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Blueprint for security and development: A four-layer geospatial intelligence framework for sustainable governance in the naxal-affected bastar Region, India

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Abstract

The Naxal-affected Bastar region of Chhattisgarh, India, represents one of the most complex geopolitical landscapes where immense natural resource wealth coexists with extreme underdevelopment and persistent insurgency. This study addresses the critical 'data vacuum' in this inaccessible conflict zone by designing, implementing and validating a comprehensive Four-Layer Geospatial Intelligence (GEOINT) Framework. Layer 1 constructs a canopy-compensated digital twin through multi-sensor data fusion (Sentinel-1 SAR, Sentinel-2 optical, ALOS PALSAR DEM), producing a high-precision Land Use/Land Cover classification and terrain model. Layer 2 maps the previously 'unmapped' human terrain through systematic grid-based manual digitization of over 1,200 settlements, coupled with Night-Time Lights analysis for electrification proxy assessment. Layer 3 quantifies the 'tyranny of distance' through a weighted friction surface model of infrastructure accessibility, revealing critical healthcare connectivity gaps. Layer 4 synthesizes all preceding layers into predictive models: a Security Risk Surface and a Development Suitability Model, integrated via a 2x2 Policy Matrix classifying the landscape into Golden Zones, Contested Zones, Stable Zones and No-Go Zones. Statistical validation using geolocated conflict incident data (2015-2024) confirms significant correlation ($p < 0.05$) between modeled high-risk zones and actual insurgent activity. The framework demonstrates that security and development in Bastar constitute a coupled socio-spatial system where geographic isolation, forest density and governance deficits are mutually reinforcing. This research provides a replicable, open-source methodology for integrated conflict-development analysis using exclusively unclassified geospatial data, applicable to other inaccessible conflict-affected regions globally.

Keywords: Geospatial intelligence; Multi-criteria decision analysis; Land use/land cover; Security risk modeling; Development suitability; Naxal insurgency; Left Wing Extremism; Bastar region; Remote sensing; GIS; Conflict geography

Introduction

The evolution of geospatial science in the twenty-first century signifies one of the most consequential technological transformations in spatial decision-making, governance and national security. Geographic Information Systems (GIS), Remote Sensing (RS), Global Navigation Satellite Systems (GNSS) and geospatial analytics have transitioned from tools of cartographic visualization to strategic instruments of governance and intelligence. Contemporary geospatial capabilities extend into predictive analytics, real-time monitoring, early warning systems, humanitarian response, security planning, precision agriculture and environmental management (Gao, 2021; Goodchild, 2007; Kitchin, 2014) [16, 19, 28]. As digital capabilities deepen, geospatial techniques increasingly serve as the backbone of sustainable development and security operations in regions marked by socio-political conflict, environmental vulnerability and developmental challenges.

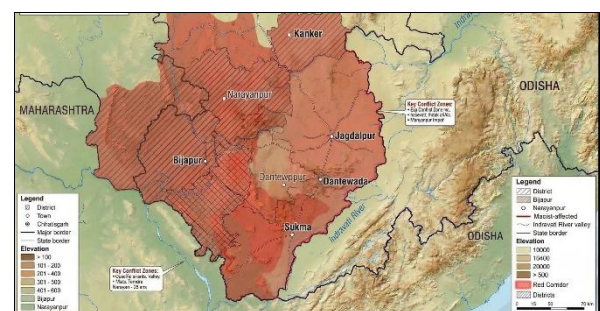
The integration of advanced technologies, including Artificial Intelligence (AI), Machine Learning (ML), Deep Learning, Big Data analytics, Internet of Things (IoT), cloud computing and high-resolution satellite constellations, has substantially enhanced the potential of geospatial science. Geospatial Intelligence (GEOINT), which synthesizes spatial science with high-end analytics, now plays an indispensable role in national security, counterinsurgency operations, border management, ecological monitoring and disaster preparedness (Coorey, 2018; National Research Council, 2010) [9]. In India, where vast

