

Journal of green economy and optimization research / 15 August 2026

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JGEOR

Journal of Green Economy and Optimization Research

Vol. 1 • № 1 • 15 August 2026

Peer-reviewed • Double-blind review • Full Open Access

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Publisher	Green Economy and Optimization Research Lab
Place of publication	Baku, Azerbaijan
Publication frequency	Bimonthly
Website	https://jgeor.org
Editorial Office	office@jgeor.org

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JGEOR promotes interdisciplinary research addressing the economic, environmental, technological and policy dimensions of sustainable development. The journal welcomes high-quality original research articles, review articles, short communications, perspectives and commentaries, and selected editorials.

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From the Editor-in-Chief

“Launching a new platform for interdisciplinary sustainability research”

“It is a pleasure to introduce the inaugural issue of the Journal of Green Economy and Optimization Research (JGEOR). The journal was established to create an open and interdisciplinary platform for research at the intersection of economic transformation, environmental sustainability, technological innovation and optimization.

The challenges associated with climate change, resource efficiency, green finance, energy transition and sustainable development increasingly require research that connects disciplines rather than treating them in isolation. JGEOR aims to support this dialogue by bringing together empirical, theoretical, methodological and policy-oriented contributions from researchers working across related fields.

Our editorial approach is grounded in academic independence, transparent peer review, research integrity and open access. We seek to provide authors with a serious scholarly venue while ensuring that published work remains accessible to researchers, practitioners, decision-makers and wider academic communities.

The publication of this first issue marks the beginning of a longer academic journey. We look forward to expanding the journal's international network, strengthening its editorial and reviewer community, and supporting high-quality research with both scholarly and practical significance.

On behalf of the editorial team, I thank all authors, reviewers, editors and colleagues who contribute to the development of JGEOR.”



Ulvi Mammadov

Editor-in-Chief

Journal of Green Economy and Optimization Research

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Article

Assessing ecosystem sustainability and green finance-based ecotourism opportunities in Akhar-Bakhar National Park

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Abstract

New ways of planning and managing protected areas are becoming more important, with an integrated approach of ecosystem management, visitor management, and sustainable financing. This study aims to evaluate ecosystem sustainability and ecotourism potential in green finance in the new Akhar-Bakhar National Park, Azerbaijan, situated in semi-arid mountain ecosystem of Alazan/Ganykh River Valley. Six coded observation points were employed, GPS-based mapping, photographic documentation, landscape and vegetation observations, visible biodiversity indicators, anthropogenic pressure assessment and a scoring matrix (1-5) for ecotourism suitability was used to assess the situation in the field. It has been concluded that Torpaggala, the Alazan/Ganykh River viewpoints and the core visitor area are high potential places for controlled ecotourism, environmental education, birdwatching and landscape photography. By contrast, the Qaramesha-direction areas include sensitive geologic formations, animal tracks, mineral surfaces and potential wildlife corridors and therefore, should be restricted to guided scientific research and conservation monitoring. The results indicate that there is potential for the use of green finance for low impact infrastructure such as safety signs, observation platforms, route marking, visitor information boards and guide services. This research proposes a preliminary field-based framework to connect the ecosystem sustainability, the planning of ecotourism, and the need for green finance in Akhar-Bakhar National Park.

Keywords: Akhar-Bakhar National Park; ecosystem sustainability; green finance; ecotourism; protected areas; field observation; visitor route planning; Alazan/Ganykh River Valley; Azerbaijan.

1. Introduction

Protected areas are now more and more expected to serve a set of multiple functions other than biodiversity conservation. They are expected to provide benefits to nature-based tourism, environmental education, local economies, and long-term ecosystem monitoring in addition to their role in protecting species, habitats and ecological processes [1,2]. This multifunctional role is significant in young protected areas in particular, where initial planning choices can have a serious impact on visitor management and conservation zoning and/or investment priorities. In these kinds of places, field-based assessment can offer pragmatic baseline data that can be used to pinpoint zones suitable for public access to ecotourism, zones for restricted use and

Academic Editor: Prof. Elnur Sadiqov

Received: 14.06.2026

Revised: 15.06.2026

Accepted: 28.07.2026

Published: 13.08.2026

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infrastructure requirements that are economically viable and can be funded in sustainable ways.

Ecotourism is one of the key elements for generating socio-economic values compatible to the conservation from protected areas. Eco-tourism, well planned, can serve as a motivation for conservation, raise awareness in the public, benefit the local community and contribute to the diversification of regional economies [3,4]. Uncontrolled visitor access can also contribute to the trampling, waste generation, disturbance of wildlife and informal expansion of trails and safety risks which can place undue pressure on fragile habitats. Therefore, in the planning of ecotourism in protected areas, it should be based on information of landscape sensitivity, accessibility, biodiversity indicators and anthropogenic pressure and visitor safety, all based on spatial information [5]. Route classification, observation platforms, warning signs, guide services and visitor information boards can minimize the negative impacts and enhance the quality of the visitor experience.

Green finance is a relevant term to connect conservation requirements with concrete investment options. Green finance can be used in protected areas to implement low impact infrastructure, habitat restoration, ecological monitoring, visitor management systems, NBTS and for green jobs, oriented towards the community [6,7]. It is particularly pertinent to newly protected areas where there may be limited infrastructure, and where funding is required to balance conservation with public use. In this sense, green finance-based ecotourism is not an invitation for mass tourism development but for a certain type of green and low impact investments that can help preserve the integrity of ecosystem and provide controlled opportunities for education, recreation and local involvement.

Akhar-Bakhar National Park is one of the newest parks in Azerbaijan. Since its formation in 2025, it occupies 23,901.99 ha in the Gakh, Samukh and Yevlakh districts [8]. The park features semi-arid mountain landscapes, river valley ecosystems, tugay-type vegetation along the Alazan/Ganykh River, and distinct and prominent geological formations. All these characteristics allow for ecotourism, birdwatching, landscape photography and scientific field research. Meanwhile, the occurrence of sensitive fauna habitat, animal tracks, mineral surfaces and erosion shaped landforms suggest the importance of a careful zoning and access regulations. The park thus offers a relevant case study to explore the combined assessment of ecosystem sustainability, ecotourism route planning, and green finance needs at an early stage in the protected area development process.

Although Akhar-Bakhar National Park has great ecological and tourism value, the scientific information on the field is limited and the needs of visitor oriented observation points, restricted research areas and green finance related infrastructure. This study attempts to fill this gap by evaluating the six coded field observation points using GPS-based mapping, photographic documentation, landscape and vegetation observation, visible biodiversity indicators, anthropogenic pressure scoring and ecotourism suitability assessment. The objective of the study is to assess the sustainability of the Akhar-Bakhar National Park ecosystem and the possibility of green finance-based ecotourism in the area and to suggest viable proposals for the future development of the routes, management of visitors and conservation investment.

2. Materials and Methods

3.1. To choose a study area and an observation design.

The study was carried out in Akhar-Bakhar National Park, Azerbaijan, a new protected area, which includes semi-arid mountain slopes, river valley landscapes, tugay-type vegetation along the Alazan (Ganykh) River, open steppe-like areas and rocky geological formations. During the field assessment six coded observation points

namely AB-01, AB-02, AB-03, AB-04, AB-05 and AB-06 located in the Gakh sector of the national park were observed. The following points were chosen to reflect a range of landscape attributes and features, level of accessibility, and opportunities for visitor use and sensitivity of ecological features.

The observation points were divided into two functional groups. AB-01, AB-02, AB-03 and AB-06 were identified as visitor-oriented observation points due to their accessibility, landscape visibility and suitability for controlled ecotourism, environmental education, birdwatching, and landscape photography. AB-04 and AB-05 in the Qaramesha direction were identified as restricted scientific access points as they contain sensitive fauna indicators, animal tracks and geological formations and possible wildlife corridors.

2.2. Investigative surveys and documentation of field images.

Observational approach in the field was used. Observation code, site name, date and time, GPS latitude and longitude, distance from the core visitor area, azimuth, compass direction, type of route, type of landscape, weather condition, visible biodiversity indicators, characteristics of the vegetation, anthropogenic influence, attractiveness of landscape, value for biodiversity observation, suitability for ecotourism, overall potential and green finance need and recommended activity were recorded at each observation point.

Field signs were direct or indirect observations of birds, animal tracks, sound-based observations, nests or possible shelter signs, all of which were visible biodiversity indicators. During the study no animals were captured, handled, marked or disturbed. Visual assessment of vegetation was carried out at the general vegetation formations level, semi-arid plants, tugay vegetation, grass cover, shrub vegetation and wooded areas. Because the study was designed as an initial field based route and sustainability assessment, species level botanical identification was not done.

Field observations were complemented by photographic documentation to illustrate, visually, the landscape characteristics and vegetation; visitor infrastructures, animal tracks and anthropogenic influences; and geological features. A coded photographic panel was used to represent each observation point. The 24 coded field images were taken following the photographic codes AB-01-F01 until AB-06-F04. The field observation table and the coded photographic panels were published as an open data set: Zenodo: Mammadov, U. (2026). Field observation dataset and coded photographic panels in ecotourism potential and ecosystem sustainability in Akhar-Bakhar National Park, Azerbaijan (v1.0) [Data set]. Green Economy and Optimization Research Lab. <https://doi.org/10.5281/zenodo.20767403>.

2.3. Mapping and spatial visualization with GIS

The field observation points were plotted using QGIS software to show their spatial distribution. The boundary of Akhar-Bakhar National Park was displayed using its official KMZ boundary file which was received from the national park administration. The points of observation were summed based on their GPS locations. Visitor-oriented observation points were marked with green, and with red the observation points recommended for restricted scientific access (so-called Qaramesha-direction points). The final map was exported and as the main spatial figure of the study.

2.4. Score matrix and green finance assessment.

The six observation points were compared in a simple 1–5 point scoring matrix. Four main criteria were considered: anthropogenic pressure, landscape attractiveness, biodiversity observation value and ecotourism suitability. A lower score was given for anthropogenic pressure as lower human impact was observed, and a higher score was

given as stronger human influence was seen. In the remaining criteria, the higher the score, the more valuable or suitable.

The overall potential score was obtained by merging landscape attractiveness, the biodiversity observation value and the ecotourism suitability, as a descriptive field-based indicator. This score is not meant to be a statistical generalization for the whole national park, but rather to compare the six observation points and to inform initial route planning and management recommendations.

Potential green finance needs were qualitatively determined on the basis of gaps observed in the infrastructure, safety needs and conservation-sensitive visitor management needs. The assessment took account of the possible need for low impact investments like safety signage, observation platforms, route marking, visitor information boards, guide services or access restrictions through management, at each of the observation points. These needs were considered as potential areas where green finance mechanisms could contribute to ecosystem sustainability as well as sustainable development of controlled ecotourism.

3. Results

3.1. Location of field observation points in space

The plan of the six field observation points is illustrated in figure 1. The points were in the official area of Akhar-Bakhar National Park and in different functional areas of the observed field sector including a panoramic historical-landscape point, river valley viewpoints and core visitor area and Qaramesha-direction research points. The distribution of points on the map suggests that the locations oriented towards visitors are primarily situated in and around the core area and the Alazan/Ganykh River panoramic points, whereas the Qaramesha-direction points are further away from the visitor core, and their access needs to be more regulated.

The core visitor area, AB-03 was the basis for assessment of distance and direction. AB-02 was the closest to core area (0.18 km to the north) and AB-06 was the closest to the north (0.90 km). The Torpaggala point (AB-01) is at a distance of about 1.10 km from the core area in north-eastern direction. AB-04 and AB-05 were in the Qaramesha direction, 2.47 km and 1.51 km from the core area, respectively. Both of these were designated as restricted scientific access points, because of the presence of animal tracks, sensitive geological formations and potential wildlife movement corridors.



Figure 1. Official boundary of Akhar-Bakhar National Park and spatial distribution of field observation points.

Green markers represent visitor-oriented observation points, while red markers represent Qaramesha-direction points recommended for restricted scientific access. The map was prepared in QGIS using the official KMZ boundary file provided by the national park administration. Base map: OpenStreetMap.

3.2. Field observation points and spatial characteristics

Table 1 shows the main spatial and functional data of the six observation points. The results indicate that the selected points vary in distance from the core visitor area, landscape type, accessibility and recommended management use. This variability is significant in the future planning of ecotourism in this area, for it offers both ecologically sensitive sites, where access is restricted, and sites suitable for visitors.

AB-01, AB-02, AB-03 and AB-06 were scored as appropriate for controlled activities for visitors. These are suitable sites for nature walks, landscape photography, environmental education and bird watching (where there is controlled movement of visitors by signs and information). By contrast, AB-04 and AB-05 were considered appropriate primarily for scientific research, specialist access and monitoring. They are far more appropriate for ecotourism, due to their ecological sensitivity and away from the core visitor area.

Table 1. Field observation points, spatial characteristics in Akhar-Bakhar National Park.

