

Data, GIS, AI and Technology for Climate-Resilient Tourism Planning

Amisha Thakur^{1*}¹Jamia Hamdard, New Delhi, IndiaDOI: <https://doi.org/10.36347/sjebm.2025.v12i11.006>

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*Corresponding author: Amisha Thakur
Jamia Hamdard, New Delhi, India

Abstract

Original Research Article

Climate-resilient tourism planning in mountain regions requires timely, spatially detailed and socially relevant information. Himachal Pradesh's tourism sector is exposed to changing temperature and precipitation patterns, extreme weather events, landslides, floods, water stress, ecological degradation, infrastructure vulnerability and socio-economic disparities. This study examines the role of data systems, Geographic Information Systems (GIS), remote sensing, artificial intelligence (AI), machine learning, Internet of Things (IoT), drones and sensor-based monitoring in strengthening climate-resilient tourism planning in Himachal Pradesh. The analysis shows that tourism planning requires four broad forms of information including climate data, environmental data, socio-economic data and infrastructure data. Remote sensing and earth observation can support land-use and environmental monitoring like drones can assist in observing disaster-prone and inaccessible sites, AI and machine learning can strengthen predictive analytics, IoT-enabled sensors can track environmental variables and GIS can integrate spatial information for decision-making. The study argues that digital technologies should not be treated as isolated technical tools. They must be embedded in governance systems, district-level planning, community participation and policy implementation. The study concludes that data-driven tourism planning can help Himachal Pradesh move from reactive crisis management toward anticipatory climate resilience.

Keywords: GIS; artificial intelligence; remote sensing; climate-resilient tourism; Himachal Pradesh; tourism planning.**Copyright © 2025 The Author(s):** This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY-NC 4.0) which permits unrestricted use, distribution, and reproduction in any medium for non-commercial use provided the original author and source are credited.

1. INTRODUCTION

Tourism planning in Himachal Pradesh increasingly requires information that is accurate, spatially specific and usable for decision-making. The state's tourism economy operates in a mountain environment shaped by climatic variation, ecological sensitivity, road dependence, seasonal visitor flows and uneven infrastructure capacity. Traditional planning methods that rely only on general policy statements or occasional reports are insufficient for such a complex setting. A climate-resilient tourism system requires continuous information about weather patterns, environmental change, disaster risk, infrastructure condition, visitor pressure, water systems and community vulnerability.

The study identifies data gaps and limited monitoring capacity as major barriers to effective climate action. Inadequate data related to climate impacts and vulnerabilities weakens planning, implementation and evaluation, while limited monitoring reduces the effectiveness of ongoing initiatives (Government of Himachal Pradesh, 2021). This problem is especially

important for tourism because the sector depends on destination safety, accessibility, environmental quality and public confidence. If planners lack timely data, they may fail to identify emerging risks until they become crises.

Digital technologies create new possibilities for tourism planning. Remote sensing, satellite imagery, drones, GIS, AI, machine learning, IoT and sensor-based systems can help monitor environmental change, forecast hazards, identify vulnerable infrastructure, track resource stress and support evidence-based decision-making. These tools are particularly useful in mountain regions where field access can be difficult, terrain is complex and hazards may develop quickly.

However, technology alone cannot produce resilience. Data must be collected, interpreted, shared and acted upon through institutions. A satellite image is useful only if planners can translate it into land-use decisions. A sensor reading matters only if it informs water management, air-quality monitoring or disaster response. A GIS map supports resilience only if it

reaches the agencies and communities responsible for tourism development. Therefore, this study treats technology as part of a wider planning and governance system.

2. Research Problem and Objectives

The core research problem is that tourism planning in Himachal Pradesh must respond to climate and environmental risks, but such planning is weakened when data systems are incomplete, fragmented or not linked with decision-making. Tourism destinations require information about climatic trends, extreme events, land-use change, vegetation cover, water resources, infrastructure conditions, population exposure, visitor movement and adaptive capacity. Without such information, tourism planning remains reactive.

The study has four objectives. First, it identifies the major categories of data required for climate-resilient tourism planning in Himachal Pradesh. Second, it examines the role of remote sensing, drones, AI, machine learning, IoT and GIS in tourism-related climate monitoring. Third, it discusses how technology can support risk anticipation, environmental management, infrastructure resilience and community-sensitive planning. Fourth, it proposes a governance-oriented framework for using digital information responsibly in tourism decision-making.

