Integrating smart technologies in ecotourism opportunities development

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Abstract

Ecotourism is recognised as a sustainable tourism paradigm that harmonises environmental preservation with economic and cultural advantages. This study examines the integration of advanced technologies, particularly Geographic Information Systems (GIS), remote sensing, and mobile applications, in evaluating and developing Alula's ecotourism opportunities. It employs a mixed-method approach to examine Alula's viability for ecotourism, including essential environmental, topographical, and infrastructural elements, as well as evaluating tourist preferences and stakeholder perspectives on technology adoption. The GIS and remote sensing research determined that Alula's mild temperature (22.5°C), low population density (2.44 individuals/km²), and slope changes (0-27%) render it an appropriate location for ecotourism. Moreover, the prominent visibility of picturesque locations, closeness to historical sites (0-15 km), and accessibility through road infrastructure augment its tourism potential. Water shortage (21 mm annual rainfall) and habitat fragmentation persist as challenges necessitating sustainable management techniques. The mobile application survey indicated a significant preference for real-time navigation, cultural heritage information, and sustainability education functionalities. Stakeholder interviews highlighted the significance of integrating smart technology to enhance visitor management, resource conservation, and tourist planning. This study combines GIS-based suitability analysis with mobile technology uptake to develop a comprehensive framework for smart ecotourism planning in ecotourism destinations. The findings emphasise the need for GIS and remote sensing for land-use optimisation, mobile apps for visitor interaction, and sustainable infrastructure policies. Tourism planners, environmentalists, and lawmakers might learn from the proposed paradigm on sustainable ecotourism and smart tourism in heritage-rich places.

Keywords: Ecotourism, GIS, remote sensing, mobile applications, smart tourism, sustainable tourism

1. Introduction

Ecotourism has become an essential component of the global tourism sector, providing a sustainable alternative to traditional tourism methods. It is characterized as responsible travel to natural regions that preserves the environment, promotes the welfare of local communities, and incorporates interpretation and education (Fennell, 2021; Honey, 1999; The International Ecotourism Society, 2020; Weaver, 2001). Its objective is to mitigate the adverse effects of tourism while enhancing its advantages for conservation and local communities. Ecotourism is founded on sustainability, environmental care, and community involvement, serving as an essential mechanism for advancing biodiversity conservation and socio-economic development in protected natural areas (Redžić, 2017; Wearing & Neil, 2009; Wood, 2002). The increasing desire for nature-based tourism experiences positions ecotourism as a distinctive opportunity to harmonize the frequently conflicting objectives of tourism development and environmental conservation.

Protected natural areas, including national parks, wildlife sanctuaries, and biosphere reserves, are increasingly acknowledged as premier ecotourism destinations (Cerda, Juan Pablo, & Mancilla, 2018; Ohadi, Dorbeiki, & Bahmanpour, 2013). These regions are distinguished by their abundant biodiversity, distinctive ecosystems, and cultural heritage, rendering them appealing to travellers desiring immersive and instructive experiences(Adeleke, 2015; Dologlou & Katsoni, 2016). Ecotourism opportunities in these areas encompass wildlife safaris, birding, hiking, cultural excursions, and community-oriented tourism activities. Ecotourism provides visitors the opportunity to engage with nature and get insights into local cultures, so enriching the tourist experience while promoting environmental stewardship and cultural respect (Açıksöz et al., 2016; Burkart & Medlik, 1981; Coria & Calfucura, 2012).

The development of ecotourism opportunities in protected natural areas is influenced by multiple elements. First, the rising awareness of environmental concerns and the pursuit of sustainable travel alternatives have resulted in heightened demand for ecotourism activities (Barkauskiene & Snieska, 2013; Coria & Calfucura, 2012; Dologlou & Katsoni, 2016). Second, governments and conservation organisations are increasingly acknowledging the potential of ecotourism as a means to generate revenue for supporting conservation initiatives and local populations (Barkauskiene & Snieska, 2013; Dologlou & Katsoni, 2016; Middleton & Hawkins, 1998). Third, technological improvements have created new opportunities for enriching the ecotourism experience, optimising resource management, and fostering sustainable tourist practices (Buckley, 1994; Burgess, Parish, & Alcock, 2011; Cai, Richter, & McKenna, 2019; Wearing & Neil, 2009).
The development of ecotourism opportunities in protected natural areas necessitates a comprehensive strategy that reconciles the interests of tourists, local communities, and the ecosystem. Essential factors encompass the recognition of ecotourism potential, the enhancement of infrastructure and amenities, the implementation of sustainable tourism practices, and the involvement of local communities in tourist planning and management (Dologlou & Katsoni, 2016; Hunter, 1997; Okan, Kose, Arifoglu, & Kose, 2016). Successful ecotourism development necessitates the incorporation of advanced technologies that can improve the tourist experience, enable environmental monitoring, and promote sustainable resource management (Hidayati, 2016; Lee, Cho, & Hwang, 2013; Orhan & Karahan, 2011; Tribe, 2006).
A primary challenge in ecotourism development is safeguarding the natural environment and local communities from adverse

