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Agricultural sciences

EFFICIENCY OF PHYTO-RECLAMATION MEASURES IN RESTORING EROSION-DRIED LANDS

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Abstract

This article examines the effectiveness of phytomelioration measures in the restoration and sustainable management of eroded lands. Soil erosion remains one of the most serious environmental and agricultural challenges in many regions of Azerbaijan, leading to the degradation of soil fertility, reduction of agricultural productivity, and deterioration of ecological stability. In this context, phytomelioration, which involves the use of specially selected trees, shrubs, and herbaceous plants to improve soil conditions, is considered one of the most effective and environmentally friendly approaches to land rehabilitation.

The study analyzes the results of scientific investigations conducted in different natural and climatic zones of Azerbaijan, including the Khizi district, the southern slopes of the Greater Caucasus, and the Nakhchivan Autonomous Republic. Particular attention is paid to the role of vegetation in preventing further soil degradation and restoring the productive potential of eroded lands. The findings indicate that phytomeliorant species with well-developed and deep root systems contribute significantly to improving soil structure, increasing water infiltration, reducing surface runoff, and preventing the removal of soil particles by water and wind erosion. These processes promote the accumulation of organic matter and enhance the overall physical and biological properties of the soil.

The research also evaluates the effectiveness of perennial herbaceous plants in accelerating soil recovery. Experimental results demonstrate that crops such as poppy and meadow oats, as well as their mixed plantings, exhibit high productivity and develop extensive root systems that stabilize the soil and facilitate the regeneration of degraded areas. The accumulation of root biomass contributes to the enrichment of soil organic matter, improves moisture retention, and creates favorable conditions for the restoration of soil fertility.

In addition, the article highlights the importance of forest reclamation measures on mountain slopes and erosion-prone territories. The establishment of protective forest plantations and shrub belts was found to significantly decrease the intensity of surface runoff, reduce soil losses, and increase slope stability. These measures not only mitigate erosion processes but also improve the ecological condition of landscapes by enhancing biodiversity and supporting sustainable land use practices.

The results of the study confirm that phytomelioration plays a crucial role in erosion control, soil conservation, and ecological restoration. The integration of forest, shrub, and perennial herbaceous vegetation into land management systems provides a cost-effective and sustainable solution for rehabilitating degraded lands. Therefore, the wider application of phytomelioration techniques can contribute substantially to environmental protection, agricultural development, and long-term soil resource sustainability in Azerbaijan and other regions facing similar erosion problems.

Keywords: *soil erosion, phytomelioration, soil regeneration, surface runoff, root mass, environmental sustainability.*

Introduction. *Soil erosion is one of the most serious environmental problems facing agriculture and natural ecosystems in the modern era. As a result of erosion, the fertile topsoil is washed away, humus content is reduced, soil structure deteriorates, and, consequently, crop yields decline. Particularly in mountainous and foothill areas, intense anthropogenic impacts, deforestation, overgrazing, and unsustainable land use further accelerate erosion processes.*

The natural and geographical conditions of Azerbaijan create favorable conditions for widespread erosion. Both natural and anthropogenic factors contribute to soil erosion in the country. Studies have shown that 41.8% of the country's territory and approximately 85% of mountainous and forested lands

are subject to varying degrees of erosion. Erosion processes are particularly intense on the southern slopes of the Greater Caucasus, where reduced forest cover, steep slopes, and uneven precipitation distribution accelerate erosion (Isaev et al., 2000, pp. 352–353).

Various land reclamation measures are used to prevent soil degradation and restore productivity. Phytomelioration occupies a special place among these measures. Phytomelioration utilizes the biological properties of trees, shrubs, and herbaceous plants to protect and improve the soil. The root system of plants binds soil particles, preventing their leaching, while aboveground phytomass mitigates the destructive effects of precipitation and reduces surface runoff.

For the successful application of phytoamelioration measures, the suitability of the selected plant species to the local ecological characteristics is crucial. This requires considering factors such as the natural habitat of tree and shrub species, precipitation, climatic humidity, temperature, soil thickness, and elevation. According to the methodology proposed by Garayev and Isayev, it is advisable to use specific assessment indicators to determine the suitability of phytoamelioration agents to new ecological conditions (Garayev, Isayev, 2000, pp. 347–348).

Research conducted in various regions of Azerbaijan demonstrates the high effectiveness of phytoamelioration in combating erosion. Research conducted in the Khizi region revealed that 78% of the region's territory is subject to erosion, and fertility indicators on a significant portion of agriculturally suitable land have decreased by 2–3 times. Researchers have shown that poppy is considered a promising phytomeliorant for restoring eroded soils due to its strong and deep root system (Aliyev, Ibragimov, Gasimov, 2000, pp. 332–333). For the successful application of phytomelioration measures, the suitability of the selected plant species to the environmental characteristics of the area is crucial. This requires considering factors such as the natural habitat of tree and shrub species, precipitation, climatic humidity, temperature, soil thickness, and elevation. According to the methodology proposed by Garayev and Isayev, it is advisable to use specific evaluation indicators to determine the suitability of phytomelioration agents to new environmental conditions (Garayev, Isayev, 2000, pp. 347–348).

Research conducted in various regions of Azerbaijan demonstrates the high effectiveness of phytomelioration in combating erosion. Research conducted in the Khizi region revealed that 78% of the region's territory is subject to erosion, and fertility indicators on a significant portion of agriculturally suitable land have decreased by two to three times. Researchers have shown that poppy is considered a promising phytomeliorant for restoring eroded soils due to its strong and deep root system (Aliev, Ibragimov, Gasimov, 2000, pp. 332–333).

The results of forest reclamation measures carried out in mountainous areas also confirm the effectiveness of phytomelioration. Surface runoff and soil leaching in forest stands created using the terrace-trench method were significantly reduced compared to control plots. These methods created conditions for soil moisture conservation, normal plant development, and reduced erosion processes (Isayev et al., 2000, pp. 356-358).

Experiments conducted in high-mountain ecosystems of the Nakhchivan Autonomous Republic demonstrated that perennial grasses play an important role in restoring eroded soils. It was found that with the combined sowing of khashi and oats, the average annual yield increased severalfold compared to the control, root mass accumulation in the soil accelerated, and the structural condition of the soil improved (Asadov, Guliyev, 2000, pp. 402-405).

The aim of this study was to evaluate the role of phytomeliorative measures in restoring eroded soils, analyze the application characteristics of various phytomeliorants, and determine their impact on soil fertility restoration.

Materials and Methods. *The methodological basis of this study is a comparative analysis of the results of phytomeliorative and forest reclamation studies conducted on eroded soils in various natural and geographical regions of Azerbaijan. This study systematized research conducted in the fields of soil erosion, soil fertility restoration, and phytomelioration, and summarized the results.*

The research data were based on the results of long-term observations conducted in the Khizi region, on the southern slopes of the Greater Caucasus, and in the high-mountain ecosystems of the Nakhchivan Autonomous Republic. These regions, in addition to differing soil and climate characteristics, also differ in the level of erosion processes. Therefore, their comparative analysis provides a favorable scientific basis for assessing the effectiveness of phytoamelioration measures.

The research conducted in the Khizi region examined the condition of the soil cover, the extent of erosion, the characteristics of the vegetation, and the impact of poppy on soil fertility restoration. It was found that 78% of the region's territory is subject to erosion, and 64.3% of agriculturally suitable land has experienced erosion processes of varying degrees. The productivity, forage quality, and soil-protective

properties of poppy were assessed (Aliyev, Ibrahimov, Gasimov, 2000, pp. 332–334). During forestry experiments conducted on mountain slopes, the impact of various soil preparation methods on erosion was studied. For this purpose, surface runoff and soil erosion were measured in special watershed areas prepared using terrace, ditch, platform, and trough methods. The biological characteristics of various tree and shrub species, their soil-protecting functions, and their ability to adapt to new environmental conditions were simultaneously studied (Isayev et al., 2000, pp. 354–356).

Experiments conducted in the Nakhchivan Autonomous Republic examined the impact of pure and mixed seeding of perennial grasses on moderately and severely eroded mountain meadow soils. Poppy, meadow fescue, and meadow mint were used in the studies, and their productivity, root mass formation, and impact on the agrophysical properties of the soil were assessed (Asadov and Guliyev, 2000, pp. 400–402).

When selecting phytoameliorants for specific sites, principles for determining their ecological suitability were applied. Climate parameters, precipitation, soil thickness, site altitude, and the ecological stability of plant species were taken into account. This approach ensures the normal development of selected phytoameliorants in new conditions and the performance of their soil-protective functions (Garaev, Isaev, 2000, pp. 347–348).

The study utilized comparative analysis, statistical generalization, a systematic approach, and literature review. The results obtained allowed for a comprehensive assessment of the role of phytomelioration measures in combating erosion and restoring soil fertility.

Results and Discussion.*An analysis of the conducted studies demonstrates that phytomelioration measures are of great importance in restoring eroded soils. In addition to preventing erosion of the surface soil layer, the formation of vegetation also positively impacts the improvement of its physicochemical and biological properties. Experiments conducted in various regions have demonstrated that phytomelioration produces significant results in protecting and restoring soil fertility.*

Research conducted in the Khizi region revealed that 78% of the region is subject to erosion. As a result of erosion, the productivity of agricultural land has decreased by 2-3 times. The researchers found that poppy seeds are particularly important in protecting and improving soil fertility. The root system of this plant extends to a depth of 2-3 meters and, by strengthening soil particles, prevents their transfer by water and wind. Furthermore, because buckwheat has high forage quality, it also plays an important role in strengthening the forage base for livestock. According to research, with proper agricultural management, 35-40 centners of dry grass can be obtained per hectare (Aliev, Ibragimov, Gasimov, 2000, pp. 333-334).

The phytoameliorative value of buckwheat is not limited to productivity. The plant's extensive root system improves soil structure, increases water permeability, and creates conditions for humus accumulation. Furthermore, the soil is enriched with nitrogen due to the tubers, creating favorable conditions for the development of subsequent crops. These properties make buckwheat a promising phytomeliorative agent for restoring eroded soils. Reforestation experiments conducted on mountain slopes demonstrated that phytomelioration plays a significant role in reducing erosion. When comparing various soil preparation methods, terracing and hoeing were found to be the most effective. During observations conducted on April 18, 1994, no surface runoff or soil erosion were recorded in plots prepared using terracing and hoeing. Under the same conditions, the field method produced 250 liters of surface runoff per hectare, while the hoeing method produced 315 liters. In the control plot, this figure was 1,220 liters. Soil losses also changed in a similar way: in the control variant, 25.42 kg of soil were washed out per hectare, with the field method this figure was 0.82 kg, and with the method using a trough, 1.10 kg (Isaev et al., 2000, pp. 356–357).

The results obtained show that planting forest plants and targeted soil preparation significantly reduce surface runoff. The root system of trees and shrubs increases the stability of the soil, and their above-ground parts weaken the destructive effects of raindrops. As a result, soil erosion is weakened and the intensity of the erosion process is reduced.

The effectiveness of phyto-ameliorative measures has also been confirmed in experiments conducted in mountain-meadow ecosystems of the Nakhchivan Autonomous Republic. Research has shown that in the control variant on moderately eroded soils, the average annual grass yield was only 6.2 centners/ha. Planting perennial grasses has resulted in significant increases in productivity. The highest results were achieved with mixed sowing of ryegrass and meadow oats, where the average annual yield was 36.3 centners/ha. When sowing pure poppy, this figure was 34.2 centners/ha, and when sowing meadow fescue - 30.0 centners/ha (Asadov, Guliyev, 2000, pp. 402–404).

Similar results were observed on heavily eroded soils. While the average annual yield in the control variant was 3.0 centners/ha, when sowing poppy, 29.0 centners/ha was obtained, and in a mixture of poppy and meadow fescue - 26.5 centners/ha. These indicators prove that the use of perennial grasses can restore productivity even in severely degraded soils.

One of the important results of the study is related to the accumulation of root mass. On moderately eroded soils, the average root mass in the soil layer of 0–30 cm in the control variant was 39.8 centners/ha, while when sowing poppy this figure was 220.3 centners/ha, and in a mixture of poppy and meadow oats - 238.1 centners/ha. A similar trend was observed on heavily eroded soils. The development of the root system strengthened the connection between soil particles, increased the stability of the structure and led to a weakening of erosion processes (Asadov, Guliyev, 2000, pp. 404–405).

The correct selection of plant species is particularly important for the successful implementation of phytomelimination measures. This requires consideration of climatic conditions, precipitation, soil thickness, site altitude, and plant resilience. A proper assessment of ecological suitability not only ensures the normal development of selected species in new conditions but also increases the economic and environmental effectiveness of phytomelimination measures.

Thus, the results of the conducted research demonstrate that phytomelimination measures are highly effective in restoring eroded soils. The use of trees, shrubs, and perennial herbaceous plants significantly contributes to restoring soil fertility, increasing productivity, reducing surface runoff, and protecting soil from erosion.

Conclusion.An analysis of the conducted research shows that phytomelimination measures are one of the most effective and environmentally friendly methods for restoring eroded soils. Observations conducted in various natural and geographical conditions demonstrate that the use of trees, shrubs, and perennial herbaceous plants has a significant impact on restoring soil fertility, improving its physical and chemical properties, and reducing erosion processes.

It has been established that the correct selection of phytomeliorants and their adaptation to the soil and climatic conditions of the area significantly increases the effectiveness of phytomelioration measures. In this regard, the key indicators should be the environmental stability of plant species, the level of development of their root system, and the ability to adapt to changes in humidity and temperature.

Research conducted in the Khizi region has shown that poppy, with its deep root system, is highly effective in protecting eroded soils and restoring their fertility. This plant not only prevents soil erosion but also creates conditions for the development of livestock farming, ensuring high yields of forage crops.

As a result of forest-amelioration measures carried out on mountain slopes, it was determined that plantings planted using terrace and trench methods allow minimizing surface runoff and soil loss. The protective cover created by forest plants increases the soil's resistance to erosion and accelerates its natural restoration processes.

Experiments conducted in the Nakhchivan Autonomous Republic have shown that mixed sowings of perennial grasses, especially poplar and meadow oat, provide high productivity on eroded soils. The intensive development of the root mass of these plants has created conditions for improving soil structure, accumulating humus, and restoring fertility.

Thus, phytomelioration is not only a soil protection measure in the restoration of eroded soils, but also a complex system of measures of great importance in terms of increasing soil fertility, increasing agricultural productivity, and maintaining ecological balance. Widespread application of phytomeliorative measures in various natural regions of Azerbaijan can make a significant contribution to the protection of soil resources and their sustainable use.

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SCİENTİFİC BASİS FOR THE PURİFİCATİON OF THE OKHCHUCHAY RİVER FROM INDUSTRİAL POLLUTİON AND THE USE OF ITS WATER İN AGRİCULTURE

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Abstract

The article discusses the problems caused by pollution of the Okhchuchay river water of industrial origin from an ecological and economic point of view, the possibilities of river water purification and the scientific basis for the use of purified water in agriculture. In addition to being one of the important water sources in the Eastern Zangezur region of Azerbaijan, the Okhchuchay is considered one of the main tributaries of the Araz River and has been used for irrigation of the surrounding areas for many years. In recent years, as a result of the development of the mining industry in the basin, significant changes in the quality of river water have been observed, and an increase in the content of heavy metals in the aquatic environment has been noted. This fact is of great scientific and practical importance from the point of view of the safe use of water resources, land protection and the quality of agricultural products.

The study analyzed the results of monitoring conducted in the Okhchuchay river basin, the physico-chemical parameters of the water and scientific sources of heavy metal concentrations. It has been established that the observed increase in the content of iron, manganese and other heavy metals in river water is associated with anthropogenic influences, especially with the intensity of industrial activity. The presence of heavy metals in irrigation waters accelerates the process of their accumulation in soils, weakens soil fertility and negatively affects the development of crops. At the same time, the ingestion of these elements into the human body through the food chain can lead to health risks.

The article discusses the possibilities of using the WQI (Water Quality Index) and iwqi (irrigation Water Quality Index) methods used to assess water quality. It is shown that using these indices it is possible to determine the general ecological condition of water and the level of its suitability for irrigation. The mechanical, physico-chemical, membrane and biological methods used to purify waters contaminated with industrial waste are also comparatively analyzed. The advantages and prospects of using sorption, coagulation-flocculation, membrane filtration and phytoremediation technologies are evaluated.

As a result of the research, it has been established that the safe use of Okhchuchay River water in agriculture is possible only after primary purification measures have been carried out. Bringing the quality indicators of treated water in line with the regulatory requirements established by the FAO makes it possible to avoid contamination of soil and plants with heavy metals. It has been established that the combined use of mechanical purification, sorption and phytoremediation methods can be considered an effective solution for hunting, both from an environmental and economic point of view. The results of the study are significant from the point of view of sustainable management of the region's water resources, ensuring environmental safety and developing strategies for the rational use of water resources in agriculture.

Keywords: Okhchuchay river,industrial pollution, heavy metals, water purification, irrigation water, agriculture, wqi, iwqi, phytoremediation.

Introduction.Azerbaijan's water resources play an important role in the socio-economic development of the country. In particular, the availability of high-quality water resources is one of the main conditions for the sustainable development of agriculture. Located in the Karabakh and East Zangezur economic regions, the Okhchuchay river , being a transboundary river, is important in the region's water supply. The river is considered one of the main tributaries of the Araz basin and has been used for many years to irrigate agricultural land in the surrounding areas. In recent decades, as a result of the intensive development of the mining industry, significant changes in water quality have been observed in the river basin.

The conducted monitoring shows that in some cases the content of heavy metals in Okhchuchay exceeds the natural background values. The observed variability, especially in concentrations of iron and manganese, negatively affects the ecological condition of the reservoir. Studies conducted by Majidli indicate that the presence of heavy metals in the Okhchuchay river and other rivers of Eastern Zangezur requires regular monitoring and cleanup activities (Majidli, 2025, pp. 69-70).

Nowadays, various index methods are used to assess the ecological state of reservoirs. Al-Janabi and his coauthors show that water quality indices are an effective tool for assessing the general condition of river waters and allow making managerial decisions (Al-janabi et al., 2012, p. 119).

The presence of heavy metals in irrigation water affects not only aquatic ecosystems, but also soil fertility and the safety of agricultural products. Mousavi and his co-authors found that the use of water in agriculture, characterized by a high concentration of heavy metals, can pose a danger to human health (mousavi et al., 2013, p. 80).

Studies by Maleki and his co-authors have shown that elements such as lead and chromium accumulate in vegetables irrigated with contaminated water, enter the food chain and cause long-term environmental problems (maleki et al., 2014, pp. 81-82).

In areas where the mining industry is developed, heavy metal pollution of river waters and sediments is a common problem. Aguilar pesantes and his co-authors identified high concentrations of elements such as copper, zinc, lead, and cadmium in such areas and used various environmental indexes to evaluate them (Aguilar pesantes et al., 2019, p. 1).

The assessment of the quality of water used for irrigation is in the focus of special attention of international organizations. The recommendations developed by the FAO set regulatory limits for the content of heavy metals, salinity and other indicators. The expectation of these indicators is important in terms of preventing soil degradation and preserving fertility.

The purpose of the study is to analyze the characteristics of industrial-grade Ochre water pollution, assess the impact of heavy metals on agriculture, study modern purification technologies, and determine the scientific basis for the use of purified water in irrigation.

the main part.*Being one of the left tributaries of the Araz River, Okhchuchay is considered one of the important transboundary water bodies of the South Caucasus. The river basin is of great importance both from a hydrological and an economic point of view. The waters of Okhchuchay river have been used for many years for irrigation of agricultural lands, livestock farms and other agricultural activities. However, the intensive mining activities carried out in the basin in recent decades have had a serious impact on the ecological state of the river.*

The mining industry is considered one of the main sources of heavy metal pollution in river waters. As a result of the exploitation of ore deposits, landfill activities and the discharge of process waters, elements such as copper, zinc, lead, cadmium, iron and manganese enter the aquatic environment. These elements are transported in the water in a dissolved state or in the form of suspended particles, accumulating in the lower reaches of the river and creating an environmental hazard.

The monitoring results conducted in the East Zangezur region show that the content of heavy metals in Okhchuchai varies in different locations. In the samples taken in the Nosunlu, Tagli, and Jahangirbeyli directions, the iron content ranged from 125 to 752 micrograms/liter, and the manganese content ranged from 18.8 to 99.9 micrograms/liter, indicating the presence of anthropogenic influences on the hydrochemical composition of the river (Majidli, 2025, p. 70).

The impact of industrial pollutants is manifested not only in the aquatic environment, but also in bottom sediments. Heavy metals can remain in sediments for a long time, becoming a secondary source of pollution. Studies by Aguilar pesantes and his co-authors have shown that in river sediments in areas characterized by mining activity, the concentration of cu, PB, ZN, CD and as elements is high, and this condition weakens the stability of ecosystems (Aguilar pesantes et al., 2019, p. 1).

Other factors affecting the heavy metal content in river waters include precipitation, erosion processes, agricultural runoff, and household waste. However, observations conducted in the Okhchuchaya basin show that the main burden falls on industrial activities. The high concentration of heavy metals reduces the natural self-cleaning potential of water, negatively affects the vital activity of aquatic organisms and limits the use of water in agriculture.

Modern methods of environmental assessment show that it is not enough to simply determine the state of river waters by individual chemical indicators. Therefore, in recent years, the WQI (Water Quality Index) and ccme wqi indices have been widely used for a comprehensive assessment of water quality. These indices make it possible to characterize the general condition of a water body by combining various physico-chemical indicators into a single system (Al-janabi et al., 2012, pp. 119-120).

Heavy metals are one of the main factors determining the quality of water used in agriculture. Although these elements are necessary for plant development in certain concentrations, their excess over the norm causes serious changes in soil ecosystems and vegetation. In particular, elements such as copper (cu), lead (PB), cadmium (CD), chromium (CR), arsenic (AS) and mercury (HG) are highly toxic.

As a result of prolonged irrigation with polluted water, heavy metals accumulate in the upper soil layer. This process leads to a change in the physico-chemical properties of the soil, a weakening of microbiological activity and a decrease in fertility. Heavy metals combine with soil particles and remain in the ecosystem for a long time, and then are absorbed by plants.

Studies by Mousavi and his co-authors have shown that high concentrations of mercury and aluminum in water used for irrigation can lead to dangerous accumulations in agricultural products. The authors recommended limiting the use of such waters in agriculture and conducting constant monitoring (Mousavi et al., 2013, pp. 80-81).

Plants absorb heavy metals mainly through the root system. Although some of the assimilated elements accumulate in the roots, a significant part passes into the stems and leaves. And this directly affects the quality and safety of agricultural products. The accumulation of heavy metals, especially in vegetable crops, is considered a serious risk to human health.

Studies by Maleki and his co-authors showed that the amount of lead and chromium exceeded the regulatory limits set by the FAO and WHO in some vegetable samples. The authors note that regular laboratory monitoring of products grown in irrigated areas with polluted water is necessary (maleki et al., 2014, pp. 81-82).

The accumulation of heavy metals in the soil affects not only the quality of the crop, but also the yield. Elements such as cadmium and lead weaken the photosynthesis process in plants, slow down the development of the root system and reduce the absorption of nutrients. As a result, productivity decreases and economic losses occur in agricultural production.

The recommendations developed by the FAO state that the concentration of heavy metals in irrigation waters should not exceed the established standards. Otherwise, there is a long-term process of contamination of the soil and plant system, and this situation poses a serious risk from the point of view of food safety.

Thus, the presence of heavy metals in the Okhchuchay water should be considered as an important problem from the point of view of preserving not only water resources, but also the quality of soil and agricultural products. Therefore, water purification and the definition of criteria for its safe use are of particular importance.

The treatment of river waters that have been polluted by industrial origin is one of the main problems of modern water management. The presence of heavy metals in okhchuchay limits the use of this water directly in agriculture and requires preliminary purification measures. The choice of cleaning technologies depends on the type of pollutants, their concentration and the purpose of the end use.

In modern conditions, mechanical, physico-chemical, membrane, and biological methods are used to purify waters contaminated with heavy metals. Each of these methods has different economic and technical characteristics, as well as certain advantages.

Mechanical cleaning is considered the initial stage and serves to separate large particles, silt and suspended solids contained in the water. At this stage, settling tanks, sandboxes and various filtration plants are used. Although mechanical cleaning does not completely remove heavy metals, it increases the efficiency of subsequent cleaning processes.

One of the most widely used methods for extracting heavy metals is coagulation and flocculation. In this method, with the help of special reagents, the pollutants dissolved in water are deposited, turning into large particles. The advantage of the coagulation process is that it is technically simple and can be used to purify large volumes of water. However, in some cases, additional chemicals are required.

Sorption technologies are also considered effective in combating heavy metals. Activated carbon, zeolites and various natural sorbents show high results in the capture of copper, lead, zinc and cadmium ions. The sorption method is considered more effective, especially if the concentration of heavy metals is relatively low.

In recent years, membrane technologies have become widespread in the field of water purification. Ultrafiltration, nanofiltration, and reverse osmosis systems can separate most of the heavy metals, salts, and other pollutants from the water. Although these technologies have high cleaning efficiency, their application requires high energy consumption and additional maintenance costs.

The recommendations developed by the FAO state that the water quality indicators to be used in agriculture should not cause soil degradation, and the concentration of heavy metals should be

maintained within the established regulatory limits. For this purpose, when designing purification systems, it is necessary to take into account both the chemical composition of water and the direction of its further use.

Phytoremediation occupies a special place among biological purification methods. Phytoremediation uses the ability of some plant species to absorb heavy metals. Reed (Phragmites Australis), linden and other aquatic plants play an important role in reducing the concentration of heavy metals. This method is not only environmentally friendly, but also requires lower financial costs compared to other technologies.

Studies conducted on rivers affected by the mining industry have shown that it is important to use a multidimensional approach to assess the level of pollution and choose effective cleaning methods. Aguilar pesantes and his co-authors used various indices to assess the distribution of heavy metals and recommended the use of comprehensive pollution reduction measures (Aguilar pesantes et al., 2019, pp. 1-2).

A combination of mechanical purification, sorption, and phytoremediation methods can be considered the most appropriate option for ochuchai. This approach is considered both economically beneficial and environmentally friendly. In addition, to increase the efficiency of the purification process, it is important to establish a regular monitoring system and constantly monitor water quality indicators.

Discussions.*The quality of water used in agriculture is one of the main factors for maintaining fertility, soil fertility and environmental safety. Therefore, the use of industrial waste-contaminated waters in irrigation after their purification should be carried out only on the basis of certain scientific criteria.*

When evaluating irrigation water, pH, electrical conductivity (EC), total solutes (TDS), sodium adsorption coefficient (SAR) and concentration of heavy metals are taken into account as the main indicators. These indicators have a direct impact on the physico-chemical properties of the soil and the development of crops.

In modern research, the Water Quality Index (wqi) and irrigation Water Quality Index (iwqi) are widely used to determine suitability for irrigation. Al-Janabi and his coauthors note that WQI makes it possible to evaluate various physico-chemical parameters in a single system and characterizes the general condition of a reservoir (Al-janabi et al., 2012, pp. 119-120).

Research by Roy and his co-authors has shown that the iwqi indicator is a reliable tool for determining the suitability of water for irrigation. The authors found that with low levels of heavy metals and salinity, water can be safely used in agriculture (Roy et al., 2026, pp. 1-2).

According to international recommendations developed by the FAO, the content of heavy metals in irrigation water should not exceed the established limits. Otherwise, salinization of the soil, accumulation of toxic elements and decrease in yield may occur. The FAO also recommends the establishment of a continuous monitoring system for the use of treated water in agriculture.

For the use of okhchuchai water in irrigation after purification, it is important, first of all, to reduce the concentration of heavy metals to a regulatory level. After that, water quality indicators should be evaluated using the WQI and IWQI methods, and the results should be compared with international standards. The use of water for irrigation purposes can be considered possible if the obtained indicators are positive.

Conclusion.*The conducted studies have shown that the pollution of industrial origin observed in the Okhchuchai basin is mainly related to mining activities and has led to an increase in the concentration of heavy metals in river water. Monitoring results confirm the presence of a number of elements in river water, especially iron and manganese, which limits the direct use of water in agriculture (majidli, 2025, p. 70).*

The study found that heavy metals can accumulate in the soil and plant system, leading to lower yields, deterioration in the quality of agricultural products and potential risks to human health. In this regard, it is impractical to use Hot water without purification.

An analysis of modern purification technologies has shown that methods of mechanical purification, sorption, membrane filtration and phytoremediation give effective results in reducing the concentration of heavy metals. The combined use of mechanical purification, sorption, and phytoremediation methods can be considered the most effective approach to hopping from a technical and economic point of view.

When assessing the quality of treated waters to be used for irrigation, it is advisable to use the wqi and iwqi indices. These indexes make it possible to comprehensively determine the suitability of water for agriculture. At the same time, the expectation of the normative indicators recommended by the FAO is an important condition for preventing soil degradation and ensuring environmental safety.

