

## **Geospatial Intelligence for Climate-Responsive Development: Policy Gap Analysis and Digital Monitoring of Development Patterns in Naran, Pakistan**

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### **Abstract**



*This paper, critically explores gaps in existing development policies in consideration of recent climatic challenges faced by Naran, KPK region in Pakistan. Known for its diverse landscape features, including forests, mountains, valleys and lakes; Naran is breath of fresh air for the eyes of anyone visiting the region. However, over the recent years, these features have been overshadowed by the increasing uncontrolled development patterns including: roads, hotels and commercial infrastructure in order to accommodate the increasing influx of visitors and locals alike.*

*The built and natural environment is influenced by the needs and impacts over time, at any place. Precisely how it has been a cause of forestation decline in case of Naran, with the alarming drop of 12% over 10-year period ranging from 2010 to 2020 [1]. As a result, the region has faced flash floods and other climatic changes. The need is to not seize development but to adapt and enable it to better coexist not only with the landform but also the meteorological conditions.*

*As the climatic decline puts not only the future development but also the existing development at risk. The outcome of this research proposes a phasal evaluation and implementation plan, which includes:*

- 1- *Evaluation of existing infrastructure and landscape through existing GIS based data*
- 2- *Proposing policies that reduce the gap between existing policies, paired with a conceptual digital monitoring system that enables policy implementation.*

**Keywords:** Spatial Decision Support Systems, Climate-Responsive Development, Policy Gap Analysis

### **Introduction**

Pakistan's most ecologically rich mountain-scape resides in the northern region, in particular the Naran valley captures the hearts of people with its exquisite beauty. Dense forests, steep mountainous terrain, river corridors, and high-altitude lakes, all encompassed together make up for healing venture. Naturally, in order to co-exist with these scenic views; the region has observed an increase in not just road infrastructure but also in architecture. With the increasing population of both locals and tourists, there is bound to be room for error when catering to the needs in rush in comparison to planned long-term development.

Narran has lost 12% forest cover during 2010 to 2020 decade, to make room for roads and architecture. Unplanned disruptions in biodiversity can lead to unpredictable climatic problems as seen in the past years as a consequence of 158% increase in the built-up area [2]. This indirectly puts the development at risk of deterioration but also threatens the lives of people residing in the area with 1739 deaths reported because of floods in 2022 [3,4], effected areas majorly included river encroachments and unregulated settlements. Environmental disruptions, in particular flash floods left 160 tourists trapped in Narran in 2025 and 200 in Saif ul Maluk as result of land sliding causing them to migrate back to Naran [5].

In the past few years, construction has proceeded without planned spatial evaluation of the land in a larger context and land-use regulations often times are overlooked. At the moment there is no integrated system that monitors the changing climatic and landscape conditions that helps stakeholders point out suitable land for expanding infrastructure based on patterns and allows for revision in policies with the evolving land conditions.

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This study plans to evaluate where policy fails implementation as well as proposes a conceptual integrated system that draws on GIS-mapping and pattern recognition of climatic and landscape changes to help plan out development that shapes the lives of people in a more meaningful manner.

### **Materials and Methods**

The methodology is divided into following components

#### **Data Collection**

1. Spatial data: satellite imagery, existing roads and built-up footprints
2. Development bylaws and environmental regulations
3. Flash flood incident reports and hazard studies relevant to the study area
4. Observation: Field photographs and surveys

#### **GIS-Based Evaluation**

- Built-up footprint mapping
- Forest cover change detection
- Encroachment along rivers & slopes

#### **Policy Gap Analysis**

- Content review of existing development and environmental policies
- Comparison of mentioned policies as opposed to actual patterns
- Identification of weak enforcement points

#### **Conceptual Development of Digital Monitoring System**

- Stakeholders integration
- Community reporting interface

#### **Literature Review**

##### **Ecological Sensitivity Of Mountain Ecosystems:**

Studies have highlighted mountain ecosystems to be one of the most ecologically sensitive landscape features, where one minor change can result in long-term and large-scale climatic impact [6,7]. Disruptions in the mountain form can cause soil erosion, landsliding, flash floods, altered ground water recharge, and accelerated glacial melt and much more. The sensitivity to climatic variability of mountain ecosystems has been noted by the Intergovernmental Panel on Climate Change (IPCC), in particular the disaster risks as a result of glacier melts and increased run-off frequency during monsoon seasons. This sensitive nature of mountains calls for extreme attention when planning development alongside terrains.

