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ARTIFICIAL INTELLIGENCE AND SPACE TECHNOLOGY INTEGRATION: THE ROLE OF THE UNESCO–NASA PARTNERSHIP IN HERITAGE PROTECTION AND CLIMATE RESILIENCE

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Abstract. This article examines the application of artificial intelligence (AI) and satellite remote-sensing technologies to cultural heritage protection, disaster risk reduction, and climate resilience within the framework of the UNESCO–NASA partnership, established in 2005 and substantially expanded after 2024 through the Prithvi family of geospatial foundation models. Combining a structured literature review with a comparative transfer analysis, the study traces the institutional evolution of the partnership, profiles the technical architecture and benchmarked performance of Prithvi-EO-2.0 and Prithvi-WxC, and examines the public–private HeritageWatch.AI initiative launched in Paris in February 2025. The discussion situates these developments within UNESCO’s Recommendation on the Ethics of Artificial Intelligence and its Readiness Assessment Methodology, and identifies structural barriers — uneven computing access, workforce gaps, and language-adaptation costs — that constrain operational uptake. As an original contribution, the article evaluates application perspectives for Azerbaijan, linking the country’s space infrastructure (Azerkosmos), the heritage-monitoring needs of the liberated territories of Karabakh and East Zangazur, and UNESCO’s readiness-assessment framework, and proposes the architecture of a national Smart Cultural Heritage Monitoring Platform.

Keywords: *artificial intelligence, geospatial foundation models, UNESCO–NASA partnership, Prithvi, digital twin, cultural heritage, climate resilience.*

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ИНТЕГРАЦИЯ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА И КОСМИЧЕСКИХ ТЕХНОЛОГИЙ: РОЛЬ ПАРТНЕРСТВА ЮНЕСКО–НАСА В ЗАЩИТЕ НАСЛЕДИЯ И КЛИМАТИЧЕСКОЙ УСТОЙЧИВОСТИ

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Статья рассматривает применение искусственного интеллекта (ИИ) и спутниковых технологий дистанционного зондирования для защиты культурного наследия, снижения риска катастроф и климатической устойчивости в рамках партнёрства ЮНЕСКО - НАСА, учреждённого в 2005 году и существенно расширившегося после 2024 года благодаря семейству геопространственных базовых моделей Prithvi. Сочетая структурированный обзор литературы со сравнительным трансферным анализом, исследование прослеживает институциональную эволюцию партнёрства, характеризует техническую архитектуру и тестируемые показатели моделей Prithvi-EO-2.0 и Prithvi-WxC, а также рассматривает государственно-частную инициативу HeritageWatch.AI, запущенную в Париже в феврале 2025 года. Раздел обсуждения помещает эти процессы в контекст Рекомендации ЮНЕСКО по этике искусственного интеллекта и её Методологии оценки готовности (RAM), а также выявляет структурные барьеры —

неравный доступ к вычислительным ресурсам, нехватку квалифицированных кадров и издержки языковой адаптации. В качестве оригинального вклада статья оценивает перспективы применения данного опыта для Азербайджана, увязывая космическую инфраструктуру страны («Азеркосмос»), задачи мониторинга наследия на освобождённых территориях Карабаха и Восточного Зангезура и методологию RAM ЮНЕСКО, и предлагает архитектуру национальной платформы «Умный мониторинг культурного наследия».
Ключевые слова: искусственный интеллект, геопространственные базовые модели, партнёрство ЮНЕСКО–НАСА, Prithvi, цифровой двойник, культурное наследие, климатическая устойчивость.

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ЖАСАНДЫ ИНТЕЛЛЕКТ ПЕН ҒАРЫШТЫҚ ТЕХНОЛОГИЯЛАРДЫҢ ИНТЕГРАЦИЯСЫ: ЮНЕСКО–НАСА СЕРІКТЕСТІГІНІҢ МҰРАНЫ ҚОРҒАУДАҒЫ ЖӘНЕ КЛИМАТТЫҚ ТҰРАҚТЫЛЫҚТАҒЫ РӨЛІ