Code	Site name	Coordinates	Distance from core area km	Direction	Landscape type	Recommended use
AB-01	Torpaggala	41.106042, 46.667520	1.10	NE	Rocky slope and panoramic area	Controlled ecotourism route
AB-02	Alazan River viewpoint 1	41.103417, 46.655806	0.18	N	River valley	Visitor-oriented viewpoint
AB-03	Core visitor area	41.101852, 46.655579	0.00	Centre	Open visitor area	Visitor orientation and route hub
AB-04	Qaramesha direction 1	41.122871, 46.665073	2.47	NNE	Mountainous and rocky area	Restricted scientific research access
AB-05	Qaramesha direction 2	41.115074, 46.659523	1.51	NNE	Mountainous fauna corridor	Restricted scientific research access
AB-06	Alazan River viewpoint 2	41.109940, 46.656021	0.90	N	River valley viewpoint	Visitor-oriented viewpoint

3.3. Visitor-oriented ecotourism points

One of the best visitor sites in the surveyed area was AB-01, Torpaggala. It takes about 40 minutes to walk to the site from the core area, and a brief climb with the existing steps set up by national park. From the upper part of Torpaggala, visitors have a broad overview of the national park landscape. The field photos reveal rocky slopes, semi-arid vegetation and open mountain-steppe landscapes and erosion shaped landforms. En route there were other indirect indications of wildlife such as tracks believed to be that of the wild boar, bear and other mammals. These features make AB-01 an appropriate site for a controlled panoramic hiking route, as well as for nature interpretation and for landscape photography. Safety signs and route marking are recommended, however, due to steep sections encountered during the ascent a small interpretation panel is also suggested.



Figure 2. Coded photographic panel of AB-01 Torpaggala.

AB-02, the first Alazan/Ganykh River viewpoint, was situated very close to the core visitor area, and offered high accessibility for short term visitors. The site has a clear view of the valley of the Alazan/Ganykh river, riverine vegetation and transboundary landscape to Georgia. The presence of existing seating infrastructure enhances its recreational use and makes it appropriate for families, short educational use and birdwatching. The field photographs show river valley vegetation, open landscape and an attractive vista point. However, when movement is unrestricted near the riverbank it can pose safety concerns. So it would be beneficial to have a viewing boundary clearly marked, warning signs and a small viewing platform for increased safety for visitors and environmental management.

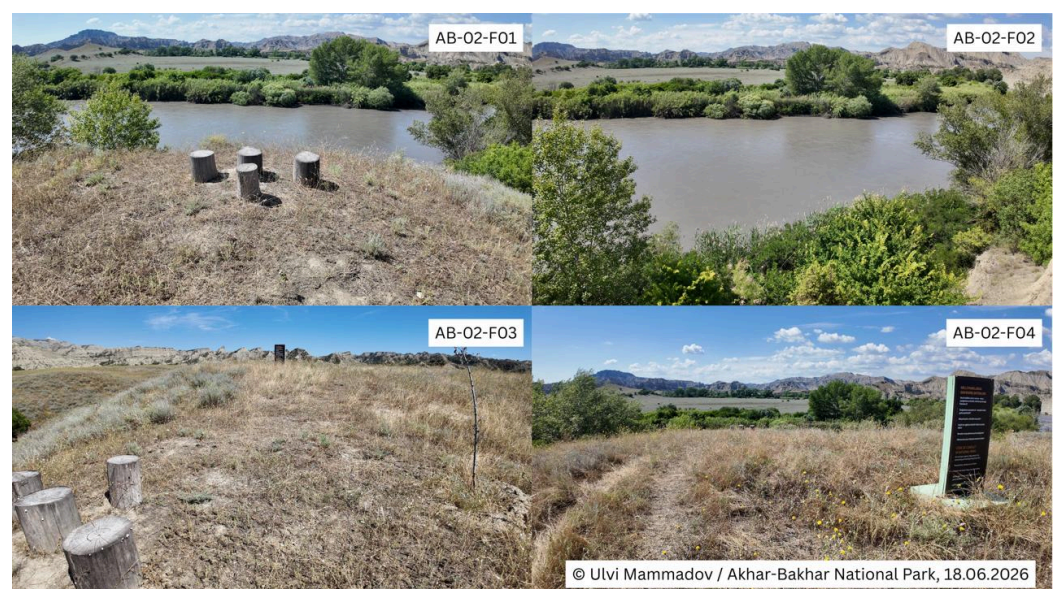


Figure 3. Coded photographic panel of AB-02 Alazan/Ganykh river viewpoint 1.

AB-03 is the main orientation and management point for ecotourism activities. Field photographs indicate a gazebo, seating area, hand washing facility, sanitary facilities, information boards, park posters, national flag and map. All of these elements show that

AB-03 is already well equipped with the basic structure needed to host visitors, run environmental education sessions in brief, and provide the visitors with various categories of routes. For visitor registration, guide co-ordination, route briefing and environmental interpretation. The findings indicate that AB-03 should be the main access entry point for both numbers of visitors and restricted access routes.



Figure 4. Coded photographic panel of AB-03 core visitor area.

The second Alazan/Ganykh River viewpoint (AB-06) was also found to be a high value landscape and interpretation point. The site provides visual access to the river valley, river islands, and to the surrounding slopes of semi-arid type and tugay type vegetation. It can be used for birdwatching, landscape photography and environmental education. Field observations were however, that some areas within the viewpoint may be unsafe if visitors are not given guidance when approaching the river edge or where areas are unstable. Therefore, it is important to develop AB-06 as a low impact viewpoint with safety barriers or natural boundary markers, warning signs and a brief information panel on the river ecosystem.

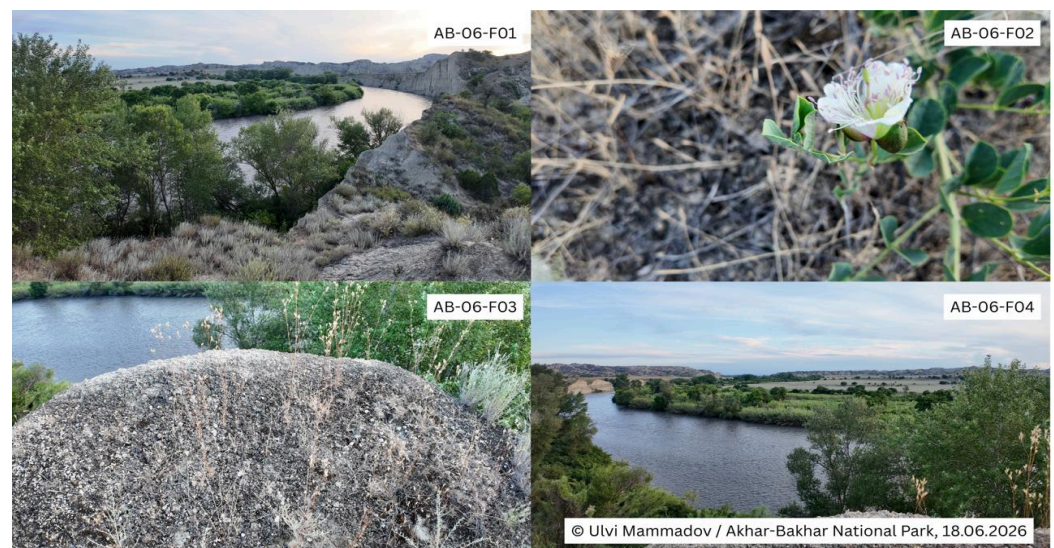


Figure 5. Coded photographic panel of AB-06 Alazan/Ganykh River viewpoint 2.

3.4. Limited scientific access opportunities in the Qaramesha direction

AB-04 and AB-05 were clearly not a visitor oriented point. The walking time, physical exertion and guided access are longer on these sites, located in the Qaramesha direction. Geological and geomorphological characteristics of AB-04 included large angular rock fragments, erosion shaped forms, narrow valley conditions and mineral/salt-like deposits on rock surfaces. These mineral surfaces can serve as natural sources of wildlife. Shrub and tree vegetation and semi-arid plant communities and habitats are also present that could be providing for wildlife movement. For these reasons, AB-04 is a site of scientific interest for the geology, geomorphology, hydrology, soil science, botany and zoology, mammal ecology, ornithology and conservation biology. It is not recommended, however, for mass ecotourism.

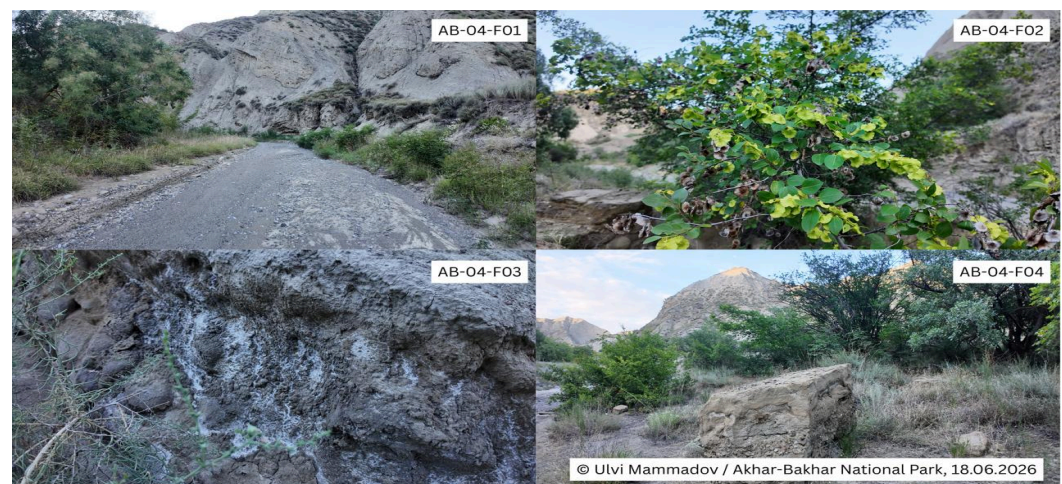


Figure 6. Coded photographic panel of AB-04 Qaramesha direction 1.

AB-05 was also a restricted scientific access point. The field photographs indicated the presence of tracks of animals, soft ground surfaces, rocky slopes, possible burrow or shelter and some sediment or rock movement due to flood water or seasonal runoff. These features indicate that it could be a wildlife movement corridor, feeding area or shelter zone. Possible fauna species that may occur in such habitats could be wild boar, bear, fox, badger, jackal, lynx and other medium to large mammals which are known to occur in similar protected areas. These areas are especially sensitive to wildlife disturbance, which is why it is important that AB-05 is not opened up to the general public. This point would best be used for guided scientific monitoring, camera-trap studies, track surveys and limited zoological or geological observations.

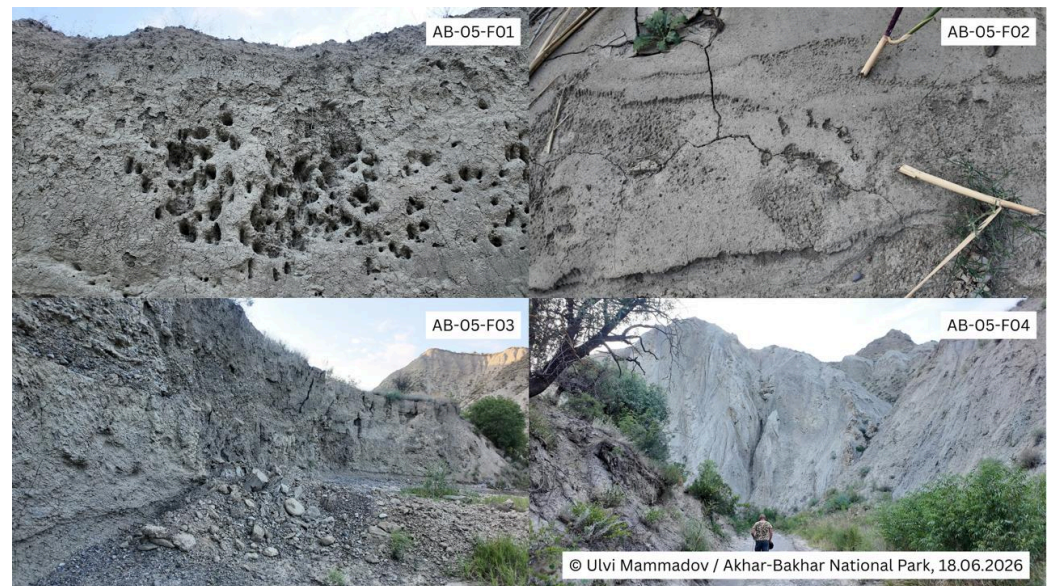


Figure 7. Coded photographic panel of AB-05 Qaramesha direction 2.

3.5. Suitability for ecotourism, anthropogenic pressure & need of green finance.

Table 2 summarizes the results of the scoring. The overall potential scores were between 4 and 5 with all six points having important value for either ecotourism or scientific monitoring. The meaning of the scores, however, varies from point type to type. Three sites, AB-01, AB-02 and AB-06 were found to have high potential for visitors due to landscape, accessibility and suitability for nature-based activities. AB-03 was high management value as it serves as a visitor orientation and route coordination point. The overall potential scores of AB-04 and AB-05 are the highest scores but these should be taken as scientific and conservation potential and not as tourism suitability for the public.

The anthropogenic pressure was generally low at most of the observation points. The core visitor area had the highest anthropogenic influence due to the presence of infrastructure, whereas anthropogenic pressure was lower in the Qaramesha-direction points. The general approach should be differentiated management; areas which are sensitive internally need restricted access whereas areas for visitors are concentrated around the core and the designated viewpoints.

