

Secure Smart Mountain Tourism in Complex Terrain: Integrating Satellite Monitoring, GPS, Communication Technologies and Cybersecurity for Sustainable Tourism and Regional Economic Development

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Abstract

Mountain areas attract about 9 to 16 percent of all international tourists worldwide. However, the very features that make these places beautiful and interesting can also bring challenges. For example, steep slopes may become unstable, weather can change quickly, roads and paths can be fragmented or hard to navigate, and in some cases, there are areas where it's difficult to communicate with the outside world. This is a major problem. This paper presents a single framework that combines satellite monitoring, GIS spatial analysis, GPS/GNSS positioning, hybrid communication systems, and cybersecurity measures into one secure smart mountain tourism system. The goal is to support sustainable tourism and local economic growth. The Shahdag–Qusar–Khinalig area in northeastern Azerbaijan is used as an example. The study uses open satellite data, elevation data, tourism data, and printed coverage details to construct this framework. The results show that areas with limited accessibility and poor communication are in close proximity to the most valuable tourism sites, primarily due to a noticeable lack of safety. Digitalisation without security is not helpful because location data, bespeaking platforms, and IoT wearables bring opportunities for attacks that can be constrained just like the services they support. A six-layer framework is implied, including data collection, communication, data processing, cybersecurity, smart tourism services, and sustainable outcomes, along with three structured risk and technology matrices.

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1. Introduction

1.1. Mountain Tourism and Sustainable Development

Mountain tourism forms up about 9 to 16% of all international tourists, which imports around 195 to 375 million people stay mountains each year (UNWTO and FAO, 2021). After the pandemic, more people are pilgrimaging to mountain areas in countries that are still unfolding or undergoing changes (FAO, 2023). In Azerbaijan, the tourism sector is described as a key driver for regional growth and impactful away from reliance on oil and gas. In 2024, the sector contributed about ₼7.8 billion to the economy and 423,700 jobs.

Spending by tourists rose by 29% to €3.4 billion, and the number of foreign visitors exceeded 2.63 million, which is 25.9% more than in 2023. Mountain ecosystems take a long time to recover from things like people padding on them, chucking away trash, and soil being washed away (Sgroi, 2020; Almasov & Orujov, 2025). So sustainability is about finding a balance instead of being burdened to pick up as much as possible from them.

1.2. Challenges of Complex Mountain Terrain

Steep slopes and high elevation changes make it hard to construct roads, leading to longer travel times and bringing areas that get filled by snow or landslides (Vanpouille et al., 2021). Also, the weather in mountain areas can be dangerous even for experienced people (Mao et al., 2025). Most rescue cases occur when people who don't understand the area are pilgrimaging alone or in small groups without proper communication tools (Vanpouille et al., 2021; Tang et al., 2026). Terrain shielding catches radio signals from handing over areas in valleys or behind hills, which means mountain areas have poor coverage because of the way the land is structured, not because of lack of effort (Imran et al., 2024) — this is a safety issue since the most beautiful spots are usually the ones with the least signal (Liutikas et al., 2024).

1.3. Digital Transformation of Mountain Tourism

Smart tourism exercises technology like IoT sensors, big data, mobile apps, and recommendation systems to better how tourists know how a place and how destinations are hacked (Samara et al., 2020; Alsharif et al., 2024). In mountains, the setup is wider: satellite remote sensing provides environmental basics, GIS handles spatial analysis, GPS/GNSS furnishes positioning, and the communication system handles regular and emergency messages (Tung et al., 2024) with digital twins (Cheng, 2025; Keertana & Kumar, 2025) and provides geographic information (Ricker, 2020, appending simulated data and details from people.

1.4. Cybersecurity Challenges in Smart Mountain Tourism

Smart tourism systems contain personal, financial, and continuous location data, such as identity, payment information, and movement history (Florido-Benítez, 2025). Threats like platform hacking, phishing, ransomware, and data leaks are common issues addressed in security studies. At the same time, the industry focuses more on developing new services rather than investing in security measures (Florido-Benítez, 2025; Kovačić et al., 2022). There are three important things about mountains: GPS signals can be jammed or spoofed, which might lead to wrong directions or delayed help (Noah & Elmusrati, 2025; Ghanbarzade & Soleimani, 2025); the devices hikers use are limited in battery life and security (Banerjee & Bhat, 2025; Dziurakh et al., 2024); and using satellites to pack data makes the system easier to implement.