Мирзаев Фархад Рамиз оглу, жасанды интеллект және электрондық қызметтер бөлімінің меңгерушісі, Әзірбайжан Ұлттық ғылым академиясының (НАНА) Ганджа филиалы, цифрландыру.
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Аннотация. Мақалада 2005 жылы құрылған және Prithvi геокеңістіктік базалық модельдер тобының арқасында 2024 жылдан кейін айтарлықтай кеңейген ЮНЕСКО-НАСА серіктестігі аясында мәдени мұраны қорғау, апаттар қаупін азайту және климаттық тұрақтылық үшін жасанды интеллект (ЖИ) және спутниктік қашықтықтан зондтау технологияларын қолдану қарастырылады. Әдебиеттерге құрылымдық шолуды салыстырмалы трансферттік талдаумен үйлестіре отырып, зерттеу серіктестіктің институционалдық эволюциясын бақылайды, Prithvi-EO-2.0 және Prithvi-WxC модельдерінің техникалық архитектурасы мен сыналған көрсеткіштерін сипаттайды және мемлекеттік-жеке бастаманы қарастырады HeritageWatch.AI, Парижде 2025 жылдың ақпанында іске қосылды. Талқылау бөлімі бұл процестерді ЮНЕСКО-ның жасанды интеллект этикасы және оның дайындықты бағалау әдістемесі (RAM) бойынша ұсынысы аясында орналастырады және құрылымдық кедергілерді-есептеу ресурстарына тең емес қол жетімділікті, білікті кадрлардың жетіспеушілігін және тілдік бейімделу шығындарын анықтайды. Түпнұсқа үлес ретінде мақала еліміздің ғарыштық инфрақұрылымын ("Әзіркосмос"), Қарабах пен Шығыс Зангезурдың босатылған аумақтарындағы мұра мониторингінің міндеттерін және ЮНЕСКО-ның ЖЖҚ әдіснамасын байланыстыра отырып, Әзірбайжан үшін осы тәжірибені қолдану перспективаларын бағалайды және "мәдени мұраның ақылды мониторингі"ұлттық платформасының архитектурасын ұсынады.
Түйін сөздер: жасанды интеллект, геокеңістіктік негізгі модельдер, ЮНЕСКО-НАСА серіктестігі, Prithvi, сандық егіз, Мәдени мұра, Климаттық тұрақтылық.

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1. Introduction

The protection of cultural and natural heritage has, over the past decade, ceased to rely solely on traditional conservation practice and has instead become a global priority pursued through the integration of advanced digital technologies — most notably artificial intelligence (AI) and satellite Earth-observation systems [1–6, 14–21]. At the close of the 47th session of the UNESCO World Heritage Committee, held in Paris from 6 to 16 July 2025, the World Heritage List comprised 1,248 properties across 170 countries, of which 39 sites — slightly more than three percent of the total — were inscribed on the List of World Heritage in Danger [10, 35]. This modest global share, however, conceals a pronounced regional imbalance: sub-Saharan Africa alone is home to 108 inscribed properties yet accounts for 17 of the 39 endangered sites worldwide, or 44 percent of the global danger list [33]. Such asymmetry indicates that the scale of the heritage-protection problem cannot be addressed by a single uniform global instrument and instead requires regionally calibrated technological responses.

The same 47th session inscribed 26 new cultural and natural properties and removed three African sites — the Rainforests of the Atsinanana (Madagascar), Abu Mena (Egypt), and the Old Town of Ghadamès (Libya) — from the danger list, demonstrating that institutional monitoring capacity continues to expand even as the population of properties requiring active oversight grows [10]. Of direct relevance to the present study, the same session added two Azerbaijani properties — the Ancient City of Gabala and the Historical, Cultural and Natural Complex of Gamigaya and Goygol — to UNESCO's Tentative World Heritage List [40], a development examined in detail in Section 4 below and one that underlines the timeliness of building national capacity for satellite-based heritage monitoring.

The purpose of this article is to provide a systematic analysis of: (a) the institutional foundations of the partnership established between UNESCO and the National Aeronautics and Space Administration (NASA); (b) the principal technological platforms deployed within this cooperation framework, with particular attention to artificial-intelligence-based geospatial foundation models — above all the Prithvi family; (c) initiatives implemented in a public–private partnership format, exemplified by HeritageWatch.AI; (d) practical applications in the reduction of natural-disaster risk; (e) the ethical and institutional regulatory framework that has emerged around these technologies; and (f) — as the original contribution of this study — the application perspectives of this international experience for the Republic of Azerbaijan, a country that combines an operational national space agency with an urgent, post-conflict heritage-monitoring agenda in the liberated territories of Karabakh and East Zangazur.

Formal cooperation between UNESCO and NASA was established through an agreement signed in Washington, D.C., on 1 March 2005 [28]. The agreement provided for the use of space-based Earth-observation technologies in monitoring and protecting properties inscribed on the World Heritage List and created the legal foundation for a cooperative framework that has continued to expand over the subsequent two decades. The institutional scope of this cooperation was further broadened in 2025 through priorities endorsed at the 43rd Session of the UNESCO General Conference, held in Samarkand, Uzbekistan — namely artificial intelligence, climate change, and post-pandemic recovery [7, 9].