Table 2. Compatibility of ecotourism, anthropogenic pressure and needs of green finance of the observation points.

Code	Anthropogenic pressure 1–5	Overall potential score	Green finance need	Management recommendation
AB-01	2	4.33	Safety signs	Controlled panoramic hiking route
AB-02	2	4.33	Observation platform	Visitor viewpoint and birdwatching point
AB-03	3	4.00	Ecotourism route support	Visitor orientation and environmental education hub
AB-04	1	5.00	No public infrastructure recommended	Restricted scientific research and monitoring
AB-05	1	5.00	No public infrastructure recommended	Restricted scientific research and wildlife monitoring

AB-06	1	4.33	Observation platform and warning signs	Controlled viewpoint and environmental education point
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The identified green finance needs in the field were primarily associated with low impact tourism management, and not large-scale tourism infrastructure. Visitor-oriented needs are, in particular, safety signs, demarcation of viewing areas, small viewing platforms, information boards on routes and guide services and ecological interpretation panels. With the Qaramesha-direction points, the main recommendation is not infrastructure development, but restricted access-management, scientific monitoring and conservation control. So, in the National Park of Akhar-Bakhar green finance should focus on small, conservation compatible interventions to enhance visitor safety and education, and to reduce the disturbance of sensitive wildlife areas.

In general, the findings suggest that Akhar-Bakhar National Park is a good candidate for zonation as an ecotourism site. The core visitor area and Alazan/Ganykh River viewpoints can accommodate short, controlled and educational ecotourism operations and Torpaggala can serve as a panorama hiking route. The Qaramesha-direction points, however, must be considered as areas for restricted scientific access because of the ecological and geological sensitivity.

4. Discussion

Results of this field-based evaluation indicate that Akhar-Bakhar National Park is a place with a lot of potential for the development of a differentiated ecotourism and conservation management model. However, not all six observation points were equally suitable for public access and the site-specific ecological sensitivity, accessibility and management purpose should be taken into account when planning the course of any future routes. This is in line with guidelines for protected area tourism, which state that visitor access, recreation infrastructure and tourism activities should be designed to meet conservation goals, considering ecological vulnerability and management capacity [9]. This kind of zoning is particularly relevant in newly established protected areas where the number of visitors may grow quickly if the access routes, the information points and the safety limits are not well defined [10].

The designation of AB-01, AB-02, AB-03 and AB-06 as visitor-oriented observation points means that the national park does already have suitable spots for providing controlled and low impact ecotourism activities. Torpaggala (AB-01) possesses good panoramic value and is suitable for development as a guided hiking and landscape interpretation route. The current steps to the viewpoint provide a low level access opportunity, although there is still a need for safety signage and direction and short ecological interpretation panels. These small scale interventions can focus visitor traffic, minimize non-traditional trails and enhance visitor safety. Such a strategy is consistent with the principles of sustainable tourism planning, which recommend that the development of infrastructure for visitors should bring not only about an increase in the number of visitors, but also directly a reduction in the ecological pressure they put on the environment [11,12].

Viewpoints along the Alazan/Ganykh River, as well as those at AB-02 and AB-06, are also significant for future plans for ecotourism. These are the points that offer visual access to the river valley, riverine vegetation, semi-arid slopes and transboundary landscape views. They are close to the visitor centre making them ideal for brief visits, environmental education, birdwatching and landscape photography. The field observations and observations, however, indicate that there is also need for safety management, particularly where visitors are likely to come near river edges or unstable sections on the viewpoint. Low impact investments, like marked viewing boundaries, warning signs and small observation platforms, should therefore be regarded priority

green finance needs. These measures can enhance the visitors experience while mitigating the risks to the visitors, and the sensitive riverbank habitats.

The main operational node of the ecotourism management for the assessed sector should be the core visitor area (AB-03). The existing infrastructure, such as information boards, resting facilities, a park map and sanitation and handwashing facilities is the foundation for structured visitor reception. This can serve as a route orientation centre, informing visitors of the areas they can access, areas they cannot, safety rules and the ecological values of the park. AB-03 can be used, from a management point of view, to help inform a route classification system which can distinguish between short visitor routes, panoramic hiking routes and restricted scientific access routes. This classification is significant because protected areas may only help to improve the local development and public awareness of the environment when the movement of visitors is managed in a way that does not conflict with conservation targets [13].

AB-04 and AB-05 are the two points to the Qaramesha-direction that need more restrictive management. While these locations had high overall potential scores, they are predominantly scientific and ecological in value and not public-tourism. These may represent wildlife movement corridors, feeding zones or sensitive habitat areas as a result of the presence of animal tracks, possible shelter signs, rocky formations, mineral/salt-like surfaces or erosion shaped landforms. General tourism access to such areas can lead to greater disturbance of mammals and birds requiring less accessible and quieter areas. Hence, AB-04 and AB-05 should be treated as 'restricted scientific access areas', where only scientific personnel or park staff/trained guides are allowed access. Activities may include camera-trap monitoring, animal track survey, geological observation, vegetation monitoring and conservation related field research.

However the results also indicate that green finance in Akhar-Bakhar National Park should not be interpreted in the light of big tourism development. Rather the most suitable model is small scale investment which is compatible with conservation and is specific to its site. Green finance can be used for safety signs, route marking, viewing platforms, information boards to visitors, training guides, monitoring equipment, and restricted-access management systems. Increasingly, the literature on biodiversity finance and protected area investment focuses on the need to invest in low impact infrastructure and other local benefits that do not require infrastructure expansion and do not preclude conservation, and in ecological monitoring [14]. The green finance can support the park's aim to balance the protection of the ecosystem with selective use by visitors in this context.

In terms of sustainability the proposed approach sees the connection of three dimensions: ecological protection, visitor management and green economic opportunity. For the ecological protection, it is recommended to limit the use of Qaramesha-direction points. Visitor management is tackled by focussing public access on the core visitor area of Torpaggala and the Alazan/Ganykh River viewpoints. Low impact activities – guided walks, environmental education, birdwatching, photography routes and provision of local services – address green economic opportunity. This integrated approach is in line with research on nature-based tourism, where it is found that tourism may have social and economic value without contradicting nature conservation goals, if it is compatible with these goals [15].

GIS mapping, GPS-based field records and coded photographic documentation were used to strengthen the reproducibility of the study. The official boundary of Akhar-Bakhar National Park was mapped together with the six observation points, allowing the spatial relationship between visitor-oriented and restricted-access points to be assessed. In addition, the field observation table and photographic panels were deposited in Zenodo, which improves transparency and allows other researchers to reuse or extend the dataset in future research [16]. Furthermore, by depositing the field observation table and photographic panels on Zenodo, the transparency of the

deposition is promoted and it becomes possible for other researchers to reuse or extend the dataset in future research.

This study has several drawbacks. First, the assessment was made at six observation points and, so, should be seen as a preliminary field-based assessment and not as a comprehensive ecological inventory of the national park. Second, the cover of vegetation was determined at the formation level and species level botanical identification was not performed. Third, the assessment of wildlife was conducted primarily through visible signs and indirect indicators rather than systematic camera trap, transect or seasonal fauna surveys. Fourth, the scoring matrix was developed as a practical field assessment tool, and is not a statistically validated index for the whole national park. Future studies should increase the number of observation points, increase the number of surveys carried out in the same season, carry out systematic inventories of flora and fauna and connect with remote sensing or habitat suitability modelling.

But, still the study paves the way for future ecotourism planning in Akhar-Bakhar National Park based on an initial evidence-based framework. It has primarily classified observation points into "visitor access" and "scientific access" categories, with GPS coordinates, field observations, coded photographic panels, scoring and GIS mapping. This approach provides a framework for determining locations in the national park that are suitable for low impact visitor facilities and those where visitor access should be restricted for conservation purposes. As such, the results can be applied as a basis for route planning, prioritisation of green financing, and monitoring of the ecosystem sustainability in the initial years of national park development.

5. Conclusions

In this study, a preliminary field assessment on ecosystem sustainability and eco-tourism opportunities based on green finance were carried out in Akhar-Bakhar National Park. The results indicate that there are visitor-oriented areas and ecologically sensitive areas in the park. The Alazan/Ganykh River viewpoints and the core visitor area are appropriate for controlled ecotourism, environmental education, as well as for bird watching and landscape photography purposes. The Qaramesha-direction points on the contrary are recommended for restricted scientific access areas due to their wildlife indicators, geological sensitivity and potential as fauna movement corridors.

The results indicate that the future development of ecotourism in the park should be oriented towards zoning and guided access to the area, as well as low-impact construction. Use of green finance mechanisms can include support for safety signs, route marking, observation platforms and visitor information boards, guide training and ecological monitoring. Looking at the overall picture, the Akhar-Bakhar National Park holds a great potential to develop conservation-compatible ecotourism model with a focus on public access at appropriate locations and protection of sensitive areas through appropriate management.

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Article

Biomimetic route planning for micro-UAVs using honeybee-inspired optimization

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Abstract

A biomimetic route optimization framework for micro-UAV systems is proposed in this work, which is inspired by the foraging process of honeybees (*Apis mellifera*) and employs AI. The research is field documented, expert interviews were held, and in combination with supporting microscopic evidence on the morphology of honeybees. The hive entry-exit processes, weather parameters, activity intensity and the environment were registered at three observation points in Goygol and Dashkasan regions of Azerbaijan at 10-minute intervals in the field. These data were analyzed as behavioral indices of adaptive resource search, route choice and group organization. Expert interviews about the behavior of honeybees revealed that honeybees select feeding sites based on distance, availability of nectar/pollen, odor, sight, and energy conservation; and that the information about promising feeding sites is transmitted within the colony through their movement. At the same time, the scientific community of artificial intelligence (AI) confirmed the validity of the use of swarm intelligence and bee colony modelling for routing, resource allocation and real-time adaptation problems in complex systems. From this the paper suggests a conceptual model to translate the searching logic of the honeybee to micro-UAV route optimization idea, such as decentralized search, adaptive path selection, exploration-exploitation balance and environmental responsiveness. Biomimetic evidence is provided by the presence of compound eyes and wing structures, in the form of the microscope images, to the concepts of multi-sensor perception and lightweight mobility. The results indicate that the bioinspired AI models can help to improve the energy efficiency, adaptiveness, and resilience of micro-UAVs, especially in the fields of environmental monitoring, search and rescue missions, and distributed observation systems.

Keywords: honeybee foraging behavior, biomimicry, artificial intelligence, micro-UAV, route optimization, swarm intelligence

Academic Editor: Prof. Elnur Sadiqov

Received: 14.06.2026
Revised: 15.06.2026
Accepted: 28.07.2026
Published: 13.08.2026

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1. Introduction

The importance of using micro-unmanned aerial vehicles (micro-UAVs) for environmental monitoring, precision agriculture, disaster response, infrastructure inspection, border observation, and search-and-rescue operations has been growing. Their small size, mobility and ability to function in areas difficult or dangerous to humans, make them useful tools in modern engineering and applied science. But, despite these merits, there are a number of limitations associated with micro-UAV

systems. They still have challenges with extensive and sustainable use due to limited battery capacity, route inefficiency, environmental uncertainty, communication constraints, and the need for real-time decision making.

In the technical aspects of micro-UAV operations, route optimization is one of the most critical issues. An inefficient route leads to higher energy use, shorter missions and less quality of data collection. Conventional methods for planning routes rely on preprogrammed routes or central logic. In such environments, where weather, obstacles, mission priorities and resource availability can vary during operation, these approaches may be inadequate. Hence, the utilization of more adaptive, decentralized and energy-efficient route optimization models is required for micro-UAV systems.

AI models based on nature can be a great conceptual approach to the challenges. One of the most pertinent approaches is the swarm intelligence. It teaches the reader how simple agents, following simple local rules, can yield complex and adaptive behavior of the group as a whole, without any central control. Various classical research studies on swarm intelligence have demonstrated the ability to translate collective systems inspired by insects, birds, or other biological systems into computational models for various optimisation, routing, coordination, and resource allocation problems (Bonabeau et al., 1999). In this respect, the honeybee colony is one of the most significant biological systems used as a model for artificial intelligence and biomimetic optimization.

For the micro-UAV route optimization, the foraging behaviour of honeybees is particularly relevant. Honeybees in natural situations base their search for food sources on distance, quality of the food, smell, color, conditions and energy budget. When a good food source is found, the information is passed on to other colony members by movement and coordinated behavioral reactions. This results in a balance of exploration and exploitation of bees as they try out new food sources and also focus activity on already known high value areas. The Artificial Bee Colony algorithm modeled this biological logic into an optimization model based on the employed bees, onlooker bees, and scout bees and with adaptive search behavior (Karaboga, 2005; Karaboga & Basturk, 2007).

Together with multi-agent systems and decentralized control, the relevance of honeybee-inspired optimization is further emphasized. Micro-UAVs are frequently deployed as single vehicles in a larger mission scenario. Like bees in a colony, every UAV can gather information from its area, assess its local situation, send out information it chooses and alter its path depending on mission requirements. The resemblance of this behavior to the honeybee's foraging strategy suggests it as a biomimetic model for the design of adaptive route selection, distributed decision making, and energy-aware navigation strategies. Another trend of biologically inspired methods, like ant colony optimization and flocking models, also shows the promise of decentralized biological principles for movement planning and routing problems (Dorigo & Stützle, 2004; Reynolds, 1987).