##### **Environmental Degradation of Mountains :**

While studies highlight that countries rely on tourism to generate economic benefits not only on a governmental level but also through local private businesses, it's important to note that some locals solely rely on tourists as a way to earn. To facilitate and accommodate large tourist influx, haphazard development has been observed across the area of Narran. Unregulated growth has resulted in deforestation, waste accumulation and hydrological disruptions. In many cases, the development has exceeded the local ecological capacity, resulting in flooding, soil instability and loss of vegetation. If this remains unchecked Pakistan is bound to face a problem greater than ever seen before.

##### **Land-Use Change**

Unplanned development has resulted in forest degradation beyond capacity; this is majorly due to influx of tourists visiting the area and local businesses expanding infrastructure haphazardly to cater to tourists in response. In 2023, peak influxes of tourists up to 60,000 were observed in a single day with over 12,000 vehicles. As a whole more than five million domestic visitors were observed in the same year. These numbers continue to stack up, as 168,000 people visited Naran in just three days during June 2025 for the Eid-ul-Azha celebrations [8].

This continuous popularity of Narran as a vacation and tourist spot has raised a demand for infrastructure both in terms of roadways and architecture. In order to appeal to the increasing mass of tourists, Narran has observed some haphazard development without any concern to the ecological capacity of the land. A direct link between deforestation and increase in development has been observed through regional land-use and land-cover (LULC) studies of Narran-Kaghan Valley. Significant reductions in NDVI values and built infrastructure dominating over forest area has been reported [9].

**Existing development patterns**

1. Roadside commercial strips
2. Unregulated extensions/encroachments along river bank edges
3. Densely packed built environment causing forest loss



Figure 1 Narran Valley development pattern (2006)



Figure 2 Narran Valley development pattern (2014)



Figure 3 Narran Valley development pattern (2022)

**Forest Cover Loss in Hazara Division (Narran-Kaghan Region) by 5-Year Period (2001-2020)**  
Between 2001 and 2020, the Hazara Division lost a total of approximately 1,988 hectares (about 2.0 thousand hectares) of tree cover.

**I. Long-Term Spatio-Temporal Decline (1998–2017)**

One of the most comprehensive studies analyzed Land Use/Land Cover (LULC) change over a 20-year period in Mansehra District [11]:

**Table A1.** This is a table caption.

Year	Forest Cover Area (Sq. Forest Km)	Cover Percentage (%)	Total Change (Since Previous Year)
1998	601 Sq. Km	14%	Baseline
2008	668 Sq. Km	15%	+67 Sq. Km Gain (Attributed to the establishment of young plantations, though this masks older forest loss)
2017	194 Sq. Km	5%	-474 Sq. Km Loss (Massive decline in the latter decade)

**Key Finding:** This part of the research shows a concerning drop in forest cover from **15% to 5%** between 2008 and 2017.

**Landsat satellite images and Object-Based Image Analysis (OBIA)** to detect these LULC changes, highlighting the impact of rapid, unplanned, and unsustainable urbanization on the forest ecosystem of the Kaghan Valley [14].