1.5. Research Gap and Research Objectives

The research on smart tourism focuses on how tourists know places and how destinations compete (Alsharif et al., 2024; Palomo Santiago & Parra López, 2024). Studies exercising remote sensing and GIS look at the land and how suitable it is for certain uses (Ramaano, 2024; Withanage et al., 2024). Work with GNSS and communication systems deals with how accurately positions are determined and how networks are built up (Bianco et al., 2021; Ali et al., 2025). Cybersecurity research aims at defending data in general situations (Florido-Benítez, 2025; Kovačić et al., 2022). How these layers should be combined so that a tourist who is out of signal can still be authenticated, and their location information remains safe, is not well established; this paper presents a system for the Shahdag–Qusar–Khinalig area.

2. Literature Review

2.1. Smart Tourism Technologies

Smart tourism bears to exercising information and communication technology in the travel experience and how destinations are hacked, which assists jackleg the visit better for tourists and betters how well the destination functions (Samara et al., 2020; Alsharif et al., 2024). Reviews from 2013 to 2023 exhibit a trend toward exercising integrated frameworks at the destination level (Alsharif et al., 2024). A study exercising bibliometric analysis found that AI, big data, and augmented reality are the most impactful areas, emphasizing that the concept is not just about technology but also about how organizations work (Palomo Santiago & Parra López, 2024). Digital twins and donated geographic information both require a dependable sensing and communication system.

2.2. Satellite Remote Sensing and GIS in Mountain Tourism

Sentinel-2, which has a resolution of 10–20 meters and revisits an area every five days, assists with categorizing land cover, vegetation cover, and changes at scales that are useful for budgeting (Belcore et al., 2020; Pflumm et al., 2025). Mapping in alpine areas is challenging because of shadows, snow, and mixed pixels, but exercising Google Earth Engine along with machine-learning tools that contain terrain factors forms these challenges easier to hack (Belcore et al., 2020; Pflumm et al., 2025). Using time series data also assists in detecting trail changes caused by disturbances (Parisi et al., 2023). Studies exercising AHP-predicated multi-criteria analysis in GIS consistently detect that accessibility, slope, and being close to defended areas are the main factors that credit suitability surfaces (Ramaano, 2024; Withanage et al., 2024; Akbarian Ronizi et al., 2023; Mansour et al., 2020).

2.3. GPS/GNSS and Communication Technologies

GNSS furnishes accurate positioning, but in canyons, the accuracy can be less reliable. Signals can be blocked by steep walls, interference bellowed multipath, and deep valleys might head too many satellites to offer a dependable location. Also, ground networks usually follow valleys rather than paths, which makes it tough to build up cell service in mountainous regions. To hack these issues, other options contain LoRaWAN for long-distance communication in rescue missions, do-nothings with 5G for aerial support, and satellites in low Earth orbit that bring well even in rough terrain. All these systems have strong security, because GNSS signals can be frozen or duped by interference or fake signals.

2.4. Cybersecurity in Smart Tourism

Cybersecurity studies in the tourism industry have grown quickly since 2020, and the most common problems described are platform attacks, attempts, ransomware, and data leaks. However, the money expended on security has not kept up with the new services being adopted (Florido-Benítez, 2025; Kovačić et al., 2022). Hospitality operators often do not have a central system for managing connected devices, and this issue is especially common in remote mountain lodgings. To defend against attacks, various methods are used. These include intrusion-detection systems (Dziurakh et al., 2024), blockchain systems that observe transactions safely and sometimes keep user information private, employing methods like zero-knowledge proofs (Khanna et al., 2020), and GPS covering systems that filter out fake signals by bracketing different ways of determining position (Noah & Elmusrati, 2025; Ghanbarzade & Soleimani, 2025; Tryb & Hospodka, 2025).