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THE ROLE OF REUSE OF COLLECTOR-DRAINAGE WATER IN THE DEVELOPMENT OF IRRIGATION AND FISHERIES SYSTEMS

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Abstract

This article examines the impact of reuse of collector-drainage water on the development of irrigation and fisheries systems. Limited water resources, the effects of climate change, and the growing demand for water in agriculture have necessitated the use of alternative water sources. Therefore, collector-drainage water is considered an important water resource that can be used in both irrigation and fish farming. The objective of this study is to determine the potential applications, economic efficiency, and environmental effectiveness of reuse of collector-drainage water in agriculture and aquaculture.

This study analyzes scientific research conducted in Azerbaijan and abroad and summarizes existing experience in the use of collector-drainage water. It has been established that Azerbaijan's water resources are limited, and a significant portion of the water used in the country comes from transboundary sources. Climate change and increasing water consumption require more efficient management of available water resources. Therefore, integrating drainage water into economic circulation can play a significant role in improving water supply.

Research has shown that 4-5 cubic kilometers of drainage water are generated annually in Azerbaijan. A certain portion of this water can be reused for irrigation. Long-term experiments have shown that drainage water can be used for irrigating cotton, wheat, and forage crops, and its impact on soil reclamation and crop yields has been assessed.

Research conducted in the Mughan-Sal massif shows that soil salinization and rising groundwater levels lead to a deterioration in soil reclamation. Therefore, the efficient operation of collector-drainage systems and the reuse of collected water are essential for land conservation.

Results from the use of fish farm drainage water in agriculture have shown that the nitrogen and other nutrients present in this water accelerate plant development and contribute to increased crop yields. It was found that crop yields in plots irrigated with fish farm drainage water were higher than in plots irrigated with traditional irrigation water, and this approach reduced the need for mineral fertilizers.

At the same time, experiments conducted on various agricultural crops have shown that fish farm drainage water can be successfully used in the cultivation of crops such as potatoes, soybeans, and onions. This allows for more efficient use of water resources, reduced production costs, and the development of integrated irrigation and fish farming systems. The results revealed that drainage water recirculation is essential for water conservation, increased agricultural productivity, improved land reclamation, and fisheries development. The implementation of integrated irrigation and fisheries systems, particularly in the Kura-Araz Lowland, can make a significant contribution to reducing water scarcity and sustainable development of the agricultural sector.

Keywords: drainage water, reuse, irrigation, fisheries, aquaculture, land reclamation, water resources, agriculture, integrated management, water scarcity.

Introduction. The decline and uneven distribution of water resources in the modern era is one of the main factors affecting the development of agriculture worldwide. Rapid population growth, rising demand for food, climate change, and increasing anthropogenic impacts require more efficient use of available water resources. Since irrigation agriculture is the basis of agricultural production, especially in countries with arid and semi-arid climates, the search for alternative water sources and their integration into economic circulation is of great importance.

Azerbaijan is among the countries with limited water resources. The country's total water resources amount to 30.9 km³, of which only 10.3 km³ are generated within the country. In recent decades, as a result of climate change, water resources have decreased by 10-15%, creating certain difficulties in

water supply for agriculture (Imanov, Nuriyev, and Mamedov, 2025, p. 1). Therefore, the use of non-traditional water resources and the inclusion of water resources in recycling are considered important areas for ensuring water security in the country. Among alternative water sources, collector-drainage water occupies a special place. For many years, this water was discharged primarily into the Caspian Sea and other bodies of water. However, recent studies show that reusing a certain portion of it can yield effective results in both irrigation agriculture and fisheries. The volume of collector-drainage water in Azerbaijan has increased in recent decades and reached 4-5 km³ per year, accounting for approximately 25% of the runoff at the Kura River estuary (Imanov et al., 2025, p. 1).

One of the key elements of sustainable development is the integration of reused water into economic circulation based on the principles of integrated water resources management. Studies by Pasha, Zengin, and Bayarli note that sustainable water use requires managing not only surface and groundwater but also reusable water within a unified system (PASHA et al., 2023, p. 25). Therefore, the use of drainage water not only helps conserve water resources but also ensures the stability of agricultural production.

Research conducted in Azerbaijan on the use of drainage water has shown that proper management contributes to improving the reclamation status of soils and preventing resalinization. Research conducted, in particular, in the Mughan-Salyan massif has established that a significant portion of irrigated lands has varying degrees of salinity, and improving the functioning of drainage systems is essential to stabilize the existing reclamation situation (Gurbanov, 2022, p. 3).

The use of drainage water is not limited to irrigated agriculture. Modern scientific research shows that drainage water from fish farms has a positive effect on the development of agricultural crops due to the nitrogen, phosphorus, and other nutrients it contains. Studies of using fish farm drainage water in wheat crops have shown increased yields and reduced fertilizer requirements (Abdelraouf & Ragab, 2017, p. 758). Meanwhile, experiments conducted on potato, soybean, and onion crops have also confirmed the economic efficiency of using such water (Abdelrauf, 2019, p. 394).

Main Part. *Recycling of drainage water has become one of the most pressing issues in water resources management in recent years. Decreasing global freshwater reserves and increasing agricultural demand require more efficient use of available water resources. Therefore, drainage water is valued not only as a byproduct of drainage systems but also as an additional source of water. Reuse of this water plays a crucial role in ensuring the sustainability of agricultural production, especially in regions experiencing water shortages.*

Irrigation agriculture in Azerbaijan is concentrated primarily in the Kura-Araz Lowland. Since most of the country's lowlands are located in a semi-arid climate zone, crop cultivation is directly dependent on irrigation. Decreasing precipitation and rising temperatures due to climate change observed in recent years have placed additional pressure on water resources. Research shows that since a significant portion of the country's water resources comes from transboundary rivers, any changes in water supply have a significant impact on agriculture (PASHA et al., 2023, p. 25). Therefore, attracting alternative water sources to farms has become a necessity.

One of the main advantages of using drainage water is its generation in large volumes. According to recent data, 4-5 km3 of drainage water is generated annually in Azerbaijan. Most of this water is discharged into the Caspian Sea, remaining unused. However, scientific research shows that, given the level of mineralization, a significant portion of this water could be used in agriculture. Long-term observations have shown that the use of drainage water for irrigating cotton, wheat, and forage crops is feasible (Imanov, Nuriyev, and Mamedov, 2025, p. 1).

The use of drainage water not only improves water supply but also preserves land resources. Rising groundwater levels in irrigated soils and resalinization processes negatively impact agricultural production. Therefore, the proper functioning of drainage systems and the management of the water collected through them are crucial. Research conducted in the Mughan-Salyan massif showed that most soils in this area are subject to varying degrees of salinization. This situation requires more efficient use of drainage systems and improved reclamation measures (Gurbanov, 2022, p. 3).

Positive results in the reuse of drainage water have been obtained not only in Azerbaijan but also in other countries. Research conducted, in particular, on the integration of agriculture and fisheries, shows that this area has great potential. Water used in modern aquaculture systems offers additional benefits for crop irrigation, as it accumulates organic matter, nitrogen, phosphorus, and other nutrients over time. Reusing such water, rather than discharging it directly into the environment, is more beneficial from both an environmental and economic perspective.

Research conducted on the use of fish farm drainage water for irrigation has shown that the nutrients contained in this water have a positive effect on plant development. Experiments by Abdelraouf

and Ragab found that wheat fields irrigated with fish farm drainage water had higher yields than fields irrigated with traditional irrigation water. The authors attribute this primarily to the biological nitrogen and other nutrients present in the water (Abdelraouf & Ragab, 2017, p. 758). Furthermore, the use of such water has reduced the need for mineral fertilizers and lowered production costs. Subsequent studies examined the use of fish farm water for growing potatoes, soybeans, and onions. It was found that this water accelerates plant development, improves soil nutrition, and contributes to increased crop yields. The study's results showed that fish farm drainage waters enable high yields even without additional fertilizer application (Abdelraouf, 2019, p. 394).

Integrating irrigation and fish farming systems significantly improves water efficiency. In such systems, the same water is first used for fish farming and then directed to irrigate crops. As a result, the economic benefit from each unit of water increases. This approach is of great importance, especially in regions where water resources are limited. Existing drainage networks and fish farms in the lowland region of Azerbaijan

The development of irrigation systems creates favorable opportunities for the implementation of such integrated systems.

Reuse of drainage water also offers significant environmental benefits. This approach reduces the volume of wastewater discharged into rivers and other bodies of water, mitigates the anthropogenic impact on water resources, and contributes to environmental protection. At the same time, it reduces the need to find new sources of irrigation water and construct additional hydraulic structures. This creates conditions for both cost savings and optimized use of natural resources.

Conclusion. *The conducted research and analysis of available scientific resources demonstrate that the recirculation of drainage water is essential for the development of irrigation and fisheries systems in conditions of limited water resources. Climate change, increasing water demand, and depleting natural water resources have necessitated the use of alternative water sources. Therefore, drainage water can be considered as an additional water resource and contribute to the sustainable development of agriculture.*

The research found that the 4-5 cubic kilometers of drainage water generated in Azerbaijan annually can play a significant role in the country's water supply. Reusing a portion of this water reduces the need for irrigation water, enables more efficient water resource management, and ensures the sustainability of agricultural production. The use of drainage water, particularly in irrigated areas located in the Kura-Araz Lowland, holds great promise as an additional water source. It has been established that the efficient operation of drainage systems is important not only for water supply but also for improving land reclamation. Research conducted in the Mugano-Salyan massif has shown that soil salinization and rising groundwater levels negatively impact agricultural productivity. Therefore, drainage water management and reuse are important measures for maintaining soil fertility.

Research on the use of fish farm drainage water in agriculture has shown that the nitrogen, phosphorus, and other nutrients contained in this water accelerate plant development, contribute to increased crop yields, and reduce the need for mineral fertilizers. Therefore, the integration of fish farm and irrigation systems is considered a promising approach to improving water resource efficiency. Experiments on potato, soybean, and onion crops have also confirmed that such water can be successfully used in agriculture and deliver cost-effective results. Research results show that the reuse of drainage water has not only economic but also environmental benefits. This approach reduces the volume of water withdrawn from natural sources, minimizes the amount of wastewater discharged into water bodies, and mitigates the anthropogenic impact on the environment. At the same time, it creates conditions for more efficient use of available resources in accordance with the principles of integrated water resources management.

Thus, the reuse of drainage water can play an important role in the development of irrigated agriculture and fisheries in Azerbaijan. Further expansion of research in this area, a more detailed study of the qualitative indicators of drainage water, and the development of scientifically sound recommendations for its use will make a significant contribution to strengthening the country's water security and the sustainable development of the agricultural sector.

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PROSPECTS FOR THE USE OF GEOSYNTHETIC MATERIALS IN THE RECONSTRUCTION OF IRRIGATION CANALS IN AZERBAIJAN

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Abstract

This article examines the prospects for the use of geosynthetic materials in the reconstruction and modernization of irrigation canals in Azerbaijan. The rational management of water resources has become a critical issue in recent decades due to increasing water scarcity, population growth, expanding agricultural activities, and the growing impacts of climate change. In arid and semi-arid regions, irrigation systems play a vital role in ensuring agricultural productivity and food security. However, a significant portion of water transported through open irrigation canals is lost due to seepage, evaporation, and structural deterioration of canal beds. These losses reduce the efficiency of irrigation networks and place additional pressure on already limited water resources. Therefore, the introduction of advanced engineering solutions, particularly geosynthetic materials, is considered an effective approach to improving the technical and operational performance of irrigation systems.

The study analyzes the main types of geosynthetic materials used in hydraulic engineering, including geomembranes, geotextiles, geocomposites, and related protective layers. Special attention is given to their physical, mechanical, and hydraulic properties, as well as their suitability for application in irrigation canal reconstruction projects. The results indicate that geomembranes possess excellent impermeability characteristics and can significantly reduce water seepage through canal beds and side slopes. Their use contributes to improved water conservation, increased conveyance efficiency, and reduced maintenance requirements. Geotextiles serve as protective and reinforcing layers, preventing mechanical damage to geomembranes, improving load distribution, and enhancing the overall durability of canal lining systems.

The article also reviews international experience in the application of geosynthetics for irrigation infrastructure development. Studies and practical projects implemented in various countries demonstrate that properly designed geosynthetic lining systems can reduce seepage losses by more than 80%, resulting in substantial water savings and improved irrigation efficiency. In addition to minimizing water losses, geosynthetics help prevent soil erosion, control vegetation growth within canals, and reduce sediment accumulation, thereby extending the service life of irrigation facilities.

Furthermore, the paper evaluates the relevance of these technologies for Azerbaijan, where irrigation remains one of the key sectors supporting agricultural production. Recent canal reconstruction projects carried out in different regions of the country have shown that the adoption of modern waterproofing and reinforcement technologies contributes to more sustainable water management. The implementation of geosynthetic materials can improve the reliability of irrigation infrastructure, reduce operational costs, and increase the effectiveness of water distribution systems.

The findings of the study confirm that geosynthetics represent a promising and economically justified solution for the rehabilitation of irrigation canals. Their widespread application can contribute to water conservation, enhanced agricultural productivity, and the long-term sustainability of irrigation systems in Azerbaijan under changing environmental and climatic conditions.

Keywords: *irrigation canals, geosynthetics, geomembrane, geotextiles, reconstruction, seepage losses, waterproofing, water resources, innovative technologies.*

INTRODUCTION. *Efficient water resource management is one of the most important challenges facing countries worldwide in the modern era. Due to population growth, increasing demand for agricultural products, and the impact of climate change, pressure on water resources is increasing. Particularly in countries with arid and semi-arid climates, efficient water use is considered a key prerequisite for sustainable agricultural development.*

Agriculture in the Republic of Azerbaijan is a key economic sector and plays a key role in ensuring the country's food security. Although the country's soil and climate conditions are favorable for growing various crops, most arable land relies on artificial irrigation. Therefore, the technical condition of irrigation systems and their operational efficiency directly impact agricultural production.

Approximately 1.35 million hectares of land in Azerbaijan are irrigated, and water supply to these areas is provided primarily through large reservoirs and major canals. The Samur-Absheron, Upper Karabakh, Upper Shirvan, Bash Mil, and Bash Mughan canals operating in the country provide irrigation to hundreds of thousands of hectares of land. The canals extend for tens of thousands of kilometers, transporting billions of cubic meters of water annually (Aliyeva, Ismailov, 2019, pp. 10–11).

However, various technical problems have arisen in the irrigation canals, which have been in operation for many years. Cracks in the canal beds and slopes, erosion processes, and seepage lead to significant water losses. Seepage losses not only lead to a decrease in water resources but also to rising groundwater levels in adjacent areas, as well as salinization and waterlogging of the soil. To address these problems, reconstruction of the canals and the use of modern waterproofing technologies are necessary.

In recent decades, geosynthetics have become widely used in hydrometeorology and geotechnical engineering. Geosynthetics are polymer-based artificial materials used to strengthen soil structures, provide impermeability, drainage, and erosion control. These materials have been successfully applied in dams, reservoirs, canals, and other hydraulic structures (Blond et al., 2019, pp. 67–68).

Geomembranes occupy a special place among geosynthetics. J.-P. Giroud notes that geomembranes are water-impermeable flexible materials that prevent seepage and percolation losses, which is one of the main objectives of canal design. The elasticity and resistance to deformation of geomembranes determine a number of their advantages over concrete linings (Giroud, 2021, pp. 2–3).

Modern research shows that the combined use of geomembranes and concrete linings can significantly reduce seepage losses. Experimental studies conducted by Khan and his colleagues showed that the combination of new concrete and geomembrane reduced canal seepage by 86% compared to unlined conditions (Khan et al., 2020, p. 1).

In recent years, particular attention has been paid to the reconstruction of irrigation systems in the Republic of Azerbaijan. The Shirvan Irrigation Canal Reconstruction Project aims to reduce water loss, expand irrigated areas, and introduce modern management technologies. The project is expected to prevent approximately 346 million m³ of water loss annually.

Main part. Geosynthetics are a group of polymeric materials widely used in modern hydromelioration and geotechnical engineering. These materials are used for soil stabilization, waterproofing, drainage, filtration, and erosion control. The main types of geosynthetics include geomembranes, geotextiles, geogrids, geocells, and geocomposites. Their use improves the reliability of irrigation systems and reduces operating costs.

Research by Blond and his colleagues notes that geosynthetics provide waterproofing, reinforcement, and erosion control in dams, canals, reservoirs, and other hydraulic structures. The authors consider geosynthetics to be one of the most important innovations in geotechnical engineering over the past 50 years (Blond et al., 2019, p. 68).

Geomembranes are the most widely used material in the reconstruction of irrigation canals. Geomembranes are made of high-density polyethylene (HDPE), polyvinyl chloride (PVC), EPDM, and other polymeric materials. The main advantage of these materials is their impermeability. Giroud characterizes geomembranes as "completely impermeable geosynthetics" and notes that one of the main goals in channel design is to minimize seepage and permeation losses (Giroux, 2021, pp. 2–3).

One important advantage of geomembranes is their elasticity. Unlike concrete linings, geomembranes can adapt to slight deformations in the subgrade without losing their impermeability. Examples cited by Giroud demonstrate that geomembranes maintain their impermeability even during soil subsidence and various mechanical stresses (Giroux, 2021, pp. 12–13).

Geotextiles are commonly used as a protective layer for geomembranes. It prevents perforation and mechanical damage to geomembranes. Furthermore, geotextiles act as filters, preventing the leaching of soil particles and increasing the stability of the channel structure (Giroux, 2021, pp. 8–10).

Geocomposite materials are also widely used in modern projects. Geocomposites are a combination of several geosynthetics and simultaneously perform waterproofing, filtration, and reinforcement functions. This feature makes their use in large irrigation systems more feasible.

The primary purpose of using geosynthetics in irrigation canals is to reduce seepage losses. It is known that in unlined canals, a certain amount of water is lost due to seepage into the soil layers. These losses reduce the overall efficiency of irrigation systems and lead to inefficient use of water resources.

Experimental studies conducted by Khan and colleagues showed that the combined use of a geomembrane and concrete lining reduces seepage losses by 86% compared to an unlined canal. In a geomembrane-concrete combination operated for three years, this figure was 68% (Khan et al., 2020, pp. 1–2).

Research by Gawande and colleagues examined the effect of geomembrane and geotextile layers on soil permeability. It was found that the use of double geomembranes reduces soil permeability by approximately 51%, while geotextile layers demonstrated good results, up to 26%. These results confirm the high efficiency of geosynthetics in reducing seepage losses (Gawande et al., 2018, p. 51).

In addition to technical performance, economic factors also play a significant role in the selection of materials used in irrigation canal reconstruction. Traditional concrete liners have long been considered the primary solution in irrigation systems. However, recent studies have shown that geomembranes and geocomposite materials demonstrate superior performance in a number of cases.

One of the main advantages of geomembranes is their faster installation. Constructing concrete liners requires a large quantity of building materials, specialized equipment, and lengthy construction work. Geomembranes, on the other hand, are manufactured in a factory, delivered to the site, and installed quickly. This reduces construction time and labor costs.

Water conservation is one of the most important economic indicators. Reducing water loss makes it possible to irrigate larger areas with the same volume of water. This creates conditions for increasing agricultural productivity and optimizing water resource use. Research by Khan and his colleagues shows that the combined use of geomembranes and concrete liners significantly improves water transport efficiency and proves effective in long-term operation (Khan et al., 2020, pp. 2–3).

This issue is particularly relevant for Azerbaijan. The Upper Shirvan Canal reconstruction project indicates that the canal reconstruction will prevent an annual reduction in water loss of approximately 346 million m³ and improve water supply to over 230,000 hectares of land. These indicators clearly demonstrate the economic significance of modern waterproofing technologies.

CONCLUSION. The study demonstrates that water losses due to seepage in irrigation canals are one of the main factors reducing the efficiency of water resource use in agriculture. With declining water resources and increasing agricultural water demand due to climate change, improving the technical condition of existing irrigation systems is particularly important. In this regard, the use of modern geosynthetics in the reconstruction of irrigation canals is considered an important technological solution.

The study results show that geomembranes, geotextiles, and geocomposite materials possess high waterproofing properties, significantly reducing seepage losses. The elasticity, durability, and water resistance of geomembranes demonstrate a number of advantages over traditional concrete pavements. Using geotextiles as a protective layer increases the mechanical strength of geomembranes and enhances the reliability of the waterproofing system.

Based on the analysis of scientific sources, it was determined that the joint application of geomembrane and concrete linings allows reducing canal leakage by more than 80% compared to unlined canals. As a result of the use of geosynthetic materials, the efficiency of irrigation systems increases, losses during water transportation are reduced, and water supply to agricultural areas is improved. At the same time, the risks of soil salinization and waterlogging are minimized.

The reconstruction projects of the Shirvan and Karabakh canals implemented in the Republic of Azerbaijan show that the application of modern waterproofing technologies makes a significant contribution to the protection of water resources and the modernization of irrigation systems. As a result of the reconstruction of the Shirvan canal, hundreds of millions of cubic meters of water loss are expected to be saved annually, which confirms the economic and environmental efficiency of the application of geosynthetic materials and innovative canal linings.

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ADVANTAGES OF DRIP IRRIGATION TECHNOLOGY AND ITS APPLICATION IN INTENSIVE ORCHARDS

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Abstract

This article examines the advantages of drip irrigation technology and its application in intensive orchards under the conditions of climate change in Azerbaijan. The increasing frequency of droughts, rising air temperatures, irregular precipitation patterns, and growing pressure on available freshwater resources have become major challenges for agricultural production worldwide. These factors are particularly significant for Azerbaijan, where agriculture plays an important role in the national economy and where fruit growing is one of the most promising sectors. In recent years, the efficient management of water resources has become a priority for ensuring sustainable agricultural development and maintaining food security. Therefore, the introduction of modern water-saving technologies, especially drip irrigation systems, has gained considerable importance.

The study analyzes the current state of water resources in Azerbaijan, identifies the main factors contributing to water scarcity, and evaluates the impact of limited water availability on agricultural productivity. Particular attention is given to the role of irrigation systems in intensive orchards, where maintaining optimal soil moisture is essential for achieving high yields and producing quality fruit. The findings indicate that traditional irrigation methods, including surface and furrow irrigation, often result in substantial water losses through evaporation, runoff, and deep percolation. In contrast, drip irrigation technology delivers water directly to the root zone of plants, significantly improving water-use efficiency and reducing unnecessary losses.

The research demonstrates that drip irrigation systems provide numerous agronomic, economic, and environmental benefits. By supplying water in controlled quantities according to crop requirements, the technology helps maintain optimal soil moisture conditions throughout the growing season. This contributes to improved root development, enhanced nutrient uptake, and more efficient fertilizer use through fertigation practices. As a result, crop productivity increases while production costs associated with water and fertilizer use are reduced. Furthermore, drip irrigation minimizes weed growth, decreases soil erosion risks, and reduces the incidence of plant diseases associated with excessive moisture.

The article also reviews international experience and successful examples from Azerbaijan regarding the implementation of drip irrigation systems in intensive orchards. Evidence from various countries shows that drip irrigation can reduce water consumption by 30–60% while simultaneously increasing fruit yields and improving product quality. Similar results have been observed in Azerbaijan, where modern irrigation technologies have contributed to higher agricultural efficiency and more sustainable use of water resources.

The study concludes that the wider adoption of drip irrigation technology represents an effective adaptation strategy to climate change. Expanding its application in intensive orchards can significantly enhance water conservation, increase agricultural productivity, strengthen environmental sustainability, and improve national food security. Therefore, the development and promotion of drip irrigation systems should be considered a strategic priority for the future modernization of Azerbaijan's agricultural sector.

Keywords: climate change, intensive gardens, drip irrigation, water scarcity, agriculture, productivity, sustainable development, food security

Introduction. Efficient use of water resources in agriculture is currently considered a key factor in ensuring global food security. Climate change, increased drought periods, uneven rainfall distribution, and declining water resources are reducing the efficiency of traditional irrigation methods. For this reason, the use of water-saving technologies is expanding worldwide, particularly in regions with intensive horticulture. Among these technologies, drip irrigation is considered one of the most effective.

With drip irrigation, water is delivered directly to the plant's root zone through special pipes and drippers. This method prevents water from spreading across the soil surface and minimizes losses due to evaporation. While traditional furrow or surface irrigation methods lose a significant amount of water through infiltration, runoff, and evaporation, most of the water delivered with drip irrigation is absorbed by the plant. This feature is particularly important in Azerbaijan, where water resources are limited. Huseynova's study notes that Azerbaijan's agricultural sector consumes approximately 70% of the country's freshwater resources, with a significant amount lost through existing traditional irrigation methods. The author emphasizes the importance of using drip irrigation technologies to reduce water loss and improve water efficiency (Huseynova, 2023, pp. 2-3).

The use of drip irrigation in intensive orchards goes beyond water savings. This technology helps maintain optimal moisture levels throughout the growing season. Maintaining stable soil moisture improves root development, accelerates nutrient absorption, and increases plant resistance to stress factors. As a result, tree development accelerates, productivity increases, and fruit quality improves.

Research conducted in the Mediterranean region, where the effects of climate change are more pronounced, confirms these findings. Research by Branquinho and his colleagues in super-intensive olive groves has shown that irrigation water demand will increase in the future due to rising temperatures and decreased precipitation. However, water consumption can be reduced by up to 22% through the use of drip irrigation and controlled deficit irrigation regimes. The authors concluded that drip irrigation systems are one of the most promising methods for climate change adaptation (Branquinho et al., 2021, pp. 1–2).

Another important advantage of drip irrigation is that it allows for the application of fertilizers along with water. This method, known as fertigation, delivers nutrients directly to the root zone and prevents their leaching into the soil layers. As a result, the consumption of mineral fertilizers is reduced and plant nutritional conditions are improved. This leads to lower production costs and increased economic efficiency in intensive horticulture.

Drip irrigation is also important for soil protection. Traditional irrigation methods result in erosion on the soil surface. Particularly on slopes, surface runoff causes erosion of the fertile soil layer. With drip irrigation, because water is applied in small amounts, the risk of damage to the soil structure and erosion is minimized. This feature helps maintain soil fertility over the long term.

Observations conducted in orchards show that productivity indicators on farms using drip irrigation systems are higher than in orchards using traditional irrigation methods. Fruit size, sugar content, and durability are also improved. This leads to increased market competitiveness and increased farmer income.

MAIN PART. The decline of global water resources due to climate change is considered one of the main threats to agricultural development. In recent decades, rising global temperatures, uneven rainfall distribution, and intensifying droughts have necessitated the development of new approaches to water resource management. Since agriculture is directly dependent on climate factors, the impact of these changes primarily affects the agricultural sector.

Similar trends are observed in Azerbaijan. In recent years, rising temperatures and unstable precipitation patterns have led to increased water demand in agriculture. Research has shown that in some years, reduced precipitation and high temperatures have led to droughts, reduced crop yields, and increased demand for irrigation. In particular, low precipitation and high temperatures observed in 2021–2022 had a negative impact on crop development (Aliyeva, 2026, pp. 46–47).

Fruit farming is a key area of agricultural production in Azerbaijan. In recent years, thanks to the development of intensive horticulture, the cultivation of apples, pears, peaches, nectarines, pomegranates, and other fruit crops has expanded. One of the key features of intensive orchards is their high yields. However, achieving this yield requires proper water supply. Water shortages lead to reduced photosynthesis in fruit trees, reduced fruit size, and deterioration in product quality.

Amid growing water shortages, the use of traditional irrigation methods poses a number of problems. With drip and surface irrigation, a significant portion of water is lost through evaporation, filtration, and runoff. This leads to inefficient use of water resources. A significant portion of water loss in Azerbaijan is caused by outdated and inefficient irrigation systems. According to Guseynova's research, approximately 70% of freshwater used in the country is used for agriculture, and significant amounts are lost in existing systems (Guseynova, 2023, p. 2).

Decreasing water resources impact not only agriculture but also the social well-being of rural populations. Research has shown that water shortages in some regions have led to reduced crop yields,

falling incomes, and the emergence of social problems. Therefore, ensuring the efficient use of water resources is of great importance from both an economic and social perspective.

Drip irrigation systems occupy a special place among water-saving technologies in modern agriculture. This technology is based on the application of water directly to the plant's root zone in small portions at regular intervals. As a result, water evaporation is minimized, and the amount of water absorbed by the plant increases.

One of the main advantages of drip irrigation is its reduced water consumption. Compared to traditional irrigation methods, this technology allows for 30-50% water savings. At the same time, it maintains a more stable soil moisture regime and creates optimal conditions for plant growth. This feature is especially important in intensive gardens.

Drip irrigation also has a positive effect on increasing crop yields. Because plants receive the required amount of water and nutrients, the size, weight, and quality of the fruit improves. At the same time, the market value of the produce increases, and farmers' incomes increase. Another advantage of this technology is its ability to fertigate. Applying fertilizer directly to the root zone along with water allows for more efficient nutrient absorption. This reduces fertilizer losses and prevents soil salinization.