effects of tourism activities. This necessitates meticulous planning and management, alongside the adoption of sustainable tourism best practices. For instance, carrying capacity assessments can ascertain the maximum visitor threshold for a site to prevent environmental degradation, while community-based tourism initiatives can ensure local communities reap benefits from tourism endeavours (Abel, 2003; Gupta & Bhatt, 2009; Suana et al., 2020). The incorporation of smart technologies in ecotourism development has the potential to transform tourism management and experiences in protected natural areas. Technologies such as Geographic Information Systems (GIS), remote sensing, and mobile applications provide innovative solutions for enhancing tourist experiences, optimising resource management, and fostering sustainable tourism practices.

GIS facilitate the mapping and analysis of ecotourism resources, the identification of optimal areas for tourism infrastructure, and the monitoring of environmental alterations. GIS facilitates informed decision-making for ecotourism development and conservation through the provision of spatial data and visualisations (Nino, Mengesha, Kefyalew Sahle, & Mamo, 2017; Sahani, 2020). Remote sensing observes vegetation cover, wildlife populations, and land-use alterations, providing essential insights for environmental management and conservation strategies (Ahmadi Sani, Babaie Kafaky, Pukkala, & Mataji, 2016; Oladi & Bozorgnia, 2010). Mobile applications improve ecotourism experiences by delivering real-time information on destinations, trails, and local biodiversity. They also facilitate visitor management through data on carrying capacities and environmental conditions, while advocating sustainable practices such as Leave No Trace principles and citizen science involvement (Jinendra, Bhagyashri, Pranav, Seema, & Parag, 2012; Kim, Thapa, Jang, & Yang, 2018).

Despite the growing interest in smart technologies for ecotourism development (Ahmadi Sani et al., 2016; Gigović, Pamučar, Lukić, & Marković, 2016; José-Alberto, Martínez-Heredia, & Rodríguez-Molina, 2019; Ohadi et al., 2013; Suphachaimongkol, Ratanatamskul, Silapacharanan, & Utiswannakul, 2019), a significant knowledge vacuum persists concerning their efficacy in enhancing tourist experiences, supporting environmental protection, and promoting sustainable tourism practices. While the existence of several case studies demonstrating the use of smart technology in ecotourism, there is a deficiency of extensive research evaluating their overall effects on tourism and ecological management. Moreover, there is a lack of thorough examination about the challenges and limitations associated with the implementation of smart technology in ecotourism.

The current research on smart technology in ecotourism primarily emphasizes particular applications, such as GIS for mapping and mobile applications for visitor management (José-Alberto et al., 2019; Ohadi et al., 2013), rather than offering a comprehensive evaluation of their potential and limitations. Research is required to investigate the integration of various smart technologies in ecotourism development and their ability to tackle intricate issues such as climate change, biodiversity decline, and socio-economic disparity. This research gap underscores the necessity for an extensive study that assesses the capacity of smart technologies to improve ecotourism prospects while promoting conservation and sustainable tourist practices.

The primary objective of this study is to examine the feasibility of incorporating smart technologies to develop ecotourism opportunities in protected natural areas. The study aims to:

1. evaluate the effectiveness of smart technologies, including GIS, remote sensing, and mobile applications, in improving the visitor experience, aiding environmental conservation, and fostering sustainable tourism practices.
2. analyse the challenges and limitations associated with the integration of smart technology in the advancement of ecotourism, especially in developing nations.
3. investigate the potential use of integrating various smart technologies to tackle complex issues in ecotourism development, including climate change, biodiversity depletion, and socio-economic disparity.
4. formulate a framework for the integration of smart technology in ecotourism planning and development, aimed at promoting sustainable tourism practices while safeguarding the natural environment.