Geographical expanses encompass dense forests, fragile ecosystems, mineral-rich belts and socio-politically sensitive regions, geospatial technologies have become essential for informed governance. The Naxal-affected Bastar region of Chhattisgarh emerges as a strategically significant case for the application of geospatial science. Located in the southern part of Chhattisgarh, Bastar encompasses dense deciduous forests, hill ranges, extensive plateaus, rivers including the Indravati and tribal communities such as the Gonds, Muria, Maria, Dorla and Bhatra whose livelihoods are deeply intertwined with the natural environment (Elwin, 1947; Sundar, 2007) [12, 41]. Despite its natural richness, Bastar remains one of India's most socio-economically backward regions, characterized by persistent naxal insurgency, infrastructural deficits, governance challenges and complex socio-political dynamics between the State, local communities and insurgent groups. Bastar's rugged landscape, dense forests, scattered settlements, limited road infrastructure and sparse telecommunication networks have historically complicated governance and service provision. The region, part of the larger 'Red Corridor' spanning multiple Indian states, is regarded as one of the most strategically challenging areas for both security forces and development organizations (Ministry of Home Affairs, 2023). The insurgency has impacted every facet of regional life, affecting access to education, healthcare, basic services, economic development, mobility, and market access and resource management. In this context, geospatial technologies present a robust framework for comprehensively analyzing the landscape, detecting insurgency trends, planning developmental initiatives, assessing environmental transformations and bolstering governance systems. Remote sensing facilitates observation of remote forest interiors where field surveys are challenging; GIS offers layered mapping that combines socio-economic, environmental, infrastructural and security data into cohesive decision-support systems; and high-resolution satellite imagery aids in identifying deforestation trends, illegal mining locations and changing settlement patterns (Ayam *et al.* 2020; Hassan *et al.* 2016) [3, 22]. The mineral resources of Bastar, particularly the high-grade hematite iron ore of the Bailadila range, present both economic opportunities and environmental challenges. These Archean-age banded iron formations, mined primarily by the National Mineral Development Corporation (NMDC), contribute significantly to regional economic potential through establishments such as the Nagarnar Integrated Steel Plant, while simultaneously raising environmental concerns, socio-political disputes and resource management challenges. The Maoist movement commonly known as Naxalism or Left Wing Extremism, emerging in the late 1960s as a radical agrarian movement advocating land reforms and socio-economic justice, gradually spread into forested areas where government presence was minimal and developmental neglect was significant. The consolidation of major Naxalite groups into the Communist Party of India (Maoist) in 2004 marked a pivotal escalation of insurgency activities. The Indian government has recognized Left Wing Extremism as one of the most severe internal security threats, leading to increased clashes between insurgent factions and security forces. This research is motivated by a central problem: the lack of comprehensive, real-time, geospatially informed data systems for security, governance, resource management

and development planning in the Naxal-affected region of Bastar. This 'data vacuum' is created and sustained by the long-standing insurgency, resulting in outdated topographic maps, fragmented datasets among government departments, restricted access to high-resolution satellite imagery, absence of continuous environmental monitoring and unreliable land-use and resource maps. This data deficit leads to improper planning, slow development and misallocation of resources. The present study aims to bridge this gap by designing, testing and validating a replicable, unclassified and open-source geospatial framework, the Four-Layer Blueprint, capable of simultaneously addressing the region's entrenched challenges including topographical isolation, insurgency, infrastructural underdevelopment, environmental vulnerability and socio-economic marginalization. The study utilizes a suite of advanced geospatial techniques including multi-sensor satellite imagery (optical and Synthetic Aperture Radar), Geographic Information Systems and multi-criteria spatial analytics to create a multi-layered digital twin of the Bastar region, serving as the primary analytical foundation for integrated security and development planning.

