As part of the study, an analytical model for land-use monitoring was implemented using the ModelBuilder environment within the ArcGIS Pro software suite. The use of visual modeling of geoprocesses made it possible to formalize and automate the sequence of spatial operations, including spatial selection, intersection analysis, calculation of area indicators, and generation of summary statistics. This ensured the reproducibility and comparability of monitoring results, as well as reduced the influence of subjective factors during the performance of analytical procedures.

The results confirm that integrating a geoinformation database with analytical and cartographic modules expands the functional capabilities of land monitoring systems. The use of a modular approach and the reuse of spatial layers allow for the effective analysis of land-use patterns, the identification of spatial changes in agricultural land, and the comparison of cadastral data with remote sensing data.

The developed approach demonstrates the practical applicability of geographic information systems as a tool for supporting the rational use of land resources and territorial planning. The results obtained can be used in the activities of land resource management agencies, research and design organizations, as well as in the development of regional and national land monitoring systems.

Overall, the research results confirm that the use of geoinformation databases in combination with spatial analysis tools and automated geoprocessing creates a methodological and technological foundation for the further development of land resource monitoring systems. The proposed approach has the potential to be scaled up to the regional and national levels and can serve as the basis for the formation of a unified spatial data infrastructure for the Republic of Kazakhstan.

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Features of Forest Conservation in Azerbaijan: Management, monitoring and prevention

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Abstract

This article examines the specific features of the implementation of forestry measures carried out in Azerbaijan. In this context, the general characteristics of the forest resources were highlighted, including issues relating to the cultivation, use, and protection of forest resources. The structure of the Republic's land holdings, together with the corresponding percentage breakdown, was presented here. In this context, particular attention was paid to the structure of forestry management in the Republic and to the specific features of the measures implemented to protect and ensure the sustainable development of forest stands. In addition, the study also carries out a comparative analysis of forest conservation in Azerbaijan and the Republic of Georgia, which is reflected in the relevant trends.

Keywords: forestry management, forest resources, protection of forest stands, sustainable development, comparative analysis

1. Introduction

Forests are one of the planet's most important natural resources and play a key role in maintaining ecological balance. They perform a lot of functions: they regulate the climate, play a role in the water cycle, protect the soil from erosion, preserve biodiversity, and serve as a source of raw materials for various sectors of the economy. In addition, forests have a significant impact on people's quality of life by providing recreational areas and helping to improve environmental conditions.

2. Forest Resources

The overall area of Azerbaijan's forests is 1,213.7 thousand hectares. Forest area per capita is approximately 0.12 ha, which is four times (0.48 ha) less than the corresponding international average (Azərbaycan Respublikası Ekologiya və Təbii Sərvətlər Nazirliyi, 2017).

Azerbaijan's forests are classified as Group I in terms of importance and are found in different forms throughout the country's regions. One of the distinctive features of these regions is the presence of various natural resources – minerals, energy, water, and land. Among these, forest resources fulfill functions that are not typical of other natural resources. Forests are considered the only natural ecosystem that provides the conditions necessary to stabilize components as vital to the biosphere as water, air, and soil.

Most of the republic's forest areas (85%) are located in the Greater and Lesser Caucasus and in the Talysh Mountain Region. Most of the forests consist of valuable tree species (oak, beech, hornbeam, linden, maple, etc.). The diversity of the republic's forests depends on the climate, soil, and varying altitudes.

In today's world, the importance of forests is growing significantly due to global environmental issues such as climate change, land degradation, and the loss of biodiversity. In this regard, effective management of forest resources and the development of clear legal regulations in this area have become particularly important. Forest legislation is the primary tool for ensuring the sustainable use, protection, and restoration of forests (Dolxanov et al., 2012).

For Azerbaijan, forests are of particular importance, even though the country's forested area covers a relatively small territory. The republic's forests have a vital role in protecting the soil, preventing desertification, regulating water resources, and preserving unique ecosystems. Government policy in this area is based on the provisions of the Forest Code of the Republic of Azerbaijan, which regulates the most important aspects of the use and protection of forest resources.

Forest legislation consists of a set of legal provisions governing relations related to the ownership, use, protection, and regeneration of forests. It defines the rights and obligations of the state, legal entities, and individuals, and establishes penalties for violations of the established rules. Effective forest management is impossible without a clear legal framework that strikes a balance between economic interests and the need to protect the environment (Balakışiyeva, 2011).

This means that studying the characteristics of forest protection and management in Azerbaijan is an important step toward understanding the mechanisms of conservation, sustainable development, and the use of natural resources.

The purpose of this study is to examine the fundamentals of forestry legislation and the forest resource management system, as well as to analyze the specific features of forestry in Azerbaijan. To achieve this goal, it is necessary to:

1. To examine the characteristics of the concepts used and the structure of forestry management in the Republic;
2. Identify the key features of the measures implemented to protect and ensure the sustainable development of forest stands;

To compare the measures being taken to protect and ensure the sustainable development of Azerbaijan's forests with those of the Republic of Georgia.

3. Discussion

Forest management in the country is carried out by government agencies, specifically the Ministry of Ecology and Natural Resources of Azerbaijan, which ensures compliance with legislation, organizes measures to protect and restore forests, and develops programs for the sustainable development of forestry.

Management Structure: Since the Ministry was established in May 2001, the scope of work related to forest restoration, tree planting, the cultivation of planting stock, seed collection, and other activities has expanded significantly throughout the republic.

By decree of G. A. Aliyev, the national leader of the Azerbaijani people, dated December 26, 2001, the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan was instructed to submit for consideration by the Cabinet of Ministers of the Republic of Azerbaijan a National Program for the Restoration and Expansion of Forests, developed in collaboration with state and local government bodies (UNECE/FAO Forestry and Timber Section, 2019).

The Forest Development Department oversees 34 regional forest conservation and restoration enterprises, 3 tree-planting enterprises, and 3 regional forest seedling enterprises (the Center for Pest and Disease Control and the Forestry Research Institute). In accordance with the Presidential Decree, the draft National Program "On the Restoration and Expansion of Forests," developed by the Ministry of Ecology and Natural Resources, was approved by Presidential Order No. 1152 of April 18, 2003, with the relevant

amendments and additions. Currently, the Ministry of Ecology and Natural Resources implements its forestry policy through the Forest Development Service.

The Forest Development Service (FDS) ensures the protection of forests within the forest fund, carries out forest restoration and planting activities, cultivates planting stock, and collects seeds from forest trees and shrubs, maintaining state records of the forest fund and the forest cadastre, carrying out forest maintenance and other silvicultural activities, managing the supplementary use of forests, and conducting targeted, effective work on auxiliary agricultural plots. The FDS ensures that the following work is carried out to enhance the functions of forest management activities: land conservation, water conservation, climate conservation, sanitary and hygienic functions, and other beneficial functions. In addition, the Service carries out measures to preserve natural complexes and sites of scientific, cultural, and recreational significance to the environment; to protect biological diversity; to safeguard the fauna species found in forest lands; and to preserve the gene pool during forest seed collection operations.

In conjunction with this, instructions have been given to develop and submit to the relevant organizations coherent and environmentally sustainable national programs related to socioeconomic development, the development of livestock farming and agriculture, national programs on the use of summer and winter pastures and hayfields, the prevention of soil erosion in mountainous areas, gorges, and ravines, as well as at river mouths, and the prevention of soil salinization in mountainous and lowland regions (Məmmədov & Əsədov, 2010).

Forest Code of the Republic of Azerbaijan: Forest management is carried out in accordance with the Forest Code and the Environmental Protection Law. The Forest Code of the Republic of Azerbaijan was adopted on December 30, 1997 (Law No. 424-IQ). It took effect following its official publication on March 3, 1998. This Forestry handbook primarily covers the following topics: basic forestry concepts; forestry legislation of the Republic of Azerbaijan; the forest fund, forest lands, and forest areas, etc.

Within the territory of the Republic of Azerbaijan, all forests, as well as lands within the forest fund that are not covered by forest vegetation (both forested and non-forested lands), constitute the forest fund of the Republic of Azerbaijan. The boundaries of the forest reserve are defined by the lines separating forest reserve lands from other lands. The inclusion of land in the forest fund and its removal from it are carried out in accordance with the procedures established by the forestry and land laws of the Republic of Azerbaijan. Forest lands include lands covered with forest vegetation and lands not covered by such vegetation but designated for forest regeneration (unregenerated logging sites, burned areas, thinned areas, clearings, dead stands, nursery areas, forest plantations with an open canopy, etc.). Non-forest lands include lands designated for forestry purposes (agricultural land, forest clearings, land under roads, etc.), as well as other lands located within the boundaries of the forest fund (marshy, stony, rocky, and other land parcels unsuitable for use). Forest fund areas include forested areas, as well as forested and non-forested land areas not covered by forest vegetation (Azərbaycan Respublikası Prezidentinin İşlər İdarəsinin Prezident Kitabxanası, 2019).

Ground-based monitoring in forests: The purpose of these inspections is to regularly monitor, on-site, the activities of forest rangers in protecting forests from illegal logging and other violations (grazing of livestock, unauthorized mowing of grass, land encroachment, etc.). Inspections are conducted at least once every two months, with a thorough survey of the entire area covered by each inspection route. This is carried out directly by the assistant forester or the forest supervisor.

During an inspection, the assistant forester or forest supervisor first reviews the reports and records prepared by the forest ranger regarding cases of illegal logging, whether the perpetrators have been identified or not. At the same time, the tree species, their sizes, and their numbers are cross-checked on site against the data specified in the reports or protocols, after which the stumps of these trees are marked with the illegal logging stamp ("QQ").

If, during an operational inspection, a forest ranger's assistant or a forest supervisor discovers illegal logging that was not previously detected or documented by a forest guard, they shall draw up a corresponding report, mark the stumps with an "illegal logging" stamp, and record the report in the forest guard's logbook.

During the inspection, reports or records are also drawn up regarding other violations of forestry laws that were not documented by the forest ranger, including: grazing of livestock; illegal grass cutting; unauthorized occupation of forest land; forest fires; and others (President of the Republic of Azerbaijan, 1999)

Forest Monitoring: This involves observing, recording, and analysing changes taking place in the environment, as well as identifying changes in nature resulting from human activity. In this area, the 'ICP-Forests Programme' is primarily used – this is the largest international forest monitoring system, established in 1985 under the auspices of the United Nations Economic Commission for Europe. This programme is used in more than 41 countries. Its key objectives are: monitoring the condition of forests, studying the impact of climate change, and ensuring sustainable forest management (UNECE/FAO, 2020).

In accordance with Article 40 of the Forest Code of the Republic of Azerbaijan, forest monitoring is carried out. The main areas of monitoring carried out by the Ministry of Ecology and Natural Resources of Azerbaijan are: studying the ecological functions of forests; monitoring the sustainable use of forests; using aerospace and remote sensing methods; assessing forest regeneration; preventing forest fires; phytosanitary measures against pests; and monitoring sanitary felling (Мамедов, 2012).

Phytosanitary measures for forest protection: These phytosanitary regulations govern the procedures for protecting forest stands from pests and diseases. The main aim of such measures is to protect forests, prevent the widespread spread of pests and diseases, identify outbreaks in good time, and implement preventative and sanitary measures to contain and eradicate them.

The protection of forest resources is ensured through systematic monitoring of the condition of forests, identifying the sources of the spread of pests and diseases, carrying out preventative, sanitary, and phytosanitary measures in affected areas, preventing the further spread of infestation, and mitigating its consequences.

Preventative and phytosanitary measures to protect the forest resources are carried out by the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, as well as by the relevant organisations within the scope of their remit

The range of measures for the protection of forest resources includes routine, field, aerial visual and other forest pathology surveys; general and initial surveys of outbreaks of pests and diseases, as well as detailed studies of these; the preparation of measures to combat pests and diseases using aerial and ground-based resources; the organisation of preventative measures against forest diseases and the eradication of pest and disease outbreaks; and monitoring the implementation of these measures.

In order to prevent the spread of pests and diseases and to improve the resilience of forest stands, compliance with phytosanitary, silvicultural and agronomic requirements is monitored. Both aerial and ground-based methods are used to carry out pest control measures. Special work plans are drawn up, technical supervision of such activities is carried out, and compliance with the regulations governing the transport and use of toxic chemicals is ensured.

Comprehensive monitoring involves determining trends in pest insect populations, identifying the causes of changes in their numbers, and developing short-term and long-term forecasts of mass pest outbreaks based on the data obtained. To this end, forestry enterprises select several plots for each type of pest and carry out inspections twice a year, taking into account the biological characteristics of the pests. If a mass outbreak of a particular pest is forecast, the list of areas subject to integrated pest management is

also extended to include forest areas where that pest is likely to spread, and detailed surveys are carried out there (UNECE, 2017).

An inventory is carried out every autumn to record active outbreaks of forest pests and diseases, and to ensure that eradicated outbreaks are promptly removed from the records. The procedure for carrying out the inventory is determined by the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. The inventory draws on data regarding the number of pest and disease outbreaks identified in previous years, as well as the results of forest pathology monitoring and observations. It is also important to note the specific characteristics of the spread of certain fungal diseases commonly found on oak trees.

Oaken polypore (*Inonotus dryophilus*, Berk., Murr) causes variegated heart rot in oak trees. This fungus is found sporadically throughout the area and infects only living oak trunks. Infection occurs via basidiospores through broken branches that already contain heartwood (Figure. 1).



Figure 1. Oaken polypore (*Inonotus dryophilus*, Berk., Murr)
on the trunk of an oak tree

In the first stage of decay, the wood turns brown. In the second stage, light-yellow areas of bleached cellulose of varying lengths appear against a brown background. In the third stage, cavities form in the wood, i.e., mottled, pitted rot develops. Yellowish clusters of mycelium form in the affected wood. The rot has a pitted, fibrous structure. The rot is spreading rapidly through the middle of the trunk. The extent of the damage reaches 6-8 m and accounts for 40% of the trunk's volume. The fruiting bodies grow on the middle section of the trunk and resemble those of the *Inonotus dryophilus* fungus. This fungus is found sporadically in the oak forests of the Greater Caucasus and therefore causes little damage.

Chicken of the Woods (*Laetiporus sulphureus*, Bull.) causes red-brown prismatic heart rot in the trunk. The fungus most commonly affects the base of the trunks of oak, ash, beech, willow, white acacia, maple, sweet cherry, walnut, and other species. The prevalence of tinder fungus in oak stands reaches 20–50%. The trunks are infected by basidiospores in the lower part of the trunk, entering through wounds and frost cracks. (Fig. 2).

Destructive type of rot. In the first stage of decay, the wood is pink in colour with white streaks. In the second stage, it turns brown, and cracks appear, in which a whitish mycelium accumulates. In the third stage, the wood is brown, and the cracks contain thick, whitish or yellowish, suede-like films of mycelium, which can easily be rubbed into a powder between the fingers. Most often, rot is found in the lower part of the tree up to a height of 2–3 m, but sometimes as high as 6–12 m, leading to the tree becoming top-dead. It is not uncommon for affected trees to be blown down by the wind.

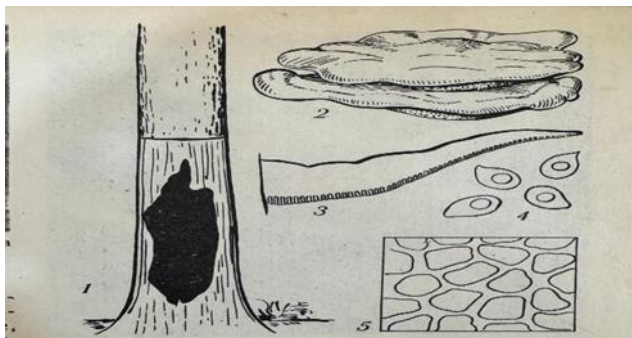


Figure 2. Chicken of the Woods (*Laetiporus sulphureus*): 1 – diagram showing the distribution of rot within the trunk; 2 – external appearance of the fruiting body; 3 – cross-section of the fruiting body; 4 – basidiospores; 5 – rounded pores

The *Laetiporus sulphureus* is found everywhere. As well as on living trees, it also grows on felled timber, products, and structures, causing considerable damage to the forestry industry. Fruiting bodies do not appear every year, so the rot often goes undetected.

To summarise the issue of protecting forest stands from pests and insects, it is worth noting that a range of sanitary and restoration measures must be carried out in forest stands. In young stands, maintenance felling should be carried out in a timely and professional manner with the aim of establishing healthy, biologically sustainable stands with an optimal species composition. In middle-aged, mature and overmature stands, selective sanitary felling should be carried out regularly, with the mandatory removal of deadwood, wind-damaged trees, as well as conifers that are dying back, weakened, wind-felled or damaged by storm, as these trees rapidly become host to large numbers of fruiting bodies of polypore fungi – the causative agents of rot, whose spores continue to infect the wood for many years. When the density is 0.3–0.4, it is advisable to carry out a clear-cutting sanitary felling. To minimise the spread of infection, it is essential to remove infected timber from the stands as quickly as possible. To prevent trunk-dwelling pests from infesting timber, it is necessary to debark it or treat it with chemicals, and to ensure that stands are not left cluttered with felling residues, windfall and storm-damaged timber, which must be removed or destroyed in a timely manner.

The fight against forest diseases and the key challenges involved in preventing their spread should be viewed not as a temporary campaign, but as a comprehensive set of measures aimed at enhancing the resilience of the forest. In the fight against forest diseases, the key factors are boosting plants' natural immunity to infections, establishing resilient plant communities, reducing the virulence of the pathogen, and eradicating the pathogen. In this regard, the main focus should be on various approaches to managing the environment, taking into account the specific ecological characteristics of the forest's growth.

General preventive measures: The development of forest management measures to combat forest diseases has so far received insufficient attention; individual studies by S. V. Shevchenko (1989), A. I. Akhundov (2005) and others provide examples of forest protection systems for specific regions and particular groups of stands.

In forest protection programmes, nationwide monitoring, forest pathology surveys, the mapping of existing and potential foci of infection, and the study and forecasting of the patterns of epiphytotic outbreaks should play a significant role. These measures should be implemented on the basis of forest typology, taking into account natural regions, on a zonal basis.