2. Method

This study employs a mixed-method approach to explore the integration of smart technologies, including Geographic Information Systems (GIS), remote sensing, and mobile applications, for ecotourism development in Alula, Saudi Arabia. The methodology is structured into three main components: (1) GIS and remote sensing analysis, (2) mobile application evaluation through surveys, and (3) stakeholder interviews. Each component is designed to provide a comprehensive understanding of the potential of smart technologies in enhancing ecotourism opportunities in Alula.

2.1 Study area

Alula, situated in the Medina Province of northwestern Saudi Arabia (about 200 km from the Red Sea coast), is a place of remarkable cultural, historical, and environmental importance. Although not officially classified as a protected area within Saudi Arabia’s national protected regions framework, Alula is administered by the Royal Commission for Alula (RCU), an organization created to supervise its sustainable development, environmental conservation, and cultural preservation (Royal Commission for Alula, 2020; Sahahiri, Griffin, & Sun, 2023). The RCU's governance architecture closely adheres to ecotourism principles, thereby establishing Alula as a protected natural area in practice. This distinctive status renders it an optimal research field for examining the incorporation of smart technology in ecotourism development (Al-Suhaibani & Al-Theeb, 2022; RCU, 2019; Repper et al., 2022).

The designation of Alula as the study area is appropriate due to its combined significance as a cultural heritage site and a burgeoning ecotourism locale. The RCU's strategic strategy emphasizes the equilibrium between tourism expansion and the preservation of ecological and cultural integrity, embodying the fundamental principles of ecotourism (Bay, 2014; Royal Commission for Alula, 2022).

Alula comprises five historically notable districts as Old Town Alula, Jabal Ikmah, Dadan, Nabataean, and Hegra each reflecting distinct strata of human culture, spanning from the ancient Lihyanite and Nabataean kingdoms to Islamic-era towns. Hegra, the inaugural UNESCO World Heritage Site in Saudi Arabia, exemplifies Nabataean rock-cut architecture and highlights the region's significance in global heritage

(Experiencealula, 2021; Gallego, Margottini, Spizzichino, Boldini, & Abul, 2022; UNESCO, 2023).

The region is characterized by striking sandstone formations, arid valleys, oasis habitats, and ephemeral watercourses (wadis), sustaining 58 plant species and a variety of fauna, including the Nubian ibex and Arabian leopard. Alula, with a population of approximately 55,010, predominantly consists of nomadic Arab tribes involved in agriculture and animal husbandry (Experiencealula, 2021; Royal Commission for Alula, 2022). Its shift towards tourism under Saudi Vision 2030 underscores the necessity for sustainable practices to save local livelihoods and ecosystems. The RCU's programs, including archaeological site restoration, and investment in sustainable infrastructure, conform to international ecotourism standards.

Although its resources, Alula encounters issues characteristic of dry regions, such as water scarcity, habitat fragmentation, and infrastructural deficiencies. The RCU aims to draw two million tourists by 2035, requiring creative strategies to avert ecological deterioration (Repper et al., 2022; Royal Commission for Alula, 2023). This study aims to utilize advanced technologies as GIS, remote sensing, and mobile applications to tackle these difficulties while improving visitor experiences and conservation results. This research focuses on Alula, offering a reproducible model for regions aiming to balance tourism expansion with environmental and cultural conservation, although lacking statutory protected status.