In this study, you will learn how to create an AI-Based Biomimetic Route Optimization Framework for Micro-UAV Systems, inspired by the Honeybee Foraging Behavior. The article relies on theoretical literature of international character and original empirical materials, previously documented by the authors. The empirical basis consists of field observations of the activity of honeybees from the Goygol and Dashkasan regions of Azerbaijan, an expert interview on honeybee food selection and environmental adaptation, and a microscopic morphology report on the structures of *Apis mellifera*. The field observations include hive entry and exit, intensity of activity, time of observation, weather conditions, temperature, humidity, wind speed and UV index at three locations. These data are taken as behavioral expressions of adaptive movement, environmental responsiveness, and activity related to resources. The expert interview about the behaviour of honeybees describes how bees chose the food sources

based on the principles of proximity, the nectar and pollen source and the olfactory sense, visual perception and energy saving. The AI expert interview validates the applicability of swarm intelligence and bee-colony based models for routing, resource allocation, real-time adaptation and multi-agent coordination problems. Moreover, microscopic analyses of the compound eye of the honeybee and its wing morphology serve as supporting biomimetic data for multi-sensor perception and lightweight mobility concepts. While the main theme of this article is behavioral route optimization, morphological evidence is provided to add weight to the biomimetic argument. In *Apis mellifera*, the compound eye is an example of parallel visual perception and distributed sensory input and the wing design exemplifies lightweight design and functional optimization. Such properties do not form the focus of the research, but they do go towards explaining the potential of using honeybees as a general biological model for micro-UAV design, perception and adaptive navigation.

This study aims to convert the honeybee's foraging logic and perform a conceptual AI-based route optimization model for micro-UAV systems. The research aims to answer the question: What is the biomimetic interpretation of the honeybee foraging behaviour for the design of adaptive and energy-efficient route optimisation of micro-UAVs? In order to answer this question, the article first gives the theoretical background of swarm intelligence and bee-inspired optimization, then provides the data sources from the empirical observation and expert-based knowledge and finally proposes the conceptual framework which links the honeybee foraging principles with the micro-UAV route planning. The scientific contribution of the study is the integration of biological behavior, artificial intelligence and applied engineering in a single interdisciplinary model. The article is not a theoretical discussion of biomimicry, but rather utilizes field-based data on honeybee activity and expert-based qualitative evidence to construct a real-world route optimization logic for micro-UAV systems. Applications of the proposed framework could include environmental monitoring, distributed observation, search missions, precision agriculture and energy-efficient flight planning of UAV. In that respect, more adaptive, resilient and resource-saving micro-UAV systems could be developed with the help of the honeybee-inspired AI-based route optimization.

Biomimicry as a research method, is known as learning from nature and transferring nature-tested principles to technological solutions (Benyus, 1997). Small drone and micro-UAVs are now frequently mentioned as potential flexible platforms for monitoring, inspection and observation of the environment, with their performance being largely driven by energy efficiency, autonomy and adaptive route planning in the case of autonomous aerial systems (Floreano & Wood, 2015).

2. Methodology

The approach in this study is a mixed conceptual-empirical one to create a biomimetic route optimization framework for micro-UAV systems based on honeybee foraging behavior using an AI-based scheme. The methodological design involves field observation data, expert interview evidence, microscopic biomimetic evidence and conceptual AI-based modelling. The goal of this step is not to develop a fully implemented UAV navigation algorithm at this stage, but to derive a route optimization logic based on the honeybee foraging principles that can be simulated and studied with prototypes.

2.1. Research design

The study was a biomimetic modelling one which was planned as an interdisciplinary study. It is an integrated approach of biology, artificial intelligence, swarm intelligence and applied aerospace engineering. The adaptive foraging behaviour of honeybees, particularly in finding food sources, assessing the quality of the environment, passing on

useful information and optimising collective movement with minimal energy expenditure, forms the biological basis of the study.

The engineering issues addressed in this research are micro-UAV route optimization. The underlying assumption of the main method is that the behavior of honey bees when they forage for food can be interpreted as a natural model of adaptive route planning. In this model, the food source is analyzed as a mission target, the movement of the hive is analyzed as the route activity, other environmental factors are analyzed as an external constraint, and the collective decision making behavior is analyzed as a decentralized AI-based route selecting behavior.

The study is divided into four phases of methodology:

1. Collection and systematisation of honeybee field activity data;
2. Expert interviews on honeybee behaviours and biomimetic applications using AI;
3. application of the data of the microscopic morphology as supporting biomimetic evidence;
4. conceptual route optimization development of a framework for micro-UAV systems.

2.2. Field observation data

The empirical basis of the study is the field observations made in 3 places of Azerbaijan – Uchtepe and Topalhasanli villages of Goygol region and Bayan village of Dashkasan region. A 10 minute period was used to record honeybee activity at each site. The observations included hive entry/exit activity, local flight activity, cases of collisions near the hive entrance, type of hive, number of hives, and environmental parameters. The different field variables employed in this study are shown in Table 1.

Table 1. Observed variables in the field for interpretation of route optimization.

Variable group	Observed indicators	Interpretation for micro-UAV route optimization
Activity dynamics	Hive entry, hive exit, total activity	Movement intensity and route demand
Environmental conditions	Temperature, humidity, wind speed, UV index, weather condition	External constraints affecting route efficiency
Location data	Observation point, altitude, coordinates	Spatial mission environment
System density	Number of hives, activity per hive, collision cases	Congestion and coordination pressure
Time factor	Observation hour and observation duration	Time-dependent route variation

The data of the field was not used as a statistical sample for predictive modelling, but as an empirical basis for identification of behavioural patterns. The comparative observations revealed that the activity of the honey bees varied with time and weather conditions. The highest total activity was found at Topalhasanli where there was a relatively balanced activity in hive entry and exits and lowest activity was found at

Bayan under rainy and colder weather conditions. It was concluded that these differences are a sign of adaptation to the different environmental constraints.

2.3. Expert interview evidence

Structured expert interview items are also included in the study. The first expert interview centered on the selection of food by honeybees, the coordination of the colony, division of labor, signaling communication and adaptation to the environment. This interview was conducted to identify biological sense of foraging behaviour. The interpretation of the experts is that honeybees choose forage sources according to the distance, the amount of nectar and pollen they can harvest, the smell, the sight, and the amount of energy they can use. The expert also highlighted the importance of movement-based signals and coordinated colony responses in communication of promising sources by bees.

The second expert interview was on how biomimicry and artificial intelligence are being used in the systems of aerospace. This interview was prepared to aid in the computational interpretation of the behavior of the honeybee. The expert reported that routing, resource allocation, real-time adaptation, and decentralized coordination are some of the applications where swarm intelligence models can be helpful. These ideas served as the foundation for making links between the foraging behaviour of the honeybee and route planning of a micro-UAV.

Thematic analysis was used for the expert evidence. Table 2 provides an overview of the main themes that emerged from the interviews.

Table 2. Themes derived from experts that explain behaviours and AI modelling.

Expert evidence theme	Biological meaning	AI-based interpretation	Micro-UAV application
Food source selection	Bees prefer nearby and resource-rich sources	Objective function based on distance and resource value	Selection of high-priority mission points
Odor and visual perception	Bees use sensory cues to identify targets	Sensor-based target recognition	Multi-sensor adjustment route
Movement-based signaling	Bees transmit information to the colony	Agent communication and information sharing	UAV-to-UAV coordination
Exploration and exploitation	Bees search for new sources and reuse valuable ones	Balance between global search and local optimization	Adaptive mission route planning
Environmental adaptation	Bees reduce or change activity under unfavorable conditions	Dynamic route adjustment under constraints	Weather-aware navigation UAV

2.4. Microscopic biomimetic evidence

The study was primarily on the foraging behaviour of honeybees, but microscopic morphology information was provided as biomimetic support. The compound eyes, wings, legs and body segmentation of *Apis mellifera* were studied under the

microscope. It was thought that these structures were natural examples of functional optimization.

The compound eye structure is a good support to the concept of distributed and parallel visual perception that could be applied in multi-sensor perception of the micro-UAV system in this study. Wing morphology serves as a lightweight mobility and aerodynamic efficiency, whereas leg structure and body segmentation serve as additional biomimetic references for adaptive contact, modularity, and system-level design.

The main route optimisation logic was not based on the microscopic evidence. Rather, this was used to bolster the overall biomimetic case that the honeybee offers both behaviour and structure-based models for engineering applications.

Table 3. Use of microscopic biomimetic evidence in the study

Honeybee structure	Observed biomimetic principle	Relevance to micro-UAV systems
Compound eye	Parallel visual perception	Multi-sensor environmental scanning
Wing	Lightweight and stable movement	Energy-efficient flight design
Leg	Adaptive contact and gripping	Landing and surface interaction mechanisms
Body segmentation	Modular biological architecture	Modular UAV system design

2.5. Optimization model for conceptual route.

The last step of the methodology was to translate the honeybee foraging behaviour into a conceptual route optimisation model for micro-UAV systems. The model is based on the following biomimetic logic:

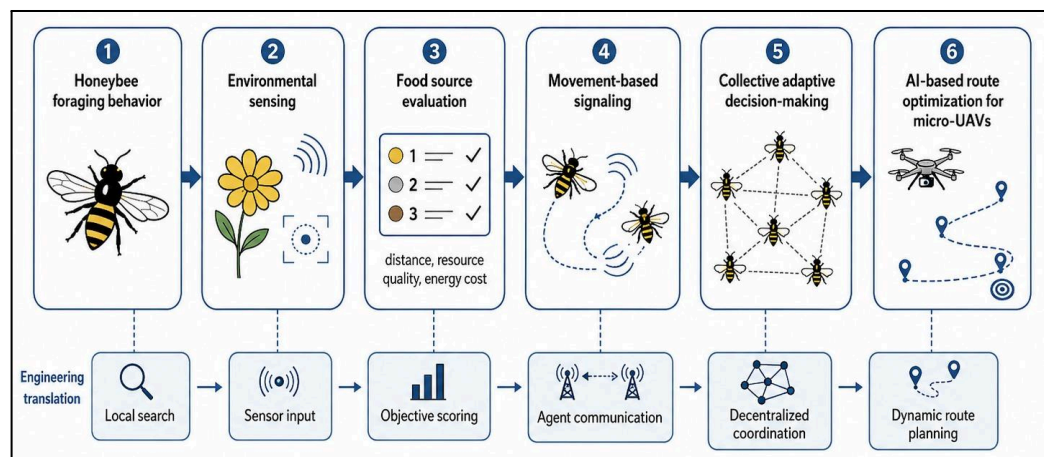
- The scout bees are understood to be UAV reconnaissance forces;
- food sources are mission targets or observation points;
- mission value/information value is interpreted as nectar/pollen quality;
- Route cost is approximated as distance to the food source;
- Operational constraints are interpreted as: weather and environmental conditions are interpreted as operational constraints;
- waggle-dance-like communication is considered to be inter-agent information exchange;
- The foraging efficiency at colony level is considered as system level route optimization.

The proposed conceptual model contains five main stages:

1. environmental scanning;
2. target identification;
3. route evaluation;
4. adaptive selection;
5. updating of routes via inter-agent communication.

This process is presented in Figure 1.

Figure 1. The transformation of a conceptual model, from a foraging behaviour of honeybees to route optimization of micro-UAVs with the use of AI.

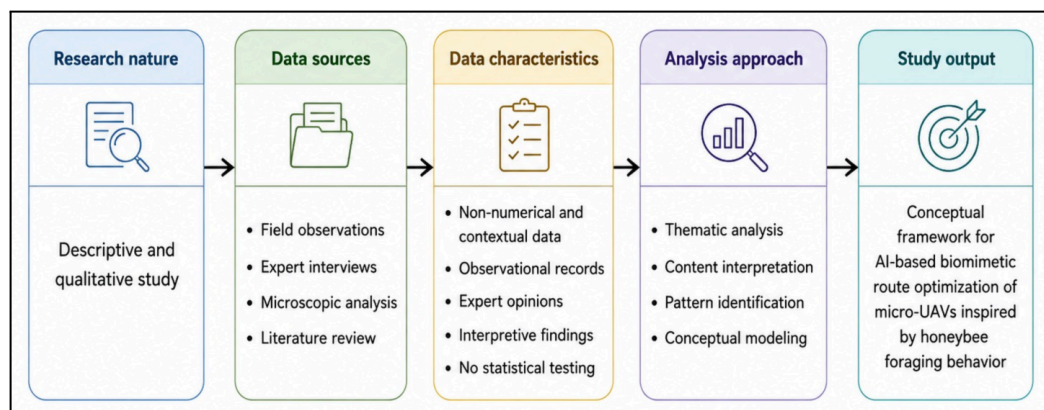


2.6. Analytical procedure

Comparative interpretation was used for the analysis instead of statistical testing of hypothesis. Field observation data were first categorised by: Location, Environmental conditions, Activity indicators. Second, the content of the expert interviews was coded in terms of behavioral and computational themes. Thirdly, micro observations were categorized based on their biomimetic significance. Lastly, all evidence groups were merged into a micro-UAV route optimization conceptual framework.