However, the primary role in combating forest diseases should be played by silvicultural measures covering the entire life cycle of the stands – from seed collection to final felling. In doing so, it is necessary to take into account the stages of disease development, linking them to specific forest protection measures, primarily biological control methods. Such a system should be introduced first and foremost in potential disease hotspots, as it is not always possible to cover all forests.

In forestry, it is essential to use planting stock of high quality in both sanitary and genetic terms when establishing forest stands. To this end, seeds must be collected from healthy, high-yielding crops, and when growing planting material, all agronomic guidelines must be followed, including disease control measures, in particular seed treatment, the implementation of a range of preventative measures in nurseries, and the protection of seedlings from adverse non-parasitic damage (frost cracks, sunscald, etc.).

Fire Prevention and Control. Fire prevention includes preventive, monitoring and suppression measures aimed at reducing wildfire risk and minimizing ecological damage. As a preventative measure, firebreaks are created, deadwood is cleared from forests, access to forests is restricted during the fire-risk period, and public awareness campaigns on safety rules are organised. Early detection of fires is carried out using satellites, drones, surveillance cameras, and ground patrols. Water, earth, backfiring, specialised equipment, and aircraft are used to extinguish the fire. Fire services, forestry organisations, and rescue services are involved in tackling large-scale fires. An important objective is to preserve ecosystems and protect animals, soil, and water resources from damage.

Following the fires, work is carried out to restore the forests, plant trees, and monitor the state of the natural environment. Modern methods of combating wildfires are aimed not only at extinguishing the fire, but also at preventing it from breaking out and preserving the ecological balance.

Between 25 April 2026 and 25 May 2026, a total of 61 VIIRS fire alerts were recorded in Azerbaijan; only alerts with a high confidence level were taken into account (Fig. 3).



Figure 3. Number of fire alerts in Azerbaijan

Between 2001 and 2025, Azerbaijan lost 1.3 thousand hectares of forest cover as a result of fires and 7.2 thousand hectares due to all other causes of loss. The greatest loss of forest cover due to fires during this period was recorded in 2014: that year, 200 hectares were lost to fires, accounting for 61 per cent of all forest cover losses that year (Figs. 4 and 5).

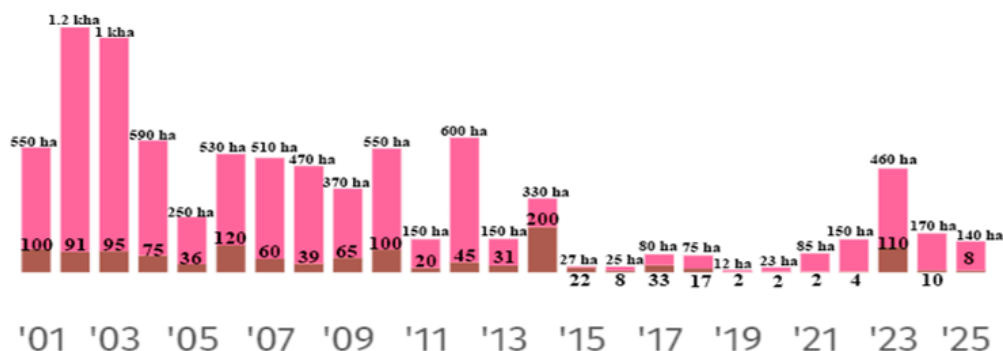


Figure 4. Loss of tree cover due to fires in 2001–2025.

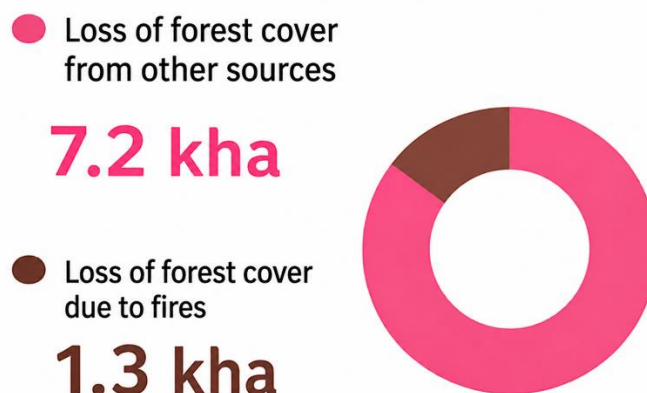


Figure 5. Forest cover loss in Azerbaijan by cause (2001–2025). Fires accounted for 15% of total forest cover loss. [17].

International practice. To examine the tasks set, a comparative analysis was carried out of Azerbaijan's forestry sector and the corresponding sectors in the Republic of Georgia.

Azerbaijan and Georgia are both located in the Caucasus region, but there is a huge difference between their forests – in terms of area, climate, biodiversity and the role forests play in the life of each country. If one were to compare the two countries specifically in terms of their natural forest resources, Georgia has a substantially higher proportion of forest cover than Azerbaijan. The main difference is the level of forest cover. In Azerbaijan, forests cover approximately 11–14% of the country's territory, whereas in Georgia the figure is around 40–41%. Historically, Azerbaijan has lost a significant proportion of its forests. According to some sources, several centuries ago, around 35% of the country's territory was covered by forests, but due to deforestation, agriculture and the expansion of pastureland, this area has more than halved. Logging also took place in Georgia, but thanks to the humid climate and lower levels of aridity, the forests were better preserved and recovered more quickly.

In terms of biodiversity, both countries are of great interest because they form part of the Caucasus biodiversity hotspot – one of the world's most biologically diverse regions. However, Georgian forests are generally considered to be richer in terms of total vegetation mass and the number of forest ecosystems. There are vast beech forests, chestnut groves, spruce forests, fir stands, and the humid subtropical jungles of Colchis. In Azerbaijan, however, the landscape is more varied: there are many steppes and arid areas, so the forests look like isolated green islands amidst the drier landscape.

Another important difference is water balance. Forests are closely linked to rainfall and water resources. Georgia has far more rivers and rainfall thanks to the mountains and the Black Sea. Azerbaijan suffers from a water shortage compared with its neighbours. This has a direct impact on forest growth and density.

From an environmental perspective, Georgia's forests play a vital role in protecting the slopes of the Caucasus from erosion, landslides and floods. Forests are also extremely important in Azerbaijan, but there they primarily serve to protect the soil from desertification and to conserve moisture in mountainous areas (Figure 6).

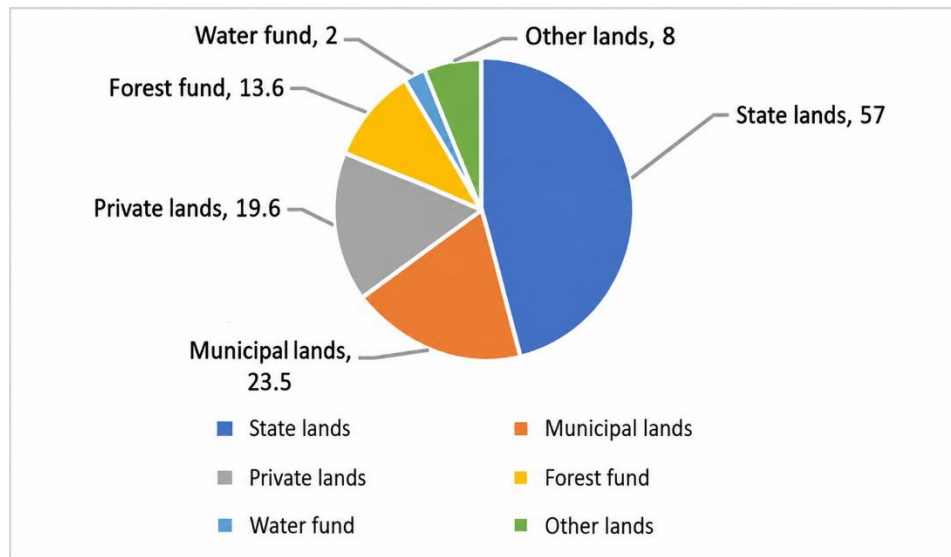


Figure 6. Land use in Azerbaijan

Economically speaking, forestry is not a major industry in any country; however, in Georgia, the potential for forestry and ecotourism in the form of national parks and mountain forests is considerably greater. Nature reserves and national parks are also being actively developed in Azerbaijan, particularly in the Hyrcanian region and the Caucasus, but the overall extent of its forest resources is smaller.

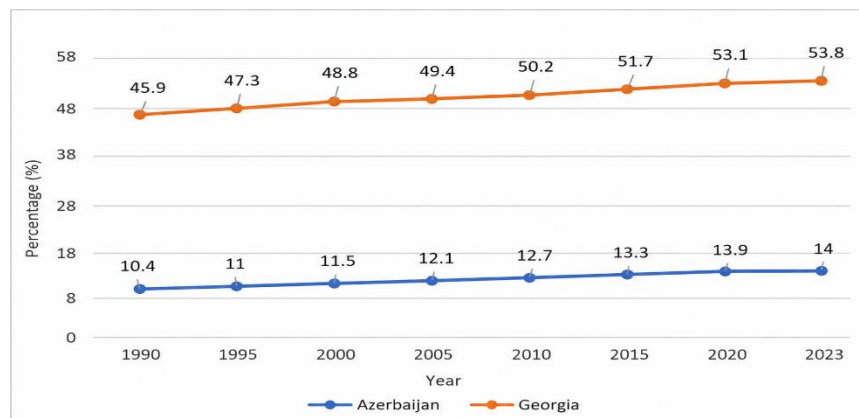


Figure 7. Comparison of forest cover in Azerbaijan and Georgia, %

In summary, the comparison can be summarised as follows: Azerbaijan is a country with limited but highly unique and rare forests, particularly relict forests; Georgia is one of the most forested countries in the Caucasus, with vast wet mountain forests and a significantly richer forest cover. In terms of volume, density and total forest area, Georgia clearly surpasses Azerbaijan; however, Azerbaijan's forests are valued for their uniqueness and rare ecosystems (Fig. 7).

For Azerbaijan to come closer to Georgia's level of forest cover, or at least to significantly improve the condition of its forests, long-term and comprehensive measures are needed. Azerbaijan's main problem is not just deforestation, but a combination of an arid climate, water scarcity, soil erosion and the historical decline in forest cover. To tackle these problems, strict controls on illegal logging must be put in place. Even small-scale illegal logging in arid regions causes enormous damage because forests take a long time to recover. Satellite monitoring, drones, digital forest inventories, and hefty fines all play a part here.

Another important area is firefighting. Due to climate change, the Caucasus is becoming drier and hotter. We need early fire detection systems, forest patrols, firebreaks, and public education. A single major fire can wipe out decades of restoration work.

In addressing these issues, the expansion of national parks and nature reserves is of great importance. The particularly valuable forests of the Hyrcanian and Caucasus regions require strict protection. Azerbaijan's relict forests are of international natural importance, as some species have survived since the Ice Age.

Another important area is the development of ecotourism as an alternative to the exploitation of forests. When a forest generates income through tourism, walking routes, hotels, and national parks, it becomes more profitable to preserve it than to cut it down.

In the long term, it is entirely feasible for Azerbaijan to increase its forest cover from its current level to approximately 18–20% over the course of several decades. This can be achieved through effective government regulation, sustainable water management, and the protection of existing forests. There is particularly great potential in the restoration of mountainous areas and the creation of green belts to combat drought.

4. Conclusion

Based on the work carried out, the following conclusions can be drawn:

1. This paper examines the specific characteristics of the meaning of forestry terminology relating to the protection and use of forest resources
2. The characteristics of the management structure and the forestry sector have been identified. This paper examines the specific features of the implementation of the Forest Code in Azerbaijan.
3. The potential applications of forest monitoring have been identified. The characteristics of monitoring methods – ground-based and remote sensing – have been identified.
4. This paper analyses phytosanitary measures to protect forests from fungal diseases affecting forest trees. It also outlines preventative measures for fire safety.
5. A comparative analysis was carried out of measures for the protection and sustainable development of Azerbaijan's forests in comparison with those of the Republic of Georgia.

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The Role of Azerbaijan's Forests in the 'Green' Economy

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Abstract

This article examines the theoretical foundations of the role of forests in the development of the green economy, as well as the concepts and nature of the green economy. In this context, the significance of forest resources within the ecological system was examined, and an analysis was carried out of the role of Azerbaijan's forests in the development of the green economy, including the current state of Azerbaijan's forest resources. In this context, particular attention was paid to the environmental role and economic significance of Azerbaijan's forests within the green economy. In addition, the paper analysed the main challenges facing Azerbaijan's forestry sector, explored ways of improving the use of forest resources within the framework of the green economy, and examined international experience of sustainable forest management. The article concludes by assessing the prospects for the development of forestry and providing practical recommendations for the development of a green economy in Azerbaijan's forestry sector.

Keywords: green economy, forest resources, ecological functions, economic significance, sustainable development, comparative analysis

1. Introduction

In recent years, particular attention has been paid in Azerbaijan to environmental protection, the sustainable use of natural resources, and the development of a green economy (OECD, 2022). Against a backdrop of climate change, increasing human pressure on natural ecosystems and the need to ensure the country's environmental security, the importance of forest resources as a key component of the state's natural capital is growing. Forests fulfil numerous environmental and socio-economic functions. They help to preserve biodiversity, regulate the water cycle in these areas, protect the soil from erosion, and contribute to the absorption of carbon dioxide and the creation of favourable climatic conditions. In addition, forests have considerable economic potential, serving as a source of timber and non-timber resources, as well as providing opportunities for the development of recreation and ecotourism.

Despite the relatively low level of forest cover in the country, Azerbaijan's forest resources are of great importance for ensuring the country's environmental sustainability. In past years, government programmes have been implemented to reforest, expand protective green spaces, and improve the forest management system. At the same time, problems persist relating to the degradation of certain forest areas, the consequences of climate change, and the need to improve the efficiency of forest resource use. The relevance of this research topic stems from the need to improve the efficiency of Azerbaijan's forest resource utilisation, to refine mechanisms for their protection and restoration, and to strengthen the role of the forestry sector in ensuring environmental sustainability and the development of a green economy.

The purpose of this study is to examine the role of Azerbaijan's forests in the development of the green economy and to draw up proposals for improving the use and conservation of forest resources. The object of the study is the forest resources of the Republic of Azerbaijan, while the subject of the research comprises the environmental and economic aspects of the use of forest resources within the framework of the green economy. The theoretical and methodological basis for the study was provided by the works of domestic

and international researchers in the fields of forestry, ecology, sustainable development, and the green economy, as well as official statistical data and regulatory and legal documents. The study employed methods including a review of the scientific literature, statistical and comparative analysis, a systems approach, generalisation, and logical analysis. The practical significance of this work lies in the possibility of using the findings and the recommendations developed to prepare measures aimed at improving the system for the protection, restoration, and sustainable use of forest resources in the Republic of Azerbaijan.

2. Discussion

The concept and essence of the green economy: In the current context of global economic development, the concept of the green economy is becoming particularly relevant, as it aims to ensure the sustainable development of society whilst making rational use of natural resources and preserving the ecological balance. The rise of environmental problems, climate change, environmental pollution, and the exhaustion of natural resources have become the main reasons why many countries have shifted to a new model of economic development based on environmental safety and the principles of sustainable use of natural resources. The term 'green economy' became widely used in the late 20th and early 21st centuries. The concept gained particular significance following the work of international environmental organisations and United Nations programmes. The United Nations Environment Programme, UNESCO, and the Food and Agriculture Organization have made a significant contribution to the development of this concept, emphasising the need to transition to sustainable development and an environmentally sound economy. According to UNEP's definition, the green economy is an economic system that promotes improved well-being and social justice whilst reducing environmental risks and the depletion of natural resources. The main aim of the green economy is to achieve economic growth without harming the environment (United Nations Environment Programme, 2011). The development of a green economy is linked to the need to tackle global environmental challenges. Among the most serious of these are climate change, land degradation, the loss of biodiversity, deforestation, air pollution, and the depletion of water resources. In this regard, the international community is placing great emphasis on the development of environmentally-oriented sectors of the economy, the rational use of natural resources, and the introduction of technologies that reduce the negative impact on the environment.

Forest resources are one of the most important components of the green economy. Forests fulfil a wide range of functions, including climate regulation, water conservation, soil protection, public health and recreation. Furthermore, forests play a significant role in reducing the concentration of carbon dioxide in the atmosphere and ensuring the environmental sustainability of natural ecosystems. In today's world, forests are regarded not only as a source of timber but also as a vital component of a country's environmental security. The sustainable use of forest resources helps to maintain the natural balance, prevent soil erosion, protect water resources, and improve the quality of the environment. The concept of the green economy is closely linked to the concept of sustainable development. The principles of sustainable development were set out in the 1987 report by the UN World Commission on Environment and Development, 'Our Common Future'. According to this concept, the development of society must ensure that the needs of the present generation are met without compromising those of future generations (OECD, 2017). Within the framework of the green economy, the main focus is on the conservation of forest ecosystems, the expansion of forest areas, the restoration of degraded land, and the improvement of the effectiveness of environmental policy. Many countries are implementing special programmes to restore forests, reduce deforestation and promote environmentally sustainable forestry. For Azerbaijan, the development of a green economy is of particular importance, as the country's natural resources play a key role in ensuring environmental sustainability and socio-economic development.

In recent years, Azerbaijan has been placing great emphasis on environmental protection, the restoration of forest areas, and the implementation of environmental programmes. The transition to a green economy not only helps to improve the state of the environment but also contributes to the creation of new jobs, the development of ecotourism, an increase in the country's investment appeal and the strengthening

of environmental security. In this respect, the sustainable use of forest resources is becoming one of the most important aspects of the state's environmental policy. Consequently, the green economy represents a modern model of sustainable development based on the rational use of natural resources, the preservation of ecological balance, and the creation of favourable living conditions for the population. In this system, forests are the most important natural resource, ensuring environmental stability, climate stability, and the conservation of biodiversity.