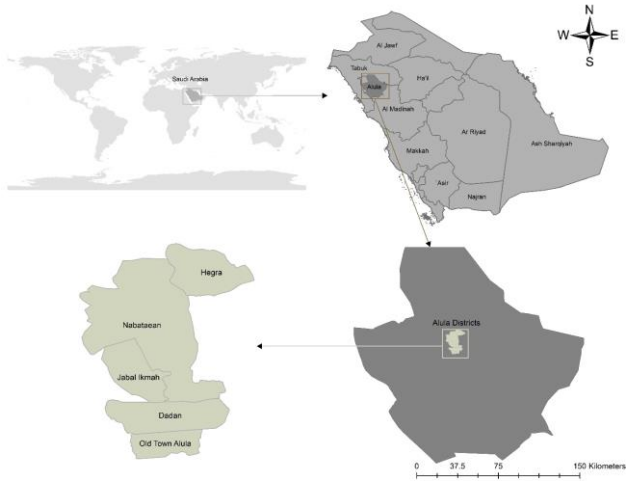

Figure 1. The location of Alula City in Saudi Arabia

2.2 GIS and remote sensing analysis

The GIS and remote sensing analysis concentrated on assessing Alula's viability for ecotourism development based on critical environmental, geographical, and infrastructural criteria. The analysis employed geographical data and satellite photos to evaluate the region's capacity for sustainable tourism. High-resolution satellite imagery (e.g., from Sentinel-2 or Landsat) utilized to ascertain vegetation density (NDVI), land-use patterns, and elevation data. Digital elevation models (DEMs) employed for the analysis of slope, elevation, and flood risk. Proximity to roadways, cultural and historical monuments, and fault lines was assessed using spatial data sourced from the Royal Commission for Alula (RCU) and publicly accessible information.

2.3 Mobile application evaluation (survey methodology)

A survey was administered to tourists visiting Alula to evaluate the potential of mobile applications in improving ecotourism experiences. The survey was concentrated on demographics, technology utilization, preferences for mobile applications, sustainability practices, and evaluations of current applications. The questionnaire was distributed using social media platforms (Twitter, LinkedIn, Snapchat, and Facebook) to engage local visitors. The necessary sample size of 381 replies was calculated using QUALTRICS (2024), based on an annual tourist population of 37,000 (Royal Commission for Alula, 2023). The survey was featured questions assessed on a four-point Likert scale (1 = Strongly disagree, 2 = Disagree, 3 = Agree, 4 = Strongly agree).

Technology usage:

1) I frequently use mobile applications during my travels.
2) Mobile applications enhance my travel experience.

Preferences for mobile applications:

1) I prefer mobile apps that provide real-time information on trails and cultural sites.
2) I find mobile apps with environmental education features useful.

Sustainability practices:

1) I am willing to use apps that promote Leave No Trace principles.
2) I would participate in citizen science projects through mobile apps.

Feedback on existing applications:

1) The mobile apps I have used in Alula are user-friendly.
2) I would recommend the mobile apps I have used to other tourists.

2.4 Stakeholder Interviews

Semi-structured interviews (50 minutes each) were performed with key stakeholders, including RCU officials, local community members, and tourism operators, to augment the GIS analysis and survey data. The interviews concentrated on contemporary practices, obstacles, technological integration, and prospective visions for ecotourism growth in Alula. The interviews were conducted face-to-face in Arabic (national language of Saudi Arabia), audio-recorded, noted, translated into English and then filtered for coding. Finally, interview responses were thematically evaluated to discern prevalent trends, difficulties, and possibilities. Illustrative inquiries encompass:

Current Practices: How are ecotourism activities currently managed in Alula?

Challenges: What are the main challenges in promoting sustainable ecotourism?

Technology Integration: How can smart technologies (e.g., GIS, mobile apps) address these challenges?

Future Vision: What are the long-term goals for ecotourism development in Alula?

This study assures ethical concerns by obtaining written informed consent from all participants, protecting their interests and privacy while upholding research integrity.

3. Results

This section presents the findings of the study, structured according to the objectives and methodologies outlined earlier. The results are divided into three main components: (1) GIS and remote sensing analysis, (2) mobile application evaluation, and (3) stakeholder interviews.

3.1 GIS and remote sensing

The GIS and remote sensing analysis evaluated Alula's suitability for ecotourism development based on critical environmental, geographical, and infrastructural criteria. The results demonstrate that Alula possesses a relatively adequate average temperature of 22.5°C (72.4°F), which, although marginally over the optimal range, remains conducive to ecotourism activities. The region's average annual rainfall of 21 mm (0.8 inches) is inadequate, underscoring the necessity for efficient water resource management (Table 1). Slope analysis indicated that the majority of Alula's territory, especially in the northeastern, southern, and central parts, had slopes ranging from 0-27%, rendering it acceptable to somewhat appropriate for the development of ecotourism infrastructure (Figure 2). Vegetation density, as assessed by NDVI values, spans from 0 to 0.5, signifying moderate appropriateness, with increased vegetation in local districts (Old town Alula, Nabataean, Dedan, Jabal Ikmah, Hegra) presenting prospects for ecotourism site development. Visibility analysis from observation points adjacent to tourist destinations indicated reasonable visibility, which is quite conducive to improving visitor experiences. The population density of Alula is 2.44 individuals per square kilometre, making it very conducive to ecotourism by reducing human-wildlife conflicts and facilitating the conservation of natural landscapes. Elevation study revealed that the majority of locations are located between 310 and 1900 meters, categorizing them within the reasonably appropriate range, which balances accessibility and aesthetic vistas. The area exhibits a low flood risk and is situated over 13 km from fault lines, making it very conducive for tourist development. Moreover, historical, cultural, and entertainment venues are located within a 0-15 km radius, offering exceptional chances for tourists, while the nearby highways are generally adequate, facilitating access without considerable environmental disturbance. The findings together illustrate Alula's potential for ecotourism development, with some areas designated as highly appropriate for recreational and tourism infrastructure.