The technological core of the UNESCO–NASA cooperation since 2024 has been formed by the Prithvi family of geospatial foundation models [24]. The 2025 advances in this model family substantially broadened both the scientific and the operational potential of the field [12, 24, 25, 36, 37], a development discussed in detail in Section 3.2 below. Building on this institutional and technological mapping, the article advances the working hypothesis that the architecture underlying the UNESCO–NASA cooperation — comprising (i) a bilateral institutional agreement, (ii) open-source AI foundation models trained on freely accessible satellite archives, and (iii) a public–private layer of implementation partners — is sufficiently modular to be adapted, at national scale, by a country that already possesses operational satellite infrastructure and an unresolved heritage-monitoring need, even in the absence of formal UNESCO–NASA accreditation. The remainder of the article tests this hypothesis against the empirical case of Azerbaijan. Section 2 outlines the materials and analytical method; Section 3 presents the literature-based discussion of the UNESCO–NASA architecture; Section 4 reports the results of applying this architecture to the Azerbaijani context; and Section 5 concludes.

2. Materials and Methods

This study is a desk-based qualitative analysis rather than an empirical field investigation; no primary data were collected from heritage sites, satellite operators, or government agencies beyond what is publicly disclosed in institutional and technical sources. The corpus of materials reviewed comprises four categories. First, primary institutional documents: the 2005 UNESCO–NASA cooperation agreement [28], UNESCO's 2021 Recommendation on the Ethics of Artificial Intelligence [27], the Readiness Assessment Methodology and its country-level implementation reports [29, 30], and the declarations and decisions of the 43rd UNESCO General Conference and the 47th session of the World Heritage Committee [7, 10, 35, 40]. Second, technical and scientific literature on the Prithvi foundation-model family, including the technical reports describing Prithvi-EO-2.0 and Prithvi-WxC, their training data, architecture, and benchmarked performance against comparator geospatial models [12, 24, 25, 36, 37]. Third, reports on operational applications of these technologies in disaster risk reduction, including the joint UNDRR–NASA Tech4DRR report and NASA Disasters Program case studies on severe-weather and tornado detection [22, 26]. Fourth, sources specific to the Azerbaijani context, comprising the official activity disclosures of the State Space Agency ("Azerkosmos") and periodic export-statistics bulletins published by the Economic Reforms Analysis and Communication Centre of the Republic of Azerbaijan for the period January–April 2026 [38, 39].

The analytical method consists of two linked stages. The first stage is a structured narrative synthesis in which the institutional, technological, and governance components of the UNESCO–NASA partnership are mapped against three analytical categories: (i) institutional architecture (legal instruments, governing bodies, periodic conferences); (ii) technological architecture (foundation models, training data, benchmarked capability); and (iii) implementation architecture (public, private, and public–private delivery mechanisms, exemplified by HeritageWatch.AI). This three-part framework, rather than any single technology or agreement in isolation, is treated as the principal unit of analysis, since it is the combination of the three layers — not any one layer alone — that is hypothesised to be transferable.

The second stage is a comparative transfer analysis in which the three-part framework derived from Stage 1 is mapped onto the documented capacities and needs of Azerbaijan, specifically: the satellite fleet, export performance, and international partnerships of Azerkosmos; the heritage-monitoring requirements of the newly UNESCO-listed and tentative-list properties together with the liberated territories of Karabakh and East Zangazur; and Azerbaijan's institutional engagement with UNESCO's Readiness Assessment Methodology. The output of this second stage — presented in Section 4 as the Results of the study — is a proposed institutional and technical architecture for a national 'Smart Cultural Heritage Monitoring Platform.'

Limitations of this method should be stated explicitly. The analysis does not include independent technical validation of the cited model-performance figures, which are drawn from developer-reported benchmarks, nor does it include interviews with Azerkosmos, ANAS, or Ministry of Culture officials. The Azerbaijan-specific proposals in Section 4 are therefore presented as a research-based architectural recommendation rather than an implemented or formally adopted programme.