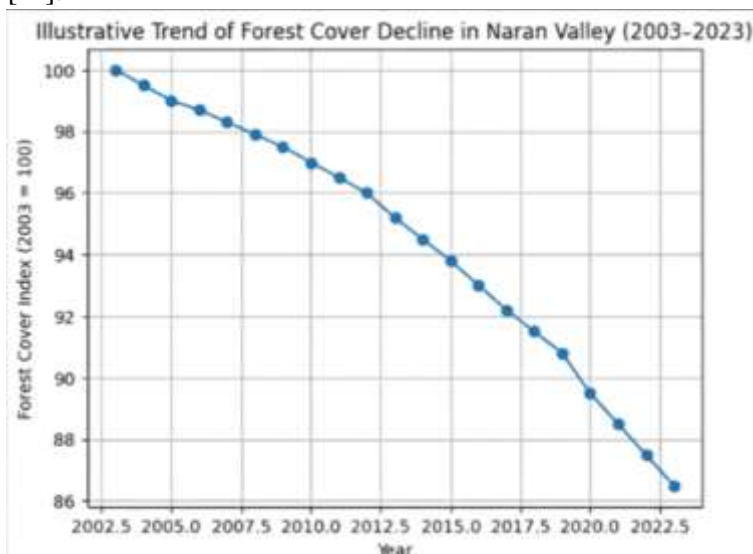


Figure 4 Illustrative trend of forest cover decline in Naran Valley (2003–2023), derived from secondary literature, regional land-use studies, and satellite-based vegetation change trends. The index is normalized to the year 2003 to demonstrate long-term decay associated with tourism-driven land-use change and infrastructure expansion. (Visualization prepared using AI-assisted tool: Gemini)

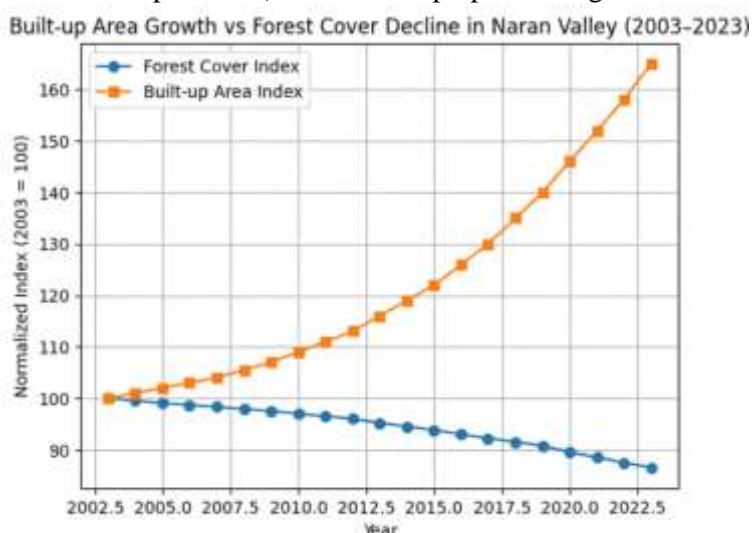


Figure 5 Comparative trend of built-up area expansion and forest cover decline in Naran Valley (2003–2023). Indices are normalized to the year 2003 to illustrate long-term land-use transformation driven by tourism-related infrastructure growth. The diverging trends indicate increasing pressure on ecological carrying capacity (Visualization prepared using AI-assisted tool: Gemini)

### Slope Instability and Flash Floods

Climate related hazards are bound to exacerbate when terrains and slopes are cut unchecked. Development without consideration of the terrain can result in soil erosion and slope instability, which in turn becomes reason for flash flooding and landsliding. Areas experiencing rapid development are at particular risk of facing glacier outbursts and flash floods during heavy rainfall as a result of narrowed drainage paths [15].

Slope cutting and excavation to make way for built infrastructure decreases slope stabilization, increase in soil exposure and run-off risk; leading to landslides and causing infrastructure to become victim of the natural drainage channel. [16].