Table 1. Identified ecotourism opportunities in GIS and remote sensing analysis

Variables	Rationale for suitability	Findings
Avg. temperature	**Suitable:** 17° C - 21° C **Moderately suitable:** 21° C - 26° C **Not suitable:** > 26° C	22.5° C/72.4° F **Moderately suitable**
Avg. annual rainfall	**Suitable:** 750-1500 mm (30-60 inches) **Moderately suitable:** 500-750 mm (20-30 inches) **Not suitable:** less than 500 mm (20 inches)	21 mm (0.8 inches) **Not suitable**
Slope	**Suitable:** 0-5% **Moderately suitable:** 5-35% **Not suitable:** >35%	Most of the area is situated between 0-27% **Suitable to moderately suitable**
Vegetation density	**Suitable** (Healthy vegetation): NDVI values from 0.6 to 1 **Moderately suitable** (Moderate Vegetation): NDVI values from 0.2 to 0.6 **Not suitable:** (very low or zero Vegetation): NDVI values from -1 to 0.2	0-0.5 **Moderately suitable**
Visibility	**Suitable (Near Range):** Visible, accessible sites near tourism hubs. **Moderately Suitable (Middle Range):** Visible regions with moderate travel or effort to reach. **Not suitable (Far Range/Not Visible):** Remote or inaccessible regions.	Middle ranges from observing points **Moderately suitable**
Population density	**Suitable:** Less than 50 People/km² **Moderately suitable:** 50-150 People/km² **Not suitable:** More than 150 People/km²	2.44 per km² **Suitable**
Elevation	**Suitable:** 100-400 m **Moderately suitable:** 400-1400 m **Not suitable:** >1400 m	Most of the Alula destinations are situated between 310 to 1900 m **Moderately suitable**
Flood risk	**Suitable:** Low **Moderately suitable:** Moderate **Not suitable:** High	Low (no flood risk in Alula) **Suitable**
Distance from fault lines	**Suitable:** 8.6-13 km **Moderately suitable:** 5.4-8.6 km **Not suitable:** 0-5.4 km	> 13 km **Suitable**
Proximity to cultural and historical sites	**Suitable:** 0-15 km **Moderately suitable:** 15-30 km **Not suitable:** 30-45 km	0-15 km **Suitable**
Proximity to roads	**Suitable:** More than 10 km **Moderately suitable:** 2-10 km **Not suitable:** Below 2 km	Between 0-110km **Suitable**
Avg. temperature	**Suitable:** 17° C - 21° C **Moderately suitable:** 21° C - 26° C **Not suitable:** > 26° C	22.5° C/72.4° F **Moderately suitable**

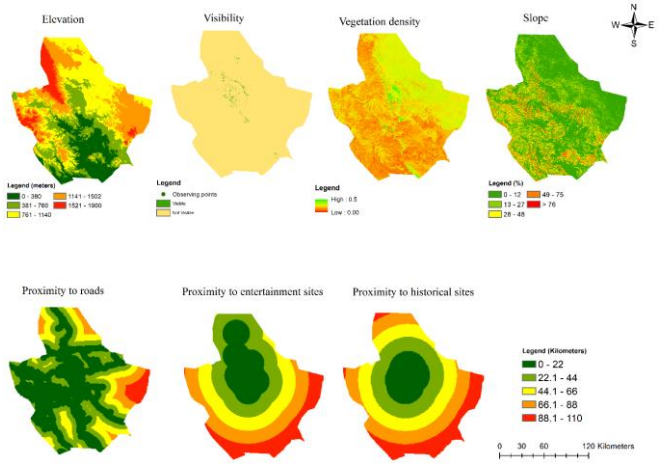

Figure 2. Landscape potentials in Alula

3.2 Mobile application evaluation

The survey findings underscore the capacity of mobile applications to improve ecotourism experiences and advocate for sustainable practices. The principal findings are encapsulated in Table 2:

Table 2. Mobile applications evaluation survey outcomes

Category	Survey Questions	Average Score (1-4)
Technology usage	I frequently use mobile applications during my travels.	3.5
	Mobile applications enhance my travel experience.	3.7
Preferences for mobile applications	I prefer mobile apps that provide real-time information on trails and cultural sites.	3.8
	I find mobile apps with environmental education features useful.	3.6
Sustainability practices	I am willing to use apps that promote Leave No Trace principles.	3.4
	I would participate in citizen science projects through mobile apps.	3.2
Feedback on existing apps	The mobile apps I have used in Alula are user-friendly.	3.5
	I would recommend the mobile apps I have used to other tourists.	3.6

- **Technology Utilization:** Participants regularly employ mobile applications while travelling, achieving an average score of 3.5 (out of 4). Mobile applications markedly improve travel experiences, evidenced by an average rating of 3.7.

- **Preferences for Mobile Apps:** Tourists prefer mobile applications that offer real-time data on trails and cultural landmarks (average score: 3.8) and incorporate environmental education elements (average score: 3.6).

- **Sustainability Practices:** Respondents indicated a readiness to utilize applications that advocate Leave No Trace principles (mean score: 3.4) and engage in citizen science initiatives (mean score: 3.2).

- **Feedback on Existing Apps:** Current applications received a user-friendliness rating of 3.5, accompanied by a strong chance of referral to other travellers, with an average score of 3.6.

3.3 Stakeholder interviews

The stakeholder interviews offered a complete overview of the current ecotourism scene in Alula, identifying important opportunities, limits, and future orientations. The topics addressed governance frameworks, infrastructure limits, technical developments, and long-term strategic goals for sustainable ecotourism growth. The findings are grouped into four primary themes and twelve key insights as shown in Table 3:

Table 3. Stakeholders' interviews outcomes

Themes	Key insights
Current Ecotourism Practices	• Ecotourism activities are managed by RCU-led efforts, ensuring structured governance and sustainable tourism policies. • Community engagement is promoted through generating employment opportunities, cultural preservation, and economic opportunities. • Sustainable tourism principles include controlled guest access, eco-friendly accommodations, and conservation-focused guided tours.
Challenges in Ecotourism development	• Infrastructure constraints, such as insufficient transport systems and a deficiency of sustainable lodging, hinder accessibility. • Environmental limitations, including water scarcity, desertification, and habitat fragmentation, threaten long-term sustainability. • Regulatory and operational constraints impede down investment and implementation of sustainable tourism projects.
Technology integration in ecotourism	• GIS and remote sensing facilitate environmental monitoring and promote sustainable land-use planning. • Intelligent tourism technologies, such as mobile applications, augmented reality/virtual reality, and digital platforms, improve visitor engagement and education. • Internet of Things (IoT) driven resource management enhances water utilisation, monitors wildlife migrations, and evaluates tourism effects.
Future vision and strategic goals	• RCU seeks to draw 2 million people by 2035 while preserving natural equilibrium. • Development of new ecotourism goods, such as eco-lodges, wellness retreats, and

	adventure tourism, to diversify offers. • Capacity building and research collaborations will improve data-driven decision-making and conservation initiatives.

3.4 Smart Technology Integration Framework (STIF)

This study resulting in the development of a comprehensive Smart Technology Integration Framework (STIF) to facilitate the use of smart technologies, specifically GIS, remote sensing, and mobile applications, into the planning and implementation of ecotourism initiatives in protected and culturally significant places (Figure 3). The framework was developed from empirical data derived from geographical analysis, tourist surveys, and stakeholder interviews, and is organised to correspond with three strategic objectives: promoting environmental sustainability, enhancing tourist engagement and experience, preserving natural and cultural heritage. The framework has three operational technology layers: spatial intelligence layer, interactive digital layer, and smart analytics layer, underpinned by foundational elements including, governance & institutional support, stakeholder engagement, and infrastructure & data standards. The framework contains a staged implementation approach that spans from early evaluation to scale and integration, featuring ongoing feedback loops for adaptive management. The framework integrates technical functions with sustainability goals, providing a practical and scalable model for smart ecotourism development, directly applicable in the Alula region and comparable arid, culturally significant areas.