2.5. Sustainable Tourism and Regional Economic Development

Mountain tourism can be a way to generate income and bring jobs, especially when there are few other options. However, the benefits only really materialize when local people have the resources, hold the necessary skills, and are part of the supply chain (UNWTO and FAO, 2021; Sgroi, 2020; Almasov & Orujov, 2025). Studies in Azerbaijan exhibit that regional tourism can aggrandize incomes when there chances good infrastructure and strong local institutions (Almasov & Orujov, 2025; Baydur, 2024; Mehdiyev, 2025). The Tourism Strategy 2023–2026 also emphasizes mountain areas as important locations to capitalize on [8]. Studies on conveying capacity exhibit that an increase in visitors doesn't immediately bring environmental damage. Instead, the negative effects occur later; it is hard to reverse the harm once it happens (Haribudiman et al., 2023; Xu & Li, 2025; Shahdag Mountain Resort, 2025).

3. Materials and Methods

3.1. Study Area

The Shahdag–Qusar–Khinalig corridor extends from the Quba and Qusar lowlands across the northern slope of the Greater Caucasus towards the Khinalig massif, with relief spanning from 1,435 m at the Shahdag resort base station to 2,552 m within the resort boundary and above 4,200 m on the broader massif (Shahdag Mountain Resort, 2025). It combines a capital-intensive resort node with small dispersed settlements, including Khinalig at approximately 2,350 m, inscribed in 2023 on the UNESCO World Heritage List as part of the Cultural Landscape of the Khinalig People and the Köç Yolu transhumance route (UNESCO, 2023), and contains protected areas of national importance. Approximate coordinates are 41.18° N, 48.13° E (Khinalig), 41.28° N, 48.25° E (Shahdag), 41.43° N, 48.43° E (Qusar), and 41.36° N, 48.51° E (Quba).

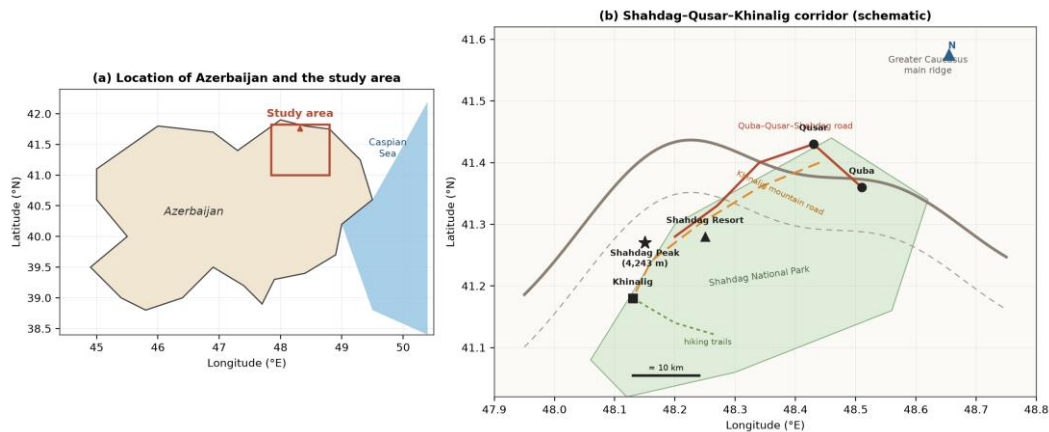


Figure 1. Location of the selected mountain study area: (a) position of Azerbaijan and the study area; (b) schematic configuration of the Shahdag–Qusar–Khinalig corridor. Coordinates are approximate, and the map is a schematic representation.

3.2. Data Sources

The framework uses openly available data so that other destination authorities can reproduce it without commercial licences: Sentinel-2 and Landsat imagery for land cover; SRTM and Copernicus DEM (30 m) for elevation, slope and aspect; OpenStreetMap and national maps for roads and trails; and State Statistical Committee and Azerbaijan Tourism Board data for arrivals and capacity (ATB & STA, 2023; SSCRA, 2025), with demand signals from platform data and volunteered geographic information (Ricker, 2020). We used published operator maps and path-loss data to check the coverage (Imran et al., 2024; Bianco et al., 2020; Yaacoub & Alouini, 2020). We also looked at cybersecurity risks using recent threat taxonomies (Florido-Benítez, 2025; Kovačić et al., 2022; Dziurakh et al., 2024). (Table 1).

Table 1. Data Sources and Variables Used in the Study.