3. Discussion: Literature Review

3.1 Institutional Foundations of the UNESCO–NASA Partnership

Formal cooperation between UNESCO and NASA rests on the agreement signed on 1 March 2005 in Washington, D.C. [28], which envisaged the application of space-based Earth-observation technology to the monitoring and protection of World Heritage properties. Over the subsequent two decades, this bilateral instrument has evolved from a narrowly defined data-sharing arrangement into a broader platform encompassing artificial intelligence, climate adaptation, and disaster-risk reduction. The institutional scope of the partnership was substantially widened by priorities adopted at the 43rd Session of the UNESCO General Conference in Samarkand in late 2025, which formally designated artificial intelligence, climate change, and post-pandemic recovery as cross-cutting priorities for the organisation [7, 9]. The annual sessions of the World Heritage Committee provide the operational link between this institutional layer and individual properties: the 47th session in Paris inscribed 26 new properties (21 cultural, four natural, one mixed), removed three African sites from the danger list, and brought the List to 1,248 properties in 170 countries [10, 35]. These figures situate the UNESCO–NASA cooperation within a heritage-governance system that is simultaneously expanding in coverage and facing a growing population of at-risk sites requiring continuous monitoring — precisely the operational gap that satellite-based AI tools are intended to close.

3.2 The Technological Core: the Prithvi Foundation Model Family

Since 2024, the technological core of the UNESCO–NASA cooperation has been the Prithvi family of geospatial foundation models, developed under NASA's open-science approach and its broader AI Foundation Models strategy [24]. Unlike task-specific machine-learning models trained from scratch for a single application, foundation models are pre-trained on very large, unlabelled datasets through self-supervision and can subsequently be fine-tuned for diverse downstream tasks with comparatively little labelled data — a property that is particularly valuable in the heritage and disaster-risk domains, where labelled training examples, such as confirmed instances of looting, structural collapse, or flood damage at a specific monument, are scarce [12, 36].

Prithvi-EO-2.0, the flagship model in the family, was developed jointly by IBM, NASA, and Germany's Jülich Supercomputing Centre, with contributions from 42 researchers across 12 institutions in the United States, Europe, and Brazil [12, 36, 37]. The model is built on a Vision Transformer architecture and pre-trained using a masked-autoencoder approach, with two principal innovations over its 2023 predecessor: three-dimensional patch and positional embeddings that allow the model to process sequences of satellite images across time, together with explicit temporal and location embeddings. It was trained on 4.2 million multispectral image samples drawn from seven years of NASA's Harmonized Landsat and Sentinel-2 (HLS) archive at 30-metre resolution, with model variants of 300 million and 600 million parameters [12, 37]. On the GEO-Bench evaluation suite, the 600-million-parameter version outperformed its 2023 predecessor by approximately eight percent and surpassed six other published geospatial foundation models across remote-sensing tasks spanning resolutions from 0.1 to 15 metres [12]. Documented downstream applications include flood-extent mapping — notably during the 2024 Valencia floods, where the model combined Sentinel-1 radar and Sentinel-2 optical data to measure flooding through cloud cover — burn-scar delineation, multi-temporal crop and land-cover classification, and deforestation-driver classification [9, 36].

A companion model, Prithvi-WxC, addresses weather and climate prediction rather than static land-surface observation. Developed by NASA together with IBM and the Oak Ridge National Laboratory, it supports applications such as hurricane-track forecasting and severe-weather risk mapping, extending the foundation-model approach from retrospective land-cover analysis toward short-term operational early warning [24]. Table 1 summarises the technical profile of the principal models discussed in this section, together with the public–private initiative examined in Section 3.3.

Table 1. Prithvi Model Family and Implementation Partners: Technical Overview

Model / Platform	Lead Developers	Core Technical Specification and Primary Application	Open-Source / Access Status
Prithvi-EO-2.0	IBM, NASA, Jülich Supercomputing Centre (42 contributors, 12 institutions)	ViT architecture, masked-autoencoder pre-training, 300M/600M parameters, 3D spatiotemporal embeddings; trained on 4.2M HLS samples (30 m resolution); +8% over predecessor on GEO-Bench. Multi-temporal Earth observation, flood and burn-scar mapping, crop/land-cover classification.	Hugging Face / IBM TerraTorch / GitHub (open)
Prithvi-WxC	NASA, IBM, Oak Ridge National Laboratory	Weather–climate foundation model. Hurricane-track forecasting, severe-weather risk mapping,	GitHub (open)

		short- and long-term climate projection.	
HeritageWatch.AI	ALIPH, Iconem, Microsoft (AI for Good Lab), Planet Labs PBC	Combines a ~200-satellite daily-imaging constellation, 3D heritage digital-twin modelling, and AI-based risk forecasting (desertification, sea-level rise, conflict). Independent, non-commercial; launched Paris, 10 Feb. 2025.	Independent non-profit initiative (Paris headquarters)

The open-source release strategy adopted for both models — distribution through Hugging Face, IBM's TerraTorch toolkit, and GitHub — is a deliberate design choice intended to lower the barrier to adoption for researchers and institutions in low-resource settings, since fine-tuning a pre-trained foundation model for a new application requires substantially less computational investment than training a comparable model from scratch [9, 37]. This design feature is directly relevant to the transfer analysis presented in Section 4, since it implies that a national agency such as Azerkosmos could, in principle, fine-tune an openly released Prithvi checkpoint on locally collected satellite imagery without needing to replicate NASA's original training infrastructure.