2. Study area

The Bastar Division of Chhattisgarh comprises seven districts: Bastar (Jagdalpur), Dantewada, Sukma, Bijapur, Kanker, Kondagaon and Narayanpur. Geologically, the region represents an extension of the Deccan Plateau, with the Bailadila Range hosting some of the world's highest-grade hematite iron ore deposits. The forests, constituting part of the vast Dandakaranya belt, are dense, biodiverse and rich in non-timber forest products (NTFPs) including tendu leaves, mahua and bamboo, which form the backbone of the local tribal economy. The Indravati River, considered the region's lifeline, traverses the landscape creating significant features including the Chitrakoot waterfalls (Map-1(b)).



coexisting with extreme poverty constitutes what scholars term the 'resource curse,' where development, when it arrives, is perceived as extractive, designed to remove resources while leaving local populations displaced and destitute. The insurgency thrives on these grievances, while the government argues that delivery of development infrastructure is impeded by the insurgency itself, which actively targets such infrastructure.

The study area boundaries were defined not solely by administrative district lines but also by the 'Security Vacuum' zones identified in Ministry of Home Affairs reports, ensuring the research focused on the core of the crisis rather than its periphery. This purposive selection approach identified Bastar as a 'Critical Case' where significant resource potential paradoxically coexists with severe infrastructural isolation.

3. Materials and Methods

3.1 Research design

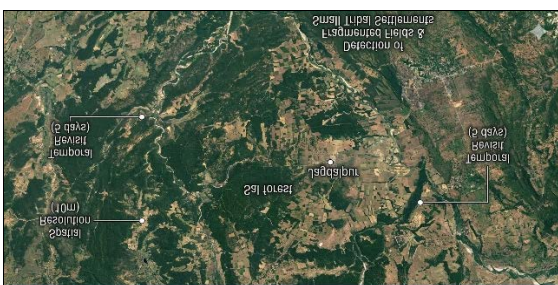
This study adopts a geospatial-first, sequential explanatory mixed-methods design organized around the creation of four distinct, interconnected geospatial layers. The methodology is fundamentally integrated and multidimensional, emphasizing the interdependence of security concerns, developmental deficits, and environmental change and governance structures. Quantitative spatial analysis, spectral interpretation, GIS-based modeling and machine learning techniques form the scientific-technical backbone, while qualitative inquiry through key informant interviews and participatory mapping exercises ensures that tribal perspectives, administrative challenges and socio-political nuances are incorporated.

3.2 Data sources and database architecture

Acknowledging that no single sensor can fully capture the intricacies of Bastar's landscape, particularly given persistent monsoon cloud cover and dense tropical forests, the database incorporates data across the electromagnetic spectrum: optical (surface reflectance), Synthetic Aperture Radar (structural backscatter) and thermal (anthropogenic emissions). The database follows a hybrid architecture combining file-based geodatabases for high-resolution imagery with structured metadata protocols.

3.2.1 Raster database

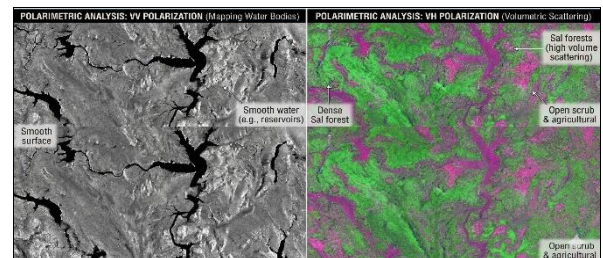
The raster database provides the spectral and radiometric foundation of the study. The Optical Backbone comprises Sentinel-2 Multi-Spectral Instrument (MSI) Level-2A data from the European Space Agency (ESA), selected for its 10-meter spatial resolution and 5-day temporal revisit capability, crucial for detecting fragmented agricultural fields and small tribal settlements (Map-4.1.1(b)).



Map-4.1.1(B): The optical backbone- sentinel-2 msi

The Structural Penetrator consists of Sentinel-1 C-band SAR data, a key innovation enabling all-weather observation. The database includes both VV (Vertical-Vertical) and VH (Vertical-Horizontal) polarizations: VV for water body mapping and VH for volumetric scattering analysis to distinguish dense Sal forests from open scrubland (Map-4.1.1(c)).