The importance of forest resources in the ecological system Forest resources are one of the most important components of the natural environment and play a significant role in maintaining ecological balance. Forests fulfil numerous environmental, climatic, water conservation, sanitary-hygienic, and socio-economic functions. In today's world, the importance of forests is growing significantly in the face of global environmental challenges, including climate change, environmental pollution and land degradation. One of the main functions of forests is to regulate climatic processes. Forests influence temperature patterns, air humidity, the amount of precipitation, and the circulation of air masses. Forests absorb carbon dioxide and release oxygen, thereby helping to reduce the concentration of greenhouse gases in the atmosphere. In this context, forests are regarded as a vital natural mechanism for combating global climate change. The ability of forests to sequester carbon is of particular importance. Through photosynthesis, trees absorb carbon dioxide from the atmosphere, which helps to reduce the negative impact of human activity on the environment. According to international environmental organisations, the conservation and restoration of forests are among the most effective ways of reducing carbon dioxide emissions. Forests play an important role in protecting the soil from erosion. The root systems of trees stabilise the soil, prevent the topsoil from being washed away, and reduce the risk of landslides. Forests are of particular importance to mountainous regions, where erosion processes are most intense. For Azerbaijan, this issue is particularly relevant given the country's complex terrain.

According to research carried out by Azerbaijani scientists, forests play an important role in water conservation. According to Q. Sh. Mammadova and K. S. Asadova, Azerbaijan's forest ecosystems play a key role in preventing erosion and conserving biodiversity (Məmmədov & Əsədov 2010). They regulate surface water runoff, help to maintain soil moisture, and prevent the onset of drought conditions. F.A. Amirov's works emphasise that forests have a significant impact on the hydrological regime of an area and help to conserve water resources. Furthermore, forest ecosystems prevent waterlogging and regulate groundwater levels (Məmmədov, 2004). An important function of forests is the conservation of biodiversity. Forests provide a natural habitat for a large number of plant, animal, and microorganism species. The degradation of forest ecosystems leads to a decline in the populations of many species of flora and fauna, a disruption of the natural balance, and a deterioration in the environmental situation. Azerbaijan is characterised by a rich biodiversity, thanks to its variety of climatic conditions and natural regions. The country is home to broad-leaved, mixed, and relict forests, which are of great ecological importance. The beech forests of the Greater Caucasus and the woodlands of the Talysh region are of particular value (Яхъяев & Абиев 2015; Hasanov et al., 2017). Forests also fulfil a public sanitary-hygienic function. They purify the air of dust, toxic substances, and harmful gases, reduce noise levels, and improve the quality of the environment. In urban and suburban areas, forests help create a favourable microclimate and has a positive impact on public health. The recreational functions of forests are of great importance. Forest areas are used for recreation, tourism, and public health. The development of eco-tourism not only contributes to the conservation of natural areas but also enhances the economic efficiency of forest resource use.

In today's world, forests are becoming increasingly important as a key element of sustainable development and the green economy. The sustainable use of forest resources helps to ensure environmental safety, improve the quality of life for the population, and create the conditions for sustainable socio-economic development. For Azerbaijan, the conservation of forest ecosystems is of strategic importance. Despite the country's relatively low level of forest cover, forests play an important role in maintaining ecological balance, preventing land degradation and protecting natural resources. In recent years,

programmes have been implemented in the country to restore forest cover, carry out afforestation, and protect particularly valuable natural ecosystems (НОВИКОВ, 2005).

Significant attention is being paid to the reforestation of the liberated territories of Karabakh. The implementation of reforestation measures helps to improve the environmental situation, prevent soil erosion, and preserve the region's natural potential. Forest resources are therefore a vital component of the ecological system and play a key role in ensuring sustainable development. The ecological functions of forests are of great importance for maintaining the natural balance, improving the quality of the environment and developing Azerbaijan's green economy.

The current state of Azerbaijan's forest resources. Azerbaijan's forest resources constitute the country's most important natural asset; however, their quantitative and qualitative characteristics indicate the need for a systematic approach to their management and restoration.

According to data from the State Statistics Committee of Azerbaijan, the total area of the forest reserve is approximately 1.213 million ha, of which around 1.037 million ha are directly covered by forest, corresponding to a forest cover of approximately 11.8% (Azərbaycan Respublikasının Dövlət Statistika Komitəsi, 2024). By way of comparison, the average forest cover across Europe is around 32%, which highlights a significant gap and the potential for reforestation. The spatial distribution of forests is extremely uneven. The highest concentration of these — accounting for around 95% of the total forest area — is found in the mountainous regions of the Greater Caucasus, the Lesser Caucasus and the Talysh Mountains (Azərbaycan Respublikası Ekologiya və Təbii Sərvətlər Nazirliyi, 2024; Əmirov, 1997). At the same time, in the arid, flat regions that make up a significant part of the country's territory, the area covered by forest is minimal. This imbalance poses serious environmental risks: low-lying areas lack natural protection against wind erosion and soil salinisation (Əliyev, 2002).

The species composition of Azerbaijan's forests is diverse and is determined by vertical zonation. The Hircanian forests of the Talysh Zone are of particular scientific and conservation value — these are relict broad-leaved forests dating from the Tertiary period, which have survived thanks to the region's unique microclimate. They are included on the UNESCO World Heritage List and represent a unique biogeographical phenomenon. An analysis of trends in forest cover over the last decade indicates a positive trend towards an increase in forested area in Azerbaijan. According to figures from the State Statistics Committee, in 2025 the area of forest covered 1,213.7 thousand ha of the forest reserve.

Despite the government's reforestation measures, the current rate of forest cover expansion is not yet sufficient to fully offset the effects of past periods of forest ecosystem degradation. In this regard, further increasing the scale of reforestation work remains one of the key priorities of the government's environmental policy (Azərbaycan Respublikasının Dövlət Statistika Komitəsi, 2024). This indicates that the expansion of forest cover is proceeding at a slow pace and has not yet fully compensated for the historical losses to the forest stock.



Figure 1. Geographical distribution of forests in Azerbaijan

Figure 1 shows the geographical distribution of Azerbaijan’s forest areas. As can be seen from the map, forests cover around 11-12% of the country’s territory and are distributed unevenly. The largest areas of forest are concentrated in the mountainous regions of the Greater Caucasus in the north-east of the country, the Lesser Caucasus in the west and south-west, and the Talysh Mountains in the south-east. In lowland and semi-arid regions, the forest cover is considerably lower due to the characteristics of the terrain, climatic conditions, and precipitation patterns. This distribution of forest resources determines their vital role in preserving biodiversity, protecting soils from erosion, regulating the water balance, and maintaining the ecological sustainability of Azerbaijan’s natural ecosystems. Furthermore, the fact that forests are concentrated mainly in mountainous areas enhances their importance in preventing landslides, mudslides, and other adverse natural phenomena.

Table 1. Trends in CO₂ emissions in Azerbaijan (2018–2021)

Year	CO ₂ emissions (million tonnes)	Change (%)
2018	33,7	—
2019	34,2	+1,5
2020	32,5	-4,9
2021	35,1	+8,0

Source: World Bank Data, 2022 [40].

As shown in the data in Table 1, despite a temporary decline in carbon dioxide emissions in 2020, linked to the reduction in economic activity during the COVID-19 pandemic, this figure rose to 35.1 million tonnes as early as 2021, an increase of 8% compared with the previous year. This indicates that the country’s economy remains dependent on sectors linked to the consumption of fossil fuels and highlights the need to step up measures to reduce the carbon footprint on the environment.

Forest ecosystems play a vital role in achieving climate targets, as they act as natural carbon sinks. Through photosynthesis, forests store carbon in their woody biomass, soil and forest litter, thereby helping to reduce the concentration of greenhouse gases in the atmosphere. According to estimates by the Food and Agriculture Organisation of the United Nations (FAO), one hectare of mature broadleaf forest is capable of absorbing an average of between 2 and 5 tonnes of CO₂ per year. Based on these figures, offsetting the increase in emissions recorded in 2021 alone would require a significant expansion of the areas set aside for reforestation.

Consequently, increasing the area of forest cover should be viewed not only as an environmental protection measure but also as an important tool for implementing green economy policies and fulfilling Azerbaijan's international commitments in the field of combating climate change. In this context, afforestation programmes, improving the effectiveness of the protection of existing forests, and the introduction of modern methods for monitoring the carbon balance of forest ecosystems take on particular significance (Global Forest Resources Assessment, 2020).

An analysis of trends in CO₂ emissions shows that the development of the forestry sector can make a significant contribution to reducing the negative impact on the climate and enhancing the country's environmental sustainability. However, in order to achieve a tangible impact, it is necessary to further expand the scale of reforestation work and improve the forest resource management system.

Table 2: Key ecological functions of forests

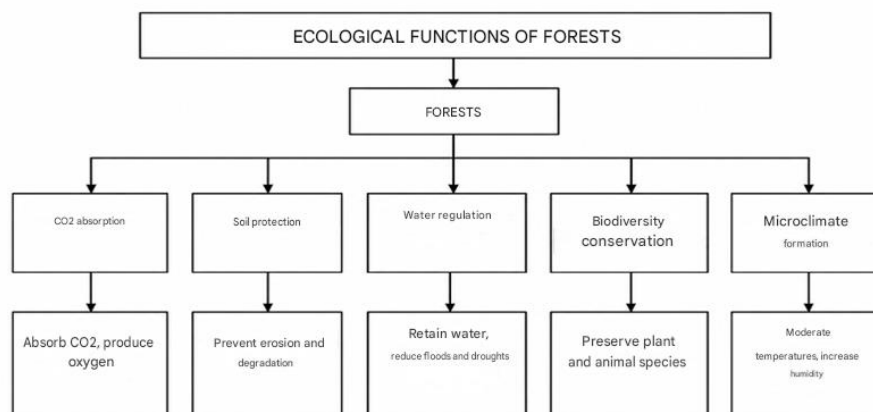


Table 2 sets out the main ecological functions of forests. As can be seen from the diagram, forests play an important role in absorbing carbon dioxide, which helps to mitigate the effects of climate change. Furthermore, they protect the soil from erosion, regulate the water balance of the area, and help to preserve biodiversity. Another important function of forests is to create a favourable microclimate. The combination of these functions ensures that ecological balance is maintained and that natural ecosystems develop sustainably.

The state of the forest resources in the liberated territories of Karabakh and Eastern Zangezur deserves particular attention. According to various estimates, between 30 and 40% of the forest cover in the area was destroyed or seriously damaged as a result of years of occupation and military operations (Azərbaycan Respublikası Ekologiya və Təbii Sərvətlər Nazirliyi, 2023). The government has begun implementing large-scale reforestation programmes in the region, but full recovery will take decades.

An assessment of the current state of Azerbaijan's forest resources highlights three key issues: a low overall level of forest cover compared with European standards; spatial disparities in forest distribution; and insufficient rates of reforestation against a backdrop of rising greenhouse gas emissions. Addressing these issues is a prerequisite for the transition to a green economy.

An analysis of the ecological role of Azerbaijan's forests: Forests play a multifaceted ecological role; however, for Azerbaijan, with its specific geographical and climatic conditions, each of these functions is of particular, and often vital, importance. Unlike countries with high forest cover, where forests are taken for granted, in Azerbaijan, every hectare of forest cover bears a heavy environmental burden.

Climate control function. The forests of the Greater Caucasus act as a natural climatic barrier, protecting the country from Arctic air masses in winter and tempering the summer heat. Studies show that

in the forested areas of Azerbaijan, the average annual air temperature is 1.5–2.5°C lower, whilst humidity is 10–15% higher than in treeless areas at the same altitude (Məmmədov, 2004).

The Girkhan forests create a unique subtropical microclimate in the south-east of the country, without which the survival of many relict species would be impossible.



Figure 2. Degradation of forest cover and the risk of soil erosion. (Qusar District, mid-mountain terrain)

Figure 2 shows areas with sparse forest cover and partially denuded slopes. This state of forest ecosystems indicates a decline in tree cover and a weakening of their protective functions. The reduction in forest cover leads to increased erosion, higher surface runoff, a deterioration in the water regime of the affected areas, and a reduction in the stability of the soil cover. Furthermore, the degradation of forest stands has a negative impact on biodiversity, as it leads to a reduction in the natural habitats of many plant and animal species.

Forests play a particularly important role in the mountainous regions of Azerbaijan, where they help to protect the soil and regulate water flows and prevent landslides, mudslides, and other dangerous natural phenomena. A reduction in forest cover may lead to a deterioration in the ecological condition of the area and a decline in the ability of natural ecosystems to withstand human impact and the effects of climate change.

The example given clearly illustrates the importance of preserving existing forest areas and implementing effective reforestation measures. The rational use of forest resources, the strengthening of measures to protect them, and the expansion of efforts to restore degraded areas are essential for ensuring environmental sustainability and preserving Azerbaijan's natural potential.

Carbon sink. In today's world, the carbon sink function has taken on a strategic economic dimension. According to estimates based on the FAO methodology, the total amount of carbon sequestered in Azerbaijan's forests is approximately 180–220 million tonnes of CO₂ equivalent [29]. This implies that the degradation and destruction of forest resources will result not only in environmental losses but also in economic ones: in the context of the global carbon market, this volume has a very specific value. According to reports by the FAO and UNEP, forest restoration is one of the key mechanisms for reducing greenhouse gas emissions and can be regarded as a 'green' financing instrument (FAO, 2006; FAO, 2012; UNEP, 2011, UNEP, 2021).

Soil-protecting function. Soil conservation is of critical importance for the country's mountainous regions. According to Azerbaijani researchers in the field of forest ecology, the rate of water erosion on treeless mountain slopes is 15–20 times higher than that in forested areas (Məmmədov, 2004). This problem is particularly acute in the Lesser Caucasus, where intensive deforestation over the past decades has led to the degradation of the soil cover across large areas.

Water conservation function. Azerbaijan's rivers, which feed both inland reservoirs and flow into the Caspian Sea, have their source in the forested mountain ranges. Scientific data clearly indicate a direct

correlation: in catchment basins with high forest cover (over 40%), river flow is more consistent, flood peaks are 20–30% lower, and low-water levels (minimum water flow) are 15–25% higher compared with deforested basins (Əmirov, 2003). Given the growing shortage of fresh water forecast for the South Caucasus by the middle of the 21st century, this function of forests takes on strategic importance.

Biological diversity. In terms of the number of plant species per unit area, Azerbaijan is one of the most biologically diverse countries in Europe and Western Asia. The country's forests are home to more than 4,500 species of higher plants, of which around 240 are endemic, found only here (İbrahimov, 2018). The Hyrcanian forests alone support around 180 relict species. The reduction in forest cover inevitably leads to the fragmentation of habitats and, in the long term, to the extinction of unique species, which represents an irreparable loss for global science and the biosphere as a whole.

Table 3. Ecological functions and quantitative characteristics of forests

Function	Quantitative description
Climate-regulating	A temperature drop of 1.5-2.5°C in forested areas
Carbon sink	Approximately 180–220 million tonnes of CO ₂ equivalent have been stored.
Soil-protection	A 15-20-fold reduction in erosion
Water conservation	A 20–30% reduction in flooding
Biological	240 species of endemic plants
Recreational	A base for the development of ecotourism

The data presented in Table 3 show that Azerbaijan's forests are not only an important natural resource but also a multifunctional ecosystem that fulfils a wide range of environmental and socio-economic functions. Forest ecosystems play a significant role in regulating climatic processes, conserving biodiversity, protecting soil from erosion, and maintaining the water balance of the land.

In today's world, the carbon sequestration function of forests is becoming particularly important. Due to their ability to absorb and store carbon, forest stands help to reduce the concentration of greenhouse gases in the atmosphere and mitigate the effects of climate change. In light of the development of international carbon regulation mechanisms, this function is taking on not only environmental but also economic significance.

Equally important are the soil conservation and water protection functions of forests. Forest vegetation helps to reduce the severity of erosion, improve soil structure, regulate surface runoff, and reduce the risk of flooding. Furthermore, forests help to preserve the natural habitats of numerous plant and animal species, thereby supporting biodiversity and the sustainability of natural ecosystems.

The environmental role of Azerbaijan's forests extends far beyond their traditional use as a source of timber. In the context of the development of the green economy, forest resources should be regarded as a key component of the country's natural capital, the conservation and sustainable use of which are essential for ensuring environmental security and sustainable socio-economic development in Azerbaijan.

The economic importance of forests within the green economy: The economic valuation of forest resources within the framework of the green economy concept differs fundamentally from the traditional approach, under which forests were regarded solely as a source of timber. Modern economic theory is based on the need to take into account the full range of ecosystem services provided by forests, including not only direct benefits (timber, non-timber products) but also indirect (carbon sequestration, water regulation, tourism) and intangible (biodiversity, aesthetic value) benefits (Одум, 1986).

Azerbaijan's forestry sector and green economy. The direct contribution of forestry to Azerbaijan's GDP remains relatively small — according to various estimates, no more than 0.5–0.8%. However, this figure drastically underestimates the actual economic contribution of forests, as it does not take ecosystem services into account. If the methodology for assessing ecosystem services developed as part of the TEEB

(The Economics of Ecosystems and Biodiversity) and OECD programmes (OECD, 2017) is applied, the total economic value of Azerbaijan's forests increases severalfold.

Eco-tourism. Eco-tourism is one of the fastest-growing sectors in the use of forest resources. Azerbaijan has exceptional potential in this field: its network of national parks and nature reserves encompasses unique natural areas ranging from the subalpine meadows of Shahdag to the subtropical forests of the Hyrcanian Nature Reserve. According to estimates by the Ministry of the Environment, with the right infrastructure and marketing, the potential for ecotourism in the country's forested areas is estimated at 50–80 million dollars annually (ETSN, 2024). By way of comparison, Georgia, having begun to actively develop ecotourism in the 2010s, had increased its revenue from this sector to \$120 million by 2019.