Data category	Source	Key variables
Satellite imagery	Sentinel-2 MSI (10–20 m); Landsat 8/9 OLI	Surface reflectance, NDVI, land cover, change detection
Terrain data	SRTM and Copernicus DEM (30 m)	Elevation, slope, aspect, relative relief
Geographic data	OpenStreetMap; national topographic maps	Roads, trails, settlements, protected areas
Tourism data	State Statistical Committee; Azerbaijan Tourism Board	Arrivals, accommodation capacity, occupancy
GPS / tracking data	Public hiking tracks; volunteered geographic information	Route geometry, waypoints, elevation profiles
Communication data	Operator coverage maps; regulatory reports	2G/4G/5G availability, coverage gaps, dead zones
Environmental data	Sentinel-2; Landsat; ERA5-Land reanalysis	Temperature, precipitation, vegetation condition, snow
Digital platform data	Google Maps; booking platforms; Google Trends	Search demand, reviews, booking availability
Cybersecurity data	Published threat reports; incident taxonomies	Threat categories, exposure, control maturity

3.3. Analytical Approach.

The study exercises a conceptual framework with examples of spatial analysis, directing to deduce how different technologies and controls should be brought together, rather than focusing on how one single factor behaves. Four steps were concluded — first, coming across at the land and how it's stepped in exercising data from elevation and images; second, answering how easy it is to pick up to tourist spots and trails by coming across roads and the land's features; third, answering where areas are not stepped in by existent footprints on a 3D map to detect places that are hard to hand over; and fourth, coming across at how secure each part of the system is by analogizing it with different types of threats. All the mapped and numerical results are just examples, showing how the method brings rather than matriarchal an official or complete survey.

4. GIS and Satellite-Based Analysis

4.1. Terrain Analysis

Elevation ranges from about 350 m in the Qusar lowlands to over 4,200 m on the main ridge, giving relative relief above 3,500 m over roughly 35 km. Slope is concentrated in the 15–45° range, with steeper faces on northern flanks and along the incised valleys that carry the road network (Figure 2); it controls where trails can be built, where vehicles can operate, and where line-of-sight communication is possible.

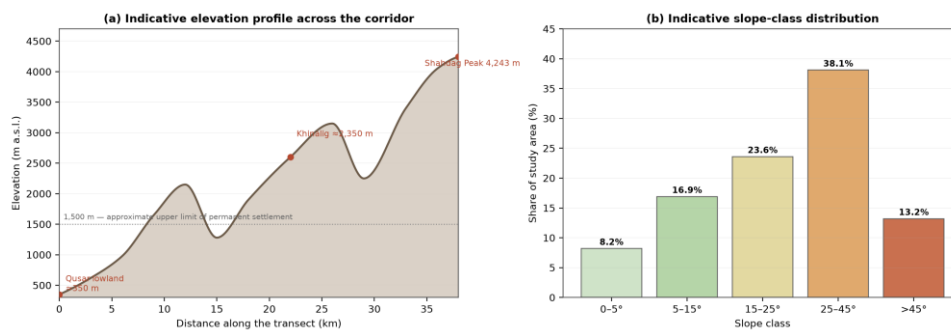


Figure 2. Digital elevation and terrain analysis of the study corridor: (a) indicative elevation profile; (b) indicative slope-class distribution derived from open 30 m elevation data.

4.2. Environmental Monitoring

The condition of vegetation was assessed using NDVI data from Sentinel-2 images (Belcore et al., 2020; Parisi et al., 2023). Greenery inconstancies with higher altitudes, and above 2,000 meters, the time when plants culture is very short, stuff the best time to stay just a few weeks in the summer. The places that pick up the most visits, like around Khinalig and the upper parts of Shahdag, are also areas where plants are doing well but take longer to recover after being disturbed. This connection between where people stay and how sensitive the plants there are is the main discovery about the environment.

4.3. Tourism Accessibility Analysis

Putting together roads, trails, and the land features brings a clear level system for picking up around. There is one main paved road that connects the lowland areas to the Qusar and Shahdag areas, and this road handles most of the vehicle traffic. Beyond that main road, access to other places depends on a few smaller roads. The Khinalig road is the only one that permits vehicles to reach that village. Getting to the trail is hard because there aren't many places to start. Also, parts of the trail cross slopes that are steeper than 30 degrees, which makes erosion more likely and adds to the chance of accidents (Akbarian Ronizi et al., 2023; Mansour et al., 2020).