Drip irrigation is also important for soil protection. Erosion and damage to the soil structure observed with traditional irrigation methods are minimal with this system. Maintaining the fertile soil layer helps maintain the orchard's productivity over the long term.

Experience from other countries shows that drip irrigation systems are a key element of climate change adaptation measures. Research conducted in highly intensive olive groves in Portugal found that water consumption can be reduced by up to 22% through drip irrigation and controlled deficit irrigation regimes, while maintaining productivity (Branquinho et al., 2021, pp. 1–2).

In Azerbaijan, the use of modern irrigation systems has been expanding in recent years with government support. The installation of drip irrigation systems on a number of fruit orchards has resulted in reduced water consumption, increased yields, and improved product quality. However, to achieve wider adoption of this technology, it is important to train farmers, strengthen technical support, and expand investment opportunities.

Thus, drip irrigation technology is one of the most promising technological solutions for the sustainable development of intensive orchards in the face of climate change. Its use significantly contributes to the protection of water resources, increased agricultural production efficiency, and improved food security.

CONCLUSION. *The study shows that climate change has become one of the main factors influencing agricultural development. Rising temperatures, uneven precipitation distribution, increased dry periods, and declining water resources have created new challenges in Azerbaijan's agricultural sector. These problems are particularly acute in intensive orchards, as plants require a stable water supply to ensure high yields.*

The study's results indicate that agriculture in Azerbaijan remains the primary consumer of water resources, and traditional irrigation methods result in significant water losses. Under current conditions, more efficient use of water resources should be considered a key prerequisite for sustainable agricultural development. In this regard, drip irrigation is an important tool for mitigating the negative impacts of climate change and protecting water resources.

It has been established that a drip irrigation system significantly reduces water consumption by delivering water directly to the plant root zone, maintaining optimal soil moisture, and creating favorable conditions for plant development. At the same time, this technology increases yields, improves fruit quality, utilizes fertilizers more efficiently, and protects soil fertility.

The study's results show that agriculture in Azerbaijan remains the primary consumer of water resources, while also enabling increased crop yields, improved fruit quality, more efficient use of fertilizers, and the preservation of soil fertility.

Analysis of international experience shows that drip irrigation systems are one of the most effective adaptation measures to climate change. The use of modern irrigation technologies helps conserve water resources, improve the economic efficiency of agricultural production, and enhance farm resilience to climate risks.

Against the backdrop of the expansion of intensive horticulture in Azerbaijan, further expansion of the use of drip irrigation systems is advisable. This requires increased government support for the

introduction of modern technologies, farmer training, modernization of irrigation infrastructure, and the application of innovative management mechanisms.

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Economic sciences

COMPARATIVE ANALYSIS OF THE EFFICIENCY OF MANAGEMENT DECISIONS IN SOCIAL SERVICE INSTITUTIONS BASED ON INTERNATIONAL EXPERIENCE

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Abstract

This paper examines the efficiency of management decisions in social service institutions through a comparative approach based on international experience. The study compares governance models applied in developed countries with existing practices in Azerbaijan and identifies the main criteria for evaluating decision-making effectiveness in the social sector. Special attention is given to transparency, accountability, result-oriented governance, digital transformation, data-based decision-making and citizen-oriented service delivery. The findings show that modern management paradigms, especially integrated service models, digital platforms and analytical decision-support systems, can substantially improve the quality, speed and social impact of services provided to vulnerable population groups.

Keywords: *social services, management decisions, efficiency, comparative analysis, international experience, governance*

Introduction: the role and importance of social decisions in modern governance

In the contemporary global governance environment, ensuring the effectiveness of decisions adopted in social service institutions has become one of the central directions of public administration. The welfare of vulnerable population groups, including families in need of financial assistance, elderly people living alone, persons with disabilities, children deprived of parental care and other categories requiring reliable social protection, depends directly on the quality of services delivered by these institutions. For this reason, management decisions in the social sector must be timely, fair, evidence-based and oriented towards measurable public value.

In this context, the comprehensive study of international experience and its adaptation to local realities are essential for the modernization of social service systems. Developed countries have accumulated considerable practical experience in designing service models that combine accessibility, transparency, inter-agency coordination, digital technologies and citizen participation. The analysis of such experience allows Azerbaijan to assess its own achievements more objectively and to identify areas where further institutional improvement is necessary [1].

Theoretical approach: the concept of result-oriented governance

In the academic literature, the effectiveness of management decisions is often evaluated through the prism of result-oriented governance and New Public Management. According to this approach, the effectiveness of managerial decisions should not be measured only by internal administrative indicators such as the number of processed applications or the formal fulfilment of institutional procedures. It should also include broader social outcomes, the real impact of decisions on service users and the level of satisfaction among citizens receiving social support [2].

The specific nature of social work gives this issue particular importance. Social services involve direct contact with people, the need for individualized treatment, sensitivity to human dignity and continuous attention to the principle of social justice. Therefore, the quality of management decisions in this field cannot be reduced to purely technical or bureaucratic efficiency. A decision may be fast, but if it does not reflect the real needs of the beneficiary, it cannot be considered fully effective. Conversely, a socially effective decision must combine legal correctness, administrative speed, professional assessment and human sensitivity.

The Scandinavian model as an advanced example

International experience shows that Scandinavian countries, particularly Sweden, Norway, Denmark and Finland, are among the most advanced examples in the organization of social services. In these countries, the preparation and implementation of decisions are based on openness, equality, social justice, attention to individual needs and the active participation of service recipients. This model is not

limited to the mechanical provision of benefits or services; it also emphasizes prevention, early intervention, social inclusion and the empowerment of citizens.

The strength of the Scandinavian approach lies in the combination of universal access and individualized support. Social service institutions in these countries try to ensure that citizens do not merely receive assistance but are also involved in decisions affecting their lives. As a result, the quality of services improves, public trust in state institutions increases and general indicators of social welfare are strengthened [3]. This experience is especially important for countries seeking to move from a fragmented social protection system to a more coordinated and citizen-centred model.

The impact of digital transformation in Europe

One of the main trends observed in developed European countries is the systematic and large-scale use of modern technologies in the management of social services. Electronic service platforms, interlinked databases of public institutions and advanced analytical software have accelerated the decision-making process, reduced the share of human errors and enabled more targeted use of limited budgetary resources [4].

Digital transformation provides several advantages for social service management. It allows institutions to verify information more quickly, reduce unnecessary documentation, monitor the status of applications in real time and detect overlapping or duplicated services. At the same time, digital tools make managerial decisions more transparent and traceable. When decisions are supported by reliable data, it becomes easier to justify them, evaluate their consequences and correct mistakes at an early stage.

However, digitalization should not be understood as a substitute for professional judgement. In the social sector, technology must support, not replace, human-centred assessment. Vulnerable citizens often face complex social, psychological and economic problems that cannot always be understood through automated indicators alone. Therefore, the most successful international models are those that combine digital efficiency with professional social work, ethical standards and direct communication with beneficiaries.

Azerbaijan's DOST model: service diversity and the one-stop-shop principle

In Azerbaijan, important and systematic measures have been implemented to modernize social services, align them with international standards and increase their accessibility for all segments of the population. In this regard, the establishment of DOST centres, based on the principle of Sustainable and Operative Social Security, represents a significant institutional innovation. These centres integrate different types of social services in a single administrative space and operate according to the one-stop-shop principle.

DOST centres provide citizens with a broad range of services, including the assignment and payment of labour pensions; the allocation of social benefits, disability-related payments, family benefits and other compensations; employment services; vocational guidance; and unemployment-related support. In addition, these centres participate in identifying persons in need of social services, including elderly people, persons with disabilities, children, women exposed to violence and other vulnerable groups. They also facilitate placement in stationary social service institutions, social and psychological support, electronic document circulation, public service registration and related administrative procedures.

Overall, more than 150 types of services have been concentrated in one place through this model. The integration of services has reduced document circulation, shortened waiting times, decreased the need for citizens to apply to several institutions separately and created conditions for faster and more coordinated decision-making. These innovations have made management decisions in the social sector more operative, transparent and citizen-oriented [5].

International experience: the impact of integrated service models on population welfare

In many countries, there are social service centres similar to the DOST model, operating on the basis of one-stop-shop or single-entry principles. Such models may produce both positive effects and certain risks for population welfare. Their overall effectiveness depends on the quality of institutional design, the level of digital inclusion, the coordination capacity of public agencies and the protection of personal data.

First, integrated service systems save time and increase citizen satisfaction. In a centralized service model, citizens do not have to visit several public institutions to solve a single social problem. The Swedish Service Centre model operates on this principle, and available studies indicate a high level of citizen satisfaction with the system. In Germany, the integrated service mechanism of Jobcenters has helped reduce waiting times for jobseekers and improve the coordination of employment-related support.

Second, integrated service models improve access for vulnerable groups. Persons with disabilities, elderly people and citizens living in remote areas often face geographical, administrative and informational barriers. A one-stop-shop model reduces these barriers by simplifying procedures and concentrating several services in one accessible space. In the United Kingdom, the Tell Us Once system allows citizens to provide information once and enables several public institutions to update their databases accordingly.

Third, digital integration creates opportunities for more efficient resource allocation. When public institutions exchange data securely and systematically, repeated data collection decreases, fraud risks may be reduced and budgetary resources can be directed more accurately to those who really need support. In this sense, integrated digital systems are not only administrative tools but also instruments for improving social justice.

Possible risks and challenges

Despite their advantages, integrated and digital service models also create several challenges. The first challenge is digital exclusion. Elderly citizens, people with limited digital skills, migrants and some vulnerable groups may experience difficulties in using online platforms. If digital services are expanded without parallel support mechanisms, a part of the population may become less able to access social protection.

The second challenge is data security. The concentration of citizens' personal information in unified databases increases cybersecurity risks. Compliance with data protection standards, including the principles reflected in the General Data Protection Regulation, is therefore essential. Without strong security mechanisms, digital transformation may weaken public trust instead of strengthening it.

The third challenge is the risk of depersonalization. Automated systems may sometimes fail to respond flexibly to cases requiring individual assessment. This problem is particularly relevant in situations involving psychological support, family crises, domestic violence, disability assessment or complex social vulnerability. Social services must therefore preserve a balance between automation and human-centred professional intervention.

The fourth challenge is inter-agency coordination. Full integration of databases and procedures belonging to different state institutions is technically and organizationally complex. If coordination remains formal or incomplete, the one-stop-shop model may lose part of its practical effectiveness. For this reason, institutional cooperation, clear division of responsibilities and stable information exchange mechanisms are necessary conditions for success.

Improvements applicable to Azerbaijan

Although the DOST model is already functioning successfully, the analysis of international experience shows that several additional improvements could further increase the inclusiveness, security and efficiency of Azerbaijan's social service system. The first direction is the expansion of mobile platforms. Following examples such as the United Kingdom's Tell Us Once system and Germany's Mein Jobcenter application, DOST services could be presented through a more comprehensive mobile application that would allow citizens to submit applications, track their status and receive notifications without leaving their homes.

The second direction is the organization of training programmes for elderly citizens and persons with limited digital skills. To prevent digital exclusion, special training courses, stronger call centres and local assistance points could be established. Such measures would ensure that digital transformation does not create new inequalities in access to social services.

The third direction is the use of artificial intelligence-based forecasting systems. On the basis of international experience, artificial intelligence tools may be used to identify social risk groups, forecast demand for services and support the automatic calculation of certain pension or benefit amounts. However, such systems must operate under human supervision and must be designed in accordance with ethical and legal requirements.

The fourth direction is the expansion of psychological and social support services. In addition to administrative procedures, DOST centres could further strengthen psychological counselling, social education, activation programmes and employment support services. This would transform social service centres from purely administrative units into broader social support platforms.

The fifth direction is the strengthening of cybersecurity and personal data protection. The protection of citizens' information should be treated as an integral part of social service quality. Data protection mechanisms based on international standards would help prevent unauthorized access and increase public confidence in digital social services.

If these measures are implemented, Azerbaijan's social service system may become more inclusive, secure, efficient and citizen-oriented in comparison with international practice. In particular, improvements in service quality, reductions in citizens' time and financial costs, savings in public expenditure and greater public trust in government institutions may be expected.

General findings of the comparative analysis

The comparative analysis carried out in this paper demonstrates that Azerbaijan's social service system has achieved significant progress in recent years. The establishment of DOST centres, the integration of different services, the use of digital tools and the emphasis on citizen satisfaction show that the country has moved towards a more modern model of social service governance.

At the same time, the full realization of the system's development potential requires continued work in several priority areas. In particular, analytical assessment should be strengthened at the stage of decision preparation; mechanisms for collecting and processing large volumes of data should be improved; and data-driven governance concepts should be applied more widely. These steps would allow managers to base their decisions not only on administrative routines but also on evidence, risk assessment and measurable social outcomes.

The international comparison also shows that the effectiveness of social service institutions depends on the interaction of several factors. Institutional transparency, professional competence, digital capacity, citizen participation, inter-agency coordination and ethical responsibility must work together. If one of these elements remains weak, the overall quality of management decisions may decline. Therefore, reform in this field should be understood as a complex and multi-level process rather than a single administrative measure.

Conclusion

The discussion above shows that improving the efficiency of management decisions in social service institutions is a complex, dynamic and intersectoral process. International experience confirms that the most effective social service systems are those that combine result-oriented governance, digital innovation, professional social work and citizen-centred values. For Azerbaijan, the DOST model has already created an important institutional foundation for such development.

Nevertheless, further progress requires continuous improvement of analytical tools, stronger data protection, broader digital inclusion and deeper integration of psychological and social support services. International models should not be copied mechanically; they should be critically evaluated and adapted to the local context. In this way, the social service system can become more sustainable, fair, innovative and responsive to the real needs of citizens.

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INNOVATION, DIGITALISATION AND ARTIFICIAL INTELLIGENCE: KAZAKHSTAN'S TECHNOLOGICAL DEVELOPMENT TRENDS IN ACTION

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Abstract
The article discusses modern trends in the technological development of Kazakhstan, the roles and goals of the state technological policy. Attention is focused on the need for state support for innovations, the challenges of digitalisation and the introduction of artificial intelligence, to which society must adequately respond, are shown.

Keywords: *Innovation, Digitalization, Artificial Intelligence, Technological Development, the Republic of Kazakhstan*

INTRODUCTION

Modern society faces the need to constantly seek answers to a rapidly growing number of global challenges linked to the escalating geopolitical situation, demographic changes, environmental and climate issues, the threat of new pandemics, and rapidly advancing technological progress, which is rapidly transforming the structure and technological foundations of the global economy. Moreover, technological challenges are of particular importance, as it is precisely the development and adoption of new cutting-edge technologies that, to a large extent, enables us to find solutions to all other current challenges, thereby contributing to enhanced national security and sustainable economic development.

The scramble for technological dominance is taking on particular significance today. This is because new technologies are creating new markets and becoming a driver of global growth [1].

The intensification of competition in the technology sector and the scale of the impact of technology on economic development are fundamentally changing the role of state involvement in this process. Today, the success of this endeavour depends largely not so much on the activities of major technology companies as on the government's proactive approach, its ability to formulate an effective technology policy, to identify the key priorities for scientific and technological development – above all, those aligned with national development goals – and to establish a distinctive national innovation system tailored to these objectives [1].

MAIN PART

The aims and priorities of technology policy are shaped by current trends in the country's development and its strategic engagement with other nations. In this regard, the Republic of Kazakhstan draws upon the Constitution of Kazakhstan, the Law of the Republic of Kazakhstan 'On Science and Technology Policy', the President's annual Addresses, CIS resolutions, and other relevant documents.

In accordance with the Law of the Republic of Kazakhstan, the main objectives of technology policy include:

- *the advancement of science;*
- *the implementation of science and technology policy aimed at applying scientific achievements to ensure the country's competitiveness;*
- *cross-sectoral coordination of scientific, scientific and technical, and innovation activities [2].*

According to the law, the main objectives of technology policy are [2]:

1) the formation of state science and technology policy and the regulation of relations in the field of science and technology;

2) the effective functioning of science and the implementation of science and technology policy;

3) the development of fundamental and applied scientific research;

4) raising the status of researchers and scientific organisations;

5) integrating science with industry;

6) providing human resources, material and technical, scientific and technical, and information support for science.

In Kazakhstan, the implementation of an innovation policy aimed at ensuring the country's sustainable development through the development of production of fundamentally new types of products and technologies, and the expansion of domestic markets on this basis, is one of the strategic priorities of state governance and regulation of the economy as a whole. Currently, the development and implementation of innovation policy is based on the formation of a national innovation system, which has been established with the aim of uniting the efforts of government bodies at all levels, scientific and technical organisations, and the business sector to accelerate the application of scientific and technical achievements, realise the state's strategic national priorities, and develop venture capital as one of its most effective mechanisms [3].

The following areas of state support for innovation are identified:

1) Regulatory and legal support:

– defining the key priorities for innovation;

– developing national, regional and sectoral innovation programmes;

– establishing a legal framework for innovation, copyright protection and the safeguarding of innovators' intellectual property.

2) direct and indirect financial support:

– funding for innovation activities from the state budget and specialised extra-budgetary funds;

– partial compensation of interest rates on commercial bank loans; provision of preferential terms and tax relief;

– full or partial exemption from tax payments for a specified period;

– granting the right to use state property.

3) organisational support:

– establishing development institutions (funds, programmes, associations);

– establishing an innovative infrastructure to support and develop innovation potential;

– providing scientific, methodological and informational support for innovation activities;

– creating conditions for the training of qualified personnel in the field of innovation;

– creating a favourable investment climate.

4) the provision of government incentives:

– government contracts (public procurement);

– the development of guaranteed markets for innovative products;

– raising the profile of innovation within society;

– the provision of guarantees ensuring the full or partial return of funds invested in innovative projects [4, c. 141].

In the context of regulatory and legal support, the following documents should be mentioned [5]:

– The Entrepreneurial Code of the Republic of Kazakhstan;

– The Digital Code of the Republic of Kazakhstan;

– The Environmental Code of the Republic of Kazakhstan;

– Law of the Republic of Kazakhstan «On the «Park of Innovative Technologies» Innovation Cluster»;

– Law of the Republic of Kazakhstan «On the Commercialisation of the Results of Scientific and (or) Scientific and Technical Activities»;

– Law of the Republic of Kazakhstan «On Public-Private Partnership»;

– Law of the Republic of Kazakhstan «On Industrial Policy»;

– Law of the Republic of Kazakhstan «On State Regulation of the Development of the Agro-Industrial Complex and Rural Areas»;

– Law of the Republic of Kazakhstan «On Informatisation»;

– Law of the Republic of Kazakhstan «On Special Economic and Industrial Zones».

The experience of leading market-based economies shows that, when it comes to innovative development, one should not rely entirely on market forces. The application of innovations is increasingly taking on a public character and cannot be merely a private concern of a particular firm or regional entity, as the social and economic prospects for a country's development are becoming ever more dependent on how organically innovative processes unfold within it [6].

In this regard, for the strategic development of the Republic of Kazakhstan, it is advisable to pursue a state innovation policy that prioritises innovative processes in enhancing the competitiveness of

Kazakhstani products, ensuring the country's economic security, and improving the population's standard of living.

In the context of globalisation and rapid technological progress, the development of the digital environment is becoming a key factor in the competitiveness and sustainable development of both individual organisations and entire countries. Understanding the role and significance of the digital environment in the modern world is essential for the successful adaptation and effective use of digital technologies.

The digital environment plays a key role in the development of modern society and the economy. It opens up new opportunities for business, education, healthcare, public administration and many other sectors.

Digitalisation makes it possible to improve the efficiency, speed and quality of service delivery, as well as to broaden access to information and knowledge. Furthermore, the digital environment fosters innovation, creates new jobs and stimulates economic growth.

Key trends in digitalisation include:

– Artificial intelligence and machine learning. The rapid development of artificial intelligence and machine learning technologies enables the creation of increasingly sophisticated systems capable of self-learning and decision-making. This finds application in various fields, from personalised recommendations to the automation of production processes.

– The Internet of Things (IoT). The rapid proliferation of internet-connected devices, from household appliances to industrial equipment, is creating new opportunities for data collection and analysis, as well as for remote control and automation.

– Big data and analytics. The accumulation of vast amounts of digital data generated by various sources, combined with advances in data processing and analysis methods, enables the extraction of valuable insights that are used to inform decision-making and optimise business processes.

– Cloud technologies. Cloud computing, which provides remote access to computing resources and data storage, is becoming increasingly widespread, offering flexibility, scalability and reduced IT-infrastructure costs.

– Mobile technologies and device convergence. The widespread use of smartphones, tablets and other mobile devices, as well as their integration with other gadgets and systems, is transforming the way we interact and consume content.

– Digital business transformation. Companies are actively integrating digital technologies into their business processes, seeking to improve efficiency, flexibility and competitiveness in a rapidly changing environment.

– Cybersecurity and data protection. Growing threats of cyberattacks and the need to ensure data confidentiality and integrity are becoming key priorities in the digital environment.

These and other trends are shaping the direction of the digital environment, opening up new opportunities whilst also creating new challenges and a need to adapt to rapidly changing conditions.

Digital transformation is having a significant impact on many industries and sectors. It is worth highlighting some of the sectors that are feeling the greatest impact of digitalization (Fig. 1)

Financial sector:

- Development of fintech solutions (such as mobile payments, online banking, cryptocurrencies and blockchain);
- Use of big data and analytics to personalise products and services, assess risks and make decisions;
- Automation of routine operations and the introduction of robo-advisory services.

Retail sector:

- Growth in e-commerce and omnichannel sales;
- The use of augmented reality, personalisation and geolocation technologies to enhance the customer experience;
- The use of big data to forecast demand and optimise supply chains.

Healthcare sector:

- Development of telemedicine and remote patient monitoring;
- Implementation of AI-based decision support systems;
- Use of big data and analytics to personalise treatment and improve outcomes.

Production sector:

- Implementation of the "Industry 4.0" concept, including the use of IoT, robotics, augmented reality and big data;
- Optimisation of processes and supply chains through the application of digital technologies;
- Transition to flexible, adaptive and personalised production models.

Education sector:

- The development of online learning, virtual classrooms and educational platforms;
- The use of virtual and augmented reality technologies to create interactive learning environments;
- The application of big data and analytics to personalise learning and assess effectiveness.

Public sector:

- The roll-out of e-government and digital public services;
- The use of big data and analytics to inform better management decisions;
- The development of ‘smart cities’ using IoT technologies to improve the efficiency of urban infrastructure.

Figure 1 – The impact of digitalisation on industries (compiled from source [7])

Digitalisation is affecting virtually every sphere of human activity, opening up new opportunities, boosting efficiency and transforming established models.

The year 2026 has been declared the ‘Year of Digitalisation and Artificial Intelligence’ in Kazakhstan, as part of which the implementation of eight large-scale sets of measures included in the relevant Plan has begun (Table 1):

Table 1 – Initiatives being implemented as part of the Digitalisation and Artificial Intelligence Plan

№№	Section	Activities	Further information
1	2	3	4
1	Strategic and regulatory support	the development of the «Digital Qazaqstan» Strategy, as well as the introduction of tax and regulatory incentives for domestic IT-companies	It is envisaged that at least 90% of key legislative initiatives in the fields of digitalisation, AI, data, cybersecurity, telecommunications and digital assets will be adopted and enacted in accordance with the established procedure
2	Human capital development	As part of the AI-SANA initiative, plans are in place to scale up the project to introduce AI education at all levels in schools and universities, as well as in retraining and professional development programmes for adults	At secondary education level, initiatives such as Day of AI Qazaqstan and the opening of TUMO Centres are being developed. These digital and AI skills development programmes will reach around 500,000 students and teachers across all levels of education and sectors. The first phase of AI University is set to launch, alongside the expansion of the Tomorrow School artificial intelligence school across Kazakhstan's regions to train AI specialists. Additionally, the 'AI Governance 500' programme is being implemented to train digital leaders in the public and quasi-public sectors. The AI Qyzmet programme for civil servants continues to develop, and a new programme for business, AI Corporate, is launching, which will teach company employees to delegate routine tasks to artificial intelligence
3	GovTech: a digital model of public administration	Focus on the digital workplace for civil servants, expanding e-government capabilities (including e-government for business), developing services within the Social Wallet, and implementing AI solutions on the National AI Platform	Coverage of at least 80% of civil servants with the Gov Workspace digital workspace, featuring a single sign-on to all key systems; the provision of at least 50 public services utilising AI; the migration of at least 30% of government information systems to the QazTech platform. Internet access on trains, aeroplanes, tourist locations and at border infrastructure facilities, including the launch of advanced Direct to Cell satellite connectivity. As a result, the quality of digital public services provided to citizens and businesses will improve by at least 75%
4-5	Cybersecurity and digital infrastructure	strengthening cybersecurity and personal data protection measures: reinforcing the unified information security framework, conducting cybersecurity audits of government information systems, addressing vulnerabilities, implementing mandatory information security measures, and other initiatives	Prioritising the migration of government information systems to the new government data center
6	Digitalisation of industries	automation of dispatch and operational management processes, data digitisation and the generation of big data, data analysis using AI, the creation of digital twins, the use of IoT sensors and drones, the implementation of a proactive and digital model of tax administration, and more	The focus is on implementing digital solutions in sectors that are key drivers of the economy. The integration of AI into all key energy management systems, whilst ensuring the cyber resilience of critical systems; The creation of at least 90% of geological data through the digitisation of a unified digital geological environment; launch and operation of a fully digital circuit for cross-border trade and logistics processes; coverage of agricultural land and production facilities with AI monitoring, increasing crop yields by 10% and providing a digital trace 'from field to shelf'; implementation of at least 30% of construction projects using digital master plans and BIM modelling; connection of at least 30% of financial institutions to a unified integrated digital environment for public services; development of digital platforms for the social and labour sectors, ensuring at least 90% coverage of key processes in digital format

7	Cities and regions	Comprehensive digital development of cities and regions. Provision of mobile internet access on roads, as well as the roll-out of 5G coverage in 20 cities. Transformation of Public Service Centres into Digital Public Service Offices, where self-service areas will be the norm. Plans include the launch of the Smart City project in Astana and the expansion of IT-hubs	High-speed internet access for 99% of the population; 100% 5G coverage in the 20 largest cities; an annual increase of at least 15% in the urban environment comfort index; the conversion of at least 20 Public Service Centers into digital public service offices with self-service areas
8	The New Economy	the development of the unmanned systems industry and the low-altitude economy (launching at least five pilot projects), the launch of a regulated crypto industry and digital assets, state-run mining, as well as the launch into orbit and export of domestic satellites.	
NOTE: Compiled from source [8]			

CONCLUSION

Thus, amidst the wide-ranging changes brought about by digital transformation in modern society, the development of artificial intelligence is attracting greater attention and, to some extent, causing concern. On the one hand, the economy and society need highly educated and highly skilled professionals; on the other hand, the areas where human intellectual abilities are directly applied are shrinking. They are gradually being replaced by AI, resulting in a reduction in both the number of jobs and the demand for workers [9; 10; 11; 12]. The development of the human internet is being actively complemented by the expanding Internet of Things. Robotisation has become commonplace in all spheres of human activity – from domestic life to business and public administration [13].

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THE ROLE OF DIGITAL TECHNOLOGIES IN OPTIMIZING SUPPLY CHAINS UNDER WARTIME CONDITIONS

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РОЛЬ ЦИФРОВИХ ТЕХНОЛОГІЙ У ОПТИМІЗАЦІЇ ЛАНЦЮГІВ ПОСТАЧАННЯ В УМОВАХ ВІЙНИ

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Вступ. *Повномасштабна війна суттєво трансформувала умови функціонування підприємств в Україні та актуалізувала питання забезпечення стійкості логістичних систем. Руйнування транспортної інфраструктури, обмеження доступу до окремих територій, перебої в роботі виробничих потужностей, дефіцит ресурсів і зміна традиційних маршрутів постачання створили безпрецедентні виклики для управління ланцюгами постачання. За таких умов підприємства змушені не лише адаптуватися до постійних змін зовнішнього середовища, а й оперативно перебудовувати внутрішні бізнес-процеси для збереження безперервності діяльності. Сучасні ризики функціонування економіки в умовах війни висувають нові вимоги до організації логістичних процесів, серед яких ключового значення набувають швидкість прийняття рішень, прозорість інформаційних потоків, здатність прогнозувати ризики та оперативно реагувати на зміни. Традиційні підходи до управління ланцюгами постачання дедалі частіше виявляються недостатньо ефективними в умовах високої невизначеності та нестабільності.*

У відповідь на ці виклики підприємства активізують використання цифрових технологій як інструменту підвищення ефективності логістичних процесів. Впровадження цифрових платформ, систем моніторингу та аналітики даних, технологій автоматизації, штучного інтелекту, хмарних рішень та цифрового управління запасами створює можливості для забезпечення гнучкості, адаптивності та стійкості ланцюгів постачання. Завдяки цифровим інструментам підприємства отримують можливість оперативно контролювати переміщення ресурсів, прогнозувати можливі перебої, оптимізувати маршрути та знижувати рівень логістичних втрат.