3. METHODOLOGY

This study uses a qualitative secondary-source design consisting of policy documents, statistical information, government reports, research studies and institutional documents associated with public agencies such as the Himachal Pradesh Tourism Department, MoSPI and MoEFCC, as well as research organisations and international development institutions included in the original document. The analysis is thematic around data needs, digital monitoring, spatial planning, predictive analytics, infrastructure assessment and tourism governance. This method interprets the role of data and technology within the climate-resilience framework.

4. Why Data Matters for Climate-Resilient Tourism

Climate-resilient tourism planning depends on knowing what is changing, where it is changing, who is affected and which systems are most exposed. Himachal Pradesh requires information about temperature, rainfall, extreme weather, floods, landslides, droughts, land use, vegetation, water resources, biodiversity, roads, buildings, energy use and socio-economic vulnerability. The historical and current temperature and precipitation records are necessary for identifying trends and anomalies. It also emphasises the need for detailed information on the frequency, intensity and impact of extreme weather events, including floods, landslides and droughts.

For tourism, this information has practical value. Temperature and precipitation records can help anticipate changes in tourism seasons. Extreme-event data can support tourist advisories, road planning and disaster preparedness. Land-use and vegetation data can indicate whether tourism expansion is damaging ecological systems. River-flow, groundwater and water-quality data can reveal whether destinations are approaching resource stress. Infrastructure data can identify vulnerable roads, bridges, buildings and energy systems. Socio-economic data can show which communities and workers have lower adaptive capacity.

The study groups data needs into several categories. Climate data help identify environmental trends and anomalies. Environmental data help monitor ecosystem health, biodiversity, river flows, groundwater levels and water quality. Socio-economic data help assess population distribution, demographic conditions and dependence on sectors such as agriculture, tourism and construction. Infrastructure data help evaluate roads, bridges, buildings, energy consumption and transport networks. Together, these categories provide a multidimensional basis for climate adaptation.

Tourism planning needs this multidimensional view because tourism risk is rarely caused by a single factor. A destination may be affected simultaneously by heavy rainfall, road fragility, water scarcity, high visitor numbers, poor waste systems and limited local capacity. If planners look only at tourist arrivals, they miss ecological stress. If they look only at climate hazards, they may miss livelihood dependence. If they look only at infrastructure, they may ignore community vulnerability. A data-driven approach can bring these layers together.

Better data can also improve prioritisation. Public resources are limited and not every destination can receive equal intervention at the same time. Data can help identify where landslide risk is high, where water pressure is rising, where roads are fragile, where visitor growth is exceeding capacity and where communities are highly dependent on tourism income. This allows government agencies to move from general recommendations to targeted action.

5. Remote Sensing, Drones and Earth Observation

Remote sensing and earth observation technologies are highly relevant to mountain tourism planning because they can monitor areas that are difficult to access regularly. Satellite imagery and drones can provide real-time or repeated observations of environmental change, land-use patterns, vegetation cover, river systems, disaster impacts and infrastructure conditions. The remote sensing and earth observation technologies as tools that provide real-time data on environmental changes and support monitoring of natural disasters and infrastructure conditions.

Remote sensing has particular value for land-use and ecological monitoring. Tourism growth can change land cover through roads, hotels, parking areas, market expansion and settlement growth. Satellite imagery can help track these changes over time. Remote sensing ecological index approaches are used in environmental quality assessment and ecological change detection (Liu *et al.*, 2024; Xu *et al.*, 2019). Such tools can help planners identify whether tourism areas are experiencing vegetation loss, built-up expansion or ecological stress.

High-resolution satellite imagery can also support local-scale planning. Very high-resolution imagery from platforms such as Google Earth and Microsoft Bing Maps can serve as reference data for spatial and temporal analysis (Lesiv *et al.*, 2018). In tourism planning, such imagery can help identify road alignments, settlement expansion, river proximity, slope conditions and built-up growth around tourist destinations. This does not replace field verification, but it strengthens preliminary assessment.