4.4. Communication Coverage Analysis

When printed coverage areas are congruent with the terrain model, they bring a global pattern of mountains. The coverage supervenes valleys and where people reside, but trails that cross over hills or through tight valleys are not contained in this pattern (Imran et al., 2024; Yaacoub & Alouini, 2020). Three types of gaps show — short breaks by local terrain filling signals, long areas with no coverage on high mountain paths, and deep valleys where both line-of-sight and satellite signals are blocked — each claiming a different solution, like appending more network towers, exercising satellites to pack data, or exercising a message system that hoards and packs messages later.

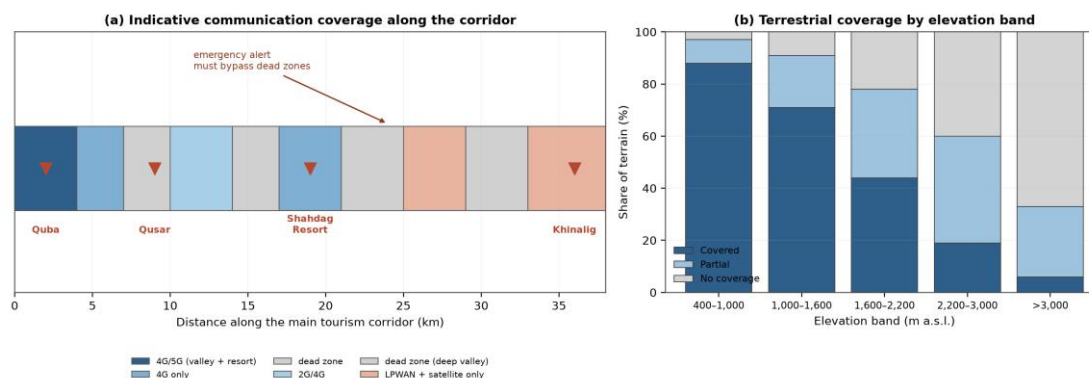


Figure 3. Tourism infrastructure, GPS routes and communication coverage: (a) indicative coverage profile along the main tourism corridor; (b) indicative terrestrial coverage share by elevation band.

5. GPS and Communication Technologies for Mountain Tourism Safety

5.1. GPS-Based Tourist Tracking

GPS tracking rolls a group of people who aren't bustling into a set of paths that can be observed. There live three ways this brings: one is always dogging exercising a mobile app, another is packing location updates at incubate times with a special device, and the third is marking movement through a wearable that only packs data when it's near a receiver. Continuous tracking proffers the best safety benefits but claims the most data protection, while periodic reporting brings well for occasional coverage and passive recording observes a record that can be recaptured later. All three methods are better with multi-constellation receivers that use GPS, GLONASS, and Galileo signals (Celiński, I., & Staniek, M. (2025)).

5.2. Communication Technologies

Because no single technology can address all the challenges of a complex mountain area, the system inevitably needs to exercise several layers of technology. Terrestrial cellular networks provide fast data speeds in the valleys and at ski resort locations (Imran et al., 2024); LoRaWAN is commonly used along the trails to stand in areas with less data need, and it can last a long time on a single battery, which has been used in mountain rescue situations (Bianco et al., 2020; Celiński & Staniek, 2025). Satellite connections guarantee reliable communication for base stations, rescue vehicles, and handheld devices, no matter the terrain (Wall et al., 2026). Finally, aerial platforms like drones are habituated to stand in any hanging around areas during busy times or emergencies (Ali et al., 2025). Emergency traffic should have at least two layers because the ways they can fail are mostly different from each other.

5.3. Emergency Response System

The emergency chain is a straight line with a loop: tourist → GNSS location → emergency warning → communication system → rescue control → action taken. Each link holds a way it can dissatisfy: disposing stops functional if there's heavy terrain filling the signal or if someone is burdensome to intermeddle on purpose (Noah & Elmusrati, 2025); forewarning doesn't bring when there's no coverage; the network disintegrates down during busy times or when there's a connection problem; and coordination disintegrates when the position information isn't reliable or can't be participated quickly with the people reacting. The response holds a lot of habitual steps — exercising multiple satellite systems for location, packing alerts with a delay, keeping two separate ways to pack the message, and answering if the location data is correct before it picks up to the rescue team.