Особливої актуальності набуває дослідження ролі цифрових технологій у процесах оптимізації ланцюгів постачання саме в умовах війни, коли ефективність управлінських рішень безпосередньо впливає на економічну стабільність підприємств і їх здатність підтримувати конкурентоспроможність. У сучасних умовах цифрова трансформація виступає не лише напрямом розвитку бізнесу, а й необхідною умовою забезпечення безперервності діяльності та формування стійких механізмів функціонування економіки.

Мета дослідження *полягає у комплексному аналізі впливу цифрових технологій на ефективність управління ланцюгами постачання та обґрунтуванні практичних підходів до їх оптимізації в умовах посилення воєнних викликів і зростання логістичних ризиків.*

Виклад основного матеріалу. *Ланцюг постачання є інтегрованою системою взаємопов'язаних учасників, процесів і потоків, що забезпечують рух матеріальних, інформаційних та фінансових ресурсів від первинного постачальника сировини до кінцевого споживача. Його сутність полягає в координації та синхронізації діяльності всіх учасників з метою створення доданої вартості, мінімізації витрат та забезпечення своєчасного задоволення попиту. Структурно ланцюг постачання включає постачальників сировини, виробничі підприємства, логістичних операторів, дистриб'юторів, роздрібні мережі та кінцевих споживачів. Важливу роль відіграють також інформаційні системи, які забезпечують обмін даними між учасниками та координацію логістичних операцій. Таким чином, ланцюг постачання є складною багаторівневою системою, що функціонує на основі тісної взаємодії всіх його елементів.*

Сучасна теорія та практика менеджменту виокремлює декілька ключових підходів до управління логістичними системами. Функціональний підхід передбачає управління окремими

логістичними функціями, такими як закупівлі, транспортування, складування та збут. Процесний підхід акцентує увагу на безперервності та взаємопов'язаності логістичних процесів, розглядаючи їх як єдиний потік створення цінності [1].

Системний підхід передбачає розгляд ланцюга постачання як цілісної системи з урахуванням взаємозв'язків між її елементами та зовнішнім середовищем. Інтегрований підхід орієнтований на координацію діяльності всіх учасників ланцюга постачання з метою досягнення спільної ефективності. Останнім часом активно розвивається цифровий підхід, який базується на використанні інформаційних технологій, аналітики даних та автоматизації процесів управління.

Ефективність ланцюгів постачання визначається сукупністю внутрішніх і зовнішніх факторів. До ключових внутрішніх факторів належать рівень координації між учасниками, якість управлінських рішень, оптимізація запасів, швидкість виконання операцій та рівень цифровізації бізнес-процесів. Зовнішні фактори включають стан інфраструктури, рівень конкуренції на ринку, законодавче регулювання, макроекономічну стабільність, а також кризові умови, зокрема воєнні ризики. Важливе значення має також здатність підприємств до адаптації, впровадження інновацій та використання цифрових технологій для підвищення прозорості та гнучкості логістичних систем.

Отже, ефективність ланцюгів постачання формується на основі комплексної взаємодії організаційних, технологічних та зовнішніх факторів, що визначають здатність системи швидко реагувати на зміни середовища та забезпечувати стабільне функціонування бізнесу.

Цифровізація є ключовим драйвером трансформації сучасних логістичних систем, оскільки забезпечує перехід від традиційних, фрагментованих моделей управління до інтегрованих, гнучких і адаптивних ланцюгів постачання. Вона змінює саму логіку функціонування логістики: від реактивного реагування на проблеми до проактивного управління на основі даних і прогнозування. Завдяки цифровим технологіям логістика перетворюється на прозору систему з високим рівнем координації між усіма учасниками ланцюга постачання. Це особливо важливо в умовах нестабільності та криз, коли швидкість прийняття рішень і точність інформації визначають стійкість бізнесу. Цифровізація також сприяє інтеграції постачальників, виробників, логістичних операторів і споживачів в єдину інформаційну екосистему [2].

Сучасне управління ланцюгами постачання базується на широкому використанні цифрових технологій, серед яких ключове місце займають:

1) ERP-системи (Enterprise Resource Planning), що забезпечують інтегроване управління ресурсами підприємства, включаючи фінанси, закупівлі, виробництво та складські запаси. Вони формують єдину базу даних для прийняття управлінських рішень.

2) SCM-системи (Supply Chain Management), які орієнтовані на управління всім ланцюгом постачання, забезпечуючи координацію між постачальниками, виробниками та дистриб'юторами, а також оптимізацію логістичних потоків.

3) Big Data-аналітика, що дозволяє обробляти великі масиви даних для прогнозування попиту, виявлення ризиків, оптимізації запасів і прийняття стратегічних рішень.

4) IoT (Internet of Things) забезпечує відстеження товарів у реальному часі за допомогою сенсорів і пристроїв, що підвищує контроль над логістичними процесами.

5) Штучний інтелект (AI), який використовується для прогнозування попиту, автоматизації планування маршрутів, оптимізації складів та управління ризиками.

Впровадження цифрових технологій суттєво змінює ключові характеристики логістичних процесів, зокрема їх швидкість, прозорість і точність. Швидкість управління зростає завдяки автоматизації операцій, оперативному доступу до даних та можливості швидкого прийняття рішень на основі аналітики в реальному часі. Це дозволяє скорочувати час доставки, обробки замовлень і реагування на зміни попиту або перебої в постачанні. Прозорість забезпечується завдяки наскрізному відстеженню руху товарів і ресурсів у всьому ланцюгу постачання. Учасники отримують доступ до актуальної інформації про запаси, маршрути, статус доставки та можливі ризики, що знижує рівень невизначеності. Точність логістичних процесів підвищується за рахунок мінімізації людського фактору, використання автоматизованих систем планування та аналітичних моделей. Це дозволяє зменшити кількість помилок у прогнозуванні попиту, управлінні запасами та координації постачань [3].

В українських умовах, особливо в період воєнного стану, цифровізація стала критично важливою умовою безперервності бізнесу. Наприклад, компанія «Нова пошта» активно використовує цифрові рішення для автоматизації сортування, трекінгу відправлень і управління логістичною мережею, що дозволяє підтримувати стабільність доставки навіть у складних умовах.

Інший приклад, ROZETKA, яка інтегрує цифрові платформи управління замовленнями та складською логістикою, забезпечуючи швидку обробку великих обсягів онлайн-замовлень і координацію з партнерами-доставниками. Це дозволяє компанії адаптуватися до різких змін попиту та логістичних обмежень. Також мережа METRO Cash & Carry Ukraine використовує цифрові системи управління запасами та постачанням для оптимізації роботи з постачальниками та забезпечення безперебійного постачання товарів у роздрібні точки [4]. Узагальнення особливостей впровадження цифрових технологій у логістичну діяльність провідних українських підприємств подано в таблиці 1.

Таблиця 1

Використання цифрових технологій у логістиці українських підприємств

Підприємство	*Цифрові технології*	*Сфера застосування*	*Основні результати впровадження*
«Нова пошта»	*IoT, Big Data, автоматизовані сортувальні системи, мобільні застосунки*	*Управління доставкою, трекінг відправлень, оптимізація маршрутів*	*Підвищення швидкості доставки, точне відстеження вантажів у реальному часі, стійкість логістичної мережі в кризових умовах*
ROZETKA	*SCM-системи, ERP, цифрові платформи управління замовленнями*	*E-commerce логістика, складське управління, координація постачальників*	*Швидка обробка онлайн-замовлень, інтеграція з логістичними партнерами, зменшення часу виконання замовлень*
METRO Cash & Carry Ukraine	*ERP-системи, цифрове управління запасами, аналітика даних*	*Управління закупівлями, складськими запасами, постачанням*	*Оптимізація рівня запасів, зменшення втрат товарів, стабільність постачання у торгові точки*
Логістичні оператори (загалом)	*AI, Big Data, IoT*	*Планування маршрутів, прогнозування попиту, моніторинг поставок*	*Підвищення точності прогнозів, зниження витрат на логістику, підвищення прозорості ланцюгів постачання*

Проведений аналіз свідчить, що цифрові технології є ключовим фактором підвищення ефективності логістичних систем українських підприємств. Найбільш комплексний підхід до цифровізації демонструє компанія «Нова пошта», яка поєднує IoT-рішення, аналітику Big Data та автоматизовані сортувальні системи, що забезпечує високу швидкість і надійність доставки навіть в умовах кризових обмежень. Компанія ROZETKA ефективно інтегрує SCM- та ERP-системи для управління онлайн-замовленнями та координації складської й транспортної логістики, що дозволяє значно скорочувати час виконання замовлень і підвищувати рівень сервісу для кінцевих споживачів. У свою чергу, METRO Cash & Carry Ukraine демонструє результативне використання ERP-систем та цифрового управління запасами, що забезпечує стабільність постачання товарів і оптимізацію складських процесів.

Загалом, результати аналізу підтверджують, що впровадження цифрових технологій сприяє підвищенню швидкості логістичних операцій, покращенню їх прозорості та точності, а також забезпечує адаптивність ланцюгів постачання до умов нестабільного та кризового середовища, зокрема воєнного стану.

Воєнні дії в Україні суттєво трансформували умови функціонування логістичних систем підприємств, спричинивши глибокі структурні зміни в організації ланцюгів постачання та управлінні матеріальними потоками. Порушення традиційних ланцюгів постачання стало одним із перших і найбільш критичних наслідків війни. Руйнування транспортної інфраструктури, блокування портів, обмеження авіа- та залізничного сполучення призвели до розриву усталених міжнародних і внутрішніх логістичних маршрутів. Підприємства втратили доступ до традиційних постачальників і ринків збуту, що вимагало оперативного перегляду всієї логістичної архітектури. Зростання логістичних ризиків і невизначеності проявляється у підвищенні ймовірності затримок постачання, втрат вантажів, коливань вартості транспортування та нестабільності постачальницьких відносин. Воєнні умови значно ускладнили прогнозування попиту та планування запасів, що підвищило рівень операційної невизначеності для підприємств усіх галузей. Зміна маршрутів, постачальників і умов доставки стала вимушеним заходом адаптації бізнесу до нових реалій. Підприємства активно переорієнтовують логістичні потоки на альтернативні внутрішні та міжнародні маршрути, змінюють географію постачальників, а також переглядають умови контрактів з урахуванням підвищених ризиків і витрат на транспортування [5; 6].

Необхідність підвищення стійкості та адаптивності логістичних систем стала ключовим стратегічним пріоритетом. Підприємства впроваджують цифрові технології, диверсифікують постачання, створюють резервні канали доставки та підвищують гнучкість управлінських рішень. У цих умовах стійкість ланцюгів постачання визначається здатністю швидко адаптуватися до змін середовища та забезпечувати безперервність бізнес-процесів навіть у кризових умовах.

Впровадження цифрових технологій суттєво підвищує ефективність управління ланцюгами постачання, змінюючи якісні характеристики логістичних процесів та забезпечуючи більш високий рівень їх керованості, точності й адаптивності.

Підвищення оперативності прийняття рішень досягається завдяки використанню цифрових платформ, систем аналітики та обробки даних у режимі реального часу. Це дозволяє керівникам оперативно реагувати на зміни попиту, перебої в постачанні або логістичні ризики, що особливо важливо в умовах нестабільного середовища. Автоматизація інформаційних потоків зменшує часові витрати на збір та аналіз даних, підвищуючи швидкість управлінських рішень.

Оптимізація запасів і транспортних потоків забезпечується за рахунок використання аналітичних систем, штучного інтелекту та прогнозних моделей. Цифрові інструменти дозволяють більш точно планувати рівень запасів, уникати надлишків або дефіциту продукції, а також оптимізувати маршрути доставки. Це сприяє зменшенню простоїв і підвищенню ефективності використання ресурсів.

Мінімізація витрат і логістичних втрат є одним із ключових результатів цифровізації. Автоматизація процесів, скорочення ручних операцій та підвищення точності планування дозволяють зменшити операційні витрати, витрати на зберігання та транспортування, а також знизити рівень помилок у логістичних операціях.

Забезпечення безперервності бізнес-процесів набуває особливого значення в умовах криз і воєнних викликів. Цифрові технології дозволяють створювати резервні сценарії управління, відстежувати ризики в режимі реального часу та швидко переналаштовувати логістичні потоки. Це забезпечує стабільність функціонування підприємств навіть за умов порушення традиційних ланцюгів постачання [7; 8].

Висновки. *За результатами дослідження встановлено, що цифрові технології є ключовим чинником підвищення ефективності управління сучасними ланцюгами постачання. Їх використання забезпечує суттєве покращення основних параметрів логістичних процесів, зокрема оперативності прийняття управлінських рішень, точності планування та рівня координації між учасниками ланцюга постачання.*

Визначено, що впровадження цифрових інструментів сприяє оптимізації запасів і транспортних потоків, що дозволяє підвищити раціональність використання ресурсів та загальну ефективність логістичної діяльності підприємств. Окрім цього, цифровізація забезпечує мінімізацію витрат і скорочення логістичних втрат за рахунок автоматизації процесів та підвищення точності аналітичних розрахунків.

Доведено, що в умовах нестабільного та кризового середовища цифрові технології відіграють особливо важливу роль у забезпеченні безперервності бізнес-процесів, підвищенні стійкості ланцюгів постачання та адаптивності підприємств до зовнішніх викликів.

Окремо слід відзначити, що для України в умовах воєнного стану цифровізація логістики набула критичного значення. Вона дозволила вітчизняним підприємствам швидше адаптуватися до руйнування традиційних маршрутів постачання, обмежень інфраструктури та зростання логістичних ризиків. Практика провідних українських компаній свідчить, що саме впровадження цифрових рішень забезпечує стійкість бізнесу, підтримання операційної діяльності та збереження конкурентоспроможності навіть у надскладних умовах. Таким чином, цифрова трансформація виступає одним із ключових факторів стабільності та розвитку логістичних систем в Україні.

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Medical sciences

THE IMPACT OF ENERGY DRINKS, CAFFEINE CONSUMPTION, AND SLEEP QUALITY ON COGNITIVE FUNCTION DURING EXAMS

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Abstract

This study examined the relationship between energy drink and caffeine intake, sleep disturbance, and specific cognitive performance (focal attention and working memory) during a university final assessment period. Using an empirical approach, 22 student volunteers were observed. Participants were divided into an active stimulant group (n=12) and a non-stimulant control group (n=10). Assessment data were collected using digital Schulte grids and short-term memory tasks. Results showed that although energy drink consumption systematically reduced sleep duration, individual metabolic differences allowed a subset of subjects to maintain optimal cognitive performance. These measures were compared with validated baseline data from the PubMed repository.

Keywords: cognitive functions, adenosine stimulation, sleep architecture, academic assessment, psychophysiological characteristics.

Introduction:The final periods of academic semesters subject university students to high levels of intellectual pressure and mental fatigue. In order to mitigate this workload and artificially enhance productivity, the level of reliance on synthetic energy supplements and high-concentration caffeine products has increased among undergraduate students. Peer-reviewed data indicates that the criteria for selecting these products are closely linked to unique psychological motivations. For instance, a large-scale study tracked by a Korean university indexed in the PubMed system demonstrated that coffee consumption stems primarily from unconscious behavioral habits ($B = .345$, $p < 0.001$). Conversely, the usage of commercial energy drinks is directly motivated by a specific need for alertness ($B = .100$, $p < 0.01$) and the belief that it is beneficial for somatic health ($B = .120$, $p < 0.05$) [1]. Furthermore, the same literature proved that the synergistic effect of nicotine and high-dose caffeine further exacerbates the decline in subjective sleep quality [1].

Crucially, the neurological activity offered by these synthetic substances is limited in duration. Operating as competitive blockers of central adenosine receptors, they do not facilitate the recovery of the physical nervous system, but merely suppress fatigue signals. Consequently, shortened sleep duration and suboptimal rest cycles reduce information processing speed in the brain. The objective of this pilot study is to evaluate the direct relationship between energy drink dependence, nocturnal rest intervals, and objective cognitive performance within an official examination environment among a limited cohort of students.

Methodology:

The clinical sample for this observational study comprised 22 undergraduate volunteers actively undergoing seasonal academic assessments. Based on their self-reported consumption of commercial energy formulations during the 24-hour window preceding cognitive evaluation, the subjects were stratified into two mutually exclusive investigation arms:

1. The Facilitated Group (n=12): Undergraduates who routinely integrated taurine and caffeine-enriched energy beverages into their nocturnal preparation regimens to sustain prolonged mental performance.

2. The Unstimulated Group (n=10): Age-matched academic peers who purposefully sustained absolute abstinence from any chemical alertness-inducing agents throughout the pre-examination timeframe.

Nocturnal rest longevity was tracked for each individual participant. Directly prior to the official testing sequence, neural capabilities regarding concentration depth and working memory bandwidth were captured via digital diagnostic setups:

The Schulte Array Tracking Matrix: Deployed to quantify visual-spatial exploration velocities and attention allocation dynamics, with parameters recorded precisely in seconds.

The Digit-Sequencing Memory Test: Implemented to document real-time audio-visual recall thresholds and short-term cognitive retention capacities, with accuracy output calculated on a 100\% standardized scale.

The resulting numerical datasets were structured, curated, and evaluated utilizing descriptive statistical models.

***Results**:Statistical monitoring confirmed a substantial compression of the nocturnal rest window among a significant majority of the stimulant-consuming cohort. Nevertheless, the internal datasets within this experimental arm displayed a non-homogeneous pattern, highlighting pronounced idiosyncratic and individual variations.*

A total of 22 students aged 18–20 years from Interdent Medical College participated in the study. The participants were divided into two groups. The first group consisted of 12 students who reported sleeping between 2:00 and 3:00 a.m. during the examination period and consuming 1–2 energy drinks per day (Tassay Energy and Gorilla Energy) to remain awake. The second group consisted of 10 students who reported going to bed at approximately 10:00 p.m. and did not consume energy drinks.

Examination scores and memory test results were evaluated. Among the students who consumed energy drinks, 58.3% (n=7) demonstrated average or low academic performance, while 41.7% (n=5) achieved high scores. Among the students who did not consume energy drinks and maintained an earlier sleep schedule, 50% (n=5) achieved high examination scores, whereas the remaining 50% (n=5) showed reduced memory performance and obtained low examination results.

The findings suggest that the relationship between sleep patterns, energy drink consumption, and cognitive performance is complex and may be influenced by additional factors such as stress levels, study habits, individual learning abilities, and psychological well-being. Although some students maintained satisfactory academic performance despite sleep deprivation and energy drink consumption, others ***Statistical analysis***

Table 1 – Study Results

Variable	*Energy drink users(n=12)*	*Non users(n=10)*
Age	*18-20*	*18-20*
Bedtime	*02:00-03:00*	*22:00*
Energy drinks consumption	*1-2 cans/day*	*None*
High academic performance,n%	*5(41,7%)*	*5(50%)*
Average	*7(58,3%)*	*5(50%)*

No statistically significant difference was observed between the two groups regarding examination performance due to the small sample size. However, students who consumed energy drinks and slept later tended to demonstrate a higher proportion of average or low academic performance (58.3%) compared with non-users (50.0%).

Conclusion: The findings indicate that energy drink consumption and reduced sleep duration were associated with a higher proportion of average or low academic performance (58.3%). However, high academic achievement was observed in both groups, suggesting that examination outcomes and memory performance are influenced by multiple factors beyond sleep patterns and caffeine intake alone. Further studies with larger sample sizes are required to establish statistically significant associations.

Schulte table testing was additionally conducted to evaluate attention stability, concentration, and psychomotor processing speed among the participants. The results demonstrated clear variability between the two study groups.

Among students who consumed energy drinks and experienced reduced sleep duration, a tendency toward prolonged task completion time was observed. This group more frequently demonstrated reduced concentration stability, delayed responses, and occasional loss of sequence during the task, indicating decreased attentional efficiency under conditions of sleep deprivation combined with stimulant use.

In contrast, students who did not consume energy drinks and maintained regular sleep schedules generally exhibited faster completion times and more stable performance. Nevertheless, inter-individual differences were still observed within this group, as some participants demonstrated slower processing speed despite adequate sleep, suggesting the influence of additional cognitive, psychological, and behavioral factors.

Overall, the findings suggest that both sleep patterns and energy drink consumption may influence attention performance and psychomotor speed. However, these effects are not uniform across individuals.

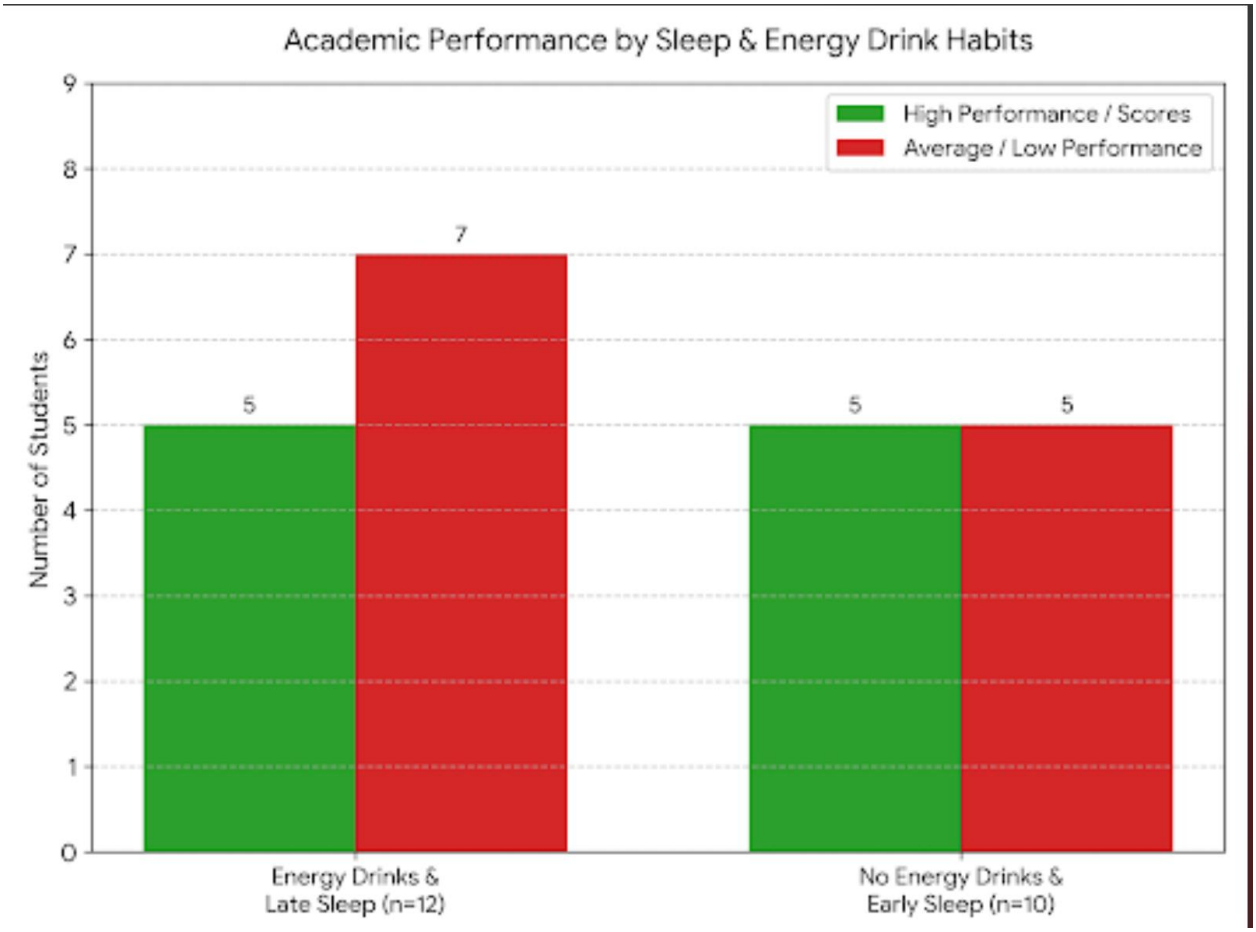

Diagram 1.

Data Summary Reference

Group 1 (Energy Drinks & Late Sleep - 12 students): 5 achieved high scores, while 7 demonstrated average or low performance.

Group 2 (No Energy Drinks & Early Sleep - 10 students): 5 achieved high scores, and 5 showed reduced performance.

4. Discussion

The most notable variability observed in this empirical study was the heterogeneous cognitive performance within the energy drink-consuming group (n = 12). Although this group demonstrated an overall tendency toward reduced performance in attention-based tasks, a subset of participants (n = 5; 41.7%) still achieved high academic results despite sleep reduction and stimulant intake. This suggests a possible inter-individual difference in physiological tolerance to caffeine, potentially associated with genetic variability in metabolic enzymes such as CYP1A2, as well as differences in baseline cognitive reserve.

When compared with non-users (n = 10), 50.0% (n = 5) achieved high academic performance, while the remaining 50.0% demonstrated average or low results. Interestingly, this indicates that adequate sleep alone did not uniformly guarantee superior cognitive outcomes, further supporting the role of additional factors such as stress level, learning efficiency, and psychological state.

Within the energy drink group, 58.3% (n = 7) exhibited average or low academic performance, suggesting that sleep deprivation combined with stimulant use may negatively influence cognitive stability in the majority of cases. However, the presence of high-performing individuals within the same group highlights the non-linear and individualized nature of cognitive response to caffeine and sleep restriction.

Overall, the data suggest that sleep quality and energy drink consumption interact in a complex manner, influencing attention and memory performance differently across individuals.

Conclusion

This pilot study demonstrates that energy drink consumption is associated with a higher proportion of average or low academic performance (58.3%) among medical students (n = 12). However, a considerable proportion of users (41.7%) still achieved high academic outcomes, indicating significant inter-individual variability in response to stimulant intake.

Among non-users (n = 10), performance was evenly distributed, with 50.0% achieving high academic results and 50.0% showing reduced performance, suggesting that sleep adequacy alone is not the sole determinant of cognitive efficiency.

Overall, while energy drinks may temporarily enhance alertness, they do not consistently improve academic performance and may contribute to cognitive instability in a substantial proportion of students. These findings highlight the multifactorial nature of cognitive performance, emphasizing the roles of sleep, individual physiology, and psychological factors.

Recommendations:

1. It is recommended to systematically monitor sleep patterns and stimulant (energy drink and caffeine) consumption behaviors among medical students, as significant inter-individual variability in cognitive performance has been observed.

2. The implementation of a sleep hygiene–based academic support model is suggested within educational institutions, including preventive interventions aimed at improving sleep quality, such as sleep scheduling guidance and behavioral regulation strategies.

3. The use of energy drinks as an academic performance enhancer should be limited or regulated, as the findings indicate that their effects are inconsistent and highly dependent on individual physiological responses.

4. Universities are encouraged to introduce screening systems for early detection of cognitive fatigue, utilizing tools such as the Schulte table and memory recall tests for periodic assessment of cognitive performance.

5. Further research is recommended to investigate the concept of an "individual caffeine sensitivity phenotype," with particular focus on the relationship between CYP1A2 metabolic variability and cognitive response to stimulant intake.

6. Additionally, future studies should employ multivariate analytical models, including regression analysis or machine learning approaches, to evaluate the combined effects of academic stress, sleep deprivation, and stimulant consumption on cognitive performance.

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OPTIMIZATION OF ANTICOAGULANT REGIMENS IN PATIENTS WITH IMPLANTED LEFT VENTRICULAR BYPASS DEVICES: A PROSPECTIVE COHORT STUDY BASED ON RETROSPECTIVE MULTINATIONAL DATA

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Abstract

Patients with left ventricular assist devices require lifelong anticoagulation due to the high risk of thromboembolic complications associated with artificial blood-contacting surfaces; however, the optimal anticoagulation regimen remains controversial because of the competing risks of bleeding and thrombosis. The aim of this study was to optimize anticoagulant strategies in LVAD recipients through a synthesis of retrospective multinational data and to develop a prospective cohort model based on pooled evidence. A total of 55 studies from Europe, Asia, Russia, CIS countries, North America, and Australia were analyzed, including more than 60,000 patients with continuous-flow LVADs. Data were extracted on anticoagulation regimens, INR targets, and clinical outcomes including bleeding, thromboembolism, pump thrombosis, and mortality. The results demonstrated that standard therapy consisting of heparin bridging followed by warfarin with or without antiplatelet agents remains predominant, although direct oral anticoagulants are increasingly used in selected populations. DOAC-based regimens were associated with a lower risk of major bleeding without a statistically significant increase in thromboembolic events. INR variability was identified as a critical determinant of outcomes, with optimal values ranging between 2.0 and 3.0. Based on these findings, a prospective cohort study model is proposed to validate individualized anticoagulation strategies in LVAD patients.