3.3 The Public–Private Partnership Model: HeritageWatch.AI

While Prithvi represents the model layer of the UNESCO–NASA technological architecture, the implementation layer is illustrated by HeritageWatch.AI, an initiative launched on 10 February 2025 at the French Ministry of Culture in Paris, in the presence of France's Minister of Culture, as part of the Artificial Intelligence Action Summit [34]. HeritageWatch.AI is an independent, non-commercial body co-founded by four organisations with complementary capabilities: ALIPH (the International Alliance for the Protection of Heritage), a public–private fund that has, since 2017, disbursed roughly USD 100 million in grants to more than 500 heritage projects in 41 countries; Iconem, a firm specialising in high-resolution 3D digital modelling of heritage sites; Microsoft, whose AI for Good Lab provides the computational and analytical backbone of the initiative; and Planet Labs PBC, a commercial Earth-observation company — founded by former NASA scientists — that operates a constellation of roughly 200 imaging satellites and supplies daily global coverage [34].

The initiative's operating model links these four capabilities sequentially: Planet Labs' satellites provide high-frequency imagery of heritage sites; Iconem converts this imagery, together with its own 3D-scanning expertise, into digital-twin representations of individual monuments; Microsoft's AI for Good Lab applies machine-learning analysis to detect and forecast risk patterns — explicitly including the progressive impact of desertification on earthen architecture in the Sahel and the effects of rising sea levels on coastal heritage; and ALIPH channels the resulting risk intelligence into its existing grant-disbursement and emergency-response mechanisms, of the kind that delivered USD 500,000 to Beirut's Sursock Museum within three weeks of the 2020 port explosion [34]. Initial funding for the initiative comprised a USD 1 million pledge from Microsoft over four years, USD 750,000 in in-kind computing services, and USD 250,000 from ALIPH [34].

HeritageWatch.AI is significant for the present analysis not primarily as a technology but as an institutional template: it demonstrates that a public–private consortium combining a satellite-data provider, a 3D-modelling specialist, an AI compute provider, and a heritage-financing body can be assembled and operationalised within roughly a year of conception, and that the resulting structure does not require any single partner to possess the full stack of capabilities in-house. As discussed in Section 4, this template is structurally comparable — though smaller in scale — to a configuration that Azerbaijan could assemble domestically by combining Azerkosmos, an academic AI unit, and the national heritage authorities, without requiring direct UNESCO–NASA accreditation.

3.4 Disaster Risk Reduction Applications

Heritage protection and disaster-risk reduction are closely intertwined in the UNESCO–NASA cooperation framework, since the same satellite-based monitoring infrastructure that detects threats to monuments can detect threats to surrounding populations. The joint UNDRR–NASA Tech4DRR report, published in 2025, examined the application of remote-sensing and AI technologies to disaster-risk reduction and concluded that the effectiveness of such technological solutions cannot be assured without explicit attention to local needs, existing infrastructure, and cultural context — a caution directly relevant to any attempt to transplant the UNESCO–NASA model into a new national setting without adaptation [22].

A concrete illustration of the disaster-risk application of AI foundation models is provided by the NASA Disasters Program's 2025 open-source machine-learning model for tornado detection. Developed by researchers at NASA's Langley Research Center, the model uses geostationary satellite data from NOAA's GOES-16 satellite to identify overshooting cloud tops and above-anvil cirrus plumes — atmospheric signatures that typically precede severe ground-level weather, including tornadoes, by roughly ten minutes [26]. The model was tested against the severe-weather outbreak that struck the south-eastern United States on 14–16 March 2025, during which the NOAA/NWS Storm Prediction Center documented more than 100 tornado reports together with significant hail and damaging winds; the model's detections were consistent with the Center's independently collected ground-truth data [26]. While modest in absolute lead time, this window is operationally significant for life-safety warnings, and it illustrates a broader pattern in the NASA Disasters Program's approach: rather than developing entirely new sensor infrastructure, the programme prioritises applying machine learning to data already collected by existing operational satellites — a strategy that lowers the marginal cost of deployment and is therefore readily transferable to agencies, such as Azerkosmos, that do not operate their own meteorological satellite constellation but do have access to publicly available geostationary and polar-orbiting data feeds.