The carbon market is a promising, but as yet not fully realised, tool for monetising forest ecosystem services. Under the Paris Agreement on Climate Change, countries are entitled to establish national carbon trading schemes and participate in international REDD+ (Reducing Emissions from Deforestation and Forest Degradation) mechanisms. According to UNEP estimates, realising the potential of REDD+ for Azerbaijan could attract additional funding of between 20 and \$40 million a year, provided that an appropriate regulatory framework is put in place (UNEP, 2011).

Protection of agriculture and water resources. The indirect contribution of forests to the economy through the protection of agricultural land is significant, although it is more difficult to quantify precisely. According to estimates by Azerbaijani agricultural economists, the damage caused by wind and water erosion of soil in the country's treeless regions amounts to at least 80–100 million annually in lost agricultural output. By preserving soil cover and moisture levels, riparian strips and water protection forests effectively subsidise the agricultural sector without receiving any market compensation in return (Məmmədov, 2004).

Table 4. The economic benefits of Azerbaijan's forests

Directionality	Estimated economic benefit
Eco-tourism	Potential of \$50-80 million per annum
The carbon market (REDD+)	Potential of \$20-40 million per annum
Protection of agricultural land	Preventable damage caused by erosion: 80-100 million per annum
Water supply	Flow control: reducing water treatment costs
Biodiversity	Intangible value: a foundation for the pharmaceutical industry and science

The data in Table 4 show that Azerbaijan's forests are of not only ecological but also considerable economic value. In addition to the traditional use of forest resources, ecosystem services linked to the development of eco-tourism, the conservation of biodiversity, the regulation of water regimes in these areas, and the mitigation of the negative impacts of climate change are becoming increasingly important.

Of particular interest is the potential for the development of ecotourism and participation in international mechanisms for reducing greenhouse gas emissions. As part of the transition to a green economy, these areas could become additional sources of economic benefits and help to attract investment in environmental protection measures. At the same time, effectively realising this potential requires improving the forest resource management system, developing infrastructure and strengthening measures to protect forest ecosystems.

The protective functions of forests are also of great importance. Preserving forest stands helps to reduce soil erosion, maintain the sustainability of agricultural land, and regulate water resources. This helps to minimise potential economic losses associated with land degradation, a decline in soil quality, and disruption to the hydrological regime of the areas concerned.

An analysis of the economic significance of forests shows that their contribution to the country's development extends far beyond the direct income generated by the forestry sector. Forest ecosystems

provide a range of environmental and socio-economic benefits that must be taken into account when formulating government policy on the use of natural resources. Against the backdrop of the development of the green economy, there is a growing need to improve approaches to the valuation of natural capital and to take fuller account of the economic value of forest resources.

The main challenges facing Azerbaijan's forestry sector: Despite the obvious environmental and economic value of forests, Azerbaijan's forestry sector faces a range of interrelated challenges which, without a systematic solution, will continue to hinder the transition to a green economy. The analysis shows that these problems are of both an objective, natural nature and a subjective nature — linked to shortcomings in governance and legislation.

Illegal logging and poaching in forests. According to the Ministry of Ecology and Natural Resources, several hundred cases of illegal tree felling are recorded in Azerbaijan every year (ETSN, 2024; Атрохин, 1982; Бельгард, 1971). The actual scale, however, is considerably greater than that identified: experts estimate that the volume of timber harvested on the black market is two to three times higher than the officially recorded figure. Despite tighter state controls and improvements to environmental legislation, cases of unauthorised timber harvesting continue to be reported in various regions of the country. The main reasons are the population's need for firewood, the economic difficulties faced by certain rural areas, and inadequate monitoring in some forest areas. Illegal logging leads to a reduction in forest area, disruption to the structure of forest stands, a deterioration in the conditions for natural forest regeneration, and a decline in the forest's ecological sustainability (Яхьяев & Абиев, 2015). The degradation of forest ecosystems caused by human activity remains a serious problem.

Degradation caused by overgrazing. The traditional practice of grazing livestock in forests continues in many mountainous regions of the country, despite the legal restrictions on it. Grazing has a multifaceted impact on the forest ecosystem: livestock destroy young trees, compact the soil—thereby preventing it from becoming saturated with water—and lead to the fragmentation of the forest cover. According to estimates by Azerbaijani forestry experts, up to 15–20% of the country's mountain forests are suffering from some degree of degradation, caused in part by overgrazing (Əmirov, 2003).

Forest fires. Given the predicted climate warming, the risk of forest fires in Azerbaijan is increasing significantly. According to the IPCC report (2021), climate change poses one of the most serious threats to forest ecosystems on a global scale (FAO, 2012; UNEP, 2019; IPCC, 2019). In the case of Azerbaijan, this means that by 2050, the number of fire-risk days per year could increase by 20–30%. At the same time, the forest fire protection system is in need of modernisation: the network of observation posts is inadequate, and there is a shortage of specialised equipment and trained personnel. This problem is particularly acute in the mountainous regions of the Greater and Lesser Caucasus, where forests play a vital role in soil conservation. The reduction in forest cover contributes to increased water and wind erosion, a decline in soil fertility, and a greater risk of landslides and mudslides. This not only worsens the environmental conditions of the areas but also results in further economic losses.

In recent years, the effects of climate change, accompanied by rising air temperatures and longer periods of drought, have contributed to an increased risk of wildfires. Forest fires lead to the destruction of woodland, a reduction in biodiversity, and a deterioration in the environmental situation in the affected areas. Furthermore, the restoration of forests following major fires requires significant financial and time resources. In this context, the development of an early fire detection system, the improvement of fire safety infrastructure, and the enhancement of the effectiveness of preventative measures take on particular importance.

A major problem is the impact of climate change on the condition of forest ecosystems. Rising average annual air temperatures, changes in precipitation patterns, and an increase in the frequency of extreme weather events are having a negative impact on the growth and development of forest vegetation. Droughts, strong winds, and other adverse climatic factors reduce the resilience of forests, increase the risk of the spread of diseases and pests, and hinder the natural regeneration of forest stands.

The issue of preserving biodiversity deserves special attention. Azerbaijan's forests are home to a large number of plant and animal species, many of which are rare or endemic. However, the reduction and fragmentation of forest areas lead to a deterioration in the habitats of certain species and a decline in the resilience of natural ecosystems. Conserving biodiversity requires the further development of the network of specially protected natural areas and the strengthening of measures to protect rare species of flora and fauna.

Another problem is the insufficient uptake of modern technologies for monitoring and managing forest resources. Effective management of forest resources requires the regular collection of reliable information on the condition of forests, the scale of reforestation, and the extent of human impact. In today's world, geoinformation systems, satellite monitoring and digital technologies play a key role in enabling the rapid detection of changes in forest cover and improving the effectiveness of nature conservation efforts. Furthermore, expanding the scale of reforestation work remains an important task. Despite the measures being taken to plant trees and restore degraded areas, there remains a need to increase the area of forest. Increasing the country's forest cover is vital for strengthening the environmental sustainability of natural ecosystems, improving climatic conditions and developing the green economy.

Consequently, the main challenges facing Azerbaijan's forestry sector are illegal logging, the degradation of forest ecosystems, soil erosion, forest fires, the impacts of climate change, a decline in biodiversity, the insufficient use of modern monitoring technologies, and the need to further expand reforestation efforts. Addressing these issues requires a comprehensive approach, including the improvement of public policy, the strengthening of environmental protection measures, the introduction of innovative technologies, and the promotion of the principles of sustainable forest management (Prilipko, 1954; Peймepc, 1990).



Figure 3. Degradation of forest areas and reduction in forest cover

Figure 3 shows an area exhibiting signs of forest cover degradation. A significant part of the area is characterised by a reduction in tree cover, the presence of dead standing trees and bare patches of soil. Such changes increase the risk of soil erosion, reduce biodiversity, and undermine the environmental sustainability of natural ecosystems.

The pace of reforestation is insufficient. F.A. Amirov's research emphasises the need to introduce more effective reforestation techniques and to improve the quality of care for young forest stands (Amirov, 2003).

Table 5. An Analysis of the Challenges Facing Azerbaijan's Forestry Sector

The problem	Scale and consequences
Illegal logging	2-3 times higher than the officially recorded figure
Overgrazing	Up to 15–20 per cent of mountain forests are in a state of degradation
Forest fires	A 20–30% increase in the number of fire-risk days by 2050
The rate of reforestation	Below 15,000–20,000 hectares per year
The Degradation of Karabakh's Forests	80,000–120,000 hectares
Poor economic assessment	Indirect ecosystem services are not taken into account

Table 5 clearly demonstrates that the problems facing the forestry sector are complex and interrelated. For example, the lack of funding for reforestation is exacerbated by the fact that the economic value of forests is officially underestimated — indirect services are not taken into account. It is a vicious circle: until forests are fully accounted for in the national system of economic accounts, their conservation will be funded on a residual basis. In recent years, work has been carried out in the liberated territories to clear forest land, create new green spaces, plant trees and shrubs, and restore specially protected natural areas. The restoration of forest resources is regarded as one of the priority areas of the state's environmental policy in the liberated territories. One of the main challenges facing the reforestation of Karabakh remains the need to carry out demining operations in the area, as the presence of mines and unexploded ordnance significantly limits the scope for reforestation activities. Further difficulties stem from the destruction of infrastructure, a shortage of specialised forest nurseries, and the need to select tree species that are best suited to current climatic conditions.

It should be noted that the restoration of Karabakh's forests is significant not only from an environmental perspective but also from a socio-economic one. Increasing the area of forest cover will help to improve the state of the environment, reduce erosion, preserve biodiversity, and promote the development of eco-tourism. Furthermore, the restored forests will be able to perform important climate-regulating functions and contribute to the achievement of Azerbaijan's sustainable development goals and green economy. The degradation of Karabakh's forests is one of the most serious environmental problems facing Azerbaijan today. Addressing this issue requires a long-term government strategy, substantial financial resources, and the use of modern methods of reforestation and environmental monitoring. Government policy on forest conservation is a key instrument in the transition to a green economy. For Azerbaijan, where forests have historically been subject to significant human impact, the quality of this policy will largely determine whether the country succeeds in realising the environmental and economic potential of its forest resources. A critical analysis of the regulatory framework and the practice of its application reveals both achievements and systemic limitations.

Legal framework. The basis of Azerbaijan's forestry legislation is the Forest Code of the Republic of Azerbaijan (Azərbaycan Respublikasının Meşə Məcəlləsi, 2017), which establishes the legal framework for the protection, use and regeneration of forests. An important achievement is the enshrinement in law of the principle of multi-purpose forest management, under which the protective functions of forests are recognised as taking precedence over their commercial functions. At the same time, experience shows that there is a significant gap between the letter of the law and its enforcement: regulations prohibiting felling in water protection zones and on steep slopes are being flouted, whilst the administrative penalties for forestry offences remain insufficiently severe. The Ministry of Ecology and Natural Resources of the Republic of Azerbaijan is the main regulatory body in the forestry sector (ETSN, 2024). However, the forest management system requires clearer coordination. Thus, issues relating to reforestation on agricultural land require a coordinated approach between the relevant authorities, which will help to improve the effectiveness of the measures being implemented.

An important aspect of government policy is the implementation of programmes for reforestation and the expansion of the forest area. In recent years, initiatives have been carried out in Azerbaijan to plant trees, restore degraded forest areas, and green up the countryside. Particular attention is being paid to the

liberated territories of Karabakh and Eastern Zangezur, where the restoration of forest ecosystems is regarded as one of the priorities of the state's environmental policy. Azerbaijan's participation in international environmental initiatives and the fulfilment of its environmental protection obligations are of great importance. The country has acceded to a number of international conventions on nature conservation, climate change, and the preservation of biodiversity. This helps to promote the adoption of modern approaches to forest resource management and to draw on international expertise in the field of forestry. In recent years, increasing attention has been paid to the digitalisation of forest management systems. The use of geographic information systems, remote sensing, and satellite monitoring makes it possible to obtain more accurate information on the state of forest resources and to promptly detect illegal logging, forest fires, and other adverse impacts. The introduction of modern technologies helps to improve the effectiveness of state oversight and the quality of management decisions.

At the same time, an analysis of existing policy reveals a number of unresolved issues. These include insufficient funding for certain forestry measures, the need to modernise the material and technical infrastructure of forestry enterprises, the limited use of economic incentives to promote forest conservation, and the insufficient application of an ecosystem-based approach in management decision-making. Improving the economic mechanisms for managing forest resources is becoming particularly important. Globally, payment schemes for ecosystem services, carbon projects, and programmes to encourage reforestation are becoming increasingly widespread. The use of such tools could help to attract additional funding for the conservation and restoration of Azerbaijan's forests. Azerbaijan's state policy on forest conservation is therefore aimed at preserving the country's forest resources, improving the efficiency of forest resource management and ensuring the country's environmental sustainability. Despite the progress made, further improvements to the legislative framework, the introduction of modern technologies and the expansion of reforestation programmes remain key prerequisites for the successful development of the forestry sector within the framework of the green economy.

Reforestation programmes: In recent years, the government has been implementing several programmes aimed at expanding the forest area. The most extensive programme is the one aimed at reforesting the liberated territories of Karabakh and Eastern Zangezur, under which it is planned to establish forest plantations covering an area of several tens of thousands of hectares [9]. A positive example is the mass tree-planting campaigns, which have become an annual event: according to the Ministry of the Environment, more than 3 million trees were planted during such events in 2022–2023 alone (ETSN, 2024)

The system of specially protected natural areas (SPNAs). Azerbaijan has a network of SPNAs comprising 11 state nature reserves, 11 national parks, and a number of wildlife sanctuaries (ETSN, 2024). The total area of protected areas accounts for around 10 per cent of the country's territory. The inclusion of the Girkhan National Park on the UNESCO World Heritage List in 2019 marked a significant international recognition of the country's conservation efforts (UNEP, 2021). At the same time, funding for protected areas remains insufficient: according to experts' estimates, effective management of protected areas requires at least 2-3 times more funding than is currently allocated.

Environmental monitoring. The introduction of remote sensing systems to monitor forest resources is one of the priorities of government policy. As part of its cooperation with the FAO and UNEP, the country is establishing a national forest inventory system that enables changes in forest area and condition to be monitored with a high degree of accuracy (FAO 2012, UNEP, 2011).

This provides the necessary information base for management decision-making.

Table 6. Assessment of government policy on forest conservation

Area of Focus	Assessment and key challenges
Legal and Regulatory Framework	Well-developed, but requires strengthening
Reforestation	The scale is growing, but monitoring of take-up is insufficient
Protected Areas	Insufficient funding and staffing
Environmental Monitoring	The system is being developed with the support of FAO/UNEP
Combating Illegal Logging	Requires stricter sanctions and digital monitoring
Karabakh Programme	Large-scale and a priority; long-term results remain to be assessed

Table 6 shows that Azerbaijan's state policy on forest conservation has the necessary regulatory and institutional framework but suffers from a gap between its stated objectives and actual results. The key areas for improvement are: ensuring the quality of reforestation work (not just the quantity), strengthening law enforcement, and providing adequate funding for protected areas. An analysis of the main areas of government policy shows that Azerbaijan has established the necessary legislative and institutional framework for forest conservation. However, the further development of the forestry sector requires a shift from predominantly administrative management methods to a comprehensive approach based on the principles of sustainable development, the digitalisation of management and the economic valuation of ecosystem services. In modern conditions, the effectiveness of forestry policy should be assessed not only in terms of the number of trees planted or the area of land restored, but also in terms of the quality of forest stands, their state of conservation, and their ability to fulfil ecological functions.

International experience of sustainable forest management: For Azerbaijan, studying international experience in sustainable forest management is not of academic interest but of purely practical importance: the country faces the need to significantly accelerate reforestation and improve the effectiveness of forest conservation within a short timeframe.

An analysis of the experience of leading forestry nations reveals both universal principles applicable in any context and specific mechanisms which, if adapted, can yield rapid results (Исаченко, 2001).

Finland: a model of sustainable forest management. Finland is a country with 73% forest cover and, at the same time, one of the world's largest timber exporters. This paradox can be explained by the application of the principle of continuous cover forestry: felling and reforestation are planned in such a way that the total area and volume of forests do not decrease but increase. The law requires forest owners to plant new trees within two years of felling and to ensure that they take root.

For Azerbaijan, the key lesson is not the principle itself (which is already enshrined in Azerbaijani legislation), but the system for monitoring its implementation: in Finland, every reforestation site is inspected by a state forester after three years.

Germany: long-term planning and climate adaptation. German forestry is known for its commitment to long-term management, with forest management plans drawn up for periods of 10–20 years. However, over the past decade, Germany has faced a serious challenge: droughts and a bark beetle infestation have destroyed around 300,000 hectares of spruce forest – a direct consequence of the monocultural plantations of the last century. Germany's response to this crisis, which involves a shift towards mixed forests using drought-resistant species, is of direct interest to Azerbaijan, where climate change also poses a threat to monoculture plantations.

China: scale as a tool. The Three-North Shelter Forest Programme, which has been running since 1978, is the largest reforestation project in human history. Over four decades, more than 66 billion trees have been planted in China, and the forest cover in the northern regions has increased from 5% to 13% (FAO, 2012). For Azerbaijan, it is not only the scale that matters, but also the organisational mechanism: the programme combines state funding with the mandatory participation of local communities, which are

granted rights to a share of the timber harvested, providing a powerful incentive to ensure high-quality care of the plantations.

Table 7. International experience and applicability

Country/mechanism	A key lesson for Azerbaijan
Finland	Mandatory monitoring of planting survival rates after 3 years
Germany	Transition to mixed drought-resistant forests
China	Involvement of local communities with rights to forest resources

Table 7 presents a comparative analysis of international experience, which shows that three areas are of particular benefit to Azerbaijan: monitoring the survival rate of plantings, transitioning to mixed and drought-resistant forests, and developing mechanisms to finance reforestation.

Practical recommendations for the development of a green economy in Azerbaijan's forestry sector: Based on the analysis carried out – covering the state of the forest resources, the ecological and economic functions of forests, an assessment of government policy and international experience – a set of practical recommendations has been drawn up. They are organised in order of priority: from measures that yield quick results to long-term structural reforms.