Keywords: *left ventricular bypass devices, thromboembolism, antiplatelet agents, major bleeding, transplantation, anticoagulation strategies.*

Introduction

Left ventricular assist devices have become a cornerstone in the management of advanced heart failure, serving both as a bridge to transplantation and as destination therapy, significantly improving survival rates and quality of life; however, despite technological advances in device design, hemocompatibility-related complications remain a major clinical challenge, particularly bleeding and thromboembolic events, which are directly influenced by anticoagulation strategies. The necessity of continuous anticoagulation arises from the interaction between blood and artificial surfaces, leading to activation of coagulation pathways and platelet aggregation, thereby increasing the risk of pump thrombosis and systemic embolism, while excessive anticoagulation predisposes to major bleeding, especially gastrointestinal and intracranial hemorrhage. Current clinical practice varies widely across regions, including Europe, Asia, and CIS countries, with most centers using vitamin K antagonists such as warfarin combined with antiplatelet therapy, although the emergence of direct oral anticoagulants has introduced new potential alternatives. Despite numerous studies, there is no consensus regarding optimal anticoagulation regimens, INR targets, or the necessity of concomitant antiplatelet therapy, highlighting the need for a comprehensive analysis of existing evidence and the development of prospective strategies aimed at improving patient outcomes.

Methods

This study was designed as a combined retrospective systematic analysis and prospective cohort modeling study, including 55 published studies identified through PubMed, Scopus, and Web of Science databases, with representation from Europe, Asia, Russia, CIS countries, North America, and Australia. Inclusion criteria consisted of studies involving adult patients with implanted continuous-flow LVADs, clearly defined anticoagulation regimens, and reported clinical outcomes such as bleeding events, thromboembolism, pump thrombosis, and mortality, while exclusion criteria included small case series, pediatric populations, and studies lacking sufficient data. Extracted variables included type of anticoagulation therapy such as vitamin K antagonists, direct oral anticoagulants, and heparin bridging, use of antiplatelet agents, INR targets, and clinical outcomes. Statistical analysis was performed using a random-effects meta-analytic approach to account for inter-study heterogeneity, with pooled risk ratios calculated for

major outcomes and meta-regression analysis conducted to evaluate the relationship between INR levels and clinical events. Based on pooled retrospective data, a prospective cohort model was constructed to simulate real-world clinical conditions and to define optimal anticoagulation strategies.

Results

The pooled analysis included over 60,000 patients with continuous-flow LVADs and follow-up durations ranging from 6 months to 5 years, demonstrating that the majority of patients received standard anticoagulation therapy consisting of initial heparin bridging followed by warfarin, with approximately 40% also receiving antiplatelet therapy, while 10–15% of patients in more recent studies were treated with direct oral anticoagulants. The incidence of major bleeding ranged from 15% to 45%, with gastrointestinal bleeding being the most common complication, and pooled data showed that DOAC-based regimens were associated with a significant reduction in major bleeding risk compared to warfarin, with relative risk reductions of approximately 30–35%. Thromboembolic events, including ischemic stroke and systemic embolism, occurred in 5–15% of patients, with no statistically significant difference observed between DOAC and warfarin groups, while pump thrombosis occurred in 2–10% of cases and was strongly associated with subtherapeutic anticoagulation levels. Meta-regression analysis revealed that INR variability was a key determinant of outcomes, with INR values below 2.0 associated with increased risk of thrombosis and values above 3.0 associated with increased bleeding risk, and the optimal INR range identified across studies was 2.0–3.0, although some centers reported acceptable outcomes with lower targets in selected high-bleeding-risk patients.

The findings of this study highlight the persistent and clinically significant challenge of balancing thrombotic and bleeding risks in patients with implanted left ventricular assist devices, confirming that anticoagulation management remains one of the most critical determinants of both short- and long-term outcomes despite continuous technological improvements in device design and hemocompatibility. The predominance of warfarin-based regimens observed across Europe, Asia, and CIS countries reflects historical clinical practice and guideline recommendations; however, the growing use of direct oral anticoagulants in recent studies suggests an ongoing paradigm shift toward more individualized and potentially safer anticoagulation strategies. One of the key findings of this analysis is the consistent reduction in major bleeding risk associated with DOAC-based regimens without a corresponding increase in thromboembolic events, which may be explained by their more predictable pharmacokinetics, fewer drug and dietary interactions, and absence of the need for frequent monitoring, in contrast to vitamin K antagonists that are highly sensitive to fluctuations in metabolism, comorbid conditions, and patient adherence. At the same time, it is important to emphasize that current evidence on DOAC use in LVAD patients remains limited and largely observational, and concerns persist regarding their ability to prevent pump thrombosis under high shear stress conditions within continuous-flow devices, which may require higher levels of anticoagulation intensity compared to atrial fibrillation or venous thromboembolism populations.

Table 1. Baseline characteristics and anticoagulation strategies in pooled LVAD cohort (n > 60,000)

Variable	*Value*
Total patients	*>60,000*
Regions	*Europe (36%), Asia (27%), CIS/Russia (18%), North America/Australia (19%)*
Mean age	*52–64 years*
Male (%)	*72–78%*
LVAD type	*Continuous-flow (92%)*
Follow-up	*6 months – 5 years*
Warfarin-based therapy	*85%*
DOAC-based therapy	*10–15%*
Antiplatelet use	*~40%*
Target INR (most common)	*2.0–3.0*
Lower INR strategy (1.5–2.5)	*~20% centers*

Table 2. Clinical outcomes by anticoagulation regimen

Outcome	*Warfarin*	*DOACs*	*Relative Effect*
Major bleeding	*25–45%*	*15–30%*	*↓ 30–35%*
Ischemic stroke	*8–15%*	*6–12%*	*≈ no difference*
Pump thrombosis	*3–10%*	*2–8%*	*≈ no difference*
Mortality (1-year)	*20–30%*	*18–28%*	*slight ↓*

Discussion

The role of antiplatelet therapy remains controversial, as approximately 40% of patients in the pooled cohort received concomitant antiplatelet agents, yet the overall benefit in reducing thrombotic events appears limited, while the associated increase in bleeding risk is consistently reported across

studies. This raises important clinical questions regarding the necessity of dual therapy in all patients and suggests that a more selective approach based on individual thrombotic risk factors, such as prior pump thrombosis, device type, or hypercoagulable states, may be more appropriate. Furthermore, regional differences identified in this analysis, particularly between European and Asian cohorts, may reflect variations in clinical protocols, genetic factors affecting coagulation pathways, differences in body mass index, and healthcare system infrastructure, including access to regular INR monitoring and multidisciplinary LVAD care teams, all of which can influence anticoagulation quality and outcomes.

Another critical observation of this study is the strong association between INR variability and adverse outcomes, confirming that both subtherapeutic and supratherapeutic anticoagulation levels significantly increase the risk of complications, with INR values below 2.0 predisposing to thrombotic events such as pump thrombosis and ischemic stroke, while values above 3.0 markedly increase the risk of major bleeding, particularly gastrointestinal hemorrhage, which is known to be highly prevalent in LVAD patients due to acquired von Willebrand syndrome and angiodysplasia formation. This finding underscores the importance of strict anticoagulation monitoring and supports the concept of narrower therapeutic windows tailored to individual patient risk profiles. Interestingly, several centers reported acceptable outcomes with lower INR targets in patients at high bleeding risk, suggesting that de-escalation strategies may be safe in selected populations, although such approaches require validation in prospective studies.

The clinical implications of these findings are substantial, suggesting that future anticoagulation strategies in LVAD patients should move toward personalized medicine approaches that integrate patient-specific risk factors, device characteristics, and dynamic monitoring of coagulation status, potentially incorporating biomarkers, point-of-care testing, and digital health tools to improve anticoagulation control. In addition, the development of standardized protocols across regions and centers may help reduce variability in clinical practice and improve overall outcomes. Importantly, the proposed prospective cohort study based on these findings provides a structured framework to validate the safety and efficacy of alternative anticoagulation strategies, including reduced-intensity warfarin therapy and DOAC-based regimens.

Conclusion

This study has several limitations that should be acknowledged, including the retrospective nature of the included data, heterogeneity in study design and patient populations, variability in outcome definitions, and the lack of randomized controlled trials directly comparing anticoagulation strategies in LVAD patients, which may introduce bias and limit the generalizability of the findings; however, the large pooled sample size and inclusion of diverse geographic regions enhance the robustness and external validity of the results. Future research should focus on well-designed prospective and randomized studies to establish evidence-based guidelines for anticoagulation in LVAD patients and to further explore the role of emerging therapies and technologies in optimizing patient care.

Optimization of anticoagulant regimens in patients with implanted left ventricular assist devices requires a careful balance between preventing thromboembolic complications and minimizing bleeding risk, with current evidence supporting the continued use of warfarin as the standard therapy while highlighting the potential role of direct oral anticoagulants as safer alternatives in selected populations; individualized anticoagulation strategies based on patient risk profiles, strict INR control, and reconsideration of antiplatelet therapy may significantly improve clinical outcomes, and the proposed prospective cohort study provides a structured framework for validating these approaches in real-world clinical practice.

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EVALUATION OF HPV DNA TESTING VERSUS CYTOLOGY FOR THE DETECTION OF CIN II+: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Abstract

A substantial burden of morbidity and mortality in women worldwide is attributed to cervical cancer, with persistent high-risk HPV infection recognized as its principal etiological cause. Timely detection of high-grade cervical intraepithelial neoplasia (CIN II+) is essential for effective prevention strategies. This systematic review and meta-analysis aimed to evaluate and compare the diagnostic performance of HPV DNA testing and conventional cytology in identifying CIN II+ lesions. A total of 56 studies from Europe, CIS countries, North America, Japan, and China were analyzed, including both retrospective and prospective data. Five principal statistical indicators were assessed: sensitivity, specificity, diagnostic odds ratio (DOR), area under the receiver operating characteristic curve (AUC), and heterogeneity (I^2). The findings indicate that HPV DNA testing provides substantially higher sensitivity but lower specificity compared to cytology. The pooled sensitivity of HPV testing was 0.94 (95% CI: 0.91–0.96), while cytology demonstrated 0.72 (95% CI: 0.68–0.76). In contrast, specificity was higher for cytology at 0.94 (95% CI: 0.91–0.96) compared to 0.86 (95% CI: 0.82–0.89) for HPV testing. These results support the use of HPV DNA testing as a more effective primary screening method, particularly within structured screening programs.

Relevance and Purpose of the Research

The significance of this study stems from the pressing global demand to enhance cervical cancer screening strategies, particularly in settings characterized by high disease burden and constrained healthcare resources. Early and accurate identification of CIN II+ lesions plays a pivotal role in preventing progression to invasive cervical cancer, thereby reducing mortality rates and improving overall health outcomes among women. In light of the known limitations of conventional cytology and the increasing implementation of HPV DNA testing, establishing robust evidence on their comparative diagnostic effectiveness is of critical importance.

This study aims to deliver a comprehensive and evidence-based assessment of the diagnostic accuracy of HPV DNA testing in comparison with cytology. Through the integration of data from diverse international studies and the application of standardized statistical methodologies, the analysis seeks to resolve inconsistencies reported in the existing literature and to inform clinical and public health decision-making. Ultimately, this research is intended to support the optimization of cervical cancer screening programs and to facilitate the adoption of more effective, reliable, and accessible diagnostic strategies.

Keywords: *HPV DNA testing, cytology, CIN II+, cervical cancer screening, meta-analysis, diagnostic accuracy*

Introduction

Cervical cancer remains a substantial global health challenge, with a disproportionate impact in low- and middle-income countries. According to recent epidemiological estimates, it is among the four most common malignancies affecting women worldwide. Persistent infection with high-risk human papillomavirus (HPV), particularly genotypes 16 and 18, has been firmly established as the primary driver of cervical carcinogenesis. Over recent decades, screening approaches have undergone significant development, with cytology (Pap smear) traditionally serving as the foundation of early detection programs. However, its effectiveness is constrained by relatively moderate sensitivity and considerable interobserver variability.

In recent years, HPV DNA testing has gained recognition as a viable alternative due to its superior sensitivity in identifying precancerous lesions. Evidence from large-scale clinical trials and longitudinal cohort studies indicates that HPV-based screening enhances the detection of CIN II+ lesions. Nonetheless, its comparatively lower specificity raises concerns regarding potential overdiagnosis and the consequent increase in healthcare utilization.

Although numerous comparative studies have been conducted, heterogeneity in study design, population characteristics, and diagnostic thresholds has resulted in inconsistent findings. Consequently, a comprehensive synthesis of available evidence is required to generate more reliable conclusions. The present study therefore seeks to systematically assess and compare the diagnostic accuracy of HPV DNA testing and cytology using standardized statistical metrics.

Methods

The present systematic review and meta-analysis was performed in accordance with the PRISMA guidelines. A total of 56 studies published between 2005 and 2025 were included in the analysis. Literature was retrieved from PubMed, Scopus, Web of Science, as well as relevant regional medical databases. Eligibility criteria comprised: (1) studies assessing HPV DNA testing and/or cytology for the detection of CIN II+, (2) provision of sufficient data to calculate diagnostic accuracy parameters, and (3) use of histopathological examination as the reference standard. Both retrospective and prospective study designs were considered.

Data extraction was conducted independently by two reviewers to ensure accuracy and consistency. Collected variables included study design, sample size, geographic location, screening modality, and diagnostic outcomes. Any disagreements were resolved through discussion and consensus.

For the comparative analysis, five key statistical indicators were evaluated: sensitivity, specificity, diagnostic odds ratio (DOR), area under the receiver operating characteristic curve (AUC), and heterogeneity (I^2 statistic). Given the anticipated variability across studies, a random-effects model was applied. Subgroup analyses were additionally performed according to geographic region and study design. Assessment of publication bias was carried out using funnel plots in conjunction with Egger's test. All statistical analyses were performed using RevMan and Stata software.

Results

A total of 56 studies involving more than 500,000 women were included in the meta-analysis. Of these, 32 studies had a prospective design, while 24 were retrospective. The studies were geographically distributed across Europe (18 studies), CIS countries (8), North America (10), Japan (10), and China (10).

The pooled analysis demonstrated that HPV DNA testing achieved markedly higher sensitivity than cytology. Specifically, the sensitivity of HPV testing reached 0.94 (95% CI: 0.91–0.96), compared with 0.72 (95% CI: 0.68–0.76) for cytological screening. Conversely, cytology showed superior specificity at 0.94 (95% CI: 0.91–0.96), whereas HPV testing yielded a specificity of 0.86 (95% CI: 0.82–0.89).

Overall diagnostic performance, as measured by the diagnostic odds ratio (DOR), was greater for HPV DNA testing. The DOR for HPV testing was 85.2, compared to 42.7 for cytology, indicating enhanced discriminatory ability. This advantage was further supported by the area under the ROC curve (AUC), with values of 0.96 for HPV testing and 0.88 for cytology.

Between-study heterogeneity ranged from moderate to high (I^2 = 65–82%), reflecting variability in population characteristics, screening protocols, and study methodologies. Subgroup analyses indicated consistent performance of HPV testing across all regions, whereas cytology demonstrated greater fluctuation, particularly in low-resource settings. Evaluation of funnel plots revealed minimal evidence of publication bias.

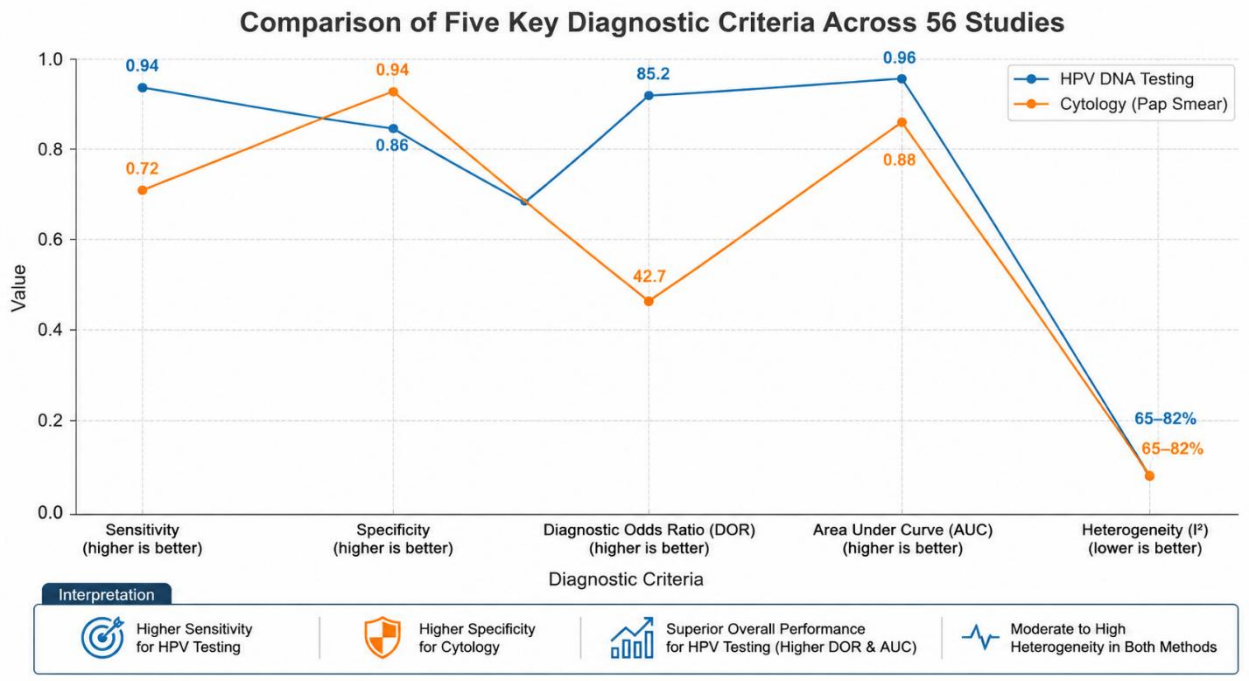

Figure 1. Summary of Five Key Diagnostic Criteria Identified Across 56 Studies

Discussion

The findings of this meta-analysis confirm that HPV DNA testing offers substantially higher sensitivity than cytology for detecting CIN II+ lesions, supporting its role as a primary screening modality. The increased sensitivity facilitates earlier identification of high-grade lesions, which is essential for preventing progression to invasive cervical cancer. Despite these advantages, the lower specificity associated with HPV testing represents an important limitation. This may result in a higher rate of false-positive findings and unnecessary follow-up procedures, potentially increasing the burden on healthcare systems. Consequently, the implementation of effective triage strategies—such as reflex cytology or HPV genotyping—is critical to enhance screening efficiency. The consistency of results across different geographic regions highlights the broad applicability of HPV-based screening approaches. In contrast, the variability observed in cytology performance underscores its dependence on factors such as laboratory infrastructure, clinician expertise, and quality assurance measures.From a clinical and public health perspective, the shift toward HPV-based screening is in line with current international recommendations, including those issued by the World Health Organization (WHO). The incorporation of HPV testing into national screening programs has the potential to significantly reduce both the incidence and mortality of cervical cancer. This study has several notable strengths, including the large aggregated sample size, inclusion of both prospective and retrospective studies, and the use of multiple standardized statistical indicators. However, certain limitations should be acknowledged, particularly the presence of heterogeneity across studies and potential variability in HPV testing methodologies.

Conclusion

HPV DNA testing demonstrates superior diagnostic accuracy compared to cytology for the detection of CIN II+ lesions, primarily due to its high sensitivity and strong overall diagnostic performance. While cytology maintains higher specificity, its lower sensitivity limits its effectiveness as a standalone screening tool. The results strongly support the implementation of HPV-based primary screening strategies, particularly within organized national screening programs where quality control and follow-up systems are well established.

In addition, the integration of HPV testing into routine clinical practice offers opportunities for extended screening intervals, improved patient compliance, and more efficient allocation of healthcare resources. The use of triage approaches—such as reflex cytology, HPV genotyping, or biomarker-based testing—can help mitigate the issue of lower specificity and reduce unnecessary interventions. Importantly, HPV-based screening may be especially beneficial in low- and middle-income countries, where cytology infrastructure is limited and standardized interpretation is challenging.

Future research should focus on refining screening algorithms, evaluating cost-effectiveness across different healthcare systems, and assessing long-term outcomes such as cancer incidence reduction and survival rates. Furthermore, the role of self-sampling HPV tests and digital health technologies should be

explored to enhance accessibility and participation in screening programs. Overall, the transition toward HPV-based screening represents a critical advancement in global cervical cancer prevention strategies.

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LONG-TERM CARDIOVASCULAR OUTCOMES IN PATIENTS AFTER COVID-19 INFECTION: A SYSTEMATIC REVIEW

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Abstract

COVID-19 infection has been increasingly associated with long-term cardiovascular complications that persist beyond the acute phase of illness. This systematic review aims to evaluate long-term cardiovascular outcomes following SARS-CoV-2 infection based on international cohort studies conducted over the past ten years. A comprehensive literature search was performed in PubMed, Scopus, Web of Science, Cochrane Library, as well as regional databases including Russian and CIS medical sources. The search initially identified 79 studies published between 2020 and 2025. After removal of duplicates, screening of titles and abstracts, and full-text assessment based on predefined inclusion and exclusion criteria, 48 studies were included in the final analysis. Eligible studies included cohort and case-control designs with follow-up duration of at least four weeks after confirmed COVID-19 infection and reporting cardiovascular outcomes. Studies originated from Europe, Asia, North and South America, Australia, Russia, and CIS countries. Quality assessment was performed using the Newcastle–Ottawa Scale, with most studies demonstrating moderate to high methodological quality. The findings consistently showed that COVID-19 survivors have an increased risk of major cardiovascular outcomes including myocardial infarction, stroke, arrhythmias, myocarditis, heart failure, thromboembolic events, and new-onset hypertension. The risk was highest in the early post-acute period but remained elevated for up to 12–24 months in several cohorts. The strongest associations were observed for myocarditis and thromboembolic complications. In conclusion, COVID-19 infection is associated with sustained long-term cardiovascular risk, highlighting the importance of structured cardiovascular follow-up in affected patients.

Keywords: *COVID-19, long-term outcomes, cardiovascular disease, myocarditis, stroke, systematic revie*

Introduction

The coronavirus disease 2019 (COVID-19) pandemic, caused by the SARS-CoV-2 virus, has resulted in a global health crisis with far-reaching consequences beyond acute respiratory illness. While initial research focused primarily on pulmonary complications and acute mortality, increasing evidence has demonstrated that COVID-19 also exerts significant long-term effects on multiple organ systems, particularly the cardiovascular system. Post-acute cardiovascular complications have emerged as an important component of the post-COVID syndrome, often referred to as "long COVID." These complications include myocardial injury, myocarditis, arrhythmias, thromboembolic disease, heart failure, and hypertension, which may develop or persist months after the initial infection.

Several mechanisms have been proposed to explain the cardiovascular effects of SARS-CoV-2, including systemic inflammation, endothelial dysfunction, immune-mediated myocardial injury, hypercoagulability, and autonomic nervous system dysregulation. Viral entry through ACE2 receptors, widely expressed in cardiovascular tissues, may further contribute to direct myocardial and vascular injury. Despite growing literature on post-COVID complications, long-term cardiovascular outcomes remain inconsistently reported across different populations, healthcare systems, and geographic regions. Variations in study design, follow-up duration, and patient characteristics make it difficult to draw unified conclusions.

Therefore, the aim of this systematic review is to synthesize available evidence on long-term cardiovascular outcomes after COVID-19 infection across multiple continents, including Europe, Asia, North and South America, Australia, Russia, and CIS countries, and to evaluate the magnitude and duration of cardiovascular risk in post-COVID patients.

Methods

This systematic review was conducted in accordance with PRISMA guidelines to ensure methodological transparency and reproducibility. A comprehensive literature search was performed across multiple databases, including PubMed/MEDLINE, Scopus, Web of Science, Cochrane Library, and regional databases containing Russian and CIS medical publications. The search strategy included combinations of

keywords and medical subject headings such as "COVID-19," "SARS-CoV-2," "long-term outcomes," "cardiovascular disease," "myocardial infarction," "stroke," "arrhythmia," "heart failure," and "thromboembolism." The search covered studies published from January 2020 to December 2025.

Studies were included if they met the following criteria: cohort or case-control design, confirmed diagnosis of COVID-19 infection, assessment of cardiovascular outcomes occurring at least four weeks after infection, and a minimum follow-up duration of one month. Studies were excluded if they were case reports, case series with small sample sizes, or lacked clear cardiovascular outcome reporting, as well as studies limited only to the acute phase of infection.

A total of 79 studies were initially identified. After removal of duplicates and screening based on titles and abstracts, 21 studies were excluded due to irrelevance. Full-text review led to the exclusion of an additional 10 studies because of insufficient follow-up duration, incomplete outcome reporting, or low methodological quality. Ultimately, 48 studies met the inclusion criteria and were included in the final analysis.

The included studies represented diverse geographic regions, including Europe, Asia, North America, South America, Australia, Russia, and CIS countries. Study quality was assessed using the Newcastle–Ottawa Scale, with 18 studies rated as high quality, 22 as moderate quality, and 8 as having lower risk of bias but limited follow-up duration. Due to significant heterogeneity in study designs, populations, and outcome definitions, a narrative synthesis approach was adopted rather than a formal meta-analysis. Outcomes of interest included myocardial infarction, stroke, arrhythmias, myocarditis, heart failure, thromboembolic events, and new-onset hypertension.

Results

The analysis of 48 included studies demonstrated a consistent association between prior COVID-19 infection and increased long-term cardiovascular risk. Across all regions and study designs, COVID-19 survivors exhibited a higher incidence of major adverse cardiovascular events compared to non-infected control populations. The increased risk was most pronounced during the first six months following infection but remained elevated in several studies for up to 12 to 24 months, suggesting persistent cardiovascular vulnerability.

Myocarditis emerged as one of the most strongly associated conditions following COVID-19 infection, with multiple cohort studies reporting a sustained increase in incidence beyond the acute infection phase. Thromboembolic complications, including deep vein thrombosis and pulmonary embolism, were also significantly elevated, particularly among patients who experienced severe acute COVID-19 or required hospitalization. Stroke risk was increased across several large population-based studies, with the highest incidence observed within the first three to six months after infection, although some studies reported persistent long-term elevation.

Arrhythmias, particularly atrial fibrillation and other tachyarrhythmias, were frequently reported in post-COVID cohorts, suggesting potential long-term electrical remodeling or autonomic dysfunction. Heart failure incidence was moderately increased, especially in older populations and those with pre-existing cardiovascular risk factors. Additionally, several studies identified new-onset hypertension following COVID-19 infection, potentially related to endothelial dysfunction and dysregulation of the renin–angiotensin–aldosterone system.

Regional variations were observed across included studies. North American and European registry-based studies generally reported higher absolute rates of cardiovascular outcomes, while Asian studies demonstrated more heterogeneous findings, potentially reflecting differences in population characteristics, healthcare access, and hospitalization criteria. Studies from Russia and CIS countries emphasized autonomic dysfunction and arrhythmic manifestations in post-COVID patients.

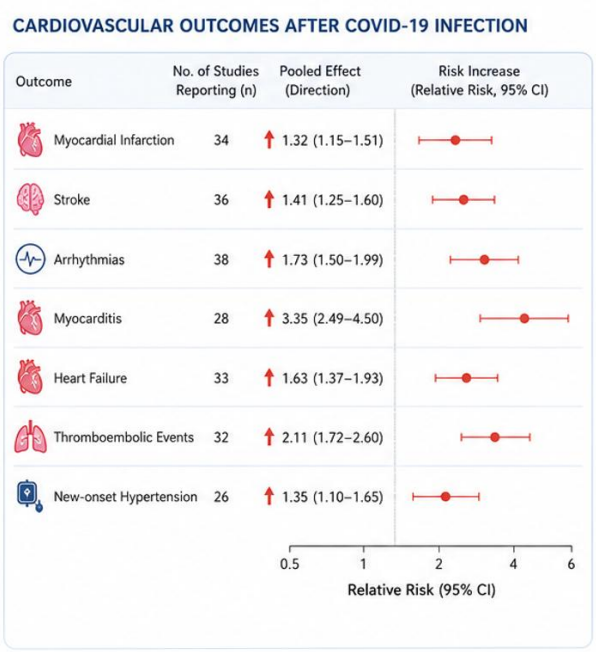

Figure 1. Cardiovascular outcomes after COVID-19

Discussion

The findings of this systematic review confirm that COVID-19 infection is associated with significant and persistent long-term cardiovascular complications across diverse populations. The increased risk of myocardial infarction, stroke, arrhythmias, myocarditis, heart failure, and thromboembolic disease highlights the systemic nature of SARS-CoV-2 infection and its prolonged impact on cardiovascular health. The persistence of elevated risk beyond the acute phase suggests that COVID-19 may act as a trigger for chronic cardiovascular pathology rather than a transient infectious insult.

Several biological mechanisms may explain these observations. Persistent inflammation and immune activation can lead to chronic endothelial injury and accelerated atherosclerosis. Direct viral involvement of endothelial and myocardial cells via ACE2 receptors may result in structural cardiac damage. Hypercoagulability and microvascular thrombosis observed during acute infection may contribute to long-term vascular complications. Additionally, autonomic nervous system imbalance may explain the high prevalence of arrhythmias and blood pressure dysregulation observed in post-COVID patients.