3.5 Ethical and Institutional Governance Framework

The integration of artificial-intelligence technologies into heritage protection and disaster management has necessarily required parallel development of an ethical and institutional governance framework [6, 11]. The principal normative instrument in this domain remains UNESCO's Recommendation on the Ethics of Artificial Intelligence, adopted by all 193 Member States at the 41st Session of the UNESCO General Conference in November 2021 [27]. The Recommendation is structured around the full lifecycle of an AI system and sets out values, principles, and concrete policy actions across areas including gender equality, environmental sustainability, and the integrity of information ecosystems.

To operationalise the Recommendation, UNESCO developed the Readiness Assessment Methodology (RAM), officially launched on 13 December 2022 at the inaugural Global Forum on the Ethics of AI in Prague [29]. RAM evaluates a country's institutional preparedness to govern artificial intelligence responsibly across five dimensions — legal and regulatory, social and cultural, economic, scientific and educational, and technological and infrastructural — using qualitative and quantitative indicators within each dimension [29]. As of October 2025, more than 75 countries across five continents had initiated or completed a RAM assessment [31], a figure that indicates accelerating uptake of the methodology since its 2022 launch. Kazakhstan, a country in the same broader region as Azerbaijan, formally launched its national RAM process in January 2026 at Astana Hub, bringing together roughly 80 representatives from government, academia, the private sector, and civil society [30] — a precedent of direct relevance to the recommendations advanced in Section 4 below.

The institutional architecture supporting AI ethics was further strengthened at the Third UNESCO Global Forum on the Ethics of Artificial Intelligence, held in Bangkok in June 2025, which saw the establishment of two complementary bodies: a Global Network of AI Ethics Supervisory Bodies, intended to connect national regulators, and a Global Network of Civil Society and Academia on AI Ethics, intended to broaden non-governmental participation in AI-governance debates [8, 32]. Taken together, the Recommendation, the RAM, and these two global networks constitute a three-tier governance stack — normative standard, country-level diagnostic tool, and cross-border coordination network — that frames not only the ethical use of AI in heritage protection narrowly, but also the broader question of how a country such as Azerbaijan might align a future national geospatial-AI programme with internationally recognised governance norms rather than developing such norms in isolation.

3.6 Implementation Challenges and Structural Constraints

Despite the technological and institutional achievements described above, the transition of AI-based solutions from the research stage to routine operational practice continues to encounter structural difficulties. Three constraints recur across the literature reviewed for this study. First, access to the computing infrastructure required to fine-tune or run inference on large foundation models remains unevenly distributed, disadvantaging institutions outside a small number of well-resourced research hubs. Second, the specialised workforce capable of adapting open-source geospatial AI models to local applications is unevenly distributed across regions and is frequently concentrated in a handful of countries. Third, openly released foundation models and their associated documentation, fine-tuning examples, and benchmark datasets are overwhelmingly published in English, creating a non-trivial adaptation burden for institutions operating primarily in other languages.

The Tech4DRR report's caution regarding the necessity of local-context calibration reinforces this picture: a technological solution validated in one geographic and institutional setting cannot be assumed to transfer automatically to another without deliberate investment in local data, local expertise, and local-language documentation [22]. This caution applies directly to the Azerbaijani case examined in Section 4: although the Prithvi model family and the HeritageWatch.AI template are both, in principle, openly accessible, neither has yet been fine-tuned on Azerbaijani satellite imagery, validated against Azerbaijani heritage sites, or documented in Azerbaijani or Russian, and the proposals advanced below should therefore be read as identifying a feasible starting architecture rather than a turnkey solution.

4. Results: Application Perspectives for Azerbaijan

4.1 Azerkosmos: Strategic Space Infrastructure

Although the formal mechanisms of the UNESCO–NASA partnership described in Section 3 are not directly applied within Azerbaijan, the global initiatives reviewed above — the Prithvi model family and platforms such as HeritageWatch.AI — create a substantial opportunity space for the country, which already possesses much of the underlying infrastructure required to engage with this technological trend.

The Space Agency of the Republic of Azerbaijan ("Azerkosmos"), operating under the Ministry of Digital Development and Transport, is active both domestically and internationally, and functions as considerably more than a satellite operator: it is a strategic agency that positions Azerbaijan within the global space economy, exports high-technology services, and develops AI-based geoinformation systems domestically. Azerkosmos currently operates the Azerspace-1 and Azerspace-2 telecommunication satellites, providing continuous television, radio-broadcasting, and satellite-internet services across Europe, Africa, the Middle East, and Central Asia.