The analytical logic of the study is presented in Figure 2.

Figure 2. The study is descriptive and qualitative in nature.



2.7. Scope and limitations of the methodology

The methodology has a number of drawbacks. First, the field observations were run in three different locations and in short, 10-minute time blocks and should be seen as exploratory behavioral data, not large-scale ecological data. Second, the proposed micro-UAV optimization model is conceptual and has not yet been validated with simulation and real flight UAV experiments. Thirdly, the expert interviews offer a qualitative interpretation but not an experimental validation. Fourth, although microscopic observations have been used to bolster the biomimetic aspect of the argument, the primary route optimization model involves mostly behavioural foraging logic.

The methodology opens the door to an AI-based route optimization framework, despite these limitations, as it offers a practical interdisciplinary foundation to transform the honeybee foraging behavior and advance its use in this context. The method can be

extended to simulation, algorithmic testing and application of micro-UAVs by prototypes.

3. Results

Study findings indicate that the honeybee foraging behavior can be regarded as a biomimetic model for adaptive route optimization for a micro-UAV system. Because of the descriptive and qualitative nature of the study, the study results are presented through comparative interpretation, expert-based analysis, field observation evidence and conceptual modelling.

The field observations in Uchtepe, Topalhasanli and Bayan revealed that the activity of the honeybee was different depending on time, weather and the surrounding environmental factors. The hives in Topalhasanli had relatively balanced hive entry and exit indicators and were the most active. This pattern could be a sign of an active foraging and route exchange phase. The activity of Uchtepe was also high, though the entry indicator was much higher than the exit indicator, which might be a return-flow phase following resource collection. Honeybee movement, however, proved to be very sensitive to environmental constraints and In contrast, Bayan showed very low activity under rainy and colder conditions.

Table 4. Micro-UAV route optimization based on integrated interpretation of honeybee foraging data.

Evidence source	Main finding	Biomimetic interpretation	Micro-UAV route optimization implication
Field observation data	Honeybee activity changed across Uchtepe, Topalhasanli, and Bayan according to weather, time, and hive activity intensity	Foraging behavior is adaptive and context-dependent	UAV routes should be dynamically adjusted according to weather, mission time, and environmental constraints
Honeybee behavior expert interview	Bees select food sources based on distance, nectar/pollen availability, odor, visual cues, and energy-saving principles	Route selection is based on cost-benefit evaluation	UAVs should prioritize mission points by distance, target value, risk, and energy cost
AI and biomimicry expert interview	Swarm intelligence is useful for routing, resource allocation, decentralized coordination, and real-time adaptation	Bee-colony behavior can be transformed into multi-agent optimization logic	UAV systems can use decentralized communication and adaptive route planning
Microscopic morphology evidence	Compound eyes, wings, legs, and body segmentation show functional optimization	Honeybees provide both behavioral and structural biomimetic models	Sensor perception, lightweight mobility, landing stability, and modular UAV design can be improved

The expert interview about the behavior of honeybees proved that the honeybees are not random in selecting food sources. They're influenced by their nearness, the quality of the food they eat, smell, sight, and energy spent. Valuable and energy-efficient path is the most important thing to be considered in route optimization of micro-UAVs, as shown in

this section. In this way, the foraging behaviour of the honeybees is a good natural model of multi-criteria route choice.

The results of the artificial intelligence and biomimicry expert interview confirmed the concept of using swarm intelligence to solve routing and resource allocation problems. The expert interpretation indicates that bee-colony inspired models are particularly pertinent to decentralized systems, where each agent makes local decisions and is an efficient member of the entire system. This logic can be directly applied in micro-UAV operations when multiple UAVs are deployed to monitor environment, search or distributed observation.

Biomimetic evidence was acquired by observations made with the microscope. In *Apis mellifera* the visual perception of the compound eye can be correlated to a parallel perception and multi-sensors scanning. The overall design of the wing structure is based on the principle of lightweight and stable mobility; the leg structure and the segmented body structure are used as reference designs to guide the adaptive landing and modular system design. These micro observations are not the primary criteria on which the route optimization model is based, but they do bolster the overall biomimetic argument put forth by the study.

Figure 3. During the recording of honeybee activity, field observation process was carried out.



One of the field observation stages was performed during the process of recording the activity of honeybees and is shown in figure 3. Empirical support for the study is provided by the images and direct field observations support the proposed biomimetic interpretation.

Figure 4. Morphology of *Apis mellifera* on a microscopic level as supporting biomimetic evidence



Microroscopic evidences from *Apis mellifera* morphology are shown in Fig. 4. It can be interpreted that this image represents the use of honeybee constructions as models of perception, mobility and functional optimisation in micro-UAV systems.

In general, the results show that it is possible to adapt the honeybee foraging behavior and apply it as a route optimisation logic for micro-UAV systems using a conceptual approach of AI. This model is proposed to be composed of five key fundamental principles: energy-aware route selection, adaptive route updating, decentralized coordination, exploration-exploitation balance, and environmental responsiveness. These principles have the potential of leading to more efficient, resilient and context sensitive micro-UAV operations.

4. Discussion

Based on the results of this research, foraging behaviour of honeybee can be considered as a promising biomimetic model for the AI-based route optimization of micro-UAV system. The biological model is most valuable for its adaptive, decentralized and energy sensitive nature. Honeybees are not random foragers, but their movements are influenced by distance, food-source quality, sensory information, environmental factors, and colony-level organization. These features directly relate to micro-UAV systems where flight routes need to be planned within battery constraints, varying weather conditions, mission priorities, and communication constraints.

The field observation results support the fact that the activity of the honeybees is sensitive to the environment. The differences in Topalhasanlı and Uçtepe with high activities and Bayan with low activity exposure indicates that the weather, temperature and the time of observation determine the degree of change in honeybee movement. This means that the problem of route optimization cannot simply be interpreted as a shortest-path problem for micro-UAV systems. Rather, it should be considered as an ongoing process of decision making where route cost and target value are considered in conjunction with safety and weather conditions and energy consumption.

An interpretation that is reinforced by the expert interview about behavior of honeybee. The expert evidence indicates that bees select lower quality food sources if they are easily located (either by smell or sight) and that they are closer to the colony and contain more nectar and pollen. This biological logic can be captured in a route optimization model using AI that prioritizes mission points based on distance, data

value, environmental risk and battery cost. In this way, the activity of the honeybee is a natural example of multi-criteria decision-making process.

The expert interview in the field of artificial intelligence and biomimicry also shows the relevance of swarm intelligence for routing and resource allocation problems. Centralized route control may be ineffective or insecure in micro-UAV operations particularly when multiple UAVs are operating concurrently. The proposed Honeybee inspired model allows each UAV to be a independent agent, assess its local situation, exchange pertinent data, and help optimize the entire mission. This can enhance resilience of the system, decrease reliance on a solitary control unit, and help in real-time route adaptation.

Further evidence for the biomimetic interpretation comes from the microscopic evidence. In this article, while the emphasis is on foraging behavior, *Apis mellifera*'s compound eye, wing and leg structure and segmented body illustrate that honeybees are not just behaviorally adaptive, but structurally optimized as well. The compound eye can be used to develop distributed visual perception, and wing morphology can be used to develop lightweight and energy efficient mobility concepts. Hence, it is possible to identify the honeybees as both behavioral and morphological model for micro-UAV design and route optimization.

The proposed framework adds to the interdisciplinary linkage between biology, artificial intelligence and applied engineering. The major contribution of this is the conversion of the principles found in honeybee foraging into a route optimization logic for a micro-UAV system. Five main ideas are incorporated into this logic: (1) energy-aware route selection, (2) adaptive route updating, (3) decentralized coordination, (4) exploration-exploitation balance, and (5) environmental responsiveness. The principles could be of use for environmental monitoring, search and rescue, distributed observation, precision agriculture and other micro-UAV applications.

But there are also limitations in the study. First, the field observations were made from only three sites and for brief observation periods, and the observations can only be regarded as exploratory evidence and not as a comprehensive behavioural data set. Secondly, the proposed route optimization model is only conceptual, and there is no simulation or real flight test of the UAV as yet. Thirdly, although the expert interviews are qualitative, they need to be backed up by engineering simulation and algorithmic testing. Future research will involve formulating a coded optimization model, as per the honeybee foraging logic, and validate the model in simulated micro-UAV mission scenarios.

To conclude, the talk demonstrates that the route optimization of micro-UAVs using AI mimicking honeybee is a viable avenue for further research on micro-UAV systems. The advantage of this way is that it brings together the natural resource-search behavior and the computational optimization and applied engineering needs. Learn from the honey bee foraging behaviour, the micro-UAV systems could be more adaptive, energy efficient and resilient to environment changes.

Furthermore, the proposed framework is relevant as UAV path-planning studies revealed that metaheuristic and swarm-based optimization techniques can enhance route selection in real-time in the presence of operational constraints (Roberge et al., 2013). Thus, the optimization of UAVs navigated using a honeybee approach can be thought of as a member of a larger family of biologically inspired approaches to adaptive UAV navigation.

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Article

Historical periodization and potential structural breaks in the fiscal policy–human capital nexus in Azerbaijan

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Abstract

This study examines the historical evolution of the relationship between fiscal policy and human capital formation in Azerbaijan over the period 1991–2024, with particular emphasis on regime changes and potential structural breaks. The analysis is motivated by the fact that Azerbaijan's post-independence development has been characterized by profound economic, institutional, geopolitical, and external shocks that make the assumption of a stable fiscal–human capital relationship unrealistic. A historical-periodization approach is combined with a structural-break-oriented econometric framework to identify distinct phases in the evolution of fiscal capacity, resource revenues, public expenditure, inflation, institutional development, and human capital financing. Eight major periods are distinguished: systemic disruption in 1991–1994; stabilization and institution building in 1995–2004; oil-driven fiscal expansion in 2005–2007; the global financial crisis in 2008–2010; maturation of the oil-financed growth model in 2011–2013; the oil-price shock and macroeconomic adjustment in 2014–2016; fiscal and tax administration reforms in 2017–2019; and the pandemic, conflict, reconstruction, and renewed energy-revenue environment during 2020–2024. The analysis suggests that the transmission of fiscal resources into education, health, and productive capabilities has varied substantially across these regimes. The study proposes the use of Zivot–Andrews, Bai–Perron, CUSUM, ARDL, and NARDL techniques for subsequent empirical verification of the identified structural changes. The findings emphasize that fiscal capacity should not be evaluated solely through aggregate revenue or expenditure ratios, since the composition, institutional quality, macroeconomic environment, and source of public revenues strongly influence their long-term contribution to human capital development.

Keywords: fiscal policy, human capital, structural breaks, oil revenues, public expenditure, Azerbaijan, ARDL, NARDL

JEL Classification: E62, H20, H50, I15, I25, O15

Academic Editor: Prof. Elnur Sadiqov

Received: 23.06.2026

Revised: 25.06.2026

Accepted: 11.08.2026

Published: 13.08.2026

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1. Introduction

The importance of using micro-unmanned aerial vehicles (micro-UAVs) for environmental monitoring, precision agriculture, disaster response, infrastructure inspection, border observation, and search-and-rescue operations has been growing. Their small size, mobility and ability to function in areas difficult or dangerous to

humans, make them useful tools in modern engineering and applied science. But, despite these merits, there are a number of limitations associated with micro-UAV systems. They still have challenges with extensive and sustainable use due to limited battery capacity, route inefficiency, environmental uncertainty, communication constraints, and the need for real-time decision making.

The relationship between fiscal policy and human capital formation is rarely stable over long historical periods. Changes in macroeconomic conditions, public institutions, government revenues, inflation, external shocks, and the composition of public expenditure can alter both the scale of fiscal resources and the efficiency with which these resources are transformed into education, health, and productive capabilities.

This issue is particularly relevant in the case of Azerbaijan. Since regaining independence in 1991, the country has experienced a transition from central planning to a market economy, armed conflict and large-scale displacement, macroeconomic stabilization, rapid expansion of hydrocarbon production, an exceptional resource-revenue boom, the global financial crisis, a major decline in oil prices, exchange-rate adjustments, tax and public-finance reforms, the COVID-19 pandemic, the 2020 war, post-conflict reconstruction, and renewed shocks in international energy markets. These developments substantially altered the volume and composition of government revenues, the real value and allocation of public expenditure, private-sector behavior, and the institutional mechanisms through which fiscal resources affected human capital accumulation (Asian Development Bank [ADB], 2020; International Monetary Fund [IMF], 2024; World Bank, 2022).

Consequently, modelling the entire period from independence as a single stable data-generating process may conceal major changes in the underlying fiscal–human capital relationship. A positive long-run association between tax revenues and human capital, for example, may coexist with weak or even negative short-run effects during periods of crisis. Similarly, oil revenues may have high marginal development effects when basic infrastructure is scarce, but their contribution may decline once major physical infrastructure gaps have been reduced and further progress becomes increasingly dependent on institutional quality, education quality, health-system efficiency, innovation, and skills.

Historical periodization therefore has an analytical rather than merely descriptive function. It allows the identification of economic regimes in which the coefficients linking taxation, oil revenues, inflation, government expenditure, institutions, and human capital may differ.