Recommendation 1. Introduce mandatory three-year monitoring of the survival rate of all reforestation plantings. The point of the recommendation is that, without monitoring the results, a significant proportion of the funding for reforestation is wasted – trees are planted but do not survive. It is proposed that an amendment be made to the Forestry Code, requiring those carrying out reforestation work to submit a report on survival rates one and three years after planting. Target: a survival rate of at least 70 per cent by the third year. Source of funding for monitoring: the cost of monitoring is included in the budget for reforestation works (Həsənov, 2015).

Recommendation 2. To develop ecotourism in forest protected areas based on a public-private partnership model. It is proposed that a register of investment proposals in the field of ecotourism in forest areas be established. The state provides the access infrastructure (roads) and marketing support, whilst the investor is responsible for developing the tourism product. According to estimates by ecotourism experts, an initial investment of 15-20 million dollars could generate annual revenue of 50-70 million dollars within 5-7 years (Əmirov, 2003).

Recommendation 3. To implement a system for real-time satellite monitoring of forest resources. The use of publicly available Sentinel-2 satellite data (European Space Agency) makes it possible to detect changes in forest cover at five-day intervals and with a spatial resolution of 10 metres.

Table 8. Summary table of practical recommendations

Recommendation	Expected outcome and timeframe
1. Survival rate monitoring	Increase planting efficiency to 70%+; timeframe: 1-2 years
2. Ecotourism (PPP)	\$50-70 million per year in 5-7 years' time; timeframe: 2-3 years
3. Satellite monitoring	Reduction in illegal logging by 40-60%; timeframe: 1-2 years

The data in Table 8 show the cumulative effect of the proposed recommendations in terms of: accelerating the pace of reforestation; attracting additional funding; and ensuring that the forestry sector makes a measurable contribution to the achievement of Azerbaijan's climate targets. It is of fundamental importance that most of the recommendations are based on proven international practices and do not require fundamentally new technologies – only political will and organisational consistency.

3. Conclusion

As a result of the study, the role of Azerbaijan's forests in the development of the green economy was examined, the current state of the country's forest resources was analysed, the environmental and socio-economic functions of forest resources were investigated, and recommendations were put forward for improving the forest resource management system. First and foremost, the theoretical foundations of the study were examined. It was established that the concept of the green economy is aimed at ensuring economic development whilst making rational use of natural resources and preserving the environment. In this system, forests play an important role, fulfilling functions relating to climate regulation, water conservation, soil protection, recreation and socio-economic development. The analysis carried out has shown that the development of Azerbaijan's forestry sector has followed a long historical path and is currently based on the principles of sustainable forest management and the conservation of natural resources.

An analysis was carried out of the current state of Azerbaijan's forest resources and their significance for the development of the green economy. The study has shown that, in recent years, measures have been implemented in the country to conserve and restore forests, which has contributed to an increase in the total area of forest land. At the same time, problems persist relating to the degradation of certain forest areas, illegal logging, the effects of climate change and the need to improve the effectiveness of forest management measures. It has been established that Azerbaijan's forests possess significant environmental and economic potential and play a vital role in maintaining ecological balance, conserving biodiversity and improving the quality of life of the population. The main areas for improving the use of forest resources within the green economy were then examined.

An analysis of government policy and international experience has shown that the efficiency of the forestry sector can be improved by expanding reforestation efforts, introducing modern monitoring technologies, improving the forest resource management system and developing mechanisms for sustainable forest management. Of particular importance is the application of leading international best practice in the fields of forest protection, biodiversity conservation and the sustainable use of natural resources.

The study conducted leads to the conclusion that Azerbaijan's forests are a vital component of the country's natural capital and play a significant role in ensuring environmental security and sustainable socio-economic development. Effective management of forest resources not only helps to preserve natural ecosystems, but also creates further opportunities for the development of the green economy.

The practical significance of this work lies in the fact that the recommendations put forward can be used in the development of measures aimed at improving the system for the protection, restoration and sustainable use of forest resources. Their implementation will help to improve the environmental sustainability of these areas, conserve biodiversity and strengthen the role of the forestry sector in the development of the national economy.

Consequently, the rational use of forest resources, the conservation of natural ecosystems and the consistent implementation of the principles of the green economy are key prerequisites for Azerbaijan's sustainable development. Further improvements to government policy on forestry will help to achieve the country's environmental, economic and social development goals.

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Environmental Assessment of the Impact of Urban Transport on Air Pollution in Baku City

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Abstract

In modern times, the increase in population density in cities and the year-on-year rise in the number of cars are among the main factors negatively affecting air quality. In particular, the intensity of road traffic in Baku increases the volume of harmful substances released into the atmosphere, having a serious impact on the environmental situation and human health. This study analyses the emissions generated on the city's four main arterial roads with the highest traffic load, and their impacts on the environment and the socio-economic sphere are assessed based on international methodological approaches. The calculations applied the EMEP/EEA methodology, the World Health Organisation's 2021 air quality recommendations, and the principles for the valuation of external costs. Analyses show that most of the country's carbon monoxide emissions, approximately 71%, and 44% of its nitrogen oxides, originate from the transport sector. Much of that pollution is concentrated in Baku and has a particularly significant impact on the environment in the capital. The average annual concentration of PM_{2.5} particles is estimated to range from 19 to 45 µg/m³, which is several times higher than accepted international health standards. This leads to an increased risk of heart and lung diseases in people breathing in polluted air for long periods. An economic assessment found that transport-related air pollution causes losses of over US\$370 million annually, due to premature deaths, additional healthcare costs, and decreased productivity of citizens. The study recommends several measures, such as phasing out old vehicles, increasing the number of electric vehicles, improving and optimizing public transport, creating low-emission zones, implementing smart vehicle infrastructure, and improving green spaces in cities. These measures have the potential to reduce PM_{2.5} emissions by 34-50% and nitrogen oxide emissions by 41-55% by 2030. The study's results show that improving air quality in Baku should not be limited to technical measures alone. Transport development and environmental policy must be integrated. These results have important implications for the development of sustainable urban transport in Azerbaijan, environmental protection, and the scientific basis for future policy decisions.

Keywords: urban transport, air pollution, emissions, environmental assessment, PM_{2.5}, air quality, socio-economic impacts

1. Introduction

The transport sector is one of the main contributors to air pollution. According to the World Health Organisation (WHO), each year air pollution causes more than 7 million premature deaths worldwide. A significant proportion of these deaths is due to fine particulate matter (PM_{2.5} and PM₁₀), as well as various harmful gases emitted by vehicles.

Over the past two decades, Baku has undergone rapid development, and both the population and the number of vehicles in the city have increased significantly. Currently, there are more than 1.3 million registered vehicles in the country, and approximately 60% of them are concentrated in Baku. Because the number of cars has increased faster than the development of road infrastructure, traffic congestion has become a persistent problem in the city. As a result, vehicles travel at lower speeds, and the constant engine restarts lead to an increase in the emission of pollutants.

The most important air pollutants related to transportation include carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO₂), volatile organic compounds (VOCs), and particulate matter (PM). These substances cause respiratory and heart diseases and increase the risk of certain types of cancer (Landrigan, 2017). Nitrogen oxides disrupt the balance of ecosystems and biodiversity by increasing the accumulation of nitrogen in soil and plants (Bobbink et al., 2010). Carbon particles are also known to contribute to climate change (Bond et al., 2013).

Baku's unique location, surrounded by the Caspian Sea from the east and mountains from the northwest, helps regulate the flow of rivers. This natural process prevents pollutants from accumulating and spreading in the lower atmosphere.

The main aim of this study was to assess the impact of traffic on air quality on selected main roads in Baku. During the study, the composition and dynamics of the vehicle fleet were investigated, the levels of key pollutants were analysed, and the results were compared with WHO Air Quality Guidelines (2021). In addition, the economic impact of air pollution was assessed, and potential measures to reduce greenhouse gas emissions were proposed.

The study monitored the intensity of traffic, used the EMEP/EEA method to calculate greenhouse gas emissions, and took the Air Quality Guidelines as the basis. The economic impact of pollution was assessed, and the results were compared with the environmental conditions of other cities in the region.

The data used were collected from the State Statistics Committee of the Republic of Azerbaijan, the Ministry of Ecology and Natural Resources, the Baku Transport Agency, the WHO AQG 2021 documents, and statistical indicators provided by the IQAir platform. In Azerbaijan, the protection of the atmosphere and the regulation of air quality are carried out in accordance with existing national legislative acts (Republic of Azerbaijan, 1999).

2. Materials and methods

This study is based on an assessment of the current state of transport and the environment in Baku, based on practical data. During the data collection phase, traffic flow calculations were carried out, and the EMEP/EEA emission factors method was used to determine emissions to the atmosphere (European Environment Agency, 2019). In this approach, vehicle type, year of manufacture, fuel used, and operating conditions were considered as the main assessment criteria. The driving cycles were selected in accordance with the standard methodologies applied in European countries (André, 2004).

The WHO AQG 2021 was used as the main reference document during the assessment phase. Air quality indicators for individual pollutants were calculated, and the obtained results were analysed by comparison with the regulatory limits.

For the economic analysis, the external cost method was used, and health impacts were estimated using the Value of a Statistical Life (VSL) (European Parliament & Council of the European Union, 2024; Maibach et al., 2008).

In the comparison stage, Baku was compared with other cities such as Tbilisi and Yerevan.

Data were collected from three main sources: stationary air quality monitoring stations, traffic count data from the Baku Transport Agency, and open data platforms such as IQAir and OpenAQ (OpenAQ, 2024). The study covers the period 2015–2023, and forecasts were made up to 2035.

3. Analysis and Discussion

During the period 2010–2023, the total number of registered vehicles in Azerbaijan increased from 671,000 to 1.31 million, almost doubling over the period. The number of vehicles per 1,000 people also rose from 76 to 128. The vehicle fleet in Baku grew at a faster rate than the national average and exceeded 760,000 units in 2023 (Table 1)

Table 1. Key indicators of the vehicle fleet in the Republic of Azerbaijan (2010–2023)

Indicator	2010	2015	2019	2023	Increase, %
Total registered vehicles(thousands)	671	866	1.093	1.310	+95,2
Share of Baku city (%)	54	56	58	58	–
Automobiles per 1000 people	76	98	112	128	+68,4
Trucks(thousands)	95	118	142	182	+91,6
Buses and minibuses (thousands)	43	55	68	85	+97,7

The age structure of the vehicle fleet is a concern. About 54% of vehicles are 10 years or older. The average age of vehicles had increased from 10.2 years in 2010 to 13.6 years in 2023. Older cars usually do not have modern emission control systems, so their emissions are around 8–12 times higher than the Euro 6 standard (European Parliament & Council of the European Union, 2007).

In terms of fuel use, about 82% of vehicles use gasoline, 14% – diesel, and only 4% use alternative fuels such as CNG, LPG, or electricity. Despite making up only 6% of the overall vehicle fleet, buses and minibuses produce 29% of NO_x emissions and 34% of PM_{2.5} emissions, chiefly due to their old diesel engines.

In Baku, private cars make up 62% of daily trips, which is much higher than the European average of 35–40%. Between 2010 and 2023, the use of private cars increased, while public transport use decreased (Cervero, 2020). This trend is one of the main reasons for the increase in transport emissions.

According to the national report of the Ministry of Ecology of Azerbaijan, the transport sector produces 71% of the country's total anthropogenic CO emissions and 44% of NO_x emissions. Baku accounts for 62–65% of all transport emissions in Azerbaijan. The analysis of data from 2015 to 2023 shows that, after a temporary decline in 2020 due to the COVID-19 pandemic, emissions increased again during 2021–2023, exceeding pre-pandemic levels (Mammadovan & Rostamnia, 2022) and reaching new record highs (Table 2).

Table 2. Annual Trends in Air Pollutant Emissions from the Transport Sector in Baku.

Pollutant	2015	2018	2020	2022	2023	Increase, %
CO (t/year)	48.200	56.700	52.400	58.600	61.300	+27,2
NO ₂ (t/year)	14.600	17.200	15.900	18.900	19.800	+35,6
SO ₂ (t/year)	3.100	3.600	3.300	3.750	3.900	+25,8
PM _{2.5} (t/year)	1.840	2.210	2.050	2.380	2.480	+34,8
PM ₁₀ (t/year)	3.120	3.750	3.480	4.020	4.160	+33,3
CO ₂ (thousand t/year)	3.840	4.520	4.180	4.780	4.970	+29,4

In Baku, traffic emissions have two peak periods during the day: 08:00–09:30 in the morning and 17:30–19:30 in the evening. During these periods, NO_x concentrations are 2.4–3.1 times higher than the daily average, showing the direct impact of traffic congestion on emissions. Field observations also show that the average speed on major roads falls to 8–12 km/h during peak hours, causing vehicles to operate under conditions that produce higher emissions. In addition, CO emissions during a cold start are 8–10 times higher than under normal driving conditions (Heywood, 2018), highlighting the effect of stop-and-go traffic in urban areas. Reducing vehicle speeds in urban areas can also contribute to improving road safety and reducing the negative environmental impacts associated with road traffic (Eastern Alliance for Safe and Sustainable Transport, 2019).

In 2023, the transport sector in Baku emitted 4.97 million tonnes of CO₂, accounting for 18% of the country's energy-related emissions. Between 2015 and 2023, transport-related CO₂ emissions increased by 29.4%, indicating a trend that is not consistent with Azerbaijan's Nationally Determined Contribution (NDC) commitments (International Energy Agency, 2023).

In 2023, the annual average PM_{2.5} concentration in busy traffic areas of Baku ranged from 19 to 45 µg/m³, which was 3.8 to 9 times higher than the DST standard (5 µg/m³). The annual average NO₂ concentration ranged from 32 to 68 µg/m³, exceeding the DST standard (10 µg/m³) by 3.2 to 6.8 times. None of the six monitoring sites met the WHO Air Quality Guidelines (Table 3).

Table 3. DST Air Quality Standards and Air Pollution Levels in Baku (2023)

Pollutant	WHO Guideline	Baku 2023 Average	Exceedance factor
PM _{2.5} (µg/m ³ , annual)	5	35	7,0×
PM ₁₀ (µg/m ³ , annual)	15	58	3,9×
NO ₂ (µg/m ³ , annual)	10	54	5,4×
SO ₂ (µg/m ³ , 24-hour)	40	48	1,2×
O ₃ (µg/m ³ , 8-hour)	60	112	1,9×

According to seasonal analysis, air pollution is most severe during the winter months (December–February). The higher frequency of temperature inversion events during this period promotes the accumulation of pollutants close to the ground. As a result, the average PM_{2.5} concentration in winter is 2.3 times higher than that recorded in summer. Elevated ozone levels during summer months also pose risks to vegetation and crops (Mills et al., 2011). Compared with other cities, Baku's annual average PM_{2.5} concentration (29 µg/m³) is similar to that of Ankara (24 µg/m³) but considerably higher than the level observed in Tbilisi (17 µg/m³). The existing network of seven permanent air quality monitoring stations is not sufficient to provide adequate coverage of the city. By comparison, Warsaw, which has a similar population density, operates 28 monitoring stations, whereas Istanbul has 44.

The results obtained using the external cost methodology indicate that the annual social cost of transport-related emissions in Baku exceeds USD 370 million (Table 4). Calculations show that the largest share of the total economic loss – 38.4% – is associated with the probability of premature death resulting from the impact of PM_{2.5} particles on human health. Expenditure on treatment and hospital care accounts for 18.2% of the total damage. Reduced work attendance and interruptions to work due to illness make up 14.6% of the economic loss. Overall, the costs associated with adverse health effects account for approximately three-quarters of the total economic loss.

Table 4. Annual External Costs of Transport Emissions in Baku (2023, USD)

Damage category	Damage (mln \$)	Share (%)
Premature Mortality Risk (PM _{2.5})	142,0	38,4
Hospital Expenditures	67,5	18,2
Workday loss	54,2	14,6
Category of loss	Damage (mln \$)	Share (%)
Medical Examination and Treatment Costs	38,4	10,4
Building and Infrastructure Corrosion	24,6	6,6
Agricultural Losses	18,7	5,1

Calculations show that the annual external economic loss per vehicle in Baku is approximately 1,520 US dollars. This figure is higher compared to Tbilisi (USD 1,240) and Yerevan (USD 1,380). The main reasons for this are the high level of traffic congestion in the city, the ageing vehicle fleet, and the high population density. Analyses also show that every US\$1 invested in transport infrastructure can generate an economic benefit of approximately US\$3.20–6.30 in the future.

The assessment shows that the BakuBus compressed natural gas (CNG) programme is the most successful currently existing initiative. It has earned an efficiency score of 4.25 out of 5. Conversely, fuel quality efforts scored 2.25, and the minibus emissions management system scored just 2.00. These low scores show the necessity of immediate reform.

Our SWOT analysis identified key structural strengths. These include Baku's metro network, large natural gas reserves, and financial backing from institutions like the Green Climate Fund and the European Bank for Reconstruction and Development (EBRD). Reliance on high-sulfur fuel and the limited capacity of the air quality monitoring system were identified as key weaknesses.

To address these issues, the study compared three policy approaches: the business-as-usual (BAU) baseline, the minimal action package, and the comprehensive strategic plan. The minimal action package combines fuel upgrades, expanded CNG programmes, and the replacement of older vehicles. The comprehensive strategic plan combines ten different measures (C40 Cities, 2022). Estimates show that the minimal action package can reduce PM_{2.5} emissions by 34% and NO_x emissions by 41% by 2030. This strategy requires a phased investment between US\$430 million and US\$630 million. Ultimately, it represents a highly efficient choice, yielding an estimated benefit-cost ratio of 3.2 to 4.4.

The full implementation of the strategic measures could reduce PM_{2.5} emissions by 67% and NO_x emissions by 74% by 2035. The highest economic efficiency among the proposed measures is attributed to the implementation of a congestion charge system in the city centre (6.3). This is followed by improving fuel quality (3.75) and expanding the CNG programme (3.25).