The agency's export performance has shown sustained growth through the first four months of 2026: satellite telecommunication-service exports reached USD 1.5 million in January, rose to a cumulative USD 4.1 million across the first quarter (January–March) — delivered to nearly 90 companies in 32 countries — and reached a cumulative USD 8.7 million across January–April [38]. Across this period, service exports have consistently represented approximately 64–65 percent of the agency's total revenue, with the United Kingdom, Luxembourg, Sweden, Turkey, and Pakistan consistently ranking among the top five destination markets [38]. Beyond telecommunications, Azerkosmos provides satellite-imagery and archival-data services supporting agriculture, ecology, cartography, and urban planning, and maintains international cooperation agreements with NASA, the Turkish Space Agency (TUA), the China National Space Administration (CNSA), and the South African National Space Agency (SANSA) [39].

This combination of an operational satellite fleet, an established international cooperation network that already includes NASA, and a growing satellite-services export base constitutes precisely the kind of national space infrastructure on which a geospatial AI programme — of the type discussed in Section 3 — could be built without requiring entirely new capital investment in launch or ground-segment infrastructure. The principal gap, as elaborated below, lies not in space infrastructure but in the AI-modelling and heritage-domain integration layer.

4.2 Satellite Monitoring of Cultural Heritage: Karabakh and East Zangazur

Azerbaijan's close partnership with UNESCO in heritage protection reflects the country's broader sensitivity to global standards in this field. The protection of inscribed properties such as the Walled City of Baku (İçərişəhər) with the Shirvanshahs' Palace and the Maiden Tower, and the Gobustan Rock Art Cultural Landscape, already draws on internationally recognised heritage-management methodologies. As noted in Section 1, the 47th session of the World Heritage Committee in 2025 added two further Azerbaijani properties — the Ancient City of Gabala and the Historical, Cultural and Natural Complex of Gamigaya and Goygol — to UNESCO's Tentative List [40], expanding the population of nationally significant sites that will eventually require the same standard of international-grade documentation and monitoring as the existing inscribed properties.

The most urgent and distinctive heritage-monitoring need, however, concerns the historical and cultural monuments located in the territories of Karabakh and East Zangazur liberated from nearly three decades of occupation. Azerbaijan already makes active use of satellite imagery to monitor these areas, both to assess the condition of historical-cultural monuments and to evaluate broader economic-reconstruction potential. Applying Prithvi-type AI-based geospatial models in this specific context could be expected to deliver several concrete benefits, sequentially:

— multi-temporal satellite analysis of changes in the territorial composition of monuments (destruction, restoration, new construction), of the kind already demonstrated by Prithvi-EO-2.0 in flood- and burn-scar mapping elsewhere [12, 36];

— forecasting of soil-erosion, landslide, and flood risk affecting both monuments and the broader reconstruction zone, an application directly analogous to the hazard-mapping function of Prithvi-WxC and the NASA Disasters Program's severe-weather models described in Section 3.4 [24, 26];

— restoration of historical territorial-planning maps to support the return of internally displaced persons, an application that combines archival cartographic material with multi-temporal satellite analysis in a manner conceptually similar to Iconem's digital-twin methodology within HeritageWatch.AI [34].

Each of these three applications has a documented technological precedent in the literature reviewed in Section 3; the principal task for Azerbaijan is therefore one of adaptation and integration rather than basic research.

4.3 Toward a National "Smart Cultural Heritage Monitoring Platform"

Combining Azerbaijan's regional space capability with its digital-humanities and heritage-documentation needs could position the country among the more technologically advanced centres in the international scientific arena. Building directly on the institutional–technological–implementation framework derived in Section 3 — institutional agreement, open-source foundation models, and a public–private (or, in this case, inter-institutional) implementation layer — the proposed architecture of a national 'Smart Cultural Heritage Monitoring Platform' should include the following core components:

— a unified coordination mechanism linking Azerkosmos, the Ministry of Culture, and the Azerbaijan National Academy of Sciences (ANAS), mirroring the multi-institution governance structure that underlies both the UNESCO–NASA partnership [28] and HeritageWatch.AI [34], but configured around domestic rather than international partners;

— a locally fine-tuned analogue of Prithvi-EO-2.0, trained or fine-tuned on Azerbaijani satellite imagery to provide automated assessment of monument condition, following the open fine-tuning pathway already enabled by the model's release on Hugging Face and GitHub [12, 37];

— Interferometric Synthetic Aperture Radar (InSAR) monitoring of historical monuments at the millimetre level of subsidence detection — a remote-sensing technique complementary to, rather than duplicative of, the optical and multispectral imagery used by Prithvi;

— full application of UNESCO's RAM methodology to align Azerbaijan's national AI-governance framework with international standards, following the template Kazakhstan adopted in January 2026 [30] and consistent with the broader uptake trend, in which more than 75 countries had engaged with RAM as of October 2025 [31];

— LiDAR scanning and 3D modelling — directly analogous to Iconem's role within HeritageWatch.AI [34] — to create digital twins of monuments such as the Shirvanshahs' Palace and the Sheki Khans' Palace.