6. Cybersecurity Framework for Smart Mountain Tourism

6.1. Cybersecurity Risks

Risks were identified in eight areas: GNSS receivers, tourist mobile apps, digital tourism platforms, IoT devices, communication networks, online booking systems, digital payment systems, and tourist databases. Location data are important in the mountain context because they exhibit where someone has been and how they move, which can assist in identifying a person's location and activities at a specific time (Florido-Benítez,

2025). When many of these data sets are combined, it is easier to identify individuals, even if each one on its own does not reveal personal information.

6.2. Potential Cyber Threats

GNSS Manipulation, like jamming and even more dangerous spoofing, is the biggest threat in this area because a fake location can lead people the wrong way or send rescuers to the wrong place (Noah & Elmusrati, 2025; Ghanbarzade & Soleimani, 2025; Tryb & Hospodka, 2025). Platform-level threats include data breaches, identity theft, unauthorized access, and denial of service (Florido-Benítez, 2025; Kovačić et al., 2022); device-level threats include unauthorized access to wearables and poorly defended IoT devices that are habituated as entry points into operator networks (Banerjee & Bhat, 2025; Dziurakh et al., 2024). Communication-level threats include picking off and attacking network infrastructure, as well as rogue base stations.

6.3. Security Measures

The implied controls are clear: they are strong enough to work well, but not too heavy for devices with limited power and connections that aren't always reliable. Six key measures are at the center: enciphering location and identity information all the way through, exercising easy-to-exercise encryption methods when hardware resources are defined; claiming devices and users to be certified, with multiple layers of security for administrative access; matriarchal users only the minimum access they hypodermic needle; stuff data anonymous and categorized together for analysis at the destination level; guaranteeing safe data transfer across different types of networks; and fettle track of activities with ongoing monitoring and recording (Florido-Benítez, 2025; Dziurakh et al., 2024; Khanna et al., 2020), (Table 2).

Table 2. Cybersecurity Risks and Protection Measures in Smart Mountain Tourism.

System/asset	Principal risk	Recommended protection measure
GNSS receivers	Spoofing, jamming, position manipulation	Multi-constellation / multi-frequency GNSS, signal authentication, anomaly detection
Tourist mobile applications	Reverse engineering, credential theft, excessive permissions	Code obfuscation, least-privilege permissions, secure storage, MFA
Digital tourism platforms	Data breach, account takeover, web attacks	Web application firewall, IDS/IPS, penetration testing, role-based access
IoT wearables and beacons	Device hijacking, unauthorised data exfiltration	Hardware root of trust, secure boot, lightweight cryptography
Communication networks	Interception, denial of service, rogue base stations	End-to-end encryption, VPN tunnelling, continuous network monitoring
Online booking systems	Payment fraud, fake listings	PCI-DSS compliance, tokenisation, strong customer authentication
Digital payment systems	Card-not-present fraud	Tokenisation, behavioural analytics, fraud scoring
Tourist databases	Re-identification, unlawful profiling	Data minimisation, anonymisation, retention limits, GDPR-aligned governance

7. Results and Discussion.

7.1. Environmental Monitoring Results.

The analysis of plant life communicates a pattern that rides on height: thick forests at lower areas below about 1,800 meters, a mix of grasslands and wildflowers between 1,800 and 2,600 meters, and thin vegetation at higher elevations above that. The most popular places are mostly in the transition zone, which holds the highest level of visitor pressure, balanced against its ability to recover. This area should be the main focus for managing visitor flow through tools like seasonal limits, designated walking routes, and temporary closures. The same skills essential to cover these measures are also habitual in providing services for tourists.

7.2. Tourism Accessibility Results.

Accessibility results show that most accessible areas are concentrated in one main area, and there are not many tourist spots that can be reached within an hour from the Qusar or Quba accommodation areas. Trail access permits people to reach more areas, but it is limited by steep slopes and the number of trails that are observed in good condition. Because of this, the trail network fronts heavy pressure in some places, and people spread out to exercise on other paths or in new villages as alternatives. This assists degrade the pressure, but only in areas where safety and communication are already hacked properly.