Figure 6 Landslide Susceptibility Map (LSM) of a Critical Corridor in the Naran-Kaghan Valley (2025). (Visualization prepared using AI-assisted tool: Gemini)

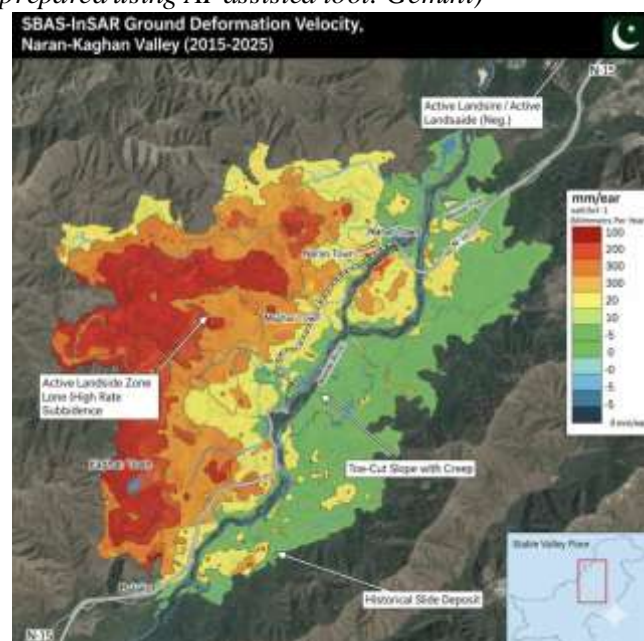


Figure 7 Figure: SBAS-INSAR Ground Deformation Velocity Map of Naran – Kaghan Valley (2015-2025) (Visualization prepared using AI-assisted tool: Gemini)

### Identifying Policy Gaps

Policy frameworks such as environmental impact assessments (EIAs), zoning regulations and provincial development guidelines, all exist as part of environmental governance in Pakistan. However, we experience gaps in the policy implementation as there is an absence of a support system and monitoring tools to help with implementation of these policies. Through comparative research on

regions such as Himachal Pardesh and Uttakhand it is apparent that paper-based policies remain static if they are not integrated with environmental data and real-time oversight [17].

### **Observational Findings**

The developmental governance in Naran not only relies on the local government bodies but also on the tourism authority, forest department and disaster management agencies. These institutes play a crucial because of the ecological sensitivity of Naran as mentioned in above discussion.

Responsible authorities include

- 1- District Government of Mansehra
- 2- KPK tourism department
- 3- Environmental protection agency (EPA)

These authorities do not have access to software licenses (ArcGIS, ENVI), and institutional mandate to process and implement complex GI data outputs (LSM, InSAR), this further becomes a barrier in creating and implementing policies that cater to the ecological sensitivity of Narran and policy implementation [12].

### **Limitations of Current Building and Environmental Acts**

The Khyber Pakhtunkhwa Building Control Act (2013) addresses clear requirements for construction permissions and land-use regulation, however the implementation of it remains weak in the mountain region as it relies on manual data collection and observation.

Similarly, Khyber Pakhtunkhwa Environmental Protection Act, 2014 (KPEPA) mandates environmental assessment for development projects. This policy is not supported by a system that foresees future environmental conditions which cannot rely on predictability in consideration of rapid climate change.

### **Key takeaways from Policy Frameworks**

#### **Absence of real-time warning systems and hazard sensitive land-use policies**

Because of the absence of a digital tracking system, the present regulatory systems rely on manual approvals and reactive inspection; which undoubtedly slow down the policy enforcement process. Human observation cannot fully help with development decisions sensitive to hazards, there is a need of integrating a digital monitoring system that regulates land-use zones and development processes.

The policy implementation can be encouraged when the stake holders and developers are informed of the hazard risks when it comes to defining land-use zones; this can be facilitated through GIS based modeling system.

#### **Need for frequent policy regulation**

The current policies rely on historical flood data and development patterns, however due to climate change Narran Valley has experienced recurring flash floods in the recent years. This goes to show the need for frequent policy regulation in order to ensure that infrastructure develops in accordance to the changing land capacity and ecological sensitivity.