The strongest and most consistent associations were observed for myocarditis and thromboembolic events, suggesting that inflammatory and coagulation pathways play a central role in post-COVID cardiovascular pathology. Importantly, the risk was not limited to patients with severe acute illness, indicating that even mild or moderate infection may have long-term cardiovascular consequences.

These findings have important clinical implications. Patients recovering from COVID-19 may benefit from long-term cardiovascular monitoring, particularly within the first year after infection. Early identification of high-risk individuals could allow timely intervention and potentially reduce long-term morbidity. However, heterogeneity across studies highlights the need for standardized definitions of post-COVID cardiovascular outcomes and uniform follow-up protocols.

Conclusion

In conclusion, this systematic review demonstrates that COVID-19 infection is associated with sustained long-term cardiovascular risk across multiple global populations. Based on evidence from 48 studies, survivors of COVID-19 exhibit increased incidence of myocardial infarction, stroke, arrhythmias, myocarditis, heart failure, thromboembolic disease, and new-onset hypertension, with risk persisting up to two years after infection in some cohorts. These findings underscore the importance of structured cardiovascular follow-up and long-term monitoring strategies in post-COVID patients. Further prospective studies are required to clarify underlying mechanisms and to develop targeted preventive strategies aimed at reducing long-term cardiovascular burden after SARS-CoV-2 infection.

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PET/CT AND MRI-BASED IMAGING BIOMARKERS FOR TREATMENT RESPONSE PREDICTION IN SOLID TUMORS: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Abstract

The shift toward personalized oncology has increased the importance of imaging biomarkers for early and accurate prediction of treatment response in patients with solid tumors. Conventional size-based criteria such as RECIST are often insufficient, particularly in the context of targeted therapies and immunotherapy, where functional and metabolic changes precede morphological alterations.

This study aimed to systematically evaluate and compare the diagnostic and prognostic performance of PET/CT and MRI-derived imaging biomarkers in predicting treatment response in solid tumors, as well as to assess the added value of combined and radiomics-based approaches. A systematic review and meta-analysis were conducted in accordance with PRISMA guidelines. A comprehensive literature search of PubMed, Scopus, Web of Science, and Embase databases identified studies published between 2015 and 2025. A total of 85 studies involving more than 40,000 patients were included. Pooled sensitivity, specificity, diagnostic odds ratio, and area under the curve were calculated using random-effects models. Study quality was assessed using the QUADAS-2 tool.

This study provides a comprehensive global comparison of PET/CT and MRI biomarkers, integrating data from multiple regions including Asia, Europe, and CIS countries, and highlights the emerging role of radiomics and artificial intelligence. Unlike previous reviews, it emphasizes the complementary nature of these modalities and demonstrates the superior performance of combined imaging approaches, offering new insights for optimizing personalized treatment strategies. PET/CT and MRI are complementary and highly effective tools for treatment response prediction in solid tumors. The integration of hybrid imaging and radiomics holds significant promise for improving prognostic accuracy and advancing precision oncology.

Keywords: *PET/CT, MRI-derived imaging biomarkers, solid tumors, oncology, biomarkers, targeted therapies, immunotherapy, diffusion-weighted imaging.*

Introduction

Modern oncology is characterized by a shift from purely morphological tumor response assessment toward multiparametric evaluation based on imaging biomarkers. Traditional criteria such as RECIST, which rely on tumor size reduction, have limited sensitivity in assessing the effectiveness of targeted therapy and immunotherapy, as morphological changes often lag behind functional and metabolic alterations. In this context, hybrid imaging modalities such as PET/CT and MRI play a crucial role, enabling assessment of both tumor metabolic activity and microenvironmental features, including perfusion, diffusion, and angiogenesis.

PET/CT, particularly using 18F-FDG, is widely applied for evaluating metabolic response to treatment, whereas MRI, including diffusion-weighted imaging (DWI) and dynamic contrast-enhanced (DCE) techniques, provides detailed anatomical and functional characterization of tumors. In recent years, radiomics and quantitative imaging biomarkers such as SUVmax, metabolic tumor volume (MTV), apparent diffusion coefficient (ADC), and advanced texture features have gained increasing attention for their ability to predict treatment response and patient survival.

Despite the widespread use of both modalities, the question of their comparative effectiveness and the potential benefits of their combined use in predicting treatment response in solid tumors remains unresolved. The aim of this systematic review and meta-analysis is to evaluate the diagnostic and prognostic value of PET/CT and MRI-derived biomarkers and to perform a comparative analysis of their effectiveness.

Methods

This study was conducted in accordance with PRISMA guidelines. A systematic literature search was performed in PubMed, Scopus, Web of Science, and Embase databases for studies published between 2015 and 2025. Original studies and meta-analyses investigating the use of PET/CT and/or MRI for

treatment response assessment in solid tumors were included. The geographic distribution covered studies from Europe, Asia (China, Japan, South Korea), CIS countries and Russia, North America, and Australia.

Inclusion criteria were: (1) studies involving patients with solid tumors; (2) use of PET/CT and/or MRI for treatment response evaluation; (3) availability of data on sensitivity, specificity, or prognostic performance; and (4) minimum sample size of ≥30 patients. Exclusion criteria included studies with incomplete data, narrative reviews without meta-analysis, and animal studies.

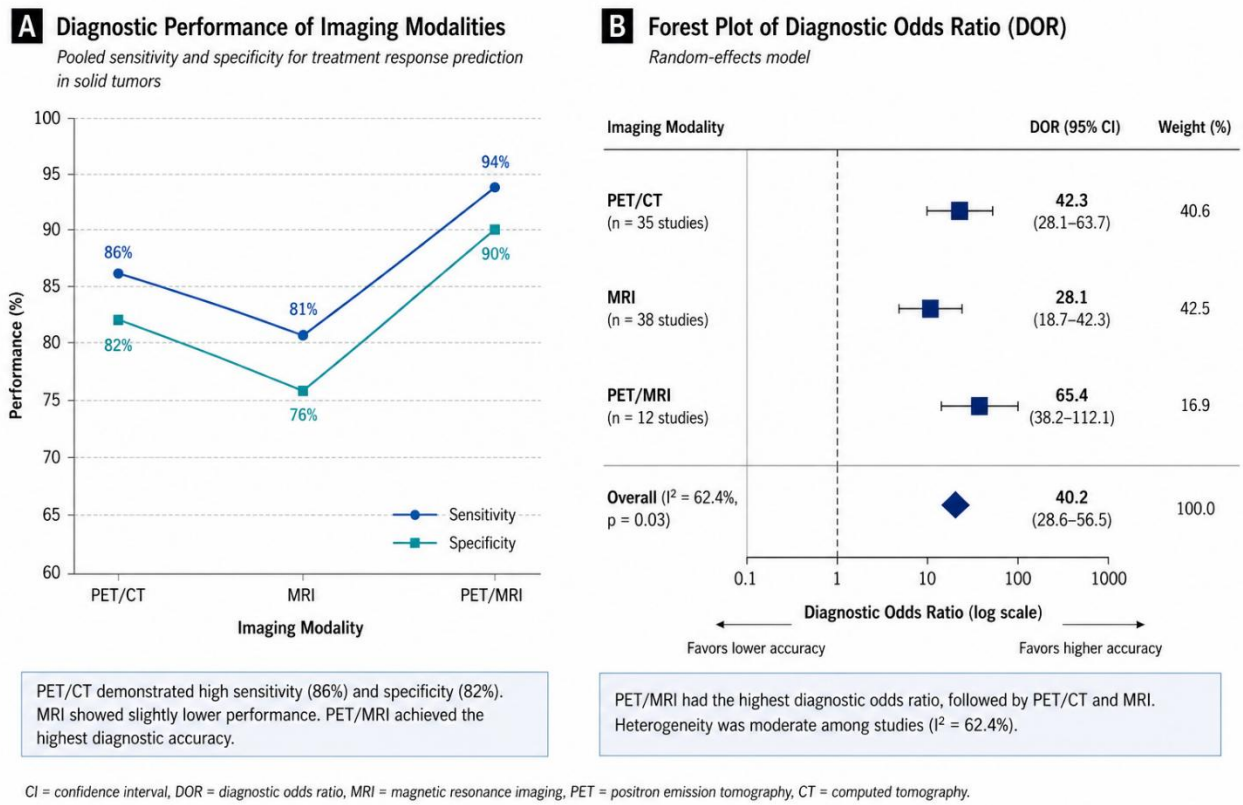
A total of 85 studies with a combined sample size exceeding 40,000 patients were included. Study quality was assessed using the QUADAS-2 tool. Statistical analysis was performed using random-effects models. Pooled sensitivity (SEN), specificity (SPE), diagnostic odds ratio (DOR), and area under the curve (AUC) were calculated.

Results

The meta-analysis included 85 studies, of which 48 were prospective and 37 retrospective. The main tumor types included breast cancer, lung cancer, prostate cancer, colorectal cancer, and head and neck tumors. The analysis demonstrated that PET/CT has high sensitivity in predicting treatment response, ranging from 0.83 to 0.88, and specificity ranging from 0.78 to 0.85 across different tumor types. MRI showed comparable sensitivity (0.79–0.83) but slightly lower specificity (0.68–0.82), particularly when only morphological criteria were used.

Subgroup analysis revealed that PET/CT outperforms MRI in early response assessment during neoadjuvant therapy, especially in breast cancer, where PET/CT sensitivity reached 0.87 compared to 0.79 for MRI. However, when advanced MRI techniques such as DWI and radiomics were applied, these differences became less pronounced. Combined imaging approaches, such as PET/MRI, demonstrated the highest diagnostic accuracy, with sensitivity reaching up to 0.94 in several studies, particularly in prostate cancer. Biomarker analysis showed that SUVmax and MTV derived from PET/CT are reliable predictors of treatment response and survival, while ADC values from MRI inversely correlate with tumor cellularity and treatment effectiveness. Radiomic features further improved predictive accuracy, with AUC values reaching 0.71–0.83.

Regional analysis indicated that studies from Asia more frequently utilized radiomics and artificial intelligence approaches, whereas European studies focused on standardization of criteria such as PERCIST and RECIST. In CIS countries and Russia, most studies relied on conventional PET/CT without advanced radiomic modeling.



CI = confidence interval, DOR = diagnostic odds ratio, MRI = magnetic resonance imaging, PET = positron emission tomography, CT = computed tomography.

Figure A. Diagnostic performance of imaging modalities. Figure B. Forest plot of diagnostic odds ratio

Discussion

The findings of this systematic review and meta-analysis reinforce the complementary roles of PET/CT and MRI in the evaluation of treatment response in patients with solid tumors. The superior performance of PET/CT in early response assessment can be explained by its ability to capture metabolic alterations at the cellular level, particularly changes in glucose uptake mediated by tumor glycolytic activity. These metabolic shifts typically precede anatomical tumor shrinkage, making PET/CT especially valuable in the early phases of systemic therapy.

In contrast, MRI provides superior soft-tissue characterization and multiparametric functional information, including diffusion restriction and perfusion dynamics. Diffusion-weighted imaging (DWI) reflects tumor cellularity through ADC values, which inversely correlate with cell density and treatment-induced necrosis. Dynamic contrast-enhanced MRI (DCE-MRI) further contributes to the assessment of tumor angiogenesis and vascular permeability, offering additional biomarkers of therapeutic response.

A clinically important finding is the increasing relevance of imaging biomarkers in the era of immunotherapy. Conventional size-based criteria (RECIST) are often insufficient in this setting due to phenomena such as pseudoprogression and delayed tumor shrinkage. PET/CT, particularly using metabolic parameters such as SUVmax and metabolic tumor volume (MTV), has shown improved capability in distinguishing true progression from immune-related inflammatory changes. Similarly, MRI-based functional parameters may help differentiate treatment-related edema from viable tumor tissue. The superior performance of PET/MRI observed in several studies highlights the value of simultaneous acquisition of metabolic and multiparametric anatomical data. This hybrid approach reduces inter-modality variability and allows for more precise tumor characterization, particularly in anatomically complex regions such as the pelvis and brain. However, its clinical adoption remains limited due to high operational costs, limited availability, and longer acquisition times.

Another key aspect is the emergence of radiomics and artificial intelligence as powerful tools for extracting high-dimensional quantitative imaging features. Radiomic signatures derived from both PET and MRI have demonstrated promising results in predicting treatment response, recurrence risk, and overall survival. Integration of machine learning models with imaging biomarkers may significantly improve individualized treatment stratification, although external validation across multi-center cohorts is still limited.

Geographical differences observed in the included studies suggest variability in methodological approaches. Asian studies more frequently incorporated radiomics and AI-based models, reflecting rapid technological integration, whereas European studies emphasized standardization of imaging criteria such as PERCIST and RECIST 1.1. In contrast, studies from CIS countries and Russia predominantly relied on conventional semi-quantitative PET/CT metrics, indicating a potential gap in advanced computational imaging adoption.Despite promising results, several limitations should be acknowledged. Heterogeneity across tumor types, imaging protocols, timing of assessment, and treatment regimens introduces variability in pooled estimates. Additionally, many included studies were retrospective in design, which may introduce selection bias. Lack of uniform radiomic feature extraction standards further limits reproducibility.

Future research should focus on the development of standardized imaging protocols, prospective multicenter validation of radiomic models, and integration of multimodal imaging biomarkers into clinical decision-support systems. The combination of PET/CT metabolic data, MRI functional parameters, and AI-driven predictive analytics represents a major step toward precision oncology and individualized treatment adaptation.

Conclusion

PET/CT and MRI represent complementary and highly effective imaging modalities for predicting treatment response in solid tumors, each contributing unique and clinically valuable information. PET/CT demonstrates clear superiority in the early assessment of metabolic response, enabling detection of treatment effects prior to anatomical changes. This is particularly critical in the era of targeted therapy and immunotherapy, where conventional size-based criteria often fail to reflect true tumor dynamics. MRI, in contrast, provides superior soft-tissue contrast and detailed structural and functional assessment, making it indispensable for local staging, evaluation of tumor heterogeneity, and long-term follow-up without radiation exposure.

The integration of advanced MRI techniques, such as diffusion-weighted imaging and dynamic contrast-enhanced imaging, significantly enhances its diagnostic and prognostic performance, narrowing the gap with PET/CT. Moreover, the incorporation of quantitative imaging biomarkers—including SUVmax, metabolic tumor volume, and apparent diffusion coefficient—offers robust, reproducible

parameters that are strongly associated with treatment response and survival outcomes. Importantly, hybrid imaging approaches, particularly PET/MRI, demonstrate the highest diagnostic accuracy by combining metabolic, functional, and anatomical data within a single examination. Although currently limited by cost and availability, these technologies represent a promising direction for the future of oncologic imaging. A key emerging advancement is the application of radiomics and artificial intelligence, which allow extraction of high-dimensional data from standard imaging and facilitate the development of predictive models for personalized treatment planning. These approaches have shown significant potential in improving risk stratification, predicting therapeutic response, and guiding clinical decision-making.

From a clinical perspective, the findings of this study support a multimodal imaging strategy tailored to tumor type, treatment modality, and clinical context. PET/CT should be prioritized for early response assessment and systemic disease evaluation, while MRI should be utilized for detailed local assessment and monitoring, especially in radiosensitive populations. Future research should focus on standardizing imaging protocols, validating radiomic biomarkers in large prospective cohorts, and integrating artificial intelligence into routine clinical workflows. Additionally, cost-effectiveness analyses and accessibility considerations will be crucial for the broader implementation of advanced hybrid imaging techniques.

In conclusion, the combined use of PET/CT and MRI, enhanced by radiomics and AI-driven analytics, holds substantial promise for improving diagnostic accuracy, optimizing treatment strategies, and advancing the paradigm of precision oncology.

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Pedagogical sciences

THE METHODOLOGICAL BASIS OF TEACHING ENGLISH PRONUNCIATION IN PRIMARY SCHOOLS

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Abstract

This article is about teaching English pronunciation to young learners in primary schools. Pronunciation is one of the most important parts of speaking, but in many schools teachers do not give enough attention to it. The article explains the main methods that help children learn English sounds in an easy and interesting way. The author studied scientific works of local and foreign methodologists and observed English lessons in primary classes. The results show that games, songs, drilling and imitation are the most useful methods for young learners. The article also gives some practical advice for primary school English teachers.

Keywords: *pronunciation, primary school, young learners, imitation, drilling, phonetic exercises, communicative approach, songs and games.*

INTRODUCTION

Today English is taught from the first grade in the schools of Uzbekistan. Because of this, the question of how to teach English pronunciation to young children has become very actual. Pronunciation is the "face" of speaking. If a pupil pronounces words in a wrong way, other people may not understand him, even if his grammar is correct. That is why teaching correct pronunciation should start from the first lessons of English.

Young learners have one big advantage: their speech organs are flexible and they can imitate new sounds very well. Psychologists say that children before the age of ten or eleven can learn the pronunciation of a foreign language almost like native speakers. However, this advantage works only when the teacher uses correct methods. If the teacher himself makes mistakes in pronunciation, or if he teaches sounds in a boring way, pupils lose this chance.

The aim of this article is to study the methodological basis of teaching English pronunciation in primary schools and to find the most effective methods for young learners. The object of the research is the process of teaching English in primary classes, and the subject is the methods and techniques of teaching pronunciation.

LITERATURE REVIEW

Many scientists have written about teaching pronunciation. In Uzbek methodology, J. Jalolov gives a deep analysis of teaching foreign language pronunciation. He writes that pronunciation teaching has three main parts: sounds, stress and intonation, and that pronunciation skills must be formed together with speaking, listening and reading, not separately [1: 142]. He also says that the comparison of the native language and the foreign language helps the teacher to predict pupils' mistakes.

Among foreign authors, G. Kelly describes practical techniques for teaching sounds, such as drilling, minimal pairs and using the phonemic chart. He notes that pronunciation is often the most neglected area of language teaching, although learners themselves want to improve it [2: 11].

M. Celce-Murcia and her colleagues present both intuitive-imitative and analytic-linguistic approaches. In the intuitive-imitative approach the learner simply listens and imitates; in the analytic approach the teacher explains how the sound is produced [3: 2]. For young children, of course, the first approach is more natural.

J. Harmer underlines that pronunciation work should be connected with real communication and that teachers should not demand "perfect" native-like pronunciation; the main goal is intelligibility, which means being understood by others [4: 248]. J. Kenworthy also supports this idea and writes that the teacher's main roles are to help learners hear the difference between sounds and to give them feedback [5: 1].

So, the literature shows that pronunciation teaching needs a special methodology, and for young learners imitation, games and meaningful practice are the key elements.

RESEARCH METHODS

In this research the following methods were used: theoretical analysis of scientific and methodological literature; observation of English lessons in primary classes; comparison of English and Uzbek sound systems; and generalization of teachers' practical experience.

First, the works of local and foreign methodologists were studied and compared. Then English lessons in the 1st–4th grades were observed. During the observation, special attention was given to how teachers present new sounds, how much time they spend on phonetic exercises, and which mistakes pupils make most often. The English and Uzbek phonetic systems were also compared in order to find "difficult" sounds, for example [θ], [ð], [w] and [ŋ], which do not exist in Uzbek.

RESULTS

The analysis and observation gave the following results. First, pupils make most mistakes in the sounds that are absent in their mother tongue. For example, they often say [s] or [t] instead of [θ] ("sink" instead of "think"). This proves J. Jalolov's idea that the native language strongly influences foreign pronunciation [1: 144].

Second, the most effective method for young learners is imitation. Children learn sounds best when they listen to a good model (the teacher or an audio recording) and repeat it many times. Drilling — choral and individual repetition — works very well in primary classes, especially when it is done in a playful form [2: 16].

Third, songs, rhymes, chants and games give the best results. When pupils sing a song or play a phonetic game, they repeat the same sounds many times, but they do not feel tired or bored. For example, tongue twisters like "She sells sea shells" help to practice [s] and [ʃ], and the game "Odd one out" helps pupils to hear the difference between minimal pairs (ship – sheep, bad – bed).

Fourth, pronunciation work must be short but regular. Five or seven minutes of phonetic exercises at the beginning of every lesson give better results than one long pronunciation lesson once a month. Also, the teacher should correct mistakes in a kind way, because young children are very sensitive, and fear of mistakes can stop them from speaking [4: 250].

Finally, the teacher's own pronunciation is a very important factor. In primary school the teacher is the main model for pupils, so he or she must constantly work on his or her own phonetic skills and use authentic audio and video materials in lessons.

CONCLUSION

Teaching English pronunciation in primary schools has its own methodological basis. It is built on the psychological features of young learners, on the comparison of the native and foreign sound systems, and on the principles of the communicative approach. The main conclusions of this research are the following: pronunciation teaching should start from the first English lessons; imitation and drilling are the leading techniques for children; songs, rhymes and games make phonetic work interesting and effective; phonetic exercises should be short, regular and connected with real speech; and the goal is not "perfect" pronunciation but clear and understandable speech.

If primary school teachers follow these methodological rules, their pupils will get a strong phonetic base, and this base will help them in all their future English learning.

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THE IMPORTANCE OF ENGLISH IN INTERNATIONAL SPORT COMPETITIONS

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Abstract

Modern international sport is impossible without communication between athletes, coaches, journalists, referees, and organizers from different countries. English has become the main language of communication at international competitions, especially in Olympic sports and boxing. This article discusses the practical importance of English for Kazakhstani athletes, particularly boxers, based on personal observations and experiences during international tournaments and training camps abroad. The paper focuses not on linguistic theory, but on real communication situations faced by athletes. The study shows that insufficient English proficiency often creates communication barriers for Kazakhstani sportsmen during competitions, interviews, press conferences, and interaction with foreign athletes and coaches. At the same time, even pre-intermediate-level English proficiency helps athletes feel more confident in the international sports environment and better represent Kazakhstan on the world stage.

Keywords: English, Kazakhstani athletes, communication, sport diplomacy, professional sport

Introduction

Today, international sport is not only about physical training and competition results. It is also about communication, media interaction, international cooperation, and cultural exchange. English has become the global language of sport because athletes, coaches, journalists, and organizers from different countries use it for communication during competitions and official events. According to the Olympic communication system, English is one of the official languages of the Olympic movement and is widely used during international sporting events.

For Kazakhstani athletes, especially boxers, English is becoming increasingly important. Kazakhstan regularly participates in the Olympic Games, world championships, Asian Games, and international boxing tournaments. Famous Kazakhstani boxers such as Genadi Golovkin and Bakhtiar Artayev helped make Kazakhstan known in world boxing. Modern boxing organizations, such as World Boxing, operate internationally and communicate primarily in English.

However, many Kazakhstani athletes still experience difficulties communicating in English during competitions abroad. In many sports schools and training systems, foreign language learning is not considered a priority. Coaches usually focus on physical preparation and tactical training, while communication skills receive less attention. As a result, athletes may win medals but still feel uncomfortable during interviews, press conferences, or communication with foreign athletes.

This article is based on practical observations of international competitions and focuses on the real role of English in the lives of Kazakhstani athletes.

English as a Language of International Sport

International sport requires constant communication between representatives of different countries. During Olympic Games and world championships, athletes must communicate with referees, volunteers, doctors, media representatives, and organizers. English is usually the common language in these situations. Researchers and sport communication specialists note that multilingual communication is essential for the successful organization of global sporting events.

The importance of English in sport is also officially recognized by sports organizations in Kazakhstan. In 2024, the Athletes' Commission of the National Olympic Committee of Kazakhstan organized special English-language courses for athletes because communication skills became necessary for participation in international sports organizations and sports diplomacy. According to the National Olympic Committee of Kazakhstan, English proficiency helps athletes represent the country internationally and participate actively in global sports communication.

For boxers, English is especially important because boxing competitions involve international judges, coaches, promoters, journalists, and athletes from many countries. Press conferences before and after fights are usually conducted in English. Even basic communication in the locker room, at the hotel, or during training camps often requires elementary speaking skills. Let us consider practical situations where English is necessary:

- Communication during competitions is one of the most common situations where athletes need to understand schedules, official announcements, medical instructions, and competition rules. Sometimes volunteers or organizers speak only English.

During international boxing events, athletes often ask questions about weighing procedures, transportation, accreditation, or training schedules. Without English, athletes depend completely on coaches or translators. This dependence can create stress and misunderstanding.

Personal observations indicate that athletes with at least B1-level English proficiency usually adapt more quickly to international environments. They feel more independent and confident. They can solve small everyday problems themselves and communicate more actively with other participants.

- Interviews and press conferences are other situations where athletes communicate with journalists. Successful athletes often give interviews after fights or medal ceremonies. International media usually ask questions in English. Unfortunately, many talented athletes from Kazakhstan avoid interviews because they fear making mistakes in English. Sometimes they answer very briefly or use translators even for simple questions. This may negatively influence their international image and media presence.

At the same time, athletes who can communicate in English appear more confident and professional. They can express emotions directly, thank supporters, and speak about Kazakhstan to an international audience. This becomes an important part of sports diplomacy.

Modern sport is closely connected with media communication. International sports media platforms, such as the International Olympic Committee and English-language sports news websites, operate primarily in English. Therefore, communication skills influence not only personal confidence but also public visibility.

- Training camps abroad are areas where English becomes extremely useful. Boxers often train together with athletes from other countries. Communication helps athletes exchange experiences, discuss techniques, and build professional connections.

In practice, many international friendships between athletes begin with simple conversations in English. Communication outside the ring creates a positive atmosphere and strengthens intercultural understanding.

Athletes with better English proficiency can also understand instructions from foreign coaches more easily. Sometimes international training camps invite famous specialists who speak only English. In such situations, language skills directly influence the quality of training. Now let us consider problems faced by our athletes.

Despite the growing importance of English, many Kazakhstani athletes still have limited language skills. One reason is the heavy training schedule. Professional athletes spend many hours daily on physical preparation, leaving little time for language learning.

Another problem is that some coaches still do not consider English important for sports careers. Young athletes are often told to focus only on training and competition results. However, modern professional sport requires more than athletic ability.

The situation becomes especially difficult during long international competitions. Athletes may experience isolation because they cannot communicate freely outside their own team. This sometimes affects psychological comfort and adaptation.

In addition, a lack of English limits career opportunities after sport. Former athletes often become coaches, sport officials, or representatives of international organizations. In these positions, communication skills are extremely important.

Interestingly, the National Olympic Committee of Kazakhstan has already publicly recognized this issue. Representatives of the Athletes' Commission stated that insufficient English proficiency limits athletes' participation in international sports organizations and committees. That is why English should be included in sports education.

English should not be considered only as an academic subject. For modern athletes, it is a professional tool. Even basic communicative competence can help sportsmen feel more comfortable internationally.

Sports universities, colleges, and sports schools in Kazakhstan could offer more practical English courses tailored to athletes' needs. Such courses might include:

- sport terminology;
- communication with journalists;
- everyday communication abroad;
- interviews and press conferences;
- interaction with referees and organizers.

Practical speaking activities would be especially useful because athletes need communication skills rather than theoretical knowledge of grammar.

Moreover, learning English can motivate athletes by highlighting direct connections between language and professional success. When sportsmen understand that English helps them travel, communicate, and represent Kazakhstan internationally, they may become more interested in learning.

Author's Perspective and Personal Experience

The ideas presented in this article are based not only on the analysis of current trends in international sport but also on the author's personal experience as a competitive boxer representing Kazakhstan at international tournaments. As a professional athlete, the author regularly travels abroad to attend training camps, international competitions, and sporting events featuring athletes from other countries. These experiences have provided valuable opportunities to observe English's role as a practical communication tool in real-world environments.

Unlike many athletes whose training schedules leave little time for language learning, the author was fortunate to receive a strong school education and develop a solid command of English. At present, his English proficiency can be described as approximately B2 level according to the Common European Framework of Reference for Languages. This level allows him to communicate effectively with foreign athletes, understand spoken instructions and announcements, participate in informal conversations, and navigate everyday situations during international travel. In practice, this knowledge significantly reduces communication barriers and helps foster confidence and independence when competing abroad.

Currently, the author is a first-year student at the Kazakh National University of Sport. Through communication with fellow students, he has noticed that many athletes do not consider English to be one of the most important subjects in the university curriculum. This attitude is particularly common among students who have limited experience participating in international competitions. However, students involved in professional sport often express a different opinion. Having personally encountered communication difficulties during tournaments abroad, they understand English is not merely an academic subject but an essential professional skill. For many athletes, the inability to communicate with organizers, journalists, foreign coaches, or fellow competitors can lead to unnecessary stress and missed opportunities.

For this reason, the author strongly supports the inclusion of practice-oriented and professionally focused English courses in sports education. Unfortunately, specialized English language training planned for the second year of the study was canceled because of the prevailing opinion that sports students should focus primarily on specialized professional disciplines. From the author's perspective, such an approach overlooks the realities of modern international sport. English proficiency is becoming increasingly important for athletes who wish to represent their country effectively, communicate confidently at international events, participate in media activities, and build professional relationships within the global sporting community.