The purpose of this study is to develop a historically grounded framework for analysing structural changes in the fiscal policy–human capital nexus in Azerbaijan between 1991 and 2024. More specifically, the study aims to: identify major fiscal and macroeconomic regimes since independence; assess how the channels linking fiscal capacity and human capital changed across these regimes; identify historically plausible structural-break periods; and develop an econometric strategy through which these breaks can subsequently be formally tested.

The study contributes to the literature by integrating Azerbaijan's resource-based fiscal transformation with human capital analysis and by emphasizing that fiscal capacity is determined not only by the amount of revenue available to the government but also by its source, stability, institutional administration, purchasing power, and allocation.

2. Materials and methods

2.1. Research design

The study applies a historical-analytical periodization framework supported by a structural-break-oriented econometric methodology. The period of analysis covers 1991–2024 and corresponds to Azerbaijan's post-independence economic development.

Historical periodization is used to identify episodes during which the mechanisms linking fiscal variables and human capital may have changed materially. The classification is based on major macroeconomic, fiscal, institutional, geopolitical, and external developments affecting Azerbaijan.

The analytical framework focuses on five broad groups of variables:

1. government fiscal capacity, including tax revenues and hydrocarbon-related fiscal resources;
2. public expenditure and its allocation;
3. macroeconomic conditions, particularly inflation and exchange-rate developments;
4. institutional and tax-administration changes; and
5. human capital outcomes and the financing of education and health.

The underlying assumption is that the transmission from fiscal resources to human capital is conditional rather than automatic. An increase in government revenue may produce different outcomes depending on inflation, expenditure composition, administrative capacity, institutional effectiveness, and the stage of economic development.

2.2. Historical periodization

Based on the major economic and institutional transformations observed since independence, the study distinguishes the following analytical regimes:

- **1991–1994:** independence, conflict, economic contraction, and systemic disruption;
- **1995–2004:** macroeconomic stabilization, transition reforms, and institutional development before the full-scale oil boom;
- **2005–2007:** rapid expansion of oil production and fiscal expenditure;
- **2008–2010:** global financial crisis under a resource-revenue-supported fiscal system;
- **2011–2013:** maturation of the oil-boom expenditure model and emerging constraints on oil-led growth;
- **2014–2016:** oil-price collapse, exchange-rate adjustment, inflation, and fiscal adaptation;
- **2017–2019:** stabilization, tax-administration modernization, formalization, and fiscal-rule reforms;
- **2020–2021:** pandemic, war, emergency expenditure, and direct risks to human capital formation;
- **2022–2024:** renewed energy revenues, inflationary pressures, reconstruction expenditure, and changes in the composition of public investment.

These periods are not interpreted as mechanically predetermined econometric break dates. Instead, they provide historically grounded hypotheses that can be compared with statistically estimated structural breaks.

2.3. Identification of structural breaks

Several complementary econometric methods are appropriate for formally evaluating structural instability.

The Zivot–Andrews test allows the unit-root hypothesis to be examined while permitting a single endogenously determined structural break in the intercept, trend, or

both. This is particularly important because conventional unit-root procedures can incorrectly classify a stationary series with a structural break as non-stationary (Zivot & Andrews, 1992).

The Bai–Perron multiple structural-break methodology can be used to identify several unknown break dates in regression coefficients without specifying all breakpoints in advance. Given the annual frequency of Azerbaijani data and the relatively limited sample size, the number of breaks should be restricted and an economically meaningful minimum segment length should be imposed to prevent excessive fragmentation of the sample (Bai & Perron, 2003).

Parameter stability can additionally be evaluated using CUSUM and CUSUMSQ tests. These tests are particularly useful after estimating ARDL or error-correction specifications because they provide evidence on the stability of the estimated coefficients over time.

2.4. ARDL and asymmetric modelling framework

The Autoregressive Distributed Lag approach is suitable when explanatory variables consist of a mixture of $I(0)$ and $I(1)$ processes, provided that none of them is integrated of order two, $I(2)$ (Pesaran et al., 2001).

A general long-run relationship may be represented as:

$$HC_t = f(TAX_t, OIL_t, GEXP_t, INF_t, INST_t)$$

where (HC) represents human capital, (TAX) denotes tax revenues or non-oil tax revenues, (OIL) denotes hydrocarbon-related fiscal resources, (GEXP) represents public expenditure, (INF) denotes inflation, and (INST) represents institutional conditions.

Structural-break dummy variables may subsequently be introduced when theoretically and statistically justified.

Because positive and negative changes in oil revenues and inflation may have different consequences for human capital, the Nonlinear ARDL model provides an additional analytical extension. NARDL decomposes changes in an explanatory variable into positive and negative partial sums and allows the researcher to test whether adverse shocks have different short- and long-run effects from favourable shocks (Shin et al., 2014).

Structural-break controls remain relevant even in a NARDL framework because asymmetry and regime change represent conceptually different forms of nonlinearity.

3. Results

3.1. Systemic disruption and erosion of fiscal capacity, 1991–1994

The first post-independence regime was characterized by the simultaneous collapse of Soviet economic structures, disruption of production and trade networks, severe macroeconomic instability, institutional fragmentation, armed conflict, and displacement.

Azerbaijan inherited relatively broad education and healthcare systems, high literacy, and considerable technical capacity. However, the fiscal and economic foundations supporting these systems deteriorated sharply.

Declining production reduced the effective tax base, while high inflation eroded the real value of government revenue and expenditure. At the same time, the emerging market economy required the reconstruction of tax administration in an environment

characterized by rapidly changing ownership relations, prices, trade patterns, and enterprise behaviour.

The state also faced substantial extraordinary expenditure pressures related to conflict, internally displaced populations, social protection, and the maintenance of essential public services.

For the fiscal–human capital relationship, this regime represents a period in which the preservation of existing human capital institutions was more important than expansion. Nominal expenditure indicators are therefore unlikely to fully capture the deterioration in real fiscal capacity. (ADB, 2020; World Bank, 2022)

3.2. Stabilization and institutional development, 1995–2004

The period between approximately 1995 and 2004 represents a transition toward macroeconomic stabilization and the construction of institutions required for a market economy.

The 1994 production-sharing agreement commonly known as the “Contract of the Century” established the legal and contractual foundation for large-scale foreign investment in the petroleum sector. However, the full fiscal consequences of large-scale oil production had not yet materialized. Lower inflation improved predictability for budgetary planning, households, and firms. Institutions relating to taxation, customs, treasury management, banking, and public administration were gradually strengthened.

A particularly important development was the establishment of the State Oil Fund of the Republic of Azerbaijan in 1999, which created an institutional mechanism for the accumulation, management, and use of hydrocarbon revenues. Human capital policy during this phase remained constrained by limited fiscal resources. The government simultaneously faced infrastructure shortages, poverty, displacement, administrative restructuring, and the need to maintain education and healthcare systems.

This period consequently provides an important pre-oil-boom benchmark for evaluating whether subsequent resource abundance fundamentally changed the relationship between government fiscal capacity and human capital development. (ADB, 2020; State Oil Fund of the Republic of Azerbaijan [SOFAZ], 2024; World Bank, 2022)

3.3. Oil-driven fiscal expansion, 2005–2007

The mid-2000s represent one of the most important structural transformations in Azerbaijan's post-independence economy.

The completion of the Baku–Tbilisi–Ceyhan pipeline, rapid growth in oil production, and favourable international prices substantially increased export receipts, GDP, government revenue, and public investment.

The resulting expansion fundamentally relaxed the fiscal constraint facing the government. Public infrastructure, regional development, social transfers, and public-sector wages could be financed on a scale that had not been feasible during the 1990s.

From a human capital perspective, higher fiscal revenues created major opportunities for investment in schools, healthcare facilities, information technologies, public-sector remuneration, and targeted social programmes.

However, the speed of fiscal expansion also created absorptive-capacity constraints. The availability of financial resources could increase more rapidly than the supply of qualified administrators, teachers, healthcare workers, contractors, engineers, and project managers. The relationship between expenditure and human capital outcomes may therefore have become increasingly dependent on the quality and efficiency of expenditure rather than its volume alone. (ADB, 2020; SOFAZ, 2024; World Bank, 2022)

3.4. The global financial crisis and fiscal stabilization capacity, 2008–2010

The global financial crisis created external shocks through international demand, financial conditions, and commodity markets. Azerbaijan entered this period with accumulated resource revenues and a substantially stronger fiscal position than during earlier crises. This regime therefore provides an important test of the stabilizing function of resource-based fiscal buffers.

A resource-rich government with accumulated financial reserves can potentially reduce the long-term human capital consequences of a temporary external shock by maintaining expenditure on education, health, public employment, and social protection despite weakening private economic activity. The main analytical difference between this episode and the early 1990s lies in the government's capacity to smooth expenditure across the economic cycle.

Thus, the same external deterioration may produce substantially different human capital effects depending on the fiscal buffers accumulated before the shock. (IMF, 2024; World Bank, 2022)

3.5. Maturation of the oil-financed development model, 2011–2013

The early 2010s constituted a more mature phase of oil-financed development. Public investment remained high and the state continued to possess substantial financial resources.

At the same time, the contribution of the hydrocarbon sector to additional economic growth began to weaken as oil production approached or moved beyond its peak. This phase is important because the marginal development return to additional government investment may have begun to change. When roads, utilities, schools, hospitals, and other basic infrastructure are severely deficient, initial investment can generate substantial social and economic returns. Once major infrastructure gaps have been reduced, however, further improvements increasingly depend on the quality of public services, maintenance, teacher and healthcare-worker performance, institutional reforms, skills, and innovation.

The fiscal–human capital transmission mechanism consequently becomes more complex as an economy moves from infrastructure accumulation toward quality-intensive development. (World Bank, 2022)

3.6. Oil-price shock, devaluation, and fiscal adjustment, 2014–2016

The decline in global oil prices beginning in 2014 created another major structural episode. Lower hydrocarbon revenues weakened Azerbaijan's external and fiscal position. Exchange-rate adjustments in 2015 increased the domestic-currency cost of imported goods and contributed to inflationary pressures. The shock revealed an important distinction between resource-supported fiscal abundance and sustainable non-oil fiscal capacity.

Government expenditure commitments had expanded during the high-revenue period, while financing conditions changed rapidly following the deterioration in the external environment. The implications for human capital operated through several channels. Currency depreciation increased the domestic cost of imported pharmaceuticals, laboratory equipment, educational technologies, scientific materials, and other inputs. Inflation reduced the purchasing power of households and the real value of nominal government expenditure. Weaker economic activity and stress in the

financial system could also negatively affect employment and private expenditure on education and healthcare.

The period therefore represents a strong candidate for structural-break testing in fiscal, inflation, exchange-rate, and human-capital-related series. (IMF, 2024; World Bank, 2022)

3.7. Stabilization and improvement in fiscal administration, 2017–2019

The post-devaluation period was characterized by stabilization and increasing emphasis on non-oil growth, fiscal discipline, formalization, and administrative reform. Digital tax administration, electronic invoicing, online cash registers, formalization initiatives, and changes in revenue administration were intended to improve compliance and expand the non-oil tax base. (ADB, 2025a; IMF, 2024)

These developments are analytically important because they potentially represent a qualitative rather than purely quantitative change in fiscal capacity. Even when the aggregate tax-to-GDP ratio changes gradually, the underlying revenue system can become more predictable, transparent, and information-intensive. Digitalization improves the government's ability to observe transactions, cross-check declarations, identify compliance risks, and target enforcement. The introduction of a fiscal rule in 2019 represented another institutional development aimed at constraining the use of oil revenues and strengthening medium-term fiscal sustainability. (ADB, 2025a; IMF, 2024)

Consequently, fiscal capacity during this period should not be evaluated exclusively through aggregate revenue ratios. Improvements in revenue administration may influence the long-run sustainability of public financing even before substantial changes become visible in headline tax indicators. (ADB, 2025a; IMF, 2024)

3.8. Pandemic, war, and direct human capital shocks, 2020–2021

The COVID-19 pandemic represented a simultaneous health, education, economic, and fiscal shock. The demand for public health expenditure and social assistance increased while restrictions disrupted economic activity, employment, education, and service delivery. Unlike many previous fiscal shocks, the pandemic directly affected the mechanisms through which human capital is accumulated. (Betthäuser et al., 2023; World Bank, 2024a, 2024b)

School closures and the transition toward distance education created risks of learning losses, particularly among students with limited access to digital devices, reliable internet connectivity, and household educational support. Although previous investments in digital infrastructure and public-sector capacity supported continuity, unequal access and the limitations of remote pedagogy remained significant concerns. The healthcare system simultaneously faced extraordinary demands while routine medical services and preventive programmes risked disruption. Declining household income could also affect nutrition, healthcare utilization, and private educational expenditure. In addition, the 2020 war created extraordinary fiscal requirements and altered subsequent public-expenditure priorities. The combined nature of these shocks makes 2020–2021 an especially important period when evaluating parameter stability in models of fiscal policy and human capital. (Betthäuser et al., 2023; World Bank, 2024a, 2024b)

3.9. Reconstruction, renewed energy revenues, and changing expenditure composition, 2022–2024

The post-pandemic period was characterized by renewed hydrocarbon revenues, inflationary pressures, non-oil economic activity, and large-scale reconstruction expenditure.