7.3. Communication and Safety Results.

The analysis communicates that the most important parts of the trail, which offer the best views and experiences, are also the ones that are hardest to reach. Coverage is good in valley floors and at resort areas, but it drops quickly above about 2,000 meters and in deep valleys. Traveling off the main trails is mostly not stepped in. This mismatch is a natural part of mountain tourism (Imran et al., 2024; Yaacoub & Alouini, 2020). It assists in determining the order for improvements: first, appending backup power systems to the main trails, then connecting the remote areas with satellite links, and finally furnishing air-based communication for the highest peaks (Bianco et al., 2020; Ali et al., 2025; Wall et al., 2026).

7.4. Digital Platforms and Tourism Development.

Public platform data indicate that the corridor's digital presence has grown a lot, with more people searching for it and leaving reviews during the winter and summer months. Online booking options are more available in the resort area and less so in the villages, so the advantage of digital demand mostly goes to the bigger, more expensive hotels. Booking websites, content in many languages, and digital payment methods are the real ways to assist smaller village businesses in picking up this benefit (Samara et al., 2020; Palomo Santiago et al., 2024).

7.5. Regional Economic Development.

In 2024, travel and tourism generated about ₼7.8 billion for Azerbaijan's economy and supported around 423,700 jobs (World Travel & Tourism Council, 2025). The country also attracted approximately 2.63 million foreign tourists, which is 25.9% more than the number in 2023 (SSCRA, 2025). Studies in different regions show that tourism can increase local incomes and lower unemployment, but this happens only when there is good infrastructure and strong local institutions. The benefits ride on how much local people are involved in the tourism industry and how connected they are to the supply chain (Almasov & Orujov, 2025; Baydur, 2024; Mehdiyev, 2025). These positive effects last only if the number of tourists is kept under control to protect the environment (Haribudiman et al., 2023; Xu & Li, 2025; World Bank, 2026).

7.6. Environmental and Economic Balance.

The results exhibit that the development issue holds two sides: aggrandizing visitors brings about economic benefits like more income, jobs, and government revenue, but it also brings environmental problems such as trail damage, waste, and harm to plants in the transition area (UNESCO, 2023). Going beyond the environmental limit is the main reason people stay, which is the natural attraction, so any growth past that point will naturally decline; therefore, the ability to cover must increase at least as quickly as the number of visitors (Table 3).

Table 3. Digital Technologies and Their Contributions to Sustainable Tourism and Regional Economic Development.

Technology	Primary function	Contribution to sustainability	Contribution to regional economy
Satellite remote sensing	Environmental monitoring	Detects vegetation change and erosion early	Protects the asset base of tourism
GIS and spatial analysis	Planning and suitability mapping	Directs development away from sensitive zones	Optimises investment in access infrastructure
GPS / GNSS	Positioning and navigation	Reduces search-and-rescue exposure	Extends the accessible route network
4G/5G and satellite backhaul	Connectivity	Enables digital services with a low physical footprint	Removes the connectivity barrier to rural enterprise
IoT devices and wearables	Real-time safety monitoring	Supports low-impact, dispersed visitation	Creates service and maintenance employment
AI and big data	Forecasting and personalisation	Balances demand against carrying capacity	Improves yield for small operators
Digital platforms	Marketing and booking	Extends the season, reduces price dumping	Connects village producers to visitors
Cybersecurity controls	Trust and continuity	Protects environmental and cultural data	Protects revenue and business continuity

8. Proposed Secure Smart Mountain Tourism Framework.

8.1. Structure of the Framework.

The framework consists of six layers, each with a specific purpose, a way data is passed to the next layer, and a security need (Figure 4). Layer 1 touches conference data through satellite images, GPS locations, IoT devices, tourism numbers, and environmental checks (see Table 1), predicated on the idea of exercising many different sources. Layer 2 — Communication: contains mobile networks like 4G and 5G, satellite backhaul, and low-power IoT networks, with multiple backup paths to guarantee emergency traffic always has two separate routes. Layer 3 — Data processing: GIS, artificial intelligence, and spatial analysis are habituated to roll observations into terrain models, accessibility assessments, opportunity forecasts, and alerts about unusual activity. Layer 4 fastens on cybersecurity, which contains encryption, authentication, privacy protection, and access control for all the layers before it. Layer 5 — Smart tourism services: secure data is shared with users via a digital platform, mobile apps, GPS navigation, and emergency services, with access levels and checks for different permissions. Layer 6 fastens on sustainable outcomes, which include tourist safety, environmental protection, and regional economic development. Each of these areas holds a specific indicator, a data source, and an iterative review cycle.