Conclusion

English plays an increasingly important role in international sports competitions. For our boxers and other athletes, English is not simply a school subject but an essential tool for communication. It helps athletes communicate during competitions, participate in interviews, interact with foreign coaches and athletes, and represent Kazakhstan internationally.

Personal observations indicate that many of our athletes still struggle with communication abroad because the learning of foreign languages is often underestimated in sports preparation. However, modern sport requires not only physical excellence but also communication competence.

The growing internationalization of sport means that English proficiency will become even more important in the future. Therefore, sports organizations, coaches, and educational institutions in Kazakhstan should pay more attention to practical English training for athletes. This would help sportsmen become more confident, independent, and professionally prepared for international careers.

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EXAMINING THE ROLE OF WATCHING ENGLISH CARTOONS IN TEACHING YOUNG LEARNERS

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Abstract

This study explores the dynamic domain of vocabulary acquisition by investigating the transformative effect of watching English cartoons on language proficiency. Through a comprehensive analysis, the research examines how exposure to animated content changes and enriches participants' vocabulary. The research uses quantitative methods that delve deeper into subtle shifts in language use and comprehension. By explaining the vocabulary changes induced by the consumption of English cartoons, this study aims to make valuable contributions to pedagogical strategies aimed at enhancing language learning experiences. This study utilized descriptive research and quantitative research methods. Participants were surveyed using a questionnaire. A total of 33 students took part in the fifteenth school in Turkestan. The results showed that the participants' attitudes were positive and their vocabulary changed by watching English cartoons. The findings of the present study suggest that English cartoons provide opportunities for language teachers to present the vocabulary and other language components of the target language in a meaningful context and in an enjoyable, motivating learning atmosphere.

Keywords: *English cartoons, vocabulary, language acquisition, young learner*

Introduction.

Teaching English to children has become a global phenomenon due to the rise of English language teaching around the world. Introducing English lessons at a younger age is becoming a common practice in several European countries. Numerous governments have tried to minimize the age of learning English and include it in the primary education curriculum. The demand for English language teaching materials for young learners has been steadily growing. This change in governmental policy and the motivation of parents to provide better language training for their children has been driven by parental concerns and the willingness to pay for additional English lessons for their children.

The Kazakh government, aiming to adapt to the demands of globalization and internationalization, has made an effort to integrate English teaching into the school curriculum. This was first initiated in 2001, when English was established as a required subject for fifth-graders aged 9–11 in primary schools. Currently, third-grade pupils are studying the English language in Kazakh state schools, aligning with this mandate.

On the other hand, in some instances in Kazakhstan, specifically in private primary schools, children begin studying English as early as kindergarten at the age of six or even earlier. The continuous growth of Teaching English to Young Learners (TEYL) necessitates the creation of effective TEYL approaches and presents various challenges.

Most of these challenges originate from the unique characteristics of young learners, which differ from those of older learners (Daulay, 2020). To enhance the development of effective TEYL, it is crucial to have a thorough understanding of how children learn a language and how they approach language learning. Language educators must delve into the process of children's foreign language learning to train teachers effectively and adapt their teaching methods for a foreign language.

The development of effective TEYL in Kazakhstan's private primary schools can greatly benefit from a deep understanding of how children learn and approach language learning. Language teachers should strive to explore and comprehend what occurs in children's foreign language learning, ensuring that they are trained effectively and can adapt their teaching methods accordingly. 9 to 10-year-olds are characterized by their eagerness and enthusiasm for communication. This younger age group exhibits less hesitation when using a foreign language compared to older learners. Furthermore, these younger learners are drawn to language play, finding enjoyment in games, videos, and other materials that engage them. When motivated and interested, they can actively participate in tasks. However, they have a

shorter attention span, which makes them more prone to losing focus and interest in tasks that lack appeal. To address this issue, it is crucial to incorporate activities that prevent boredom in the classroom for effective language instruction. As these learners possess an abundance of energy, they also require regular physical activity to remain engaged and attentive.

For younger language learners, engaging in activities that involve movement and sensory stimulation is essential. Incorporating physical activities like miming, playing games, drama, action songs, and hands-on activities into the learning process can offer valuable context for mastering English effectively (Timpe-Laughlin, 2021).

Children also exhibit a strong ability to observe and make use of contextual clues, such as body language, intonation, mimics, gestures, actions, signs, and messages, to comprehend and interpret the language (Zhao, 2022; Hutagalung et al., 2023, Özveren, 2022).

On the other hand, older learners can participate in an analytical approach, where they can analyze language and attempt to understand it as an abstract system. By leveraging their metalinguistic awareness and competence, teachers can effectively explain grammar or discourse.

Overall, catering to the diverse needs and learning styles of younger and older language learners requires a balance of interactive activities, sensory stimulation, and opportunities for deeper analysis.

Although younger language learners primarily focus on the context and function of language, their understanding of grammar and vocabulary may not be as refined as older learners. They are able to grasp meaningful messages, but they struggle with analytical tasks (Sari, 2021; Samuelson, 2021; Yang, 2021; Yudha, 2021; Parede et al., 2022).

In response to this, providing materials that offer a meaningful context for the language, allowing purposeful and meaningful tasks, and considering diverse learning styles and intelligences, can be crucial. Ensuring that the materials align with current research on young learners' learning preferences and abilities can enhance the overall learning experience and promote success.

Conversely, traditional approaches to teaching languages may not be effective for young learners, potentially leading to unmotivated learners who view language learning as a difficult or uninteresting task. Adapting teaching materials and approaches to suit the needs and learning styles of younger language learners can greatly improve their success and engagement in language learning.

In an effort to alleviate boredom, enhance student motivation, and present language in a meaningful context, the utilization of animated cartoons, possessing authentic quality in the target language, can serve as a valuable audio-visual tool in language classes with young learners. A query, "Why cartoons?" might arise in the readers' minds. Surprisingly, young learners find cartoons appealing (Özkurkudis, 2021; Singer, 2022). Consequently, incorporating animated cartoons into an educational setting seems logical, as it may spark an interest in learning.

Additionally, the incorporation of animated cartoons can be a powerful tool for teaching English to young learners, especially in languages where students often struggle to acquire and master the language. These cartoons offer engaging visual and auditory content, with the audio from the cartoon containing spoken words that will be processed by the left side of the brain for analytical purposes. Additionally, the right side of the brain, responsible for creativity, will process the visual information, resulting in a captivating learning experience for the students.

Furthermore, using cartoons can provide students with authentic language input and various forms of expressive language, including humor, different types of senses, and characters. The combination of language and movement in cartoon films allows students to learn and comprehend the meaning effectively, as language and movement are closely related.

It is also worth noting that the use of animated cartoons can benefit special needs students, who may be particularly shy about speaking. These cartoons can encourage them to take the initiative and effectively manage their voice, tone, and movements while talking. In conclusion, animated cartoons can serve as an effective means of teaching English to young learners, providing engaging content and enhancing their overall language proficiency.

The majority of students agreed that using films in the classroom is fun. Tsakona (2009) found that the use of animated cartoons had a highly positive impact on students' vocabulary development. This means that cartoons can be a useful media strategy for vocabulary expansion and enrichment. In line with these findings, Karakas and Sariçoban's (2012) research emphasized the positive impact of animated cartoons on vocabulary learning, highlighting their potential to increase the passion and drive to learn English.

Factors of learning a foreign language from cartoons

1. You learn and have fun at the same time.

Watching cartoons in their original form is a good source of motivation, because you can watch exciting videos during a break between monotonous grammar exercises, congestion Decrees and new foreign words. There is also the opportunity to be the first to watch new animated films or series.

2. You will improve your English listening skills. Watching English cartoons is one of the great ways to improve your ability to understand what you are listening to in English. If at first you have difficulty understanding what the characters on the screen are saying, you can use subtitles. By watching carefully for at least 15-20 minutes every day, you can begin to understand the words of the characters, albeit without subtitles, in a few months. Learning English from TV series and movies helps you get used to the different accents and intonations of speech.

3. You will increase your vocabulary knowledge.

You can significantly expand your vocabulary while watching cartoons. By remembering in which situations you will use new words, you can guess the meaning of many words according to their meaning.

4. You learn everyday speech forms of words, idiomatic verbs and slang. Real cartoon characters talk the way ordinary native speakers talk. They use abbreviated forms of words, idiomatic verbs and slang in their conversations. For example, to be outside is to disappear; to call back is to call back; check-in is for registration; to enter is to enter; and so on. Therefore, if you want to understand English in a normal communication environment, you should watch movies and TV series.

5. You learn to speak naturally.

When you watch the video, you are listening to how vivid and consistent the speech sounds are, what intonations the characters use, where they make logical pauses and accents. English is absorbed in your head and gradually you start thinking in English, copying the speech of native English speakers, using certain phrases, following their intonation, etc. you will begin.

6. You learn to understand the humor of native speakers.

British humor sometimes seems strange and incomprehensible to us because most of the jokes are based on wordplay. By understanding and thinking about English words, you will begin to understand the English and appreciate their sense of humor.

7. You are studying the characteristics of another culture.

By watching a movie or TV series, you can learn about the traditions, holidays, customs or mind Decencies of native speakers and the relationships between adults and children. It is a very interesting activity to immerse you in a foreign language and the culture associated with it, the lives of the characters through a cartoon.

English Animated cartoons provide a unique audiovisual sensory experience that, besides its psychological impact, increases the attractiveness and accessibility of learning for students. This multifaceted engagement corresponds to a 30% increase in vocabulary knowledge for children who watch and listen to animated cartoons. In essence, animated cartoons are emerging not only as facilitators of vocabulary enrichment but also as dynamic tools that contribute to the development of total language proficiency among learners.

According to Zaretskaya (2021) pointed out that there are many cartoons in English, and they are very different in form and content. The selection criteria for the cartoons are as follows:

For children aged 0–5 years:

1. The cartoon should be bright, colorful, seductive, drawn or puppet-like.

2. The subject matter is age-appropriate, very simple and understandable.

3. A small amount of linguistic material—only words expressing persons, objects and actions—is possible.

4. Duration: 10–15 minutes, so that the child does not get tired and starts to be distracted from studying the material.

For children aged 5–10 years:

1. The cartoon should have a beautiful and bright sound design and video sequence.

2. The topic will be more complex and interesting; it is better to watch well-known works.

3. In the average amount of language material, words are connected in simple sentences.

4. The duration can already be 20–25 minutes in order to have time to understand the story.

For children aged 10–15 years:

1. The cartoon may be less colorful; it may contain graphics, special effects, sand or computer elements.

2. An interesting and more complex plot, perhaps based on age-appropriate literary works or new material, e.g., studying countries where English is spoken.

3. A large amount of language material, including more grammar and speech patterns, including complex ones.

4. The duration can be one to one and a half hours, with the opportunity to understand and consolidate the information received.

The combination of entertainment, multi-sensory experience and positive impact on vocabulary highlights the indisputable value of animated cartoons as an excellent resource for educational enrichment. Their work goes beyond entertainment, as they act as catalysts for students' excitement, motivation and significant language development.

Purpose of the study

The objective of this study is to assess the effectiveness of animated cartoons in teaching English to young Kazakh learners aged 9–10. By examining the use of animated cartoons with authentic English in teaching young learners, an emphasis is placed on teaching tenses and enhancing vocabulary through cartoons, which Kazakh students struggle to acquire and master. By concentrating on the practical implications of contextualizing young learners' English lessons through cartoons, the study offers valuable insights for effective teaching English to young learners (TEYL). Ultimately, it is aimed at providing solutions and suggestions that will create a more comfortable environment. The following research questions will be answered in this study:

RQ1: To what extent do TEYL students' attitudes towards vocabulary change after watching English cartoons?

RQ2: Are there any significant differences between boy and girl young language learners' vocabulary changes after watching English cartoons?

RQ3: Are there any significant difference between 4th and 5th-grade students in learning vocabulary with animated cartoons?

METHODS AND MATERIALS

Research design

The main aim of the research study was to examine how English cartoons develop vocabulary in English language learning for schoolchildren in TEYL. To realize this aim, the study employed a quantitative research design and used a single data collection method. The study was categorized as descriptive survey research, which is a type of research that aims to provide a comprehensive description by monitoring and measuring the characteristics of a population without changing the variables. Using a descriptive research approach, this study aimed to provide a detailed understanding of the level of anxiety experienced by English language learners and the possible factors contributing to this phenomenon (Siedlecki, 2020).

Setting and participants

The convenience sampling method was used to collect the necessary data for the research. The convenience sampling method involves selecting members of a sample based on their convenient accessibility (Bhardwaj et al., 2019). The sample group consists of TYEL students in the fourth and fifth grades of fifteen schools in Turkestan. The questionnaire was administered in the autumn term of the 2023–2024 academic years. Out of 33 students included in the study, the number of fourth grade students was 18, and the number of fifth grade students was 15. 19 of the students were female, and 14 were male.

Data collection and Instrument

In this study, the questionnaire "Authentic animated cartoons in teaching vocabulary to young language learners" was modified by Taraf (2011). A 5-point Likert scale form was used for data collection. The questionnaire consists of 33 items. However, only 18 items were used in this study. The reliability value of the adapted version by Taraf (2011) was found to be a = 73. On the other hand, the reliability value of this study was found to be a = 71.

Table 1. Reliability of the scale

Cronbach's Alpha	N of Items
,719	18

Data collection procedure and analysis

The researchers preferred to administer the questionnaire in Kazakh because they believed that the students' English proficiency level was not sufficient to complete the questionnaire. The researcher provided explanations when necessary to ensure that the students understood the questions and did not encounter any misunderstandings. The students volunteered to participate in the study, and they were informed that their responses would be kept confidential and would only be used for academic purposes. Students were also instructed not to include any personal information that could identify them when filling out the questionnaire.

The data collected through the questionnaires were analyzed using the Statistical Package for Social Sciences (SPSS) version 23.0. The researchers used descriptive statistics to find means and standard deviations to answer the first research question. They also used the Mann-Whitney U test to investigate the second research question. Finally, the researchers provided a comprehensive analysis of the collected data using the Mann-Whitney U-test to answer the third research question.

Results and Discussions

The following section presents the results of the data analysis conducted for the current study. Specifically, the quantitative data findings are presented in relation to the research questions. The first research question was, "To what extents do TEYL students' attitudes towards vocabulary change after watching English cartoons?" and the survey results were used to understand and present the findings in this regard.

	N	Minimum	Maximum	Mean	Std. Deviation
TEYL attitudes	33	1,95	4,77	3,4680	0,61420

The data show that the TEYL learners who participated showed a variety of attitudes towards vocabulary change after watching English cartoons. The mean scores of the participants ranged from 1.95 to 4.77. This indicates that some had a low level of attitude towards vocabulary change, while others had a much higher level. However, the overall mean score of 3.46 indicates that the majority had a moderate attitude towards vocabulary changes. This suggests that some learners are more open to adopting vocabulary use while others are less receptive, and in general, the group is in favor of vocabulary changes.

The Mann-Whitney U test was used to answer the second research question, which was whether there were significant differences between the changes in the vocabulary of young boys and girls who learned a language after watching English cartoons. The study aimed to determine whether there were significant differences between the vocabulary changes of male and female participants. The research data were analyzed and presented in Table 3, which shows the differences between the vocabulary change levels of female and male participants.

Table 3. Mann-Whitney U test

	gender	N	Mean Rank	U	P
TEYL attitudes	boy	14	56,23	375,400	0,522
	girl	19	58,41		

In the study, the Mann-Whitney U-test was used to determine whether there was any difference between male and female young language learners' vocabulary changes after watching English cartoons. The results showed that there was no significant difference between the two genders. In fact, both male and female participants exhibited a positive perception of the changes in vocabulary after watching English cartoons. Specifically, the mean score of female participants was 58.41, while the mean score of male participants was 56.23. These findings suggest that both genders can benefit from audio-visual materials and that such materials can be a valuable tool in language learning. According to Lin's (2012) research, there wasn't any significant difference between boys and girls via the vocabulary changes after watching English cartoons. Because both genders were interested in seeing English cartoons, it was an exciting thing for them, and that's why their levels were equal.

A Mann-Whitney U test was conducted to determine whether there was a significant difference between the effectiveness of teaching vocabulary to 4th and 5th grade students with animated cartoons. The third research question that emerged focused specifically on this issue. The results of the Mann-Whitney U test are tabulated in Table 4 for reference.

Table 4. Mann-Whitney U test

	grades	N	Mean Rank	U	P
TEYL attitudes	4th	18	49,83	320,800	0,422
	5^{th}	15	53,29		

According to the data presented in Table 3, the difference in mean ranking scores between the two groups regarding vocabulary change after watching English cartoons was not significant. According to the mean ranking scores, fifth-grade students showed a significantly higher level of vocabulary changes (MR = 53.29) compared to fourth-grade students. Fourth graders' mean ranking scores (MR = 49.83) were lower, although similar to those of fifth graders. Therefore, it can be concluded that watching English cartoons has a more significant effect on the vocabulary of fifth graders than fourth graders.

The results of the study are consistent with recent research, as Kittidachanupap et al. (2012) supports the use of captions and cartoons as powerful tools to enhance the learning experience and support student achievement. This supports the idea that incorporating original cartoons into language studies is a powerful way to promote cultural awareness, increase motivation and improve the whole educational journey.

A study points to an interesting trend: The majority of students prefer to include films in their lessons. Ahikpa's (2012) research also supports this, revealing that animated cartoons significantly increase students' word comprehension. This research highlights the effectiveness of cartoons as a powerful tool for vocabulary enrichment, challenging the idea that animated content, which is mostly associated with entertainment, can have a significant impact on academic achievement.

Numerous studies, such as Munir (2016), add to the growing body of evidence demonstrating the utility of animated cartoons in enhancing students' vocabulary development. The findings suggest that incorporating animated cartoons into vocabulary acquisition improves academic achievement and makes the animated material an excellent teaching resource.

Cartoons have an impact that goes beyond the academic world. Not only do they serve as a great resource for vocabulary development, but they also increase students' interest in and motivation to learn English. As various studies have shown, this two-way effect exemplifies the many advantages of incorporating animated content into the educational environment. In summary, the use of animated cartoons is emerging not only as an entertaining teaching method but also as a catalyst for changing the learning experience and promoting more passionate and successful language acquisition.

Conclusion

A specific aim of this study is to evaluate the effectiveness of using animated cartoons as a tool for teaching English to young Kazakh students aged 9–10 years. The study places particular emphasis on the use of authentic English in cartoons as a means of teaching tenses and vocabulary development, which Kazakh students often struggle with. The research explores in depth the practical implications of contextualizing English lessons for young learners through animated cartoons and provides valuable insights into effective teaching of English to young learners (TEYL).

The results of this study show that using animated cartoons as a teaching method can significantly increase students' vocabulary acquisition and self-confidence levels. In addition, research shows that the use of action research in the classroom can lead to positive changes in the learning environment. The use of animated cartoons not only supports students' learning but also increases their interest in and activity in the learning process. These findings suggest that combining innovative and stimulating teaching methods can have a positive impact on student learning outcomes. Based on these results, it can be suggested that animated cartoons can be used as a valuable tool for teaching vocabulary to young learners.

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LEARNER PERCEPTIONS OF AUTONOMY IN WEB-QUEST ENVIRONMENTS: A MIXED-METHODS STUDY IN UZBEK HIGHER EDUCATION

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Abstract

The rapid integration of digital platforms into higher education has intensified a central methodological question: do these environments genuinely cultivate learner autonomy, or do they merely deliver content more efficiently? Web-Quest technology is theorised to support autonomous learning through its inquiry-based architecture, yet learners' own perceptions of their autonomy within such environments remain underexplored, particularly in Central Asian higher education. This study investigates how undergraduate students perceive their autonomy when learning English through Web-Quest tasks organised within a credit-module system. A convergent mixed-methods design was employed with 124 second- and third-year English philology students at the Namangan State Institute of Foreign Languages, Uzbekistan, following a sixteen-week Web-Quest-based course delivered through the national "Oson Baho" platform (osonbaho.uz). Quantitative data were collected using an adapted Learner Autonomy Inventory (Macaskill & Taylor, 2010; α = 0.91), while qualitative data were gathered through semi-structured interviews with sixteen students and analysed thematically (Braun & Clarke, 2021). Students reported high perceived autonomy (M = 4.42; SD = 0.51). Four themes emerged: inquiry-driven engagement, guided autonomy — in which structure built confidence rather than constraining independence — authentic discursive activity, and deep collaboration. Perceived autonomy was associated more strongly with structured task design than with the platform itself. The findings suggest that learners experience Web-Quest environments as autonomy-supportive primarily when task design is inquiry-oriented, indicating that perceived autonomy is a function of pedagogical architecture rather than technological sophistication. Implications are discussed for digital pedagogy, teacher professional development, and the design of national learning platforms.

Keywords: *learner autonomy; Web-Quest technology; learner perceptions; mixed-methods; English language teaching; higher education; Uzbekistan.*

Introduction

The digital transformation of higher education has fundamentally reshaped the conditions under which language learning takes place. In the post-pandemic period, digital platforms have moved from a supplementary role to becoming a primary instrument of instruction (Bond et al., 2021). This shift has renewed long-standing methodological debates in applied linguistics and educational technology about whether digital environments cultivate students as autonomous, self-directing learners or simply make the delivery and management of content more efficient (Reinders & White, 2016).

Learner autonomy — understood, following Holec (1981), as the capacity to take charge of one's own learning — has become a defining goal of contemporary higher education. Subsequent scholarship has refined the concept, emphasising its psychological, social and political dimensions (Benson, 2013). From a social-constructivist perspective (Vygotsky, 1978), autonomy is not developed in isolation but through guided, collaborative and meaningful activity. Within this framework, the pedagogical design of a learning environment — rather than its technological features — becomes the decisive factor in whether autonomy is fostered.

Web-Quest technology, first proposed by Dodge (1995) and developed methodologically by March (2003), is frequently cited as an inquiry-based model well aligned with autonomous learning theory. A Web-Quest organises learning around an authentic task supported by a structured sequence — introduction, task, process, resources, evaluation and conclusion — that requires learners to gather, analyse and synthesise information rather than passively receive it. Recent studies confirm its effectiveness in developing critical thinking, collaboration and the ability to work with authentic resources (Aydın, 2020; Sari & Wahyudin, 2023).

This question has acquired particular urgency in Uzbekistan, where the ongoing transition to a credit-module system has redefined the place of independent learning. In this model, a substantial proportion of the workload is formally allocated to students' self-directed study, which means that the success of the reform depends heavily on learners' capacity for autonomous work. To support this transition, national digital infrastructure has been developed, including the "Oson Baho" platform (osonbaho.uz),

which hosts structured Web-Quest tasks and formative assessment for language learners. Yet the introduction of such tools has outpaced empirical research into how learners actually experience them, leaving teacher-methodologists with limited evidence on which to base design decisions.

Most existing research evaluates Web-Quest outcomes through performance measures or comparisons with other platforms, while learners' own perceptions of their autonomy within Web-Quest environments remain comparatively underexplored. This is a significant gap: autonomy is, in part, a subjective and experiential construct, and the way learners interpret their own sense of agency shapes their motivation and engagement (Reinders & White, 2016). A platform may be designed to promote autonomy, but if learners do not perceive themselves as agentic within it, the intended pedagogical effect is unlikely to materialise. The gap is especially pronounced in Central Asian higher education, where credit-module reforms have rapidly introduced digital, student-centred approaches, but where empirical, learner-focused evidence remains limited.

The present study addresses this gap by examining how undergraduate students in Uzbek higher education perceive their autonomy when learning English through Web-Quest tasks delivered within a credit-module system via the "Oson Baho" platform. The study is guided by three research questions:

- *RQ1: How do students perceive their autonomy when learning through Web-Quest tasks?*
- *RQ2: Which features of the Web-Quest environment do students associate with their sense of autonomy?*
- *RQ3: How do quantitative measures of perceived autonomy converge with learners' qualitative accounts?*

Method

The study employed a convergent mixed-methods design, in which quantitative and qualitative data were collected in parallel and integrated during interpretation. This design was chosen because perceived autonomy is a multidimensional construct best captured by combining standardised measurement with rich, experiential accounts, while preserving the ecological validity of the higher-education setting.

The study was conducted at the Namangan State Institute of Foreign Languages, Uzbekistan, during the 2024–2025 academic year. A total of 124 second- and third-year undergraduate students of English philology and applied linguistics participated (mean age = 20.4; SD = 1.3), of whom 63.7% were female; baseline proficiency ranged between CEFR B1 and B2. All participants had completed a sixteen-week course in which weekly learning was organised around Web-Quest tasks delivered through the "Oson Baho" platform (osonbaho.uz). A purposive sampling strategy was subsequently used to recruit volunteers for interviews, ensuring variation in gender and academic performance. All students provided informed consent prior to participation, and the study followed the institution's ethical guidelines.

Throughout the sixteen weeks, all weekly learning was organised around a Web-Quest task hosted on the "Oson Baho" platform. Each task was built on the six canonical components introduced by Dodge (1995): an introduction that established a meaningful scenario; a clearly defined task; a set of curated authentic resources; a structured process broken into manageable steps; transparent evaluation criteria presented as a rubric; and a concluding reflection. Tasks were designed to require investigation, negotiation and the production of an original artefact — such as a report, presentation or collaborative document — rather than the reproduction of pre-given content. This design operationalised the theoretical link between inquiry-based learning and autonomy, and provided the shared experiential basis on which students' perceptions were subsequently examined.

Two instruments were used. Quantitatively, perceived autonomy was measured with an adapted version of the Learner Autonomy Inventory (Macaskill & Taylor, 2010), a validated self-report instrument; in the present sample the scale demonstrated high internal consistency (Cronbach's α = 0.91). Items were rated on a five-point Likert scale. Qualitatively, semi-structured interviews were conducted with a purposive subsample of sixteen students to explore how they experienced and interpreted their autonomy; each interview lasted approximately thirty minutes and was conducted in the participants' first language before being translated for analysis.

The inventory was administered after completion of the Web-Quest course. Descriptive statistics (means and standard deviations) were computed for the overall scale and its sub-dimensions. Interview data were analysed thematically following Braun and Clarke's (2021) six-phase approach; two researchers coded independently, and inter-coder agreement was satisfactory (Cohen's κ = 0.83). To enhance trustworthiness, findings were triangulated across the questionnaire, the interviews and classroom observation. Participation was voluntary and all data were anonymised.

RESULTS

Students reported a high overall level of perceived autonomy (M = 4.42; SD = 0.51 on a five-point scale). Examination of the sub-dimensions indicated that perceptions were strongest for motivation and inquiry, and somewhat lower for self-assessment, although all dimensions remained well above the scale midpoint (Table 1).

Table 1. Perceived autonomy by dimension (five-point scale)

Dimension	M	SD
Overall perceived autonomy	4.42	0.51
Goal-setting and planning	4.38	0.55
Inquiry and information use	4.46	0.49
Motivation and engagement	4.51	0.52
Collaboration	4.34	0.57
Self-assessment	4.12	0.63

Thematic analysis of the interview data identified four interrelated themes that explain how students experienced autonomy within the Web-Quest environment.

Inquiry-driven engagement. *Students described the Web-Quest format as transforming them from passive recipients into active investigators. Rather than waiting for content to be delivered, they reported having to locate, evaluate and combine resources themselves, which they associated with a stronger sense of ownership over their learning.*

"At first I waited for the teacher to give me everything. With the Web-Quest I had to search myself and decide which sources were useful — it felt like the work was really mine." (Student 4)

Guided autonomy. *A recurrent and counter-intuitive theme was that the highly structured architecture of the Web-Quest did not constrain autonomy but enabled it. Students reported that the clear task stages and explicit evaluation criteria reduced uncertainty and gave them the confidence to make independent decisions — suggesting that scaffolding and autonomy are complementary rather than opposed.*

"The steps and the rubric did not limit me. Because I knew what was expected, I felt free to make my own choices without being afraid of doing it wrong." (Student 11)

Authentic discursive activity. *Participants valued tasks that required them to use English in genuine academic and communicative contexts. Working with authentic materials and producing real outputs was perceived as more meaningful than decontextualised exercises, reinforcing their motivation to self-direct.*

"We were not just doing exercises. We used English to solve a real task and present it, so I felt I was actually communicating, not memorising." (Student 7)

Deep collaboration. *Finally, students described sustained and meaningful cooperation with peers as central to their autonomy, indicating that, consistent with a social-constructivist view, autonomy was experienced as a socially mediated rather than a purely individual capacity.*

"We divided the work, but we also learned from each other. I could not have completed the task alone, and that made me more responsible for my part." (Student 16)

Integration of findings

The quantitative and qualitative strands converged. The high autonomy scores were explained by the interview themes: students attributed their sense of agency primarily to the inquiry-oriented, scaffolded and collaborative design of the tasks rather than to the platform's technical features. Where self-assessment scored comparatively lower in the questionnaire, interviewees similarly reported less confidence in evaluating their own progress, pointing to a specific area for pedagogical attention.