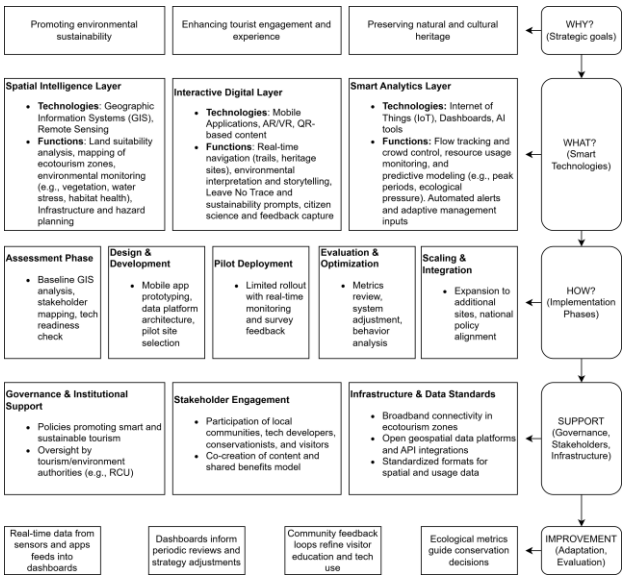

Figure 3. The Smart Technology Integration Framework (STIF)

3.5 Discussion

This study examines the integration of smart technologies, such as GIS, remote sensing, and mobile applications, for the development of ecotourism opportunities in Alula, Saudi Arabia. The study seeks to evaluate the appropriateness of Alula for ecotourism by examining essential environmental, topographical, and infrastructural factors, while also assessing the impact of mobile applications on improving visitor experiences and fostering sustainable tourism practices. The study utilises a mixed-method approach incorporating GIS and remote sensing analysis, surveys on mobile application usage, and stakeholder interviews to establish a comprehensive framework for sustainable ecotourism development in arid landscape.

The findings show that Alula provides substantial potential for ecotourism development. The GIS research indicated that Alula's moderate temperature (22.5°C), low population density (2.44 individuals/km²), and slope range (0-27%) render it suitable for ecotourism infrastructure. Visibility studies indicated that several of Alula’s important tourism destinations provide magnificent views, further improving the region’s attraction. The proximity of historical and cultural landmarks within 0-15 km facilitates the amalgamation of cultural heritage tourism with ecotourism experiences. Water shortage (21 mm yearly rainfall) and habitat fragmentation were recognised as concerns for sustainable resource management measures.

The mobile application survey indicated that tourists heavily rely on digital resources for trip planning and navigation. Tourists exhibited an extensive inclination towards applications that offer real-time trail information, cultural heritage content, and environmental education capabilities. Notably, there was a notable interest in mobile applications supporting Leave No Trace principles and citizen science efforts, suggesting that technology may facilitate responsible tourism practices. Stakeholder interviews corroborated these findings, with participants highlighting the necessity for the deployment of intelligent technologies to mitigate infrastructure constraints, conserve habitats, and manage visitors effectively.

This research extends on previous research by incorporating GIS-based suitability assessments and mobile technology uptake into a cohesive ecotourism framework tailored for dry desert regions. Research by Mansour, Al-Awhadi, and Al-Hatrushi (2020) and Gigović et al. (2016) has utilised GIS and remote sensing to evaluate ecotourism potential, predominantly concentrating on tropical and wooded ecosystems. This study, however, utilises similar methodologies in a desert terrain, so expanding the geographic scope of ecotourism research. Moreover, current studies on mobile technology in ecotourism (Dickinson, Robbins, & Lumsdon, 2010; Jinendra et al., 2012; Sullivan et al., 2014; Suphachaimongkol et al., 2019) have predominantly focused on user interaction, neglecting the incorporation of spatial analysis in tourism planning. This study addresses the gap by illustrating how GIS-based evaluations may guide mobile application development, ensuring that digital tools are congruent with sustainable site selection and conservation initiatives.