Higher energy prices strengthened the external and fiscal position, demonstrating once again the importance of commodity-price cycles for Azerbaijan's public finances. At the same time, the composition of public expenditure changed substantially.

Reconstruction in Karabakh and Eastern Zangezur required expenditure on transport networks, utilities, housing, public administration, schools, healthcare facilities, digital infrastructure, and security. (ADB, 2025b; IMF, 2025)

These investments may positively affect regional development and long-term human capital formation. However, newly created infrastructure also generates recurrent expenditure obligations associated with staffing, service delivery, maintenance, and administration. The development impact of reconstruction expenditure therefore depends not only on initial capital investment but also on the capacity to finance and manage the resulting public-service networks over the longer term. (ADB, 2025b; IMF, 2025)

4. Discussion

The historical evidence indicates that the relationship between fiscal policy and human capital formation in Azerbaijan cannot reasonably be assumed to have remained constant between 1991 and 2024. At least four broad transformations are particularly important. First, Azerbaijan moved from severe fiscal scarcity in the early independence period to substantial resource-based fiscal abundance during the oil boom. This transformation changed the binding constraint on human capital policy. During the 1990s, the central challenge was maintaining essential systems under severe resource constraints. During the oil-boom period, the challenge increasingly shifted toward efficient allocation and absorptive capacity.

Second, the source of fiscal revenue matters. Hydrocarbon revenues can finance large public investments without requiring a corresponding expansion of domestic taxation. However, resource revenues are highly exposed to global commodity-price cycles. Non-oil taxation, by contrast, can provide a more stable connection between domestic economic activity and government revenue.

Consequently, aggregate government revenue may conceal substantial differences in fiscal sustainability. Third, the real value of fiscal resources is influenced by inflation and exchange-rate movements. The 2014–2016 episode illustrates how nominal expenditure can provide a misleading picture of actual fiscal support for human capital when currency depreciation increases the cost of imported medical, educational, technological, and scientific inputs.

Fourth, the institutional quality of fiscal management may modify the effects of taxation and expenditure even in the absence of major changes in headline fiscal ratios. Digital tax administration and formalization policies introduced during the later 2010s potentially increased the predictability and information content of non-oil revenues. These observations have important econometric implications. Potential structural breaks are unlikely to occur at identical dates for every variable. Oil revenues may exhibit breaks associated with the expansion of production, the 2014 oil-price decline, the pandemic, or subsequent energy-price shocks. Non-oil tax revenues may instead show changes around major tax-administration and formalization reforms.

Government expenditure may change when the scale of oil-fund transfers or reconstruction commitments changes. Inflation and exchange-rate series are likely to be especially sensitive to the macroeconomic stabilization of the 1990s and the

exchange-rate adjustments of 2015. An additional measurement issue arises when tax revenues are expressed as a percentage of total GDP. During an oil boom, rapid expansion of nominal GDP may reduce the observed tax-to-GDP ratio even when nominal tax collections increase. Conversely, the ratio can move mechanically during a recession.

The ratio of non-oil tax revenues to non-oil GDP may therefore provide a more informative supplementary indicator of domestic fiscal capacity. The proposed econometric sequence should consequently begin with unit-root tests allowing for structural change, followed by endogenous break identification. ARDL specifications can then estimate short- and long-run relationships, while CUSUM-type diagnostics can evaluate parameter stability.

If strong asymmetries are expected for oil revenues or inflation, NARDL models can test whether negative shocks generate different consequences from positive shocks. The historical periodization developed in this study should not substitute for econometric breakpoint estimation. Its function is instead to provide an economically meaningful interpretation of statistically identified breaks and to prevent purely data-driven breakpoint estimates from being interpreted without institutional context.

5. Conclusion

This study develops a historical framework for analysing the changing relationship between fiscal policy and human capital formation in Azerbaijan over the period 1991–2024.

The analysis identifies several fundamentally different fiscal regimes, beginning with the severe economic and institutional disruption of the early independence period and progressing through macroeconomic stabilization, the emergence of hydrocarbon revenues, rapid fiscal expansion, external crises, the oil-price shock, fiscal-administration reforms, the COVID-19 pandemic, conflict, reconstruction, and renewed energy-related fiscal revenues.

The central conclusion is that the fiscal policy–human capital nexus in Azerbaijan should be treated as structurally unstable over the full post-independence period. The scale of government revenue alone is insufficient to explain changes in human capital outcomes. The source and volatility of revenue, expenditure composition, inflation, exchange-rate dynamics, institutional capacity, tax administration, and the stage of infrastructure development all affect the efficiency with which fiscal resources are transformed into education, health, and productive capabilities.

The historical evidence identifies the mid-2000s oil expansion, the 2014–2016 oil-price and exchange-rate shock, the 2017–2019 fiscal-administration reform period, and the 2020–2021 pandemic and conflict episode as particularly important candidates for formal structural-break analysis. Future empirical analysis should test these historically motivated regimes using Zivot–Andrews and Bai–Perron procedures and should incorporate statistically supported break variables into ARDL and NARDL specifications.

Such an approach would allow the analysis to distinguish between temporary shocks, persistent structural changes, and asymmetric fiscal effects.

For Azerbaijan, this distinction is particularly important because long-term human capital development increasingly depends not on the simple expansion of fiscal resources but on the stability, quality, productivity, and institutional effectiveness of public finance.

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Article

Enhancing digital banking service quality and customer experience in Azerbaijan

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Abstract

The rapid digitalization of banking has transformed mobile and internet-based channels from supplementary service instruments into core platforms for customer interaction. In Azerbaijan, this transformation has increased the importance of service quality as customers increasingly expect banking applications to provide fast, accessible, reliable, transparent, and secure services regardless of time and location. This study aims to identify the main directions for improving the quality of digital banking services in Azerbaijan and to develop an integrated framework that can guide banks in enhancing customer experience. The research applies a structured qualitative literature synthesis based on seven peer-reviewed studies published between 2022 and 2025, including research focused specifically on Azerbaijan as well as comparative international evidence. The selected studies were examined according to recurring dimensions of digital banking service quality, including usability, system performance, reliability, security and trust, information transparency, customer support, and technology readiness. The findings indicate that digital banking quality should not be treated exclusively as an information technology issue. Instead, it requires the coordinated management of technical performance, interface design, customer communication, cybersecurity, transparency, and digital inclusion. Based on the synthesis, a six-pillar improvement framework is proposed for Azerbaijan's banking sector: user-centred simplicity, speed and system performance, reliability and continuity, security and trust, transparency and customer support, and inclusive digital adaptation. The study concludes that continuous measurement of these dimensions can strengthen customer satisfaction, loyalty, financial inclusion, and readiness for emerging services such as open banking.

Keywords: digital banking, service quality, mobile banking, customer satisfaction, digital transformation, financial inclusion, Azerbaijan

JEL classification: G21, O33, L86, G28

Academic Editor: Dr. Elnur Arifzade

Received: 22.06.2026

Revised: 23.06.2026

Accepted: 10.08.2026

Published: 14.08.2026

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1. Introduction

The importance of using micro-unmanned aerial vehicles (micro-UAVs) for environmental monitoring, precision agriculture, disaster response, infrastructure inspection, border observation, and search-and-rescue operations has been growing. Their small size, mobility and ability to function in areas difficult or dangerous to

humans, make them useful tools in modern engineering and applied science. But, despite these merits, there are a number of limitations associated with micro-UAV systems. They still have challenges with extensive and sustainable use due to limited battery capacity, route inefficiency, environmental uncertainty, communication constraints, and the need for real-time decision making.

Digital transformation has significantly changed the way banking services are delivered. Mobile applications, internet banking, digital identification, instant payments, and remote customer services have become important components of modern banking. Consequently, customers increasingly evaluate banks according to the speed, convenience, security, and reliability of their digital channels.

This development is particularly relevant to Azerbaijan, where digital financial services and cashless payments have expanded in recent years. Abbasov (2024) argues that the development of digital banking in Azerbaijan is also associated with the future adoption of open banking and highlights ease of use, reliability, security, and trust as important factors in this process. Abbasova (2024) similarly emphasizes accessibility, transparency, innovation, and customer orientation in the development of banking products and services.

Digitalization alone, however, does not guarantee high service quality. Customers may still face complicated navigation, transaction failures, unclear fees, slow processing, or difficulties obtaining support. International research confirms that system quality, information quality, and interface design significantly affect customer satisfaction with mobile banking (Al-Zu'bi & Al-Gasawneh, 2022). Reliability, responsiveness, and security are also important determinants of online banking satisfaction (Gazi et al., 2024).

Digital quality can additionally influence customers' choice of bank. Akhundov (2024) identifies service speed, quality, innovation, and service variety among the factors affecting bank selection in Azerbaijan. At the same time, differences in users' technological readiness influence satisfaction and loyalty in mobile banking environments (Ho et al., 2025).

Digital banking quality should therefore be considered not only an information technology issue but also a broader customer-experience and management challenge. Hajiyeva et al. (2025) connect banking digitalization in Azerbaijan with technological development, competition, marketing, and changing customer expectations. The aim of this study is to identify the principal dimensions of digital banking service quality and propose practical directions for improving digital services in Azerbaijan's banking sector.

The study addresses two research questions:

RQ1. What are the main determinants of digital banking service quality identified in the literature?

RQ2. How can these determinants be transformed into practical improvement priorities for Azerbaijani banks?

2. Materials and methods

The study applies a **structured qualitative literature synthesis**. Seven academic studies published between 2022 and 2025 were selected according to their relevance to digital banking, service quality, customer satisfaction, technological readiness, bank selection, and digital transformation.

Four studies focused directly on Azerbaijan and examined digital banking and open banking (Abbasov, 2024), banking products and services (Abbasova, 2024), bank-selection behaviour (Akhundov, 2024), and digital banking transformation (Hajiyeva et al., 2025). Three international studies were used to strengthen the

conceptual framework through evidence on mobile banking quality (Al-Zu'bi & Al-Gasawneh, 2022), technology readiness (Ho et al., 2025), and online banking satisfaction (Gazi et al., 2024).

The literature was analysed thematically. Recurring factors were grouped into six dimensions: usability, speed and system performance, reliability, security and trust, information transparency and support, and technology readiness.

The conceptual relationship applied in the study can be summarized as:

Digital service quality → Customer satisfaction → Continued use and loyalty

3. Results

3.1. Usability and system performance

The literature consistently identifies simplicity, interface quality, and system performance as important components of digital banking quality. Abbasov (2024) highlights perceived ease of use as an important factor in digital and open banking adoption. Al-Zu'bi and Al-Gasawneh (2022) also demonstrate that interface design and system quality significantly influence customer satisfaction.

For Azerbaijani banks, this means that frequently used services such as login, transfers, payments, card management, and transaction history should require as few unnecessary steps as possible. Applications should also operate quickly and consistently.

Akhundov (2024) shows that service speed and quality influence customers' bank-selection decisions in Azerbaijan. Therefore, poor application performance can affect not only satisfaction but also competitiveness.

Important indicators may include:

- application loading time;
- transaction completion time;
- successful transaction rate;
- task completion rate;
- transaction abandonment rate.

These measures allow banks to evaluate digital quality from the customer's perspective rather than relying only on technical infrastructure indicators.

3.2. Reliability, security, and trust

Reliability is particularly important in financial services because technical failures directly affect transactions and customer confidence. Gazi et al. (2024) identify reliability and security as significant determinants of online banking satisfaction. Abbasov (2024) likewise emphasizes trust, reliability, and security in the development of digital banking in Azerbaijan.

Banks should therefore ensure high system availability, accurate transaction processing, rapid recovery from technical problems, and effective customer communication during service interruptions.

Security measures should protect customers without making digital banking unnecessarily complicated. Biometric authentication, transaction notifications, device verification, and risk-based authentication can provide protection while maintaining convenience.

Useful performance indicators include:

- system uptime;
- transaction failure rate;
- authentication success rate;
- number of security-related complaints;
- average system recovery time.

The main objective should be to achieve a balance between security and usability.

3.3. Transparency, support, and digital inclusion

Information quality is another important dimension of customer satisfaction. Al-Zu'bi and Al-Gasawneh (2022) demonstrate that accurate and understandable information positively affects mobile banking satisfaction. Abbasova (2024) also highlights transparency and accessibility as important areas for the development of banking services.

Customers should therefore clearly see fees, exchange rates, conditions, and transaction details before confirming financial operations. Error messages should also explain both the problem and the possible solution rather than displaying generic technical notifications. Customer support is equally important. Gazi et al. (2024) identify responsiveness as a component of online banking service quality. Digital channels should consequently provide accessible support through live chat, structured help sections, or efficient connections with customer service representatives.

Banks must also consider differences in digital literacy and technology readiness. Ho et al. (2025) demonstrate that technology readiness affects the relationship between customer satisfaction and loyalty. This is particularly relevant to financial inclusion because customers with limited digital experience may require simplified interfaces, clear instructions, and additional assistance.

For Azerbaijani banks, digital inclusion may be improved through step-by-step onboarding, understandable terminology, short instructions, accessible interface design, and educational messages on security and fraud prevention.