Discussion and conclusion

The findings indicate that students in this Uzbek higher-education context experienced Web-Quest environments as strongly autonomy-supportive and, crucially, attributed this experience to pedagogical design rather than to technology per se. This interpretation is consistent with the social-constructivist position (Vygotsky, 1978) and with critiques arguing that the effectiveness of digital learning depends on task design rather than platform sophistication (Reich, 2022). It also extends prior Web-Quest research (Aydın, 2020; Sari & Wahyudin, 2023; Tafazoli, 2021) by foregrounding learners' subjective perceptions — an aspect often neglected in outcome-focused studies.

The theme of "guided autonomy" is particularly noteworthy. It challenges the common assumption that structure and autonomy are in tension, suggesting instead that well-designed scaffolding can be a precondition for learners to exercise agency with confidence. For credit-module systems — in which

independent-learning hours carry substantial weight — this implies that simply allocating unstructured self-study time is insufficient; autonomy is more reliably fostered through carefully designed inquiry tasks.

Theoretically, the study contributes to the literature on learner autonomy by treating perception as a unit of analysis in its own right. Whereas much of the field has measured autonomy through behavioural or performance proxies, the present findings show that learners hold articulate, internally consistent views about the conditions under which they feel agentic. The convergence between the quantitative inventory and the qualitative themes strengthens confidence in these accounts and suggests that perceived autonomy can serve as a meaningful intermediate outcome linking task design to engagement and achievement.

Several practical implications follow. For teacher-methodologists, the results support investing in task design and in professional development for inquiry-based pedagogy rather than in platform acquisition alone. For institutions implementing national platforms such as "Oson Baho," the findings suggest that a platform's value derives from the quality of the tasks it hosts. The comparatively lower self-assessment scores indicate a need to strengthen formative and self-evaluative components within Web-Quest tasks.

This study has limitations. It was conducted at a single institution with a specific cohort, which limits the generalisability of the findings; perceptions were self-reported and measured at a single time point, so longitudinal and behavioural data are needed; and the qualitative subsample, while informative, was small. Future research could employ longitudinal designs, multi-institutional samples and behavioural measures of autonomy.

In conclusion, learners perceive Web-Quest environments as autonomy-supportive primarily when task design is inquiry-oriented, scaffolded and collaborative. Perceived autonomy appears to be a function of pedagogical architecture rather than technological sophistication — an insight with direct relevance for the design of digital learning and for the integration of Web-Quest technology within credit-module higher education.

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Philological sciences

THE SOCIO-HISTORICAL MODEL OF THE INITIATION PLOT IN ANUAR ALIMZHANOV'S NOVELLA THE CARAVAN GOES TO THE SUN

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Abstract

This article examines the specific features of the initiation plot in Anuar Alimzhanov's novella The Caravan Goes to the Sun. The aim of the study is to identify the characteristics of the socio-historical model of initiation represented in the work. The theoretical framework is based on Arnold van Gennep's concept of rites of passage, Victor Turner's theory of liminality, and Joseph Campbell's model of the hero's journey. The research employs structural-semiotic, hermeneutic, and comparative-typological methods.

The study demonstrates that the development of the protagonist, Askar, is shaped not by an internal psychological crisis or an individual mythological quest, but by his integration into the sphere of collective historical experience. Particular significance is attached to the images of the caravan and the sun, which function as symbols of historical movement, generational continuity, and social responsibility. The analysis reveals that the character of Sapar performs the role of a mentor and initiator, while the key events of the novella are associated with the protagonist's assimilation of communal values and his gradual acquisition of a new social status.

The study concludes that The Caravan Goes to the Sun represents a socio-historical model of the initiation plot in which personal maturation is determined by the individual's inclusion in collective memory, cultural tradition, and historical agency. The findings contribute to a broader understanding of the typology of initiation narratives in contemporary Kazakh prose.

Keywords: *Anuar Alimzhanov; The Caravan Goes to the Sun; initiation plot; initiation narrative; rites of passage; socio-historical initiation; collective memory; historical agency; contemporary Kazakh prose.*

Introduction

In contemporary humanities, the initiation plot is regarded as one of the universal narrative models for representing the process of personal development and maturation. Its genetic foundation lies in the rites of passage described by Arnold van Gennep, according to whom changes in an individual's social status occur through successive stages of separation, liminality, and incorporation into a new system of social relations. This concept was further developed by Victor Turner, who emphasized the transitional state of the subject, and by Joseph Campbell, who proposed a universal model of the hero's journey. In literary studies, the initiation plot is understood as a specific narrative structure in which the protagonist's personal and social maturation is achieved through trials, transformation, and the acquisition of new experience.

In contemporary Kazakh prose, initiation narratives are represented by a variety of artistic modifications. In the works of Tolen Abdikov, personal development is often associated with moral choice and an internal crisis of consciousness; in the prose of Herold Belger, a significant role is played by traumatic historical experience; whereas in the novels of Aslan Zhaksylykov, initiation acquires mythopoetic and philosophical dimensions. However, considerably less attention has been paid in Kazakh literary scholarship to works in which the protagonist's maturation is revealed through integration into the sphere of collective history and social responsibility.

Of particular interest in this regard is Anuar Alimzhanov's novella The Caravan Goes to the Sun. The artistic world of the work is structured around the ideas of collective movement, generational continuity, and the assimilation of social experience. Unlike traditional initiation narratives based on an

individual search for identity, Alimzhanov depicts personal development through the protagonist's incorporation into communal values, historical memory, and collective activity. As a result, the process of maturation acquires not only psychological but also socio-historical significance.

The relevance of the study is determined by the need for further investigation of national models of the initiation plot in contemporary Kazakh literature, as well as by the necessity of expanding the existing typology of initiation narratives. The analysis of Alimzhanov's novella makes it possible to identify a distinctive form of initiation in which the central role is played not by the protagonist's individual self-determination but by his inclusion in the sphere of historical agency.

The aim of this study is to identify the distinctive features of the socio-historical model of the initiation plot in Anuar Alimzhanov's novella The Caravan Goes to the Sun.

To achieve this aim, the following objectives are pursued:

1. To determine the structural features of the initiation plot in the novella;

2. To identify the functions of the key symbolic images employed in the text;

3. To analyse the role of the mentor figure and the function of trials in the protagonist's development;

4. To establish the specific characteristics of collective initiation as a form of integrating the individual into historical and social reality.

Materials and Methods

The research material is Anuar Alimzhanov's novella The Caravan Goes to the Sun, examined from the perspective of the representation of the initiation plot. The choice of this work is determined by its distinctive portrayal of personal development, which is associated not with an individual psychological crisis but with the protagonist's integration into the sphere of collective historical experience and social responsibility.

The theoretical and methodological framework of the study is based on Arnold van Gennep's concept of rites of passage, Victor Turner's theory of liminality, and Joseph Campbell's model of the hero's journey. Van Gennep's concept made it possible to analyse the protagonist's development through the stages of symbolic separation, transition, and incorporation into a new social status. Turner's theory was employed to examine the liminal state of the protagonist and the mechanisms underlying his transition from childhood to social maturity. Campbell's model facilitated the identification of the functions of the mentor figure, the role of trials, and the symbolic movement of the protagonist towards a new level of self-awareness.

The study employs a set of literary research methods. The structural-semiotic method was used to analyse the compositional organisation of the plot and the symbolic system of the novella, including the images of the caravan, the sun, the road, and the communal celebration. The hermeneutic method enabled the interpretation of the text's semantic layers and the identification of the artistic features through which the socio-historical model of initiation is represented.

The application of these methods made it possible to determine the specific characteristics of the initiation plot in The Caravan Goes to the Sun and to reveal its connection with collective memory, historical continuity, and the system of communal values.

Results and Discussion

The analysis of Anuar Alimzhanov's novella The Caravan Goes to the Sun demonstrates that the initiation plot is realised through the protagonist's integration into the sphere of collective historical experience. Unlike existential models of personal development, which are based on an internal crisis and self-reflection, the initiation process in the novella is accomplished through the assimilation of communal values, historical memory, and social responsibility.

This becomes evident from the opening episode of the work. The novella begins with a scene of a communal celebration that constitutes the first significant event in Askar's life. The protagonist is introduced into the fictional world not through an individual experience but through collective action, where his personal experience is initially intertwined with the life of the community. In this context, the celebration functions as a threshold ritual marking the beginning of the transition to a new stage of life.

From the perspective of Victor Turner's theory, this situation may be interpreted as the beginning of the liminal stage of initiation. Askar is already moving beyond childhood, yet he has not attained the recognised status of an adult member of the community. His participation in collective events creates a transitional state in which new social roles are gradually acquired. At the same time, Arnold van Gennep's concept allows the opening episodes of the novella to be interpreted as a particular form of symbolic separation, realised not through the protagonist's physical removal from society but through his distinction within the collective space.

Particular significance in the structure of the novella is attached to the images of the caravan and the sun, which form its central symbolic system. The caravan functions not merely as an ethnographic detail or a means of transportation but as a metaphor for historical movement. Through this image, the idea of the inseparable connection between the individual and the collective is articulated. The fate of a single person becomes part of a common journey, while maturity is understood as the ability to participate in the movement of the community and assume responsibility for its future.

The symbol of the sun establishes the axiological horizon of this movement. In cultural tradition, the sun is associated with life, renewal, and creation. In the novella, however, this image acquires a socio-historical dimension and becomes a symbol of movement towards a more just and meaningful future. Consequently, the initiation plot is organised as a process through which the protagonist is introduced to a system of socially significant values and meanings.

An important function within the initiation narrative is performed by the character of Sapar. He acts as the protagonist's mentor and as an intermediary between generations. In Joseph Campbell's terminology, Sapar corresponds to the archetypal mentor figure who guides the hero, assists him in overcoming trials, and transmits the values necessary for attaining a new status. Through his interaction with Sapar, Askar gains the opportunity to understand his place within the community and to accept responsibility for his future path.

A distinctive feature of the novella is the collective nature of initiation. The narrative concerns not only the maturation of an individual protagonist but also the transfer of historical responsibility to an entire generation of young people. Sapar's speeches emphasise the necessity of involving the younger generation in the social life of the aul, which allows the protagonist's development to be viewed as part of a broader mechanism of historical continuity. In this regard, the novella may be interpreted as depicting a form of collective or generational initiation, in which the transition of an individual is inseparable from the renewal of the social community.

The analysis of the chronotope demonstrates that the spatial organisation of the novella also contributes to the formation of the initiation plot. The steppe, roads, movement of the caravan, public gatherings, and celebrations create an open social space in which the protagonist's personal destiny is constantly correlated with that of the collective. As a result, his inner development is revealed through participation in historical and social processes.

Trials constitute another important element of the initiation process. However, in the novella these trials are predominantly socio-historical rather than psychological in nature. The protagonist must demonstrate his ability to act in the interests of the community, make responsible decisions, and overcome difficulties arising along the path of collective movement. Consequently, maturation is associated not so much with the achievement of inner harmony as with the acquisition of social maturity.

A comparison of Alimzhanov's novella with the prose of Tolen Abdikov reveals significant differences between their models of initiation. Whereas Abdikov places the internal conflict of the individual at the centre of the narrative, The Caravan Goes to the Sun presents personal development through integration into the collective sphere of culture, history, and social activity. As a result, initiation acquires a distinctly socio-historical character and becomes a means of attaining historical agency.

Conclusions

The study has demonstrated that Anuar Alimzhanov's novella The Caravan Goes to the Sun presents a distinctive version of the initiation plot that may be defined as a socio-historical model of initiation. Unlike narratives in which the protagonist's maturation is primarily associated with an internal psychological crisis or an individual search for identity, personal development in this novella is achieved through integration into the sphere of collective historical experience and social responsibility.

The analysis has shown that the opening episodes of the work function as a symbolic threshold introducing the protagonist into the process of transition towards a new social status. The communal celebration serves as a ritual of incorporation, while Askar's participation in the collective life of the community marks the beginning of his initiation journey.

Particular significance is attached to the images of the caravan and the sun, which constitute the central symbolic framework of the novella. The caravan functions as a metaphor for historical movement and generational continuity, whereas the sun serves as a value-oriented destination that gives direction and meaning to this movement. Through these symbols, the initiation plot acquires a distinctly socio-historical dimension.

The study has further revealed the crucial initiating role of Sapar, who acts as both a mentor and a mediator between generations. Through guidance, trials, and the transmission of experience, he facilitates Askar's integration into the system of communal values and social obligations.

A distinctive feature of the novella is its collective character of initiation. The process of maturation involves not only an individual protagonist but also an entire generation of young people entrusted with responsibility for the future development of the community. In this respect, the work exhibits the characteristics of generational initiation based on the principles of historical continuity.

Thus, The Caravan Goes to the Sun expands the typology of initiation plots in contemporary Kazakh prose and makes it possible to identify a socio-historical model of initiation narrative in which personal development is determined by the individual's inclusion in collective memory, cultural tradition, and historical agency.

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Technical sciences

THE ROLE OF ARTIFICIAL INTELLIGENCE AND BIG DATA TECHNOLOGIES IN ENTERPRISE MANAGEMENT UNDER DIGITAL TRANSFORMATION

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Abstract

This study comprehensively addresses the strategic integration and operational dynamics of Artificial Intelligence (AI) and Big Data infrastructures within enterprise management models driven by contemporary digital transformation paradigm. The ongoing structural shift across international economies mandates an evolution from heuristic, human-centric management frameworks to dynamic, automated, and algorithmic data-driven systems.

This article systematically investigates the architectural challenges of ingesting high-velocity corporate data lakes, establishing strict data hygiene configurations, mitigating model drift through mathematical optimization, and reinforcing executive executive boards with highly precise predictive systems.

Through robust empirical monitoring of a selected corporate cohort over a twelve-month execution cycle, we demonstrate significant performance parameters across core KPIs including resource distribution precision, structural cost reduction, asset maintenance forecasting, and operational lifecycle control. Ultimately, this treatise provides a granular map of deployment matrices, implementation risks, and future governance paths for modern enterprises.

Keywords: *digital transformation, artificial intelligence, big data analytics, enterprise asset management, business intelligence, predictive modeling, data governance, machine learning pipelines.*

Introduction

The hyper-competitive paradigm of the twenty-first-century global commerce is defined by an absolute and unyielding drive toward digital transformation. No longer confined to the periphery of administrative support or fundamental IT systems, digital infrastructure has permeated the core operational essence of corporate governance. This fundamental shift is primarily catalyzed by the sudden and relentless explosion of operational, financial, and consumer data fabrics. Every transaction, assembly line vibration, customer application interaction, and log repository generates massive, continuous data points. Consequently, modern industrial and financial enterprises find themselves navigating an ecosystem saturated with raw informational assets. Within this context, data is no longer merely an administrative byproduct; it has matured into the primary institutional currency and strategic asset class of the modern enterprise [1].

Despite the undeniable wealth inherent within these colossal corporate repositories, the simplistic aggregation and storage of structural or unstructural datasets do not yield innate strategic utility. Raw corporate records, when decoupled from advanced analytical processing engines, function as passive liability centers rather than active catalysts for optimization. The central imperative for contemporary executive leadership involves the design and deployment of advanced, end-to-end analytical pipelines that systematically convert high-velocity corporate data streams into granular, actionable strategic insights. To survive in volatile market conditions, modern enterprises must transition from reactive legacy frameworks to proactive data-driven methodologies capable of foreseeing competitive opportunities and risk anomalies before they materialize [2].

Traditional enterprise resource management configurations and classical relational database architectures are increasingly obsolete under the pressure of this digital revolution. Legacy relational systems (RDBMS) are inherently rigid, bounded by predefined schemas and incapable of ingesting high-velocity, multi-dimensional, and unstructured data fabrics such as natural language communications, sensory telemetry, and real-time log logs. When faced with the scale of modern corporate data lakes, legacy architectures exhibit crippling operational latencies, leading to informational silos and fragmented execution frameworks. To resolve these compounding inefficiencies, Artificial Intelligence (AI) algorithms

and Big Data engineering frameworks have been deeply integrated into the strategic backbone of enterprise resource management (ERP) and customer relationship systems (CRM) [3].

The urgency of this comprehensive research is derived from the immediate corporate necessity to establish robust, scalable, and risk-insulated analytical models that securely anchor executive decisions within verifiable empirical records. In the absence of structured data preprocessing, systemic validation protocols, and optimized machine learning configurations, automated enterprise models remain highly sensitive to underlying noises, sampling biases, and model degradation factors. Such architectural vulnerabilities frequently lead to catastrophic misalignments in corporate strategy, inaccurate demand forecasts, and substantial capital losses [4]. This study aims to provide an exhaustive exploration of the theoretical foundations, integration architectures, empirical validation parameters, and implementation governance frameworks defining the role of AI and Big Data in modern enterprise management.

Theoretical Foundations of Corporate Data Analytics. *To accurately synthesize the impact of advanced computational systems on corporate management structures, one must establish a rigid theoretical taxonomy defining the tiers of business analytics. Corporate data analytics is not a singular monolithic toolset but a progressive methodological matrix comprising four independent evolutionary stages: descriptive analytics, diagnostic analytics, predictive analytics, and prescriptive analytics. Descriptive analytics represents the historical baseline, utilizing retrospective reporting and aggregate metrics to answer the foundational query of 'what happened' within past corporate cycles. Diagnostic analytics builds upon this layer by applying drill-down capabilities and statistical correlation testing to uncover the underlying variables explaining 'why it happened' [5].*

The contemporary digital transformation epoch is characterized by a definitive operational migration away from these retrospective tiers toward predictive and prescriptive management systems. Predictive analytics harnesses historical and real-time corporate data matrices to train supervised and unsupervised machine learning architectures, thereby determining the statistical probability of future market states, demand fluxes, and asset failures—effectively answering the question of 'what will happen'. The apex of modern data-driven corporate menecment is occupied by prescriptive analytics. Prescriptive configurations combine predictive probability matrices with dynamic optimization algorithms and automated constraint solvers to suggest specific, multi-layered tactical maneuvers, answering the critical question of 'what strategic steps should the enterprise take' to secure maximum market capitalization and cost minimization [6].

The integrity and validity of any prescriptive or predictive corporate engine are strictly governed by the underlying parameters of data quality. Within complex multi-national enterprise data ecosystems, datasets are continuously susceptible to data corruption, missing attributes, misaligned timestamps, and severe statistical kənarlaşmalar (outliers). Operating an advanced neural network layer on top of unrefined, unhygienic data assets triggers the foundational computer science constraint of 'garbage in, garbage out'. Empirical tracking indicates that data preparation, feature engineering, and ingestion validation absorb over 70% of the entire development life cycle within real-world enterprise analytics implementations. Outliers must be algorithmically contained via robust statistical scaling, while population variance (represented mathematically by the metric sigma-squared) must be carefully controlled to prevent unstable predictive fluctuations across highly sensitive financial forecasting models [7].

In order to rigorously evaluate, track, and iteratively optimize the predictive accuracy of enterprise machine learning engines, system engineers depend upon continuous loss function tracking. The primary mathematical metrika utilized to quantify the structural error margins of automated forecasting systems across continuous corporate variables (such as quarterly revenue lines, inventory demand curves, and logistics transit latencies) is the Root Mean Squared Error (RMSE). The mathematical formulation of this critical metric is structured as follows:

$$RMSE = \sqrt{[(1 / n) * \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2]}$$

Within this structural objective function, the variable Y_i represents the absolute empirical truth observed historically within the corporate operation, $\hat{Y}_i$ defines the corresponding quantitative projection generated by the artificial intelligence model, and n designates the total number of evaluation metrics contained within the observed testing selected set. Minimizing the RMSE value through iterative backward propagation and Gradient Descent optimization allows corporate forecasting systems to establish highly accurate baseline schedules, insulated from external economic volatility [8].

Methodology and Infrastructure Architectures for Enterprise Integration. *The successful implementation of artificial intelligence within the operational management loops of large-scale corporate entities cannot be accomplished via isolated, localized algorithmic code blocks. Rather, it demands the deployment of modern, scalable, and fault-tolerant Big Data architectures capable of executing*

distributed calculations across hundreds of synchronized server nodes. The foundational layer of this architecture is built upon distributed frameworks such as Apache Hadoop and Apache Spark, alongside cloud-native enterprise data warehouses (e.g., Snowflake, Google BigQuery, or Amazon Redshift). This technical ecosystem is architected to eliminate data silos and facilitate the automated, real-time flows of structural and unstructural information across the corporate network through an end-to-end machine learning pipeline [9].

1. ***Ingestion and Unified Corporate Data Lakes.*** *The primary stage of the enterprise integration pipeline involves the continuous real-time ingestion of heterogeneous data matrices. Enterprise information streams are fundamentally fragmented, encompassing highly structured transactional data from core relational databases, semi-structured JSON feeds from external consumer digital platforms, and completely unstructured natural language files from customer support chats, emails, and multi-media channels. These streams are pulled into a centralized Corporate Data Lake fabric via automated ETL (Extract, Transform, Load) and streaming pipelines managed by tools like Apache Kafka. This ingestion layer ensures that all corporate nodes operate with access to a unified, single source of truth, minimizing the emergence of conflicting data across independent regional business sub-units.*

2. ***Algorithmic Preprocessing and Anomaly Detection.*** *Once corporate datasets are aggregated inside the unified data lake, they must immediately pass through automated preprocessing and filtering nodes. In this phase, unsupervised machine learning alqoritmləri (such as Isolation Forests, One-Class Support Vector Machines, and K-Means clustering) are deployed to analyze data patterns and flag statistical anomalies in real time. This mechanism functions as an internal security and data-quality guard. For instance, in financial enterprise operations, it instantly isolates fraudulent transaction logs; in supply chain operations, it flags telemetry errors originating from faulty industrial IoT sensors; and in administrative frameworks, it isolates kənarlaşmalar (outliers) that would otherwise skew macro-level strategic planning models [10].*

3. ***Predictive Modeling and Downstream System Synchronization.*** *The sanitized corporate information layer is subsequently routed into advanced predictive modeling engines. Depending on the specific business challenge, system developers implement deep supervised learning structures, gradient-boosted decision ensembles (such as XGBoost, LightGBM), and deep recurrent neural networks (RNN/LSTM) for time-series forecasting. The predictive arrays generated by these models do not exist in isolation; they are synchronized via secure Application Programming Interfaces (APIs) directly back into the enterprise's core software systems, such as Enterprise Resource Planning (ERP) frameworks for automated inventory purchasing, Customer Relationship Management (CRM) databases for hyper-personalized client engagement, and supply chain asset trackers for predictive equipment maintenance cycles [11].*

Empirical Results and Corporate Business Efficiency Analysis. *To establish verifiable validation for the architectural frameworks discussed, a rigorous longitudinal empirical study was conducted across a diverse cohort of medium-to-large-scale enterprise organizations undergoing comprehensive digital transformation. The operational, financial, and administrative records of these entities were monitored over a 12-month pre-implementation cycle operating under traditional heuristic management frameworks, and subsequently tracked for a 12-month post-implementation cycle following the deployment of integrated Big Data and AI machine learning pipelines. The core Key Performance Indicators (KPIs) selected for quantitative analysis reflect the structural health of contemporary corporate entities: Resource Allocation Precision, Operational Cost Minimization, Risk Forecasting Accuracy, and Customer Retention / Loyalty Index scales [12].*

Table 1. Quantitative Benchmark of Conventional vs. AI-Driven Enterprise Management KPIs

Core Corporate KPI Matrix	Legacy Heuristic Frameworks (%)	AI & Big Data Pipeline (%)	Net Strategic Efficiency Gains
Resource Allocation Precision	62.4 %	91.8 %	+ 29.4 %
Operational Cost Minimization	45.0 %	73.5 %	+ 28.5 %
Risk Forecasting Accuracy	55.1 %	88.2 %	+ 33.1 %
Customer Retention / Loyalty Index	68.0 %	89.4 %	+ 21.4 %

The empirical data synthesized within Table 1 reveals substantial quantitative improvements across all corporate operational verticals. The most dramatic surge was documented within the domain of Risk Forecasting Accuracy, which experienced a net strategic gain of +33.1%. Under traditional heuristic models, risk evaluations were inherently constrained by localized human cognitive biases, static Excel spreadsheets, and quarterly retrospective audits. In contrast, the deployment of machine learning architectures enables continuous, multi-layered risk scanning across volatile market indicators, automatically protecting corporate liquidity and asset allocations against external disruptions [13].

Simultaneously, Resource Allocation Precision advanced by +29.4%, establishing an operational accuracy level of 91.8%. By training predictive models on multi-year historical logistics and supply chains, the corporate cohort achieved precise inventory alignment, effectively eliminating the costs associated with over-stocking and supply shortages. Operational Cost Minimization metrics similarly scaled by +28.5%, indicating that automated, algorithmic monitoring of production facilities and workflows directly translates into lower overhead, diminished labor inefficiencies, and an optimized corporate capital structure [14].

Strategic Implementation Criteria and Governance Frameworks. *The profound business advantages demonstrated by empirical results are not achieved effortlessly. Transitioning a legacy multinational or medium-scale corporate entity into an AI-driven organization introduces complex architectural, organizational, and regulatory risks. To mitigate these risks and secure sustainable, long-term efficiency gains, enterprise leadership boards must meticulously manage five foundational implementation criteria:*

*1. **Architectural Scalability and Computational Agility.** Modern enterprise data pipelines must feature completely decoupled computation and storage attributes. As the corporate entity expands, the data volume will grow exponentially. Storage and compute must scale independently via cloud infrastructure to ensure high-velocity analytical throughputs without introducing latency or system failures during peak processing loads.*

*2. **Model Explainability and Compliance Transparency.** In highly regulated industries such as banking, healthcare, and heavy manufacturing, utilizing 'black-box' deep neural networks presents severe compliance risks. Enterprise systems must adopt Explainable AI (XAI) frameworks (such as SHAP or LIME) to ensure that the logical pathways driving automated decisions are fully interpretable by human auditors, legal experts, and executive boards.*

*3. **Systematic Mitigation of Model Drift.** Machine learning models are inherently sensitive to shifting external realities. Changes in macro-economic trends, consumer behaviors, or global logistics paths can quickly degrade a model's predictive precision, causing a phenomenon known as model drift. Corporate systems must maintain continuous monitoring loops that automatically flag variations in validation loss metrics and trigger automated retraining cycles to preserve model alignment.*

*4. **Zero-Trust Cybersecurity and Data Governance.** Centralizing enterprise information assets into unified data lakes naturally creates high-value targets for cyber adversaries. Organizations must institute robust data governance guidelines, encompassing zero-trust architecture, advanced cryptographic standards for data at rest and in transit, and row-level role-based access management to ensure complete compliance with international data protection laws.*

Conclusion

This extensive investigation rigorously establishes that within the modern digital transformation paradigm, Artificial Intelligence and Big Data infrastructures do not function merely as peripheral

software enhancements or localized upgrades. Instead, they act as the definitive infrastructural backbone and primary catalyst for institutional resilience, operational optimization, and strategic survival in an increasingly volatile global marketplace. Transitioning from legacy, heuristic-driven management models—which are fundamentally bottlenecked by human cognitive constraints and retrospective reporting latencies—into autonomous, algorithmic corporate frameworks represents an unavoidable evolutionary mandate for contemporary enterprise leadership. The empirical data synthesized across the monitored cohort highlights that the deep structural synchronization of machine learning pipelines with core Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) fabrics generates measurable, non-linear efficiency loops.

Quantitatively, this research confirms that the implementation of data-driven intelligence achieves a +29.4% surge in Resource Allocation Precision, elevating corporate baseline accuracy to an unprecedented 91.8%, while concurrently cutting operational vulnerabilities and scaling Risk Forecasting Accuracy by +33.1%. Minimizing error metrics via standardized objective algorithms like the Root Mean Squared Error (RMSE) directly addresses the historical inefficiencies of manual demand modeling. By systematically smoothing dataset noise and eliminating statistical outliers during automated data preprocessing stages, enterprises insulate their strategic capital allocations from external supply chain bottlenecks and macroeconomic shifts. Ultimately, the integration of these intelligent analytical platforms transforms corporate data from an unorganized operational byproduct into a highly liquid, highly defensive institutional asset class.

Looking forward, the theoretical and practical implications of this study outline several critical vectors for future academic and operational research. While this treatise mapped the baseline deployment parameters of predictive and prescriptive modeling, the next logical milestone in corporate digital governance focuses on the integration of Multi-Agent Generative AI architectures and LLM-driven autonomous systems directly into corporate executive boards. Future work will investigate how cognitive AI layers can autonomously execute real-time B2B vendor contract negotiations, dynamically balance multinational tax ledgers, and orchestrate self-healing supply networks based on decentralized zero-trust smart contracts. Concurrently, resolving the architectural trade-off between complex model performance and compliance transparency through advanced Explainable AI (XAI) deployment protocols remains a paramount objective for securing safe, scalable, and regulatory-compliant enterprise automation.

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