Drones can support monitoring in inaccessible or hazard-prone areas. In mountain regions, landslides, floods, road blockages and remote valleys may be difficult to inspect quickly. Drone imagery can help observe damaged roads, unstable slopes, riverbank changes, trail conditions and environmental degradation. UAV and satellite remote sensing are also relevant to inland water-quality assessment (Wasehun *et al.*, 2024). This matters for tourism because water quality affects both residents and visitors.

Remote sensing can also support forest and ecosystem vulnerability assessment. For tourism, forest condition is important because forests support landscape quality, biodiversity, slope stability, water regulation and eco-tourism potential. Monitoring forest change through ecological indices and repeated image analysis can therefore support conservation planning as well as tourism resilience (Liu *et al.*, 2024; Xu *et al.*, 2019).

The limitation is that remote sensing data must be interpreted carefully. Images can show land cover, vegetation condition, surface change or infrastructure damage, but they do not automatically explain social vulnerability, institutional capacity or local perception. Remote sensing should therefore be combined with socio-economic data, field knowledge and local consultation.

6. AI, Machine Learning and Predictive Analytics

Artificial intelligence and machine learning can strengthen tourism planning by identifying patterns in large and complex datasets. AI and machine learning enhance predictive analytics, support more accurate forecasting of climate trends and extreme weather events and improve analysis of complex datasets. This is

important because climate-resilient tourism requires anticipation, not only response.

AI has growing relevance in environmental monitoring (Alotaibi & Nassif, 2024). Machine learning can help process climate records, satellite imagery, sensor data, visitor trends and infrastructure information. It can detect patterns that may not be obvious through manual analysis. For example, machine learning can support analysis of repeated environmental change, hazard likelihood, visitor pressure, water demand or road disruption risk.

Natural disaster prediction is another important application. AI and machine learning have been discussed as tools for predicting natural disasters (Venkadesh *et al.*, 2024). In Himachal Pradesh's tourism context, predictive systems could help anticipate high-risk periods for floods, landslides, heat stress or route disruption. Such systems would be especially valuable if connected to tourism advisories, transport planning, hotel communication and emergency services.

Big data approaches can also transform ecological research and environmental analysis (Peters *et al.*, 2014). Tourism destinations generate multiple data streams like weather records, satellite imagery, booking trends, traffic movement, social media signals, water use, waste generation and disaster reports. When organised responsibly, these datasets can help identify destination stress before visible crisis emerges. For example, repeated visitor surges combined with water-use data could indicate rising scarcity risk. Road disruption history combined with rainfall data could help identify vulnerable corridors.

Transfer learning and deep-feature approaches in remote sensing can also support spatial analysis where local labelled data are limited (Xie *et al.*, 2016). This is relevant because mountain regions may not always have dense monitoring networks. AI-assisted interpretation of satellite imagery can help identify land-use change, road expansion or environmental stress where field data are incomplete.

However, predictive analytics must be used cautiously. Models are only as reliable as their data, assumptions and validation. A poorly designed model can produce misleading risk classifications. AI systems can also exclude local knowledge if treated as purely technical solutions. Tourism planners should therefore use AI as decision support, not as a substitute for human judgement, field verification and community input.

7. IoT, Sensors and Real-Time Monitoring

The Internet of Things can strengthen environmental and infrastructure monitoring through sensor networks. The IoT can track environmental parameters such as temperature, humidity and air quality, while IoT-enabled smart infrastructure can optimise

resource use and improve system resilience. In tourism destinations, such monitoring can support water management, air-quality assessment, energy use, waste systems and early warnings.

Sensor networks are especially valuable where conditions change quickly. Temperature, humidity, rainfall, air quality, water levels and slope movement can shift within short periods in mountain regions. Real-time monitoring can provide early signals of stress. Wireless sensor networks combined with big data analytics, machine learning and artificial intelligence have been discussed for environmental monitoring (Shaikh *et al.*, 2020). Such systems can help create a more responsive planning environment.

For tourism, IoT-based monitoring can support destination management in several ways. Water meters can track consumption by hotels and public facilities. Air-quality sensors can identify pollution peaks during tourist seasons. Weather sensors can inform visitor advisories. Smart infrastructure can monitor energy demand and system stress. Sensors near vulnerable routes can support risk alerts. These tools can make tourism management more evidence-based.