International experience also confirms the effectiveness of these approaches. In London, after the implementation of the Ultra Low Emission Zone (ULEZ), roadside NO₂ concentrations decreased by 44%. In Seoul, the combined implementation of bus rapid transit (BRT) and an urban road charging system reduced PM₁₀ levels by 32%. For Baku, priority measures include converting 8,000 minibuses to run on CNG. The proposal includes switching to cleaner fuel, the creation of three new BRT corridors, the implementation of a subsidy programme for the scrapping and renewal of old vehicles, as well as the introduction of a congestion charging system in the city centre. According to the developed monitoring plan, the primary objective is to reduce PM_{2.5} concentrations to 18 µg/m³ and NO₂ concentrations to 24 µg/m³ by 2030. The promotion of electric mobility and the expansion of EV charging infrastructure are also

important measures for reducing transport-related carbon emissions and supporting the transition to low-carbon urban transport (Green Climate Fund, 2022).

Table 5. A Four-Block System of Transport and Environmental Recommendations for Baku City.

Block	Specific recommendation	Target	Timeframe	Responsible Institution
Regulatory and legal measures	1. Fuel sulfur limit: 50 ppm in 2026, 10 ppm in 2028.	SO ₂ : -85%	2025-2028	Ministry of Energy SOCAR
	2. A complete ban on the import of vehicles below Euro 4.	Average fleet age -2,5 years	2026	Customs Committee
Technology upgrade	3. Conduct quarterly emission inspections for minibuses using camera-based monitoring systems.	Nonconformity 60%	2026	Ministry of Transport BNA
	4. Low-interest financing scheme for converting 8,000 minibuses to CNG over five years	NO _x : -68%, PM: 79%	2025-2028	Ministry of Finance
	5. Build three dedicated Bus Rapid Transit (BRT) routes	Shift toward public transport +18%	2025-2030	BNA, Urban planning
	6. Establish 500 EV charging points through cooperation between the public and private sectors	EV Share: +10%	2025-2027	Ministry of Energy
	7. Expand the metro system by adding four new stations	Modal shift +10%	2027-2033	Baku metropolitan area
Economic incentive	8. Financial incentives (4-6AZN per day)	Traffic: -22%	2027	BNA, Ministry of Finance.
	9. City centre access fee vehicles: 5000AZN	Fleet renewal +15%	2025-2030	Ministry of Finance
Public behavior	10. Addition of an eco-driving module to the driver's licence exam	Fuel -8%	2025	Ministry of Transport
	11. School zones around schools designated as car-free- 20 schools pilot	School NO ₂ : 40%	2025-2026	Ministry of Education BNA
	12.5% tax relief for businesses implementing remote work	Pik traffic: -14%	2025	Ministry of Finance

This table presents a set of recommendations for the transport and environment sector in Baku, identifying specific actions, implementation timelines, and expected outcomes in four main blocks: regulatory and legal measures, financial resources, technological infrastructure, and public behavior. The actions within each area clearly complement each other and create a synergistic effect. This shows that a

systemic approach is more effective than a fragmented approach. Therefore, this four-block matrix of recommendations constitutes a practical implementation plan for decision-makers.

4. Conclusion

In conclusion, the study shows that the transport sector is the main source of air pollution in Baku. The number of vehicles has almost doubled between 2010 and 2023, with 54% of them being over a decade old. In addition, 62% of all city trips are made by private car, which is a major structural factor in the increase in greenhouse gas emissions.

Air pollution on Baku's main roads frequently violates the 2021 WHO Air Quality Guidelines. Levels of PM_{2.5}, NO₂, and ozone remain dangerously high, which increases risks for public health and creates severe economic losses, estimated at US\$370 million per year.

This study demonstrates that an integrated package of regulatory, technological, and economic measures can substantially reduce transport-related air pollution in Baku while improving public health and supporting sustainable urban development.

The BakuBus programme achieved the highest efficiency score at 4.25/5. In contrast, fuel quality efforts scored the lowest at 2.25/5. A baseline package of fuel reform, CNG adoption, and vehicle replacement requires a phased investment of US\$430 to US\$630 million. However, despite the cost, this package will reduce PM_{2.5} and NO_x emissions by 34% by 2030. The estimated cost-benefit ratio is between 3.2 and 4.4. More broadly, if the entire strategic package of 10 steps were implemented by 2035, particulate matter (PM_{2.5}) emissions could be reduced by 67% and nitrogen oxide emissions (NO_x) by 74%.

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Ecological Assessment of Cotton Cultivation in the Kura-Aras Lowland

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Abstract

This study investigated the impact of the intensive use of mineral fertilizers in cotton production in the Kura-Aras Lowland of Azerbaijan on the environment. The study focused on the risks associated with the long-term use of nitrogen and phosphorus fertilizers and their impact on soil and water resources. The main aim was the assessment of the environmental impact of these fertilizers by analyzing chemical transport mechanisms, while taking into account the specific agricultural conditions of the study area. To achieve that aim, both field and laboratory experiments were conducted. Soil samples were taken at mid-elevation plots, nitrogen and phosphorus transport rates were determined, and spectrophotometry, colorimetry, and electrochemical analysis methods were used. The studied soil was characterized by low humus content (1.2-1.8%), slightly alkaline pH (7.8-8.3), and overirrigation. Together, these factors significantly alter the storage, transport, and transfer of nutrients, as well as their environmental impacts. The results indicate that the efficiency of mineral fertilizer use in the study area has been decreasing. The use of nitrogen fertilizers at a rate of 180-200 kg/ha leads to a nitrogen deficit of about 90 kg/ha. This means that about 50% of the added nitrogen is not absorbed by plants but instead remains as a mobile compound in the agroecosystem. Most of this excess nitrogen leaks into groundwater, and some of it is also released into the atmosphere. The use of phosphate fertilizers also leads to a nitrogen deficit of about 65 kg/ha in the environment. Over a decade of cultivation, this leads to the accumulation of approximately 650 kg/ha of unavailable phosphate compounds in the soil profile. The data obtained indicate a high risk of groundwater pollution, secondary soil salinization, eutrophication of water bodies, and the accumulation of heavy metals introduced with phosphorus fertilizers. Thus, the study results indicate that current approaches to fertilizer application in cotton production exceed the ecologically acceptable load level for the soil and climatic conditions of the Kura-Aras Lowland and require a transition to more precise and adapted plant nutrition management systems.

Keywords: cotton cultivation, mineral fertilizers, Kura-Aras Lowland, soil degradation, groundwater contamination

1. Introduction

The current critical state of the global food chain is maintained by a high and nearly metabolic dependence on the use of chemical fertilizers in soil. In agronomic circles, it is known that the abrupt stop of mineral and organic amendments would cause a catastrophic loss of 40-50% of crop production. However, the cost to the environment is high. Self-sustaining soil ecosystems have become open-ended industrial systems, which are releasing nutrients into the environment at a rate that is not sustainable.

The main disruption is due to the amount of chemicals applied being greater than the plants can tolerate. Nitrogen is one such element whose nitrate salts are highly mobile and often pass completely through the

root zone to pollute deep aquifers. At the same time, nitrous oxide (N_2O) is being released into the atmosphere, which is adding to the depletion of the ozone layer, a phenomenon that has been exacerbated by a focus on increased productivity. However, phosphorus has a special, problematic relationship. It is known to bind to soil particles and is later transported downstream via surface runoff, where it can stimulate the rapid growth of algae that consume oxygen. Residuals from livestock farming, which are frequently touted as being natural alternatives, create their own issues. If not properly treated, manure and poultry litter have the potential to release heavy metals and harmful pathogens into the environment.

The above factors are reflected in the use of encapsulated smart fertilizers and field-specific fertilizer application technologies. The main objective of the study is to balance the economic and biological realities of existing pesticides with the realities of future agricultural practices.

In order to address this critical environmental debt, the present article investigates the intersection of agrochemistry and ecology. The article establishes the theoretical foundations and historical context of the problem and details the methodological framework that was utilised to measure and model nutrient migration. The application of these theoretical models to a specific geographical context – namely, cotton cultivation in the Kur-Aras Lowland – enables the quantification of the precise physical and chemical parameters of nutrient loss.

2. Research object and methodology

It is imperative that assessment of agrochemical pollution commences long before any laboratory testing. The study commences with an examination of the spatial geometry of field sampling. The collection of typical topsoil to a depth of 20 cm is not enough for environmental monitoring. Nitrate N has high hydrological mobility, so our protocol requires that deep soil cores to at least 1 m be taken. The avoidance of the critical downward flux of pollutants to the water table is the reason for stopping at the arable layer.

After stabilization, drying, and delivery to the lab, the analytical emphasis is on the determination of the remaining macronutrients. The dangerous over-accumulation of phosphorus is measured by spectrophotometry and target extraction. We separate the 'mobile' phosphates from the soil matrix through the use of certain acidic or alkaline extractants chosen specifically to the natural baseline acidity of the particular plot. We do this for a certain reason. We are not just looking at what is available for plant use, but rather are selecting the plant nutrient fraction most susceptible to surface runoff and thus possible to cause eutrophication in the receiving waters.

The analytical procedure used in the case of Nitrogen is quite different. Nitrates are very soluble in water, so they are removed from the soil samples with a weak salt (saline) solution. This means that during the testing phase, the N is not further biologically transformed. Subsequent analysis – typically using ion-selective electrodes or more sophisticated colorimetric techniques – can give a very accurate measurement of the N-NO_3 concentration.

3. Results and discussion

This particular data is used as the baseline for the ecological assessment. The measurement is a direct and quantifiable indicator of the potential for contamination of the aquifer. The utilisation of deep-profile chemical baselines obviates the necessity for subjective estimations when ascertaining the efficiency of fertilisers. These numbers from the extraction data allow us to calculate the actual environmental loss incurred by the farming activity and to see what was left behind after the harvest.

Table 1. Site-specific extraction reagents and analytical instrumentation

Soil Typology / Baseline Acidity	Primary Extractant Reagent	Target Pollutant / Mobile Fraction	Final Analytical Instrumentation
Acidic (e.g., Sod-podzolic)	0.2M Hydrochloric Acid (HCl)	Phosphates (P_2O_5)	Spectrophotometry
Neutral to Slightly Acidic (e.g., Chernozems)	0.5M Acetic Acid (CH_3COOH)	Phosphorus Exchangeable Potassium	Flame Photometry
Alkaline (e.g., Carbonate soils)	1%Ammonium Carbonate	Trace Phosphates / Nitrates	Ion-selective Electrodes
Deep Profile (All types)	Dilute Saline Solution (1% KCl)	Nitrate Nitrogen ($N-NO_3$)	Advanced Colorimetry

The selection of the extractant is not an arbitrary choice but is determined with reference to the inherent nature of the soil in terms of its pH and genetic characteristics. The ecological risk assessment of a universal solvent will be totally misinformed if it is conducted on completely different landscapes in a different laboratory. There is a need to ensure that the numbers are representative of real field conditions, and that specific chemical protocols are matched to the specific field conditions. Table 1 decomposes these methodological combinations, which show how we will optimize the extraction process to obtain the most reliable information on remaining contaminants.

As per the strict methodological directions set by the classical agrochemical schools of L.A. Mikhailova and A.Kh. Sheudzhen, the generic categories are highly specific, standardized analytical procedures. For example, the extraction of mobile phosphorus from acidic podzolic soils is performed using the Kirsanov method (based on chemical dissolution of Al and Fe phosphates with 0.2 M HCl), which is chemically formulated to aggressively extract potentially mobile Al and Fe phosphates. The alkaline and often very carbonate-rich soils, such as the sierozems in the Kur-Aras Lowland, are in stark contrast: Here, the Machigin method is strictly prescribed. Using 1% ammonium carbonate solution in this protocol will keep the soil analytical extractant from being neutralized by native soil calcium carbonate. This particular chemical buffer has enabled the very accurate quantification of the calcium-bound phosphate fraction, which represents the main reservoir of long-term eutrophication in this extreme environment. In addition, it is imperative to adhere to physical preparation standards from field collection to laboratory bench to prevent catastrophic data loss. When analyzing raw soil cores, it is necessary to first transform them into a standardized "fine earth", as V.V. Lapa's systemic monitoring framework states. This protocol prescribes air-drying of samples in special chambers away from direct UV radiation and high temperature to avoid thermal degradation of organic matter and artificial volatilization of ammoniacal compounds. After stabilization, the soil is mechanically homogenized and filtered through a standard 2.0 mm analytical sieve to get a soil sample that can be used for analysis (Кротких & Михайлова, 2013, pp. 115-118; Шеуджен et al., 2006, p. 342).

The preparation protocol is even more time-sensitive and stringent, however, for nitrate-nitrogen ($N - NO_3$) analysis. The soil microbiota, which is naturally alive, can also continue to affect the nitrate levels by ongoing nitrification or denitrification in transit, even after removal from the soil. For deep-profile samples to be analyzed for nitrogen, they must either be processed in a mobile field laboratory or be "frozen" biochemically. This is accomplished by keeping the cores at a constant 4°C to artificially inhibit enzymatic bacterial activity until the 1% KCl extraction can be made. Returning to the spatial geometry of field sampling discussed above, many soils in agriculture are highly micro-heterogeneous, making isolated, single cores too few for statistical considerations (Lapa et al.2009, pp. 22-25).

To remove the random space anomalies (for instance, the core hitting another undissolved fertilizer granule), the protocol requires a "composite sample" to be formulated. One composite sample is created in the polygon from 15-20 individual diagnostic samples collected by the classical "envelope" (grid) trajectory following V.G. Mineev's standards "Ecological Agrochemistry". Finally, high-precision optical and electrochemical instrumentation is used in the analytical phase of the terminal to assure part-per-million

(ppm) accuracy. Nitrate nitrogen is usually measured by sophisticated photocolorimetry. This includes adding certain chromogenic reagents (e.g., the Griess-Ilosvay reagent after the cadmium-reduction of nitrates to nitrites) that result in a specific, colorimetric change that can be detected using a spectrophotometer at particular nanometer wavelengths. These are strict site-specific extraction geometries and highly sophisticated optical verifications that remove statistical noise from the resulting chemical baselines. It is asserted that they provide a mathematically incontrovertible basis for the calculation of the exact ecological debt and the mass balance of pollutants not assimilated (Минеев, 2008, p. 180).

The object of the study is the Kura-Aras Lowland in the Republic of Azerbaijan. Cotton (*Gossypium hirsutum*) is an economically significant crop in the region. However, it imposes considerable ecological stresses on the regional biosphere due to its specific agronomic requirements.

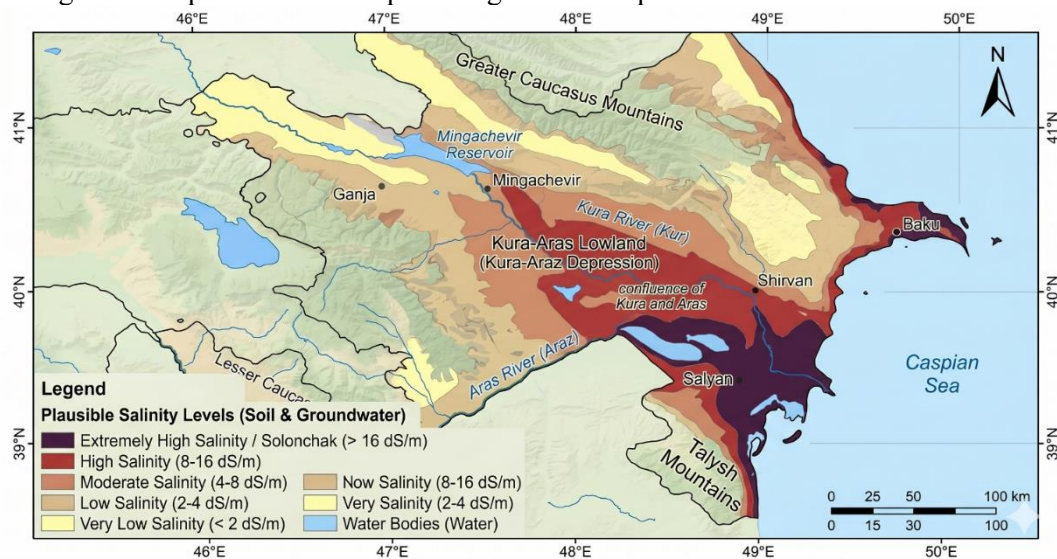


Figure 1. Soil and Groundwater Salinity Levels

This map (Figure.1) illustrates the spatial distribution of soil and groundwater salinity levels across the Kura–Aras Lowland of Azerbaijan. The highest salinity levels have been recorded in the southeastern and coastal areas near the Caspian Sea, particularly around Salyan and the Kura-Aras river confluence (see Figure 1). These areas have been identified as those most vulnerable to soil degradation and salinization.

The genesis of the soils in this region is the most significant factor determining the environmental vulnerability of this region. The soil types are mainly irrigated sierozems and meadow-sierozems with a semi-arid climate profile. The extraction procedures were utilised in order to establish our baseline. The chemical composition of these soils is indicative of the risk factors involved. The humus content of the upper horizon of arable soil is found to be generally low, with values ranging from 1.2% to 1.8%. This finding suggests that the biological buffering capacity of the soil is minimal, and the absence of an organic sponge-like material naturally absorbing and retaining excess synthetic nutrients is evident. Due to high calcium carbonate content, the soil pH was found to be highly alkaline (7.8-8.3). This is due to a high calcium carbonate content.

The soils of the Kura-Aras Lowland necessitate the use of large amounts of nitrogenous mineral fertilizers and superphosphates (Бабаев, 1984, pp. 45-48; Mammadov, p. 112). The arid climate of the region requires regular irrigation. Excessive irrigation water leads to an additional increase in nitrates that percolate from soil layers to groundwater through advection. Because of this, irrigation is a major source of groundwater pollution by agricultural chemicals.