3.4. Proposed digital banking service quality framework

The synthesis identifies six interconnected dimensions that can form a practical framework for Azerbaijan's banking sector.

Table 1.

Dimension	Main objective	Possible indicator
Usability	Reduce customer effort	Task completion rate
Speed	Reduce waiting time	Transaction completion time
Reliability	Ensure continuous service	System uptime
Security and trust	Protect users and transactions	Authentication success rate
Transparency and support	Improve understanding and problem resolution	Response and resolution time
Digital inclusion	Support different user groups	Onboarding completion rate

The framework demonstrates that digital banking quality should be evaluated as an integrated customer experience rather than through isolated technological indicators.

4. Discussion

The results suggest that digital banking service quality is multidimensional. Technical performance alone is insufficient because customers experience the application, security mechanisms, information, and support services as parts of the same banking relationship.

This is consistent with Hajiyeva et al. (2025), who associate banking digitalization in Azerbaijan with technological development, competition, and changing customer behaviour. Therefore, responsibility for digital service quality should extend beyond IT departments to include product development, marketing, cybersecurity, and customer service.

The findings also indicate that reliability and usability have both technical and behavioural consequences. Slow or unstable systems reduce customer satisfaction, while unclear security or fee information can weaken trust. Gazi et al. (2024) particularly emphasize reliability in online banking, while Al-Zu'bi and Al-Gasawneh (2022) identify system quality as a major determinant of mobile banking satisfaction. The Azerbaijani context also demonstrates the competitive importance of digital experience. Akhundov (2024) shows that speed and service quality influence bank-selection decisions. As most banks increasingly provide similar basic digital functions, competitive advantage may depend less on whether digital banking exists and more on how effectively it works.

Furthermore, improving current digital banking services may facilitate the transition toward open banking. Abbasov (2024) indicates that customer experience with digital financial services is relevant to the future use of open banking in Azerbaijan. A reliable and understandable digital environment can therefore strengthen readiness for more advanced financial technologies.

Banks should consequently introduce a small set of continuously monitored indicators such as system uptime, successful transaction rate, transaction completion time, customer-support response time, and onboarding completion rate. These indicators would allow service quality to be monitored as an ongoing process rather than only during major technological upgrades.

5. Conclusion

Digital banking has become a central part of customer interaction with financial institutions. For Azerbaijan's banking sector, improving digital service quality can strengthen customer satisfaction, competitiveness, financial inclusion, and readiness for further financial digitalization.

The literature synthesis identifies six principal dimensions of digital banking quality: usability, speed, reliability, security and trust, transparency and support, and digital inclusion. These dimensions are strongly interconnected and should therefore be managed within a unified customer-experience framework.

Azerbaijani banks should simplify common digital operations, improve system stability and transaction speed, maintain strong but convenient security mechanisms, provide transparent information on fees and conditions, strengthen digital customer support, and design services suitable for customers with different levels of technological readiness.

The main limitation of the study is its reliance on secondary literature rather than primary customer data. Future studies may test the proposed framework through surveys of Azerbaijani banking customers or comparative evaluations of mobile banking

applications. Overall, the competitiveness of digital banking will increasingly depend not on the availability of mobile and online services but on their ability to provide a simple, fast, reliable, secure, transparent, and inclusive customer experience.

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Article

Features of the digital transformation process in enterprises: digital management systems, erp and financial software implementation, electronic document cycle

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Abstract

Buying expensive software is not enough, because digitalization is more about breaking down internal resistance and breaking old habits. We need to analyze this reality, namely ERP systems, internal financial programs, and electronic document management (EDM) used in production. In our study, we examined the real opinions of 231 respondents from 47 medium-sized industrial enterprises covering the period 2021-2024. It turned out that the main issue that determines the fate of technological transition is the level of internal readiness ($\beta = 0.47$, $p < .001$). Although management support also plays a role internally, this effect is not as decisive as readiness ($\beta = 0.29$, $p < .01$). We also tested the old myth that older employees have difficulty accepting new systems. Surprisingly, we see that age does not pose any obstacle to the quality of training and system adoption ($p = .342$). On the other hand, we can see that the internal integration of document management with ERP does not give the same economic benefits in every enterprise, the results show that it is justified in 62% of cases. The regression model we built explains 59% of the total fluctuation observed in the system ($R^2 = .59$, $F = 8.74$, $p < .001$). The main result is the power of organizational memory: we can see that enterprises that have previously experienced similar projects ($M = 4.12$) adapt more easily than those that digitize for the first time ($M = 3.28$) ($t(45) = 3.21$, $p < .01$). Thus, success is based not on biological indicators, but on the past experience of the organization.

Keywords: Digital transformation, ERP implementation, Organizational readiness, Electronic document flow

JEL classification: G21, O33, L86, G28

Academic Editor: Dr. Elnur Arifzade

Received: 22.06.2026

Revised: 23.06.2026

Accepted: 10.08..2026

Published: 14.08.2026

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1. Introduction

In the modern business world, what we call digital transformation is not just a simple option. In fact, it is the only way to maintain internal efficiency. In the modern era, companies have begun to allocate large amounts of money to ERP programs, new generation financial networks, and electronic document flow to regulate internal workflows (Aliyev, 2018; Hasanov, 2019). However, there is a serious question: why, despite such large investments and technological capabilities, most of the projects

ultimately fail, that is, companies cannot survive the meeting. Indeed, the fact that the systems remain incomplete despite such costs forced us to conduct this study (Mammadova, 2020).

When we look at the scientific works written on the subject, we see that experts focus on internal infrastructure, management's strategic commitment to the project, and the level of training of the staff (Guliyev, 2021; Rustamov, 2022). However, scientific figures about the internal strength of these factors are still not fully consistent. While one study considers internal preparation to be an absolute factor, another author revealed a weaker and conditional relationship. Such disagreements may point to other regulating (moderating) factors in the internal system that have not yet been fully discovered.

In this study, we tried to approach the issue from a different angle. Because in most studies, the implementation of ERP platforms and electronic document circulation are analyzed as if they are completely separate from each other, as independent processes. In a real industrial environment, these systems are effective when they work together. We can also reveal how the age of the workforce, internal integrations, and the past project history of the enterprise affect this process through empirical analyses.

We can state some of our main claims that we put forward. First, we argue that organizational readiness (H₁) and direct support from top management for the process (H₂) have a positive impact on project success. On the other hand, it can be assumed that employee age will play a moderator role in the relationship between training intensity and system adoption, meaning that younger teams will adapt faster (H₃). Finally, we focus on the idea that document workflow integration has an internal impact on the relationship between ERP implementation and overall success (H₄).

2. Materials and methods

2.1. Sample and Procedure

To collect data, we collected data from 47 medium-sized manufacturing sites operating in Europe for the years 2021-2024. 231 respondents from different positions participated in our survey. These participants included middle and senior managers, IT and intranet specialists, financial controllers, and end users who work with the system every day. When selecting enterprises, we paid special attention to their recent real-world experience with ERP and ESD implementations.

All scales and questions used in the survey were instruments that had undergone internal reliability tests (internal reliability Cronbach $\alpha > 0.80$ was recorded). We considered whether or not electronic document management was implemented in conjunction with ERP as a binary (coded) variable in the analysis.

2.2. Data Cleaning

In our study, we did not directly analyze the data and carried out serious cleaning work. While reading the answers, we were forced to completely discard the questionnaires of 11 respondents who wrote completely opposite and contradictory approaches to each other in terms of internal logic. Some respondents said that while we rated internal preparation with the highest score, the management did not support this work at all. Such contradictory answers would have undermined the integrity of the analyses or prevented us from drawing conclusions in our study. We did not rely on any of these decisions to automatic programs; we carefully recorded each questionnaire ourselves by hand. In the end, we were able to take into account the results of the questionnaires of 210 respondents from 44 enterprises that were fully suitable for analysis.

2.3. Statistical Analysis

We used a hierarchical regression model to better test the hypotheses. We included factors such as enterprise size, industry type, and internal project experience as control variables in the analysis so that we could obtain more accurate results of the main relationships. We also conducted subgroup analyses to understand the internal differences between companies. We performed all statistical calculations using SPSS 28 software.

3. Results

3.1. Descriptive Statistics

When starting the calculations, we first looked at the correlation relationships. We concluded that there was a fairly strong and positive correlation between the degree of organizational readiness and transformation success ($r = 0.61$, $p < .001$). Among the factors, internal support from management also had a positive effect on success ($r = 0.42$, $p < .01$). On the other hand, no statistical relationship was found between the age of employees and the degree of system adoption, that is, there was no relationship between the age of employees and adoption ($r = -0.08$, $p = .245$). Although the integration of document flow was also positively correlated with the final results, this dependence was much weaker than our initial hypotheses ($r = 0.23$, $p < .05$).

3.2. Hypothesis Testing

The final results of the regression show that organizational readiness as the strongest factor determines the success of digital transformation ($\beta = 0.47$, $p < .001$), thus we can see that our hypothesis H1 is fully confirmed. Top management support for the project also has an effect, but its impact is relatively weak compared to the level of readiness ($\beta = 0.29$, $p < .01$). We can also see that this result confirms the validity of hypothesis H2. The regression model we built can explain only 59% of the total variance in the dependent variable ($R^2 = .59$, $F = 8.74$, $p < .001$).

We can see that the hypothesis H3, which claims that the age structure of the workforce has an effect on the effectiveness of training, is not confirmed ($\beta = -0.08$, $p = .342$). The interaction parameter indicating the effect of age difference was found to be statistically insignificant and increased the power of the model ($\Delta R^2 = .01$, $p = .402$).

On the other hand, although the moderating effect of document workflow integration (H₄) appeared significant at the general sample level ($\beta = 0.18$, $p < .05$), in-depth subgroup analyses revealed a more complex picture. It turned out that the positive effect of this integration was considered statistically significant in only 62% of the enterprises studied. In the remaining enterprises, no relationship could be established between the presence of integration and project success. This heterogeneity suggests that integrating document workflow with ERP does not automatically lead to success and that the efficiency of the process depends on the individual internal structure of the company.

3.3. Subgroup Analyses

When grouping enterprises according to their past digital project experiences, internal differences can become very apparent. The success rates of companies that had previously gone through similar technology projects ($M = 4.12$, $SD = 0.87$) were significantly higher than those that had no experience ($M = 3.28$, $SD = 0.91$), $t(45) = 3.21$, $p < .01$. The study proves that organizations, like people, “learn” and store past experiences in their internal memory.

However, we did not see the expected differences when we grouped them by the

average age of the workforce. Companies with younger employees did not adopt these new systems any faster or more smoothly than others. In fact, in three different companies, teams with a majority of older employees had the highest adaptation rates, although this was statistically significant as a general trend.

4. Discussion

When we approach our results from a conceptual perspective, we can see that most of our hypotheses are confirmed. The leading role of organizational training and management support is fully consistent with the theoretical approaches in the existing scientific literature in the field (Aliyev, 2018; Hasanov, 2019). However, the fact that employee age does not have any regulatory effect on the progress of the project is considered to be something that needs to be analyzed in depth. It shows that in modern times, the biological age factor, rather than the individual digital literacy level or the individual's internal psychological readiness for change, has a greater weight.

Document flow integration produces different results in different enterprises. This is also a very thought-provoking issue. Why does this integration accelerate internal processes in some places, while in others it turns into just a bureaucratic burden? makes one think. The problem is not in the technical indicators of the applied program. The main issue is that in order to automate document flow, it is considered more effective to first fundamentally rebuild internal business processes and transfer them to a different management culture. Companies that dare to make these changes see the benefits, while others simply "seem to be using" the system.

We can also say that the influence of organizational experience once again proves the "organizational learning theory". Companies that have gone through digital projects in the past know better where and what mistakes they can make and how to manage internal resistance. This means that digital transformation can be seen as a cumulative process that accumulates over time and is absorbed into the internal structure.

4.1. Limitations and Future Research

Of course, our study also has some limitations. The size of the analyzed sample group is relatively limited. Since we are based on a cross-sectional research design, it can be considered difficult to claim cause-and-effect relationships with absolute certainty. Also, we were unable to include in our model all the hidden corporate factors that lie behind the heterogeneity that appears in different companies. We can get more effective results by recommending future researchers to study the effects of these invisible corporate factors on the speed of digitalization in more depth.

5. Conclusion

Managing digital transformation in industrial enterprises is not limited to technological innovations. Our study also showed that the level of organizational readiness and the strategic commitment of management to the project are the main pillars of this process. However, the widespread stereotype that "young employees adopt new systems more easily" did not justify itself in the face of our empirical data. The integration of document management with ERP gives different results in different enterprises. This also shows the importance of designing digitalization projects according to the unique internal environment.

Before purchasing expensive ERP and ESD licenses, enterprises should assess their internal readiness level with objective criteria and make sure that management truly believes in and supports this process. When building teams, it is important to give

priority not to the age of employees, but to their ability to adapt to change and their individual digital literacy.

Digital transformation should not be seen simply as a technological transition, but as an evolution of internal culture and business processes. The historical experience of the enterprise, its internal culture and its ability to learn are considered to be of paramount importance in this process. Uncovering the precise mechanism of influence of these internal and often difficult to measure factors on digitalization is a key area of further scientific research.

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