IoT systems can also improve accountability. If environmental data are collected regularly and shared transparently, local authorities and communities can see whether destinations are becoming more stressed. Public dashboards can display water levels, air quality, road advisories and weather alerts. This can help tourists make informed decisions and encourage businesses to comply with sustainability norms.

However, sensor systems require maintenance, calibration, funding and institutional responsibility. Installing devices is easier than sustaining a reliable monitoring system. Data must be stored, analysed, protected and converted into action. If sensors are installed but not maintained, they become symbolic infrastructure. Therefore, IoT planning should include budgets, responsible agencies, data standards and response protocols.

8. GIS and Spatial Decision-Making

GIS is central to climate-resilient tourism planning because it integrates different layers of spatial information. The GIS supports climate action by enabling mapping and visualisation of climate impacts, while also supporting informed decision-making among policymakers and stakeholders. GIS tools can support natural-resource management and conservation by showing where risks, resources and development pressures overlap.

Tourism planning is inherently spatial. Destinations are connected by roads, rivers, slopes, settlements, forests, markets, hotels and visitor routes. GIS can map these features together. It can show whether

a proposed tourism facility lies near a flood-prone river, unstable slope, water-stressed area, forest boundary or fragile road corridor. It can also help identify where public facilities, evacuation routes, health centres and emergency shelters are located.

GIS-based landslide hazard zonation has been applied in parts of the mid-Himalaya in Himachal Pradesh (Kumar *et al.*, 2019). While this study does not focus on landslides as its main topic, this example shows the value of spatial analysis for tourism safety. Tourist routes and facilities can be overlaid with hazard maps to identify vulnerable corridors and sites. Such mapping can guide route advisories, infrastructure investment and development restrictions.

GIS can also support environmental management. Land-use change, vegetation cover, river systems, groundwater zones, tourist facilities and waste sites can be spatially linked. This helps planners understand cumulative pressure. For example, a destination may have high visitor numbers, limited water, expanding built-up area and weak waste infrastructure. GIS can help visualise these interactions and support carrying-capacity decisions.

A GIS-based tourism planning system should be accessible to multiple agencies. Tourism, disaster management, public works, environment, rural development, urban local bodies and local governments all require spatial information. If each department maintains separate maps and datasets, planning remains fragmented. Integrated GIS platforms can improve coordination.

9. Data Governance and Institutional Integration

The value of technology depends on governance. Data must be reliable, updated, shared, interpreted and used. Himachal Pradesh's tourism planning requires a system in which climate data, environmental data, socio-economic data and infrastructure data are connected. The study identifies data gaps and limited monitoring as barriers to climate action (Government of Himachal Pradesh, 2021). Addressing this requires institutional reform, not just software.

A data-governance framework for tourism should specify what data are collected, who collects them, how often they are updated, who verifies them, who has access and how they influence decisions. For example, if rainfall and road data indicate high travel risk, there must be a protocol for issuing advisories. If water sensors indicate stress in a destination, there must be a response mechanism. If satellite data show land-use change near sensitive zones, planning authorities must act.

Data integration should also include local knowledge. Communities, guides, drivers, homestay

owners, panchayats and local businesses often observe risks before they appear in formal datasets. They know which roads fail repeatedly, which springs are drying, which trails are overused and where waste accumulates. Technology should create channels for local reporting rather than replacing local observation.

Privacy and ethics also matter. Tourism data may include visitor flows, business activity, location data or community information. Such data must be used responsibly. Climate resilience should not become surveillance. Data systems should protect sensitive information while enabling public-interest planning.

Capacity building is essential. Officials, local bodies, tourism operators and community organisations need training to use data platforms, interpret maps, respond to alerts and communicate risks. Without capacity, even high-quality data may remain unused. Therefore, technology adoption must be accompanied by institutional learning.

10. From Reactive Planning to Anticipatory Tourism Governance

The main contribution of data, GIS, AI and technology is that they can shift tourism planning from reaction to anticipation. Reactive planning responds after roads close, water runs short, disasters occur or destinations degrade. Anticipatory planning identifies risks early and acts before damage becomes severe. Himachal Pradesh needs this shift because climate and environmental risks are becoming more complex.