The specific physicochemical properties of the soils in the Kura-Aras Lowland largely determine the patterns of nutrient migration and transformation. The sierozems of the region are characterized by a slightly alkaline to alkaline soil reaction (pH 7.8-8.3) and a high content of calcium carbonate (CaCO_3). Under these

conditions, the effectiveness of traditional phosphate fertilizers is significantly reduced due to the chemical fixation of phosphorus. As shown by the studies of L. A. Mikhailova, after the application of water-soluble superphosphates, the dissolved orthophosphate ions quickly combine with calcium in the soil solution. The resulting compounds are poorly soluble. The initially formed dicalcium phosphate is converted into more stable mineral phases, such as octacalcium phosphate and hydroxyapatite, which are not absorbed by plants. As a result of severe phosphorus fixation, the rate of use of phosphate fertilizers is significantly reduced. In order to maintain the required level of productivity, farmers are forced to increase their consumption, thereby compensating for the lack of phosphorus available to plants. As a result, arable land gradually turns into a reservoir for the accumulation of relatively inactive phosphate compounds. This practice not only reduces the profitability of fertilization but also leads to the accumulation of impurities associated with phosphate raw materials in the soil. The gradual increase in the concentration of heavy metals, in particular cadmium and strontium, which are characteristic impurities of industrial phosphate fertilizers, poses a certain environmental threat. Their accumulation in the soil increases the risk of pollution of agricultural ecosystems, reduces the quality of agricultural products, and has a negative impact on the environment.

At the same time, the low organic matter content of the soil (humus content is only 1.2-1.8%) significantly impairs the agrochemical properties of the soil, in particular, the cation exchange capacity (CEC). According to V. G. Mineev's research on the agrochemical transformation of the soil, the soil adsorption complex is poorly developed in soils poor in humus, which limits their ability to retain and temporarily absorb mobile forms of agrochemical compounds. Under these conditions, the application of high doses of nitrogen fertilizers (including urea and ammonium nitrate) leads to rapid transformation. High summer temperatures in the Kura-Aras Lowland stimulate microbial activity, accelerate the enzymatic nitrification of nitrogen-containing compounds, and increase the formation of mobile nitrate forms that easily migrate in the soil profile. Nitrate ions (NO_3^-) formed during nitrification have high solubility and remain mobile in the soil solution due to the lack of sufficient organic matter for adsorption. Soils with low humus content have a very low nitrogen retention capacity, which significantly increases the risk of nitrogen migration beyond the root zone. As previously mentioned, cotton cultivation in the region depends on intensive irrigation, which causes water to flow downwards in the soil profile. This water flow becomes the main transport mechanism for the vertical migration of dissolved substances. In the end, nitrate ions that are not retained by soil adsorption complexes are filtered below the root zone (at a depth of about 1.5 meters) and enter the upper groundwater layer, polluting it (Aliyev, 2009, pp. 15-18; Savci, 2012).

The arid climate further contributes to the soil deterioration in the Kura-Aras region. According to the agroecological studies of A.Kh. Sheudzhen, the combination of the overuse of mineral fertilizers and intensive irrigation creates a complex hydrological regime that contributes to the development of various salt migration processes. Irrigation water initially facilitates the movement of nitrates and other highly soluble compounds through the soil profile. However, during the subsequent dry period, when evaporation predominates, soil moisture rises to the surface by capillary action. This upward flow carries dissolved salts to the upper soil layers. Then, as water evaporates, salts concentrate and crystallize, leading to secondary soil salinization. This process causes changes in soil biogeochemical functions, which ultimately accelerate overall soil degradation.

Thus, the physicochemical characteristics of the soil of the Kura-Aras Lowland show that the use of traditional mineral fertilization systems, developed without considering regional soil-climatic conditions, does not guarantee the efficient use of fertilizers and creates significant environmental risks. The limestone soils of the region are unable to retain existing phosphorus forms for a long time due to strong chemical binding, and the low content of organic matter seriously limits the ability of the soil to retain mobile nitrogen compounds. As a result, the soil cover acts not as a natural reservoir of nutrients, but as a means of facilitating their transformation and active transport, which increases the risk of soil and groundwater pollution. Determining the quantitative characteristics of these physicochemical processes is of great importance for the development of predictive models of the ecological state of agricultural landscapes. In particular, the assessment of parameters describing the delay coefficient of phosphorus compounds and the

minimum retention of nitrates in the soil profile allows us to determine the magnitude of environmental deficit (ΔE), calculate the rate of pollutant migration, and predict the potential toxicological load in the regional watershed.

To evaluate the observed patterns, the material balance of fertilizers used in the agroecosystems of the Kura-Aras Lowland was calculated. The results allow the comparison of theoretical estimates with real nutrient flows to quantify the efficiency of fertilizers and identify possible impacts on soil and water resources. Aggressive fertilization is playing a big role in the agricultural approach to these areas in order to generate cotton production at higher and higher levels. But when one looks at the biological efficacy of these inputs, one has to admit that there is a huge disconnect between the input and the processing that the plant system can do. The average application rate of mineral nitrogen (N), based on agronomic practices in commercial cotton production under standard regional conditions in relation to irrigated sierozems, is about 180-200 kg/ha per season. We have to compare this huge input with the actual nutrient removal in the harvest by using the mass balance equation derived in Section 2.2. The biological nitrogen requirement is still limited for a representative and optimistic yield of 3.0 tons of seed cotton/ha. Agronomic data show that about 30 to 35 kg of nitrogen is used to produce one ton of raw cotton. Our formula:

$$\Delta E_N = 180 \text{ kg/ha} - (3.0 \text{ t/ha} \times 30 \text{ kg/t}) = 90 \text{ kg/ha}$$

makes for an astounding 50% inefficiency. [8, pp. 34-37; 1, p. 24]

In practical terms, this is equivalent to 90 kg of active nitrogen, which cannot be explained per hectare of cotton grown. However, this surplus is not the same as it was in the past. It is the first "ecological deficit." We need to understand where this 90 kg of 'residual' nitrogen ends up as a threat to the environment. About 25-30% of this loss is volatilized as ammonia and denitrified to the atmosphere each year due to the high mobility of the nitrate form and the very warm summer temperatures in Azerbaijan. This is a direct effect on greenhouse gas emissions. The other 60-70% goes into the downward hydrological flux due to heavy irrigation in cotton. It percolates through the permeable soil column into the shallow, saline groundwater of the lowland. The case of phosphorus (P) is much more complicated and still more harmful to the environment. Cotton has a relatively low P demand to N demand (P: N). Only around 12 to 15 kg of P_2O_5 per hectare is removed from the crop for the same yield of 3.0 tons. This has not prevented the application of between 100 and 120 kg/ha of superphosphates as compensation for the "fixation" effect in the soil in accordance with the standard practice in the region. The efficiency is even worse for phosphorus, at 65 kg/ha relative to a potential of:

$$10 \text{ kg/ha: } \Delta EP = 110 \text{ kg/ha} - (3.0 \text{ t/ha} \times 15 \text{ kg/t}) = 65 \text{ kg/ha}$$

Phosphorus is not easily leached to groundwater as compared to nitrogen. In the highly alkaline (pH 8.0+) soils of the Kur-Aras Lowland area, however, the excess phosphorus will rapidly retrograde. The 65 kg/ha Deficiency interacts with native calcium, creating very insoluble calcium phosphate compounds. This may appear to be less harmful than groundwater pollution, but may result in a large "Cumulative Ecological Debt". In the course of a conventional 10-year crop rotation period, one hectare of land retains almost 650 kilograms of non-retrievable chemical residues. This man-made storage alters the natural physical soil condition, reduces native soil microorganism activity, and creates a very polluted, eutrophication-causing runoff event when heavy seasonal rains occur. Finally, these quantitative deficiencies are used as the source terms, S , in the Convective-Dispersion Equation that we have defined above. They show that the way they are currently being fertilized exceeds the environmental capacity to sustain them in the region, creating permanent environmental problems from agricultural inputs (Кротких & Михайлова, 2013, pp. 90-95; Pimentel, 1996).

To fully grasp the severity of these permanent environmental problems, the quantitative data of the ecological deficit must be analyzed through the advanced toxicological framework established by V. G. Mineev and A.Kh. Sheudzhen. The loss of 25–30% of nitrogen through gaseous emissions—representing nitrogen that was not utilized productively—should be viewed not only as a reduction in fertilizer

application efficiency but also as a significant environmental factor. When approximately 90 kg/ha of unassimilated nitrogen is present in the soil, the alternation of irrigation and intense evaporation creates favorable conditions for microbiological denitrification. Through the metabolic activity of facultative anaerobic microorganisms, nitrate ions (NO_3^-) are sequentially reduced to nitrites, nitric oxide (NO), and nitrous oxide (N_2O). According to current concepts in environmental agrochemistry, nitrous oxide is one of the most significant greenhouse gases, with a global warming potential approximately 300 times that of carbon dioxide.

A large part of the nitrogen is transported downwards into the groundwater at a rate of about 54-63 kg/ha each year. Calculations based on the convective dispersion equation (CDE) model show that the long-term maintenance of current fertilization and irrigation practices can lead to an accumulation of nitrates in the aquifer. Mathematical modeling shows that the concentration of nitrates in drinking water is likely to exceed the World Health Organization limit of 50 mg/L and put the quality of groundwater and the health and safety of rural areas at severe risk.

Another equally important environmental aspect is the accumulation of significant amounts of residual phosphorus in the soil. In a ten-year crop rotation, this amount can reach about 650 kg/ha. According to the fundamental research of L. A. Mikhailova, commercial phosphate fertilizers, including superphosphates, contain not only the main active substance but also trace element impurities and xenobiotics obtained from natural phosphate raw materials (apatites and phosphate rocks). The precipitation of poorly soluble calcium phosphates in the alkaline environment of calcareous sierozems is accompanied by the simultaneous immobilization of several heavy metals such as cadmium (Cd), lead (Pb), and strontium (Sr). Among them, cadmium poses the most environmental risk, since the similarity of its ionic radius to that of calcium facilitates the isomorphic substitution of the latter both in the mineral structure of the soil and in the physiological mechanisms of nutrient absorption and transport in plants. Cadmium can bioaccumulate, increasing the risk of contamination of agricultural produce and negatively affecting ecosystems and population health.

According to V. G. Mineev, these changes result in the depletion of the soil at a biogeochemical level. If these conditions keep persisting, the agricultural system gradually loses its ability to self-regulate, and soil fertility becomes increasingly dependent on the continuous use of mineral fertilizers.

Therefore, a quantitative assessment of the ecological deficit of particulate matter (ΔE_n) and phosphorus (ΔE_p) allows for determining the degree of nutrient loss and evaluating the environmental impact of current fertilization practices in the Kura-Aras Lowland. The results show that a significant part of the applied fertilizer is not used by plants. On the contrary, it participates in migration and transformation processes and has a negative impact on terrestrial and aquatic ecosystems. The determination of the amount of pollution, including about 90 kg/ha of unproductive waste and 65 kg/ha of phosphorus converted into less absorbable forms, provides the basis for a comprehensive ecological and economic assessment of the efficiency of fertilizer use. The results can be used to calculate economic losses, develop environmental regulation mechanisms, improve state regulation of the use of natural resources, and justify environmental protection measures. The modeling results show the urgent need to transition to science-based and sustainable agricultural management (Минеев, 2008, pp. 312–315).

4. Conclusion

In conclusion, it becomes apparent that currently applied agricultural practices in the Kura-Aras cotton production are not sustainable and do not consider the natural properties of the soil. Low humus content, soil alkalinity, and overirrigation increase nutrient mobility and reduce the efficiency of fertilizers, causing significant harm to the economy and environment.

The results show nutrient deficits of approximately 90 kg/ha for nitrogen and 65 kg/ha for phosphorus. Unabsorbed nitrogen leads to groundwater pollution and greenhouse gas emissions, including nitrous oxide. Long-term accumulation of phosphorus residues leads to an increased risk of eutrophication and the

disruption of natural biogeochemical cycles. The accumulation of heavy metals associated with phosphate fertilizers creates additional ecological problems.

The study confirms the urgency to improve the situation by transitioning to science-based methods of plant nutrition management that consider the soil properties and climatic characteristics of the Kura-Aras region. The implementation of monitoring, modern fertilizer technologies, and consideration of the spatial heterogeneity of soils and their agrochemical characteristics will increase the efficiency of nutrient use, reduce fertilizer losses, and reduce the anthropogenic load on soil and water ecosystems. This will contribute to the long-term preservation of soil fertility in the Kura-Aras Lowland, increase the sustainability of agroecosystems, and ensure the continuation of cotton production.

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Characteristics of Afforestation in Azerbaijan: Oak Afforestation

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Abstract

This study examines the characteristics and prospects of artificial afforestation in Azerbaijan, with particular emphasis on the establishment and regeneration of oak plantations, especially chestnut-leaved oak (*Quercus castaneifolia*). The study provides an overview of the geographical distribution, forest resources, dominant tree species, and ecological significance of Azerbaijan's forests, while highlighting the importance of artificial afforestation and reforestation for sustainable forest management and biodiversity conservation. Particular attention is given to the distribution, ecological characteristics, and silvicultural potential of chestnut-leaved oak (*Quercus castaneifolia*) within the forest ecosystems of Azerbaijan. The study discusses the main methods of establishing oak plantations, including continuous and partial afforestation, seed sowing, planting, and combined approaches. Detailed recommendations are presented concerning acorn collection and storage, soil preparation, sowing techniques, planting density, species mixing patterns, protection of young plantations, and agronomic management. The findings suggest that appropriate sowing techniques, particularly the row-and-hole and square-cluster methods, combined with effective soil preparation and plantation protection, significantly improve the successful establishment and long-term sustainability of oak plantations. The study also highlights the potential for expanding chestnut-leaved oak plantations in suitable forest areas, including the Ismayilli Forest Fund, as an important measure for forest restoration, biodiversity conservation, and sustainable forest management in Azerbaijan.

Keywords: Afforestation; Oak plantations; Chestnut-leaved oak; *Quercus castaneifolia*; Forest restoration

1. Introduction

1.1. The geographical location and forest resources of Azerbaijan

The Republic of Azerbaijan is situated in the south-eastern part of the South Caucasus. Mountains cover almost half of the country's territory: the Greater Caucasus mountain range in the north-east, the Lesser Caucasus mountain range in the south-west, and the Talysh Mountains in the south. The Republic of Azerbaijan covers an area of 86.6 thousand km², of which: 11.8% is covered by forests, 1.6% by water reservoirs, and 50.0% by arable land. Azerbaijan is characterized by diverse natural landscapes, and its forests play a crucial role in maintaining ecological stability, biodiversity conservation, and the provision of ecosystem services. (Figure 1) (12). Its territory is home to vast plains lying below sea level and mountain peaks over 4,000 metres high, as well as hot deserts, cool alpine meadows and subtropical forests. Low-lying areas account for more than half of the territory.



Figure 1. Geographical location and major forest regions of Azerbaijan

Over the past 200 years, the world's forest cover has been reduced by more than half. In the 18th and 19th centuries, 35% of Azerbaijan's territory was covered by forests. The total area of forest in Azerbaijan currently stands at 1,021 thousand hectares. This also accounts for 11.8% of Azerbaijan's territory. In the Russian Federation, this figure stands at 44%, in Latvia at 41%, and in Georgia at 39%. The main role of forests in nature is to absorb 10-20 tonnes of carbon dioxide per hectare per year and, in return, to release oxygen. One hectare of forest absorbs 8 kg of carbon dioxide per hour, which is equivalent to the amount of carbon dioxide exhaled by 200 people in an hour.

Distribution of forests by natural zones and main tree species. 48% of our country's forest resources are located in the Greater Caucasus, 34% in the Lesser Caucasus, 16% in the Talysh region and 2% in the Aran region (including the Nakhchivan Autonomous Republic). In Azerbaijan, there are 0.11 hectares of forest per person (Aliiev, 1984). Azerbaijan's vast forest areas stretch across the southern and south-eastern slopes of the Greater Caucasus mountain range. The forests cover an area in the south-west of the north-eastern part of Azerbaijan, mainly within the administrative districts of Qusar, Quba, Devechi, Siyazan and Khizi. From the Khizi district, the area of the forest gradually decreases towards the south-west and gives way entirely to treeless terrain. In the southern part of the Greater Caucasus mountain range, within the Shamakhi District, work is underway to restore a forest area that stretches right up to the border with the Republic of Georgia and forms a continuous canopy on the mountain slopes. The forests here mainly cover the mountainous areas of the administrative districts of Ismayilli, Gabala, Oguz, Sheki, Gakh, Zakatala and Balaken (Grossheim, 1939–1967; Khalilov, 2008).

A third of the forests are situated on the slopes of the Lesser Caucasus. Here, forests cover the northern, north-eastern and eastern slopes of the main mountain ranges in the form of separate massifs. It is only in the South Karabakh region that the forest belt breaks off and does not extend as far as the Iranian border. Furthermore, in the Shahbuz District of the Nakhchivan Autonomous Republic, on the slopes of Mount Kukudag, forests occur in the form of isolated patches. One of the extensive forest areas also covers the slopes of the Talysh Mountains. The forests here are situated within the administrative districts of Astara, Lankaran, Lerik, Masalli, Yardymly, Jalilabad and, in part, Bilesuvar. The Astar District accounts for the largest proportion of forest cover in the republic – 58% (Сафаров, 1979; Ibrahimov, 2012). A small proportion of the forests forms narrow, ribbon-like strips along the banks of the Kura and Aras rivers, forming riparian forests (Huseynov, 2022). Azerbaijan has gained worldwide renown for its enchanting beauty, rich natural resources, and diverse flora and fauna. There are 4,500 species of higher plants here, belonging to 125 families and 930 genera (Прилипко, 1970). Of these, 435 species of trees and shrubs, belonging to 48 genera and 135 families, grow in the Republic's forests. This accounts for 10% of the plant species that make up the Republic's flora. Azerbaijan's tree flora comprises 70 regionally endemic species. This also accounts for 16% of the total number of tree and shrub species. Despite the rich diversity of

Azerbaijan's tree species, there are few major forest-forming species here. Azerbaijan's forests consist mainly of broad-leaved species.