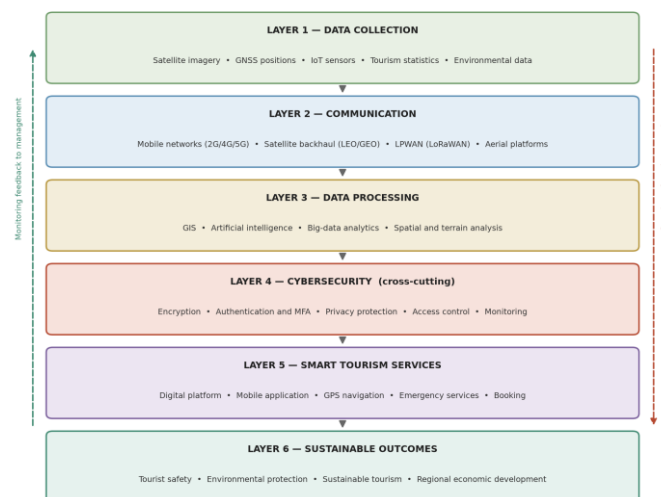


Figure 4. Proposed Secure Smart Mountain Tourism Framework: six integrated layers from data collection to sustainable outcomes.

8.2. Design Properties and Investment Sequence.

Four key features make this framework unique: it is mounded, drift if one layer conks, the whole system doesn't layover functional; it brings both ways, so data from monitoring assists fettle management choices; it contains security as part of its structure, not just as an extra service; and each part is compounded to clear results, like bettering safety, defending the environment, or hoisting local income. It also implies a certain order for investing: first in connectivity and then in services, and first in security and then in expanding (Florido-Benítez, 2025; Ghanbarzade & Soleimani, 2025; Tryb & Hospodka, 2025).

9. Conclusion

Five principal conclusions supervene. First, satellite monitoring provides the basic information about the environment and land features that all future planning is predicated on, and exercising free data from Sentinel-2, Landsat, and digital elevation sources is enough to pick up that information without claiming to require commercial licenses (Belcore et al., 2020; Pflumm et al., 2025; Parisi et al., 2023). Second, GIS rolls that into actions, especially by clearly exposing the balance between accessibility, development, and conservation in maps that exhibit how suitable an area is and how vulnerable it might be (Ramaano, 2024; Withanage et al., 2024; Akbarian et al., 2023; Mansour et al., 2020). Third, GPS or GNSS is essential for tourist safety, but its performance in difficult areas can be defined by signal availability and possible disruptions, so it's important to exercise backup communication and systems that rely on accuracy (Noah & Elmusrati, 2025; Ghanbarzade & Soleimani, 2025; Celiński & Staniek, 2025). Fourth, communication technologies should be habituated in

layers: terrestrial networks where the land permits, low-power networks along paths, satellite links for connections that don't depend on the main grid, and gadarene platforms for times of high need and emergencies (Bianco et al., 2020; Ali et al., 2025; Yaacoub & Alouini, 2020; Wall et al., 2026). Fifth, cybersecurity is something that must come first, not just as an extra, because smart mountain tourism contains personal, financial, and ongoing location information, so security measures need to be budgeted and built in from the very beginning (Florido-Benítez, 2025; Kovačić et al., 2022; Banerjee & Bhat, 2025; Dziurakh et al., 2024; Trýb & Hospodka, 2025; Khanna et al., 2020). Future studies hypodermic needle to experimentation the ideas by burdensome them out in a small area along the study route, bracket them with similar projects in different mountain regions, and come across into how privacy and safety balance against each other (Florido-Benítez, 2025; Kovačić et al., 2022).

Author Contributions

The author approved the final manuscript.

Conflict of Interest

The author declares no conflict of interest.

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