The proposed STIF offers an innovative and pragmatic strategy for developing ecotourism in areas marked by environmental sensitivity and cultural importance. This concept integrates spatial intelligence layer, interactive digital layer, and smart analytics layer into a unified, adaptable system, in contrast to fragmented systems that see technology and sustainability as distinct elements. The design immediately addresses the stated research gap about the absence of integrated, context-specific instruments for ecotourism development in dry and heritage-rich areas like Alula. Moreover, the integration of stakeholder participation and incremental implementation guarantees both institutional viability and communal significance. The framework's focus on feedback loops and adaptive management

corresponds with modern sustainable tourist planning models, enhancing its potential for enduring influence. The framework enhances the discourse on smart ecotourism by operationalising smart technologies to concurrently fulfil environmental, experiential, and cultural objectives, providing both theoretical and practical contributions, as well as a repeatable model for other protected areas worldwide.

Moreover, the study's results have numerous implications for ecotourism planning and policy formulation. The prioritisation of GIS and remote sensing in ecotourism planning is essential for optimising land-use decisions, mitigating environmental damage, and bolstering conservation initiatives. Secondly, mobile applications must have customised elements, including interactive trail maps, heritage interpretation, and sustainability standards, to augment tourist engagement and encourage responsible tourism practices. Third, investment in sustainable infrastructure, water conservation technology, and waste management systems is crucial to ensure that the rise of ecotourism does not jeopardise Alula's ecological integrity.
Fourthly, the STIF offers a practical model for integrating smart technologies into ecotourism planning in environmentally and culturally sensitive areas. It supports data-driven decision-making while promoting sustainability, visitor engagement, and heritage preservation. Ultimately, cooperation among the Royal Commission for Alula, local communities, and technology suppliers can enable the effective implementation of smart tourism initiatives, establishing a sustainable ecotourism model that harmonises tourism expansion with conservation efforts.
By demonstrating how smart technologies can be harnessed to assist ecotourism in a historically and ecologically significant location, this research provides useful insights for policymakers, environmentalists, and tourism operators. Future studies could build upon this research by increasing GIS-based assessments, adding real-time environmental monitoring, and examining the long-term impacts of smart tourism policies. Ultimately, the work contributes to the greater discourse on sustainable tourist development, presenting a reproducible paradigm for incorporating smart technologies into ecotourism planning in arid and semi-arid areas.

Conclusion

This study highlights the significant potential of Alula, Saudi Arabia, as an ecotourism destination through the integration of advanced technologies such as GIS, remote sensing, and mobile applications. The GIS and remote sensing analysis verified that Alula has essential environmental and infrastructural characteristics conducive to ecotourism development, such as appropriate slope variations, moderate elevations, excellent visibility of picturesque landscapes, and proximity to cultural and historical sites. Nonetheless, water shortage and habitat fragmentation persist as concerns that require resolution through sustainable tourism planning and conservation methods.
The mobile application survey indicated a growing dependence on digital platforms for trip planning and visitor interaction. Tourists demonstrated a pronounced preference for real-time navigation, interactive cultural heritage information, and sustainability-enhancing elements, suggesting that mobile applications can significantly contribute to promoting responsible tourism practices. Stakeholder interviews underscored the imperative of adopting smart technology to improve guest experiences, optimise resource management, and foster sustainable tourism development.
The study's results present numerous significant implications for ecotourism planning and policy. Initially, GIS and remote sensing must be incorporated into Alula's tourism development strategy to enhance land-use decisions and facilitate conservation initiatives. Secondly, mobile applications must be customised to improve visitor experiences while advocating for ethical tourism behaviours. Third, infrastructure development must prioritise sustainability by investing in water management, environmentally appropriate accommodations, and waste reduction measures. The proposed STIF provides a scalable and sustainable approach to integrating smart technologies in ecotourism development, particularly in heritage-rich, arid regions like Alula. Ultimately, cooperation among politicians, conservationists, and technology suppliers is essential for aligning smart tourism initiatives with sustainable development objectives.

This study offers a reproducible paradigm for incorporating smart technologies into ecotourism planning in dry and culturally significant environments by merging spatial analysis with mobile technology assessment. Future study ought to broaden GIS-based evaluations, integrate real-time environmental monitoring, and measure the long-term effects of digital tourist projects. The results further the discussion on sustainable tourism development, illustrating how smart technologies can improve ecotourism experiences while safeguarding natural and cultural resources.

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