The forest area is divided between the dominant tree species roughly as follows. Pine – 0.3, juniper – 1.3, beech – 31.9, oak – 30.5, hornbeam – 22.4, ash – 0.9, maple – 0.3, shrubs – 2.2, birch – 0.14, poplar – 0.81, alder – 0.82, linden – 0.10, other species – 8.06%. Although forests vary in structure, broadleaf forests mainly consist of tree species such as beech, oak and hornbeam. These three species account for 85% of the forest area.

The importance of artificial afforestation and reforestation. Forests are key to the planet's stability and the sustainable development of society, and are of ecological, economic and social importance. The main purpose of establishing forestry enterprises is to meet the demand for forest products from the public and the national economy. The main product of the forest is timber, and the forest remains its sole source. Timber is used either directly or as a raw material for the manufacture of 20,000 different types of products. The growing demand for firewood is leading to the rapid destruction of forests. According to FAO figures, 5.2 million hectares of forest were lost worldwide each year during the first five years of the 21st century.

Since 1990, the area of primary, undisturbed forests worldwide has fallen by more than 80 million hectares. More than 100 million hectares of forest are at risk of damage from forest fires, pest infestations, diseases, droughts and extreme weather events. Research also clearly demonstrates the impact of human activity on the Earth's forest cover. According to scientists' estimates, around 15 billion trees are felled each year, and around 5 billion are planted to compensate for this.

Net forest loss (taking into account reforestation) has fallen significantly since the 1990s; however, the world is still far from achieving the target set out in the UN Strategic Plan on Forests, which is to increase forest cover by three per cent by 2030. Whilst deforestation is taking place in some areas, in others forests are being restored through natural regrowth or targeted measures. Consequently, the net loss of forest area is lower than the rate of deforestation, and is also declining – from 8.3 million hectares per year in the 1990s to 5 million hectares per year in 2010–2020. In absolute terms, the world's forest area has decreased by 178 million hectares (Figure 2).

Sustainable forest management requires, first and foremost, an accurate assessment of forest resources. The FAO has taken on this task and has been carrying out this assessment every five years since 1990 (1990, 1995, 2005, 2010, 2015 and 2020). The Global Forest Resources Assessment (GFRA) has been carried out by the FAO every five years since 1990 (1990, 1995, 2005, 2010, 2015 and 2020). The results of the GFRA study are used to promote sustainable development and sound forest management. According to GFRA data, forests cover 30% of the Earth's land area, and their total area is almost 4 billion hectares, which equates to 0.51 hectares of forest cover per person. More than half of the world's forests are concentrated in five countries rich in forest resources (the Russian Federation, Brazil, Canada, the United States and the People's Republic of China). In 10 countries, there is no forest cover at all, whilst in 54 countries, the proportion of land covered by forest is less than 10%. Although there is a downward trend in the rate of deforestation, it remains at a level that gives cause for serious concern.



Figure 2. Logged areas of woodland

2. Results and Discussion

1. Key aspects of establishing afforestation sites. The main aim of establishing afforestation schemes is to meet the ever-increasing demand from the national economy and the population for various types of forest products, to enhance the positive impact of forests on agriculture, to improve public health, to improve the water regime of our rivers, and so on.

It is therefore important, when establishing man-made (artificial) forests, that all planting methods and operations are consistent with the objectives of the planting programme. This approach, which takes into account the potential impact of the forest stand, ensures compliance with the requirements for the cultivation of a specific stand, as well as for a specific dominant species and its quality.

Artificial forests, in the strictest sense of the word, are of an agricultural nature; they are also referred to as man-made forests. At the same time, afforestation is not merely a source of raw materials, but also constitutes an integral and highly significant part of the biosphere, as well as an element of the geographical landscape that forms part of a unified forest system. Broadly speaking, plantation forests are open biological systems managed by humans for a specific economic purpose. The term 'afforestation' is usually used to refer to artificially created forest areas. When establishing afforestation schemes, wild species or genera of wild-growing trees are generally used.

In international practice, the generally accepted classification system for afforestation can be presented as follows:

- *Systems – closed, open;*
- *Types – contiguous, partially;*
- *Breeds – purebred (single breed), mixed;*
- *Shapes – simple, complex*

A system of closed forest crops. In the near future, the closed-canopy system involves the establishment and cultivation of forest plantations on areas scheduled for planned clear-cutting; for this reason, such plantations are referred to as 'under-canopy' or 'primary' plantations. Primary afforestation reduces the time needed for forest regeneration.

The open-field system. The open-field system is regarded as the primary system in the field of artificial afforestation. Open woodland is defined as land that is planted with trees but not covered by forest. Open woodland is characterised by the fact that it is divided into areas devoid of tree cover, in the form of forest stands or copses. Such afforestation projects are also known as follow-up plantings. Forest stands are classified into two types: monocultures and mixed stands, depending on the presence of young trees of commercially valuable species and the even distribution of cultivated plants within the forest stand.

Contiguous forest plantations. Due to the relatively even distribution of areas for sowing or planting within these plantations, the dominant (cultivated) species is ensured to prevail in the future plantation. When establishing new forests, only monocultures are created, as there is no second source for the forest's further development.

Contiguous reforestation is carried out in areas where natural regeneration is observed or expected in the plantations. Therefore, the establishment of partial afforestation is regarded as a combined method of afforestation, combining natural and artificial forest regeneration. As a rule, partial reforestation is carried out on areas that have been clear-cut, where natural regeneration of the main tree species is taking place. They are widely used in forestry and park management.

In forests managed as continuous cover plantations, the forest stand is established without any natural regeneration taking place. The cultivation techniques, sowing patterns and variety mixtures, as well as the composition of this stand, are more diverse, and its potential is greater. Continuous-cover afforestation stands are characterised by a greater richness and diversity in terms of species composition, density, soil preparation methods, as well as planting patterns and species mixtures, compared with other types of stands.

Continuous and patchy forest stands may consist of monocultures, that is, single-species stands, or mixed stands comprising two or more species. As a generally accepted practice, monocultures are simple, whereas mixed stands represent a complex (two-component or multi-component) form of artificial cultivation.

Forest plantations can be established in three ways: by planting saplings, by sowing seeds, and by a combined method.

The planting method is almost universally regarded as a more reliable and cost-effective way of producing forest plants. At present, the majority of new forest plantations in the country's forestry sector (over 80% of them) are established through planting. The sowing method is considered to be more ancient and, in essence, closer to the natural process. The advantage of this method is that it does not require seedlings; the young plants have a naturally developed root system, and the planting technique is simpler. The combined method involves both planting and sowing on the same forest plot. It is used when creating mixed plantings with oak.

2. Characteristics of oak afforestation in Azerbaijan. Nine species of oak grow in Azerbaijan, the most common of which are the Iberian oak, the Chestnut-leaved oak, the Eastern oak, the Araxian oak and the Pedunculate oak.

Oak forests, found mainly in foothill and mountainous areas (up to 2,000 m), account for a significant proportion of the country's forest cover – up to 30%. It forms dense thickets on the southern slopes of the Talysh Mountains and the Greater Caucasus. These forests are also of significant ecological and economic importance (Figure 3).



Figure 3. Chestnut-leaved oak (*Quercus castaneifolia*)

One of the main species of oak is the chestnut-leaved oak (*Quercus castaneifolia*) – a relict tree species in Azerbaijan, belonging to the ancient Arctic Tertiary (Turkayan) Hircanian flora (Асадов & Асадов, 2001). It is mainly found in the Lenkoran biogeographical province (in the Talysh Mountains). It is listed in the ‘Red Book of Azerbaijan’. The chestnut-leaved oak is a species of tree that thrives in warm, sunny conditions. This majestic tree can reach a height of 40-45 metres, and its trunk can measure 1,5-2 metres in diameter. Leaves: generally 10-15 cm long, lanceolate, lanceolate-elliptic or oblong-lanceolate, with a coarsely toothed margin. It flowers in April-May, and the seeds ripen in September-October. The weight of 1,000 seeds is 7 kg (Figure 4). It is a very long-lived plant; it can live for 400–500 years, and sometimes even longer. Due to its hardness and value, this timber is used in shipbuilding, woodworking, and the furniture industry, as well as in the manufacture of barrels. Range:



Figure 4. Acorns of chestnut-leaved oak

Ancient and giant specimens of this species can be found in Hirkan National Park. It grows in Iran (Gilan, Mazandaran), in the Caucasus, including the Talysh Mountains in Azerbaijan (from the plains up to 2,000 metres above sea level) (Асадов & Асадов, 2001). It grows faster than other species of oak and produces a bountiful crop of acorns every year. Natural regeneration from seed occurs successfully in moist forest ecosystems. It adapts quickly to local conditions and is therefore easy to plant and grow in a variety of climatic and soil conditions.

3. Key considerations for establishing plantations of chestnut-leaved oak. The ongoing decline in the range of the chestnut-leaved oak, combined with the ever-increasing demand for this species, has made it necessary to establish artificial plantations of this tree. The creation of artificial afforestation schemes, which are an important element of Azerbaijan’s tree flora and a significant factor in ensuring the sustainable development of biodiversity, remains a matter of the utmost importance (FAO, 2020).

The artificial restoration of oak forests and the establishment of new plantations are therefore regarded as the most important forestry measures for protecting and improving the condition of the forest ecosystem (Stanturf et al., 2014). Although the establishment of oak plantations in our country became more widespread from the second half of the last century onwards, for a long time these plantations failed to yield the desired results. In the case of partial plantings, this was due to the difficulty of ensuring timely thinning, whereas in the case of full-row plantings, it was due to the lack of soil preparation, the difficulty of protecting the trees from adverse natural phenomena, and the unsuccessful acclimatisation of the oak (Figure 5).



Figure 5. Artificial establishment of oak plantations

Oak forests are currently being restored in Azerbaijan as part of government programmes (Forest Code of the Republic of Azerbaijan, 2020). 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 tree species, especially in the liberated territories and in the forests of Tugay (the Kura-Araz Plain), using methods designed to ensure the success of oak plantations.

Continuous oak plantations. These crops are grown using rain-fed farming methods on unirrigated soils in foothill, low-mountain and mid-mountain regions. These crops are grown on old logging sites, in clearings and fields, on land no longer used for agricultural crops, and on mountain slopes, using two methods based on a 2×2-metre grid: either by ploughing furrows with tractors, or by preparing 1×1-metre plots by hand. In continuous plantations, the stand develops without any natural regeneration taking place. The cultivation techniques, sowing patterns and species mixtures, as well as the composition of this stand, are more diverse, and its potential is greater. Compared with partial afforestation, continuous afforestation is characterised by greater diversity in terms of species composition, planting density, soil preparation methods, as well as planting patterns and species mixtures.

In the partial afforestation process, the land is prepared, and a monoculture is planted; in some cases, however, mixed woodland areas form as a result of natural forest regeneration. The advantage is that the plantation is established within a forest environment, which prevents the formation of natural grass cover and helps to reduce the need for planting material, labour and resources.

4. The method of sowing in oak plantations and its stages. In oak plantations, the sowing method should generally be used. This is because, in their first year, oak acorns develop strong vertical roots that penetrate the soil to a depth of up to one metre. 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 those of fresh seedlings grown from seed.

a) Supply of seeds. The acorns of the chestnut-leaved oak ripen in mountain forests in late October – early November. Seeds must be fully ripe before they can be used in afforestation schemes and nurseries. This process may drag on until 15 November. The seed pods are harvested by hand once the seeds have ripened and been sown in 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, and any that are diseased or damaged should be removed.

In the mountainous and foothill regions of the Greater Caucasus and Talysh, it is more advisable to leave oak acorns in the forest until spring arrives. The area of woodland set aside for seed storage must first be cleared of shrubs. Nevertheless, whilst cleaning, you must not touch the dead layer or the leaves that have fallen to the ground. The seeds are sown to a depth of 5-6 cm and then covered with a layer of leaves 15-20 cm thick. If frosts are expected or likely, the depth of the layer of leaves covering the surface should be increased to 30 cm.

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.

b) 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 availability of machinery.

When carrying out broadcast sowing on steep slopes in hilly terrain, on old felling sites, in clearings and forest aisles, on land cleared of crops, and on exposed hillsides:

- Where mechanical tillage is possible, ploughing to a depth of 60-80 cm promotes good root system development.
- Once the field has been harrowed, furrows are dug at 2 metre intervals for sowing the seeds.

Often 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 ploughed not across the slope but in furrows (50 per hectare) (Figure 6).



Figure 6. Soil preparation for oak afforestation

In areas where machinery cannot be used, the field is tilled in 1×1 metre squares measuring 2×2 metres, amounting to 2,500 squares per hectare. When planting forests, partial sowing is carried out in areas where

natural regeneration is occurring or is expected to occur. At present, between 1,200 and 1,500 plots of various layouts and sizes have been prepared in the open-air areas. On flat terrain, a combination of methods is used to establish protective oak shelterbelts, including the ‘row-and-hole’ and ‘square-cluster’ methods.

c) Sowing seeds: Sowing is carried out using the ‘row-and-hole’ and ‘square-cluster’ methods. In the ‘row-and-hole’ sowing method, seeds are sown into holes made along the sowing rows, with 3-5 seeds planted in each hole; the resulting plants form a biogruppe.

When using the ‘square-cluster’ method, sections of varying sizes are created in the sowing rows at distances corresponding to the planting pattern (in our example, a 2×2 m pattern, with sections measuring 1×1 m); these sections (forming a ‘square’) are created, in each of which 4 holes are made, with 3–5 seeds sown into each hole. Plants collected both in the nest and in the field form a single biogroup.

d) Protection: Artificially restored areas must be fenced off to protect the young saplings from damage caused by wild animals and livestock. A barrier, preferably in mountainous areas, 1.0 metres wide. This can be achieved by digging trenches 1.5 metres deep and 1.0 metre wide, with the excavated soil piled up on the inside to form berms, and local materials (branches and poles obtained from tree pruning, as well as shrubs, etc.) used on top of these berms. As this type of fencing is both cheaper and more effective, it is considered suitable for all afforestation projects in mountainous areas.

5. Sowing methods, mixing patterns and planting density in oak-based afforestation schemes (in mountainous areas)

When sowing in continuous rows using the ‘row-and-hole’ method (in a 2×1 m pattern), 50 furrows are dug per hectare at intervals of 2 metres. The holes are dug in furrows spaced 1 metre apart, and 3-5 acorns are sown in each hole. Given that the average weight of a single seed (of the chestnut-leaved oak) is 7 grams, the seed yield per hectare can range from 105 to 175 kg, and the number of one-year-old seedlings from 15,000 to 25,000.

When sowing continuously using plots (in a 2×2 m pattern) by the ‘square-cluster’ method, 2,500 plots measuring 1×1 metre are prepared per hectare (Figure 7).



Figure 7. *Mixing pattern and planting density in oak plantations*

Four holes are prepared in each plot (square), one in each corner, and 3-5 seeds are sown in each hole. Consequently, there are 10,000 seed points per hectare. Given that the average weight of a seed (of the chestnut-leaved oak) is 7 grams, the seed yield per hectare can range from 210 to 350 kg, and the number of one-year-old seedlings from 30,000 to 50,000. When planting forests under natural regeneration conditions, sowing is carried out in partial plots (in a 2×2 metre grid) using the ‘square-cluster’ method, with between 1,200 and 1,500 plots, each measuring 1 square metre, allocated per hectare.

Four holes are made in each plot (square), and 3–5 seeds are sown into each hole. Consequently, approximately 4,800–6,000 sowing points are established per hectare. Under these sowing conditions, the number of seedlings may range from 14,400 to 30,000 per hectare, while the seed requirement varies between 100 and 240 kg per hectare.

From 1950–1951, work began in Azerbaijan on the creation of shelterbelts under the leadership of Ibrahim Safarov, the Republic's Honoured Forester. When establishing shelterbelts, preference was given to oak species (chestnut-leaved oak, pedunculate oak and Iberian oak). The oak seeds were sown using the 'square-cluster' method, with the holes arranged in blocks across the plots. This method was mainly used in arid conditions. The oak seeds were sown using Lisenko's 'hole' method, with some modifications. When sowing using Lisenko's 'hole' method on a 5×3 metre grid, the planting holes are arranged in groups (of 5 holes per plot) on 1×1 metre plots (667 plants per hectare), with 6–7 seeds sown in each hole. Oak seedlings are grown for 2–3 years, whilst agricultural crops are grown in the rows between them.

As soon as it becomes clear that the planting has been successful and the oak acorns have taken root, a row of companion species is planted between the rows of oak saplings, and rows of shrubs are planted between the companion species and the oaks. Growing oak in bio-groups on plantations will be more environmentally sustainable, whilst using the spaces between rows to grow crops will provide an additional yield and reduce operating costs (IPCC, 2022/In any case, it is important to clear the planting area of weeds, stones and shrubs.

6. Agronomic management of oak plantations. Agronomic management comprises a range of agronomic measures aimed at improving the growing conditions for tree and shrub species cultivated on oak plantations, creating more favourable conditions and ensuring optimal conditions.

In continuous oak plantations, the main aim of management is to ensure that the site remains free of weeds through systematic soil cultivation or inter-row cultivation, thereby reducing competition for light and water. In partial oak plantations, the main objective of this measure is, first and foremost, to remove excess oak stumps from the site through timely thinning, and to prevent them from hindering the successful growth of higher-quality trees; it is also aimed at preventing oak stands from being displaced by faster-growing species during their early years. In arid desert conditions, whether planting in pits or furrows, two 3–5-year-old oak saplings should be left in each planting hole, and the rest should be removed.

3.Conclusion

Based on the findings of the studies and investigations carried out, the following can be noted:

1. A brief general overview of the distribution patterns and ranges of oak trees in Azerbaijan is provided.

This section also examines the distribution patterns of the chestnut-leaved oak.

2. This paper presents the results of research and surveys concerning the distribution of the chestnut-leaved oak in the forest areas of Ismayilli, its ecological and silvicultural characteristics, its response to anthropogenic and climatic changes, and the general current status of this species.

3. This article examines the prospects for the spread of the chestnut-leaved oak across the lands of the Ismayilli Forest Fund, as well as the potential for establishing plantations of this species there.

4. The article also provides detailed information on the mixing and planting schemes that can be proposed for establishing chestnut-leaved oak plantations.

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