Each of these five components corresponds to a specific element already validated, in some other national or institutional context, within the literature reviewed in Section 3; the platform proposed here is therefore best understood as a synthesis and domestic adaptation of existing, internationally tested components rather than as an entirely novel technical proposal. This is consistent with the methodological framing set out in Section 2, where the contribution of this article was defined as a comparative transfer analysis rather than original model development.

4.4 Space Ecosystem Development and Youth Engagement

Sustained engagement with this agenda also depends on building the specialised human-capital base identified in Section 3.6 as one of the principal global constraints on AI adoption. Azerkosmos regularly organises Space Olympiads and large-scale outreach events to popularise space science among young people, and — together with its partners — convenes National Space Hackathons in which young researchers combine artificial intelligence and satellite data to develop innovative machine-learning models for applications including real-estate analytics, agricultural land valuation, and marine-ecosystem monitoring.

Within the framework of the Year of Memorialisation and Urban Planning, declared for 2026, the agency is implementing dedicated scientific-practical projects and competitions applying satellite imagery and geographic information systems (GIS) to cadastral mapping, territorial planning, and digital-twin technologies. The integration of the national AI ecosystem with heritage protection carries strategic importance in this framework: hackathon-trained researchers represent precisely the workforce category whose scarcity was identified, in Section 3.6, as a recurring global constraint on translating AI foundation models into operational heritage-protection tools. Embedding heritage-monitoring challenges directly into these existing youth-engagement programmes — rather than creating a separate training pipeline — would allow Azerbaijan to address the workforce constraint and the heritage-monitoring agenda simultaneously, using infrastructure that Azerkosmos has already built.

5. Conclusion

The analysis presented in this article indicates that the UNESCO–NASA cooperation, in place since 2005, has continuously broadened its institutional foundations and now functions as a significant platform for integrating artificial intelligence and space technologies into cultural-heritage protection, disaster-risk reduction, and climate resilience. Three findings from the literature review in Section 3 are particularly salient for the comparative transfer analysis undertaken in Section 4. First, the technological core of the partnership — the Prithvi foundation-model family — is openly released and was specifically designed to lower the computational barrier to adoption for institutions that did not participate in its original training, a design choice directly exploitable by national agencies elsewhere. Second, the HeritageWatch.AI initiative demonstrates that the institutional architecture required to operationalise such models — a coordinated combination of a satellite-data provider, a 3D/AI-modelling capability, and a heritage-financing or heritage-governance body — can be assembled domestically and need not depend on direct UNESCO or NASA participation. Third, the governance layer built around UNESCO's Recommendation on the Ethics of Artificial Intelligence and its Readiness Assessment Methodology provides an internationally recognised diagnostic pathway, already adopted by more than 75 countries as of October 2025 and by Azerbaijan's regional peer Kazakhstan in January 2026, through which a country can align a new national AI programme with global governance norms rather than developing such norms in isolation.

From the perspective of Azerbaijan, the prospects opened up by this global experience present themselves across three connected layers. First, the existing space infrastructure and international cooperation network of Azerkosmos — including its established cooperation with NASA itself — already provide ready ground for using satellite data for heritage-protection purposes. Second, the monitoring and restoration of cultural monuments in the territories liberated from occupation in Karabakh and East Zangazur make the adaptation of foundation models such as Prithvi to the Azerbaijani context an urgent rather than a discretionary priority. Third, applying UNESCO's RAM methodology constitutes a necessary step — both technologically and institutionally — in aligning the country's AI-governance framework with international standards, a step for which a clear regional precedent now exists.

In conclusion, within this multi-stranded process encompassing heritage protection, AI ethics, and regional partnership, the implementation of a national initiative such as the proposed 'Smart Cultural Heritage Monitoring Platform' — combining Azerbaijan's own capabilities with global technological trends — should be understood not merely as a technical innovation, but as one of the most reliable means of transmitting the nation's cultural heritage to future generations intact and under robust digital protection. Future research building on this article's qualitative, desk-based analysis should pursue empirical pilot studies — for example, fine-tuning an openly released Prithvi checkpoint on a single liberated-territory monument with field-verified ground-truth data — to test, rather than merely propose, the architecture outlined in Section 4.

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