Anticipatory tourism governance requires multiple information layers. Climate records show trends. Remote sensing shows land and ecological change. Sensors show real-time environmental conditions. GIS shows spatial relationships. AI detects patterns and supports forecasts. Socio-economic data identify vulnerable communities. Infrastructure data reveal weak systems. When combined, these information layers can support better planning.

The challenge is integration. Technologies are often introduced in separate projects, one agency may collect weather data, another may manage roads, another may monitor forests and another may promote tourism. If these data remain separate, tourism planning cannot benefit fully. Integrated platforms and interdepartmental coordination are essential.

The second challenge is scale. State-level data are useful for broad policy, but tourism decisions often require district, destination and site-level information. A state climate trend does not tell a local homestay cluster whether its water source is stressed. A district hazard map may not show a specific trail condition. Therefore, data systems must work across scales.

The third challenge is actionability. Data should be designed around decisions. Planners need to know whether to restrict construction, issue advisories, upgrade infrastructure, limit visitor numbers, improve water systems or support vulnerable communities. A data system that produces information without decision pathways will have limited impact.

Finally, technology must support inclusive resilience. If only government agencies and large businesses access data, small operators and communities may remain vulnerable. Public-facing advisories, community dashboards, local-language alerts and participatory reporting can make technology more democratic. Tourism resilience requires that information reaches those who need it.

11. Recommendations

First, Himachal Pradesh should create a climate-resilient tourism data platform integrating climate, environmental, socio-economic, infrastructure and visitor-related data. This platform should support district-level and destination-level decision-making. Second, GIS-based tourism risk maps should be developed for major and emerging destinations. These maps should include roads, slopes, rivers, forests, water sources, tourist facilities, settlements, emergency services and climate-risk zones. Third, remote sensing should be used to monitor land-use change, vegetation cover, built-up expansion, river conditions and ecological stress around tourism destinations. Satellite imagery should be combined with field verification. Fourth, drone-based assessment should be used for inaccessible or disaster-affected sites, especially after extreme weather events, road blockages, slope failures or riverbank changes. Fifth, AI and machine learning tools should be used as decision-support systems for climate trend analysis, hazard anticipation, visitor-pressure assessment and infrastructure-risk identification. These tools should be validated and used with human oversight. Sixth, IoT-based monitoring should be piloted in selected tourism destinations to track temperature, humidity, air quality, water levels, groundwater use and infrastructure stress. Sensor data should be linked with response protocols. Seventh, data-sharing mechanisms should be established among tourism, disaster management, public works, environment, forest, rural development, urban local bodies and local governments. Eighth, local communities should be included in data systems through participatory reporting. Guides, drivers, homestay owners, panchayats, women's groups and local businesses can provide valuable ground-level information. Ninth, public communication tools should be developed for tourists and operators. Weather alerts, road advisories, destination-risk information and environmental guidelines should be available in accessible formats. Tenth, capacity-building programmes should train officials, local bodies, tourism operators and community organisations in GIS, data

interpretation, digital reporting and climate-risk communication.

12. CONCLUSION

Data, GIS, AI and technology can play a major role in climate-resilient tourism planning in Himachal Pradesh. The state's tourism sector operates in a mountain environment where climate trends, extreme events, infrastructure fragility, ecological stress and community vulnerability interact. Planning such a system requires more than general policy. It requires timely, spatial, environmental and socio-economic information.

The study has shown that tourism resilience depends on multiple data categories: climate data, environmental data, socio-economic data and infrastructure data. Remote sensing and drones can monitor environmental change and inaccessible sites. AI and machine learning can support predictive analytics. IoT sensors can provide real-time environmental information. GIS can integrate spatial layers for decision-making. Together, these tools can help Himachal Pradesh anticipate risks and plan more effectively.

However, technology must be embedded in governance. Data must lead to action. Monitoring must be connected with public communication, infrastructure planning, environmental regulation and community participation. Local knowledge must complement digital systems. Small operators and communities must be included, not left outside technical planning.

The climate-resilient tourism in Himachal Pradesh requires a shift from reactive management to anticipatory governance. Digital technologies can support this shift if they are integrated, maintained, ethically governed and used for inclusive decision-making. A data-driven tourism planning system can help protect destinations, support communities, guide infrastructure investment and strengthen the long-term resilience of Himachal Pradesh's tourism economy.

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