#### **GIS and Spatial Evaluation**

Literature emphasizes the need of visualizing risks, measuring ecological capacities and identifying patterns that would remain hidden if Geographic Information Systems (GIS) tools are not utilized for mapping land-use changes and hazard prone areas. This integration can not only enhance foresight but aid in quick, real time planning decisions.

Utilizing Landsat data in a GIS environment (e.g., Google Earth Engine or QGIS) helps identify changing patterns overtime [17] as a result the system can be enabled to better help with policy development and implementation if made part of the governance framework.

#### **Community Participation Paired with Digital Monitoring Systems**

GIS tools will become more effective if paired with a digital monitoring system that reduces policy and implementation gaps. The conceptual proposed digital monitoring system will be a two-way facilitation system that only integrates data from the GIS tools but notifies stakeholders and alerts users of any potential risks based on pattern recognition.

#### **Policy Support Prototype Framework**

##### **Phase 1 — GIS-Based Infrastructure & Landscape Evaluation**

*Digital Monitoring Solution:*

- **Recommendation:** Implement mandatory Geospatial Hazard Zoning. Permits must be denied for any structural development within the Very High Susceptibility Zones identified by the LSM.

- **Actionable Digital Monitoring:** Use high-resolution satellite imagery (e.g., Sentinel-2) and drone mapping to conduct annual Audits of Encroachment, legally empowering regulatory bodies to dismantle illegal construction on river terraces and unstable slopes.

**Digital Monitoring Solution (A)**

- **Recommendation:** Adopt Climate-Proofing Standards. All new infrastructure must be designed to withstand a 100-year flood event based on current and projected climate models, not just historical data.
- **Actionable Digital Monitoring:** Utilize Hydraulic Modeling (HEC-RAS) integrated with high-resolution DEMs to map Flood Inundation Zones for different return periods (e.g., 25-year, 50-year, 100-year events). These maps should inform bridge and road placement/design.

**Digital Monitoring Solution (B)**

- **Recommendation:** Establish a Cloudburst and Slope Stability Early Warning System (EWS).
- **Actionable Digital Monitoring:** Integrate real-time rain gauges across the Naran valley with the Slope Stability Index. Automated alerts should be triggered when rainfall intensity and duration surpass the critical threshold identified by the model, enabling targeted evacuation messaging to high-risk zones.

**Phase 2 — Policy Gap Reduction**

- Suggested revisions
- Linking spatial evidence to policy requirements
- Simple, actionable governance instructions
- **Recommendation:** Mandate the establishment of a dedicated Geospatial Risk Management Unit within the relevant regional development authority, staffed by GIS specialists.
- **Actionable Digital Monitoring:** Ensure all technical reports and hazard maps are digitized and legally adopted into local planning bylaws, making the use of GI mandatory for all project approvals.

**Phase 3 — Digital Monitoring System**

- Dashboard functions
- Real-time compliance checks
- Two-way communication (authorities ↔ locals)
- Reporting violations
- Understanding land usage capacity



Figure 8 conceptual interface for digital monitoring system operated by stakeholders (made using canva)



Figure 9 conceptual interface for digital monitoring system operated by locals and visitors (made using canva)

**Results**

The addition of a digital monitoring system can allow for the existing policies to be implemented in a more efficient way aiding the stakeholders and locals alike by understanding the gradual land changes as well as predicting future changes.

**Conclusions**

This study shows how vulnerability in Naran is more a function of enforcement and a lack of coordination rather than a lack of policies. A combination of geospatial intelligence with a digital monitoring system not only highlights a way in which this can be achieved but provides a model of governance to make decisions related to development in such regions.

**Patents**

Not applicable

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**Conflicts of Interest:**

The authors declare no conflicts of interest.

**Abbreviations**

The following abbreviations are used in this manuscript:

NDVI Normalized Difference Vegetation Index

LULC Land Use Land Cover

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