The Terrain Architect utilizes the ALOS PALSAR Radiometric Terrain Corrected (RTC) Digital Elevation Model at 12.5-meter resolution, a significant improvement over standard 30-meter SRTM DEM. This resolution enables precise calculation of tactical variables such as the Topographic Ruggedness Index (TRI) (Fig-4.1.1(c)).



Map- 4.1.1(c): The structural penetrator- sentinel 1 SAR

Night-Time Lights data from the Visible Infrared Imaging Radiometer Suite (VIIRS) provides proxy indicators of electrification and state presence. The raster database multi-temporal, multi-sensor stack is illustrated in Fig-4.1.1(a).

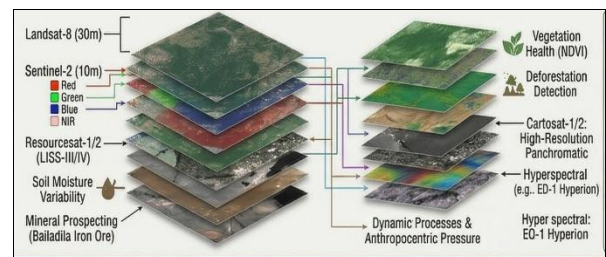
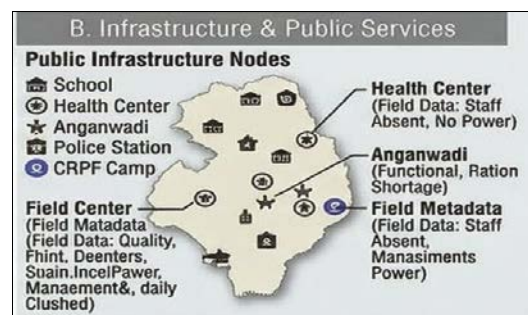


Fig- 4.1.1(a): The raster database multi-temporal, multisensor stack

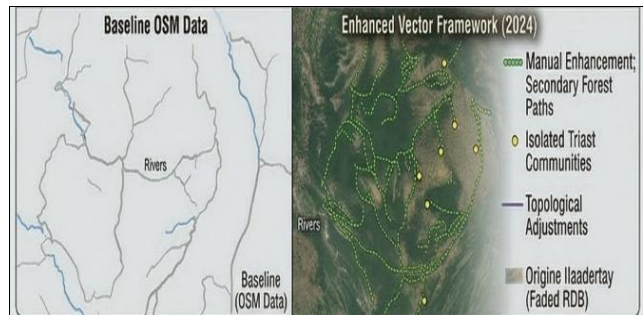
3.2.2 Vector database

The vector database contextualizes the terrain through multiple thematic layers including administrative boundaries (state, district, block, panchayat, village), road networks from highways to forest paths, river networks and drainage lines, settlement footprints, public infrastructure nodes (schools, health centers, Anganwadis, ration shops, police stations, CRPF camps), agricultural parcels, mining lease boundaries, forest compartment lines and protected area boundaries (Map-4.2.2(a)).



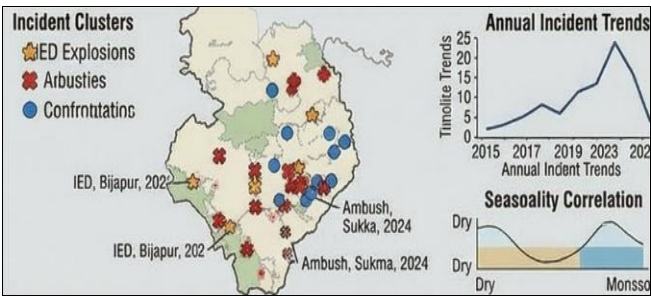
Map 4.2.2(A): Infrastructure & public service

OpenStreetMap (OSM) data served as the initial skeleton framework for road and river networks. However, visual comparison with satellite imagery revealed notable omissions, particularly regarding secondary forest paths and isolated tribal communities, necessitating extensive manual enhancement and topological adjustments (Map-4.2.2(b)). Demographic data were sourced from the 2011 District Census Handbook, supplemented by the Local Government Directory (LGD) for official village boundaries.



Map 4.2.2 (b): OpenstreetMap as a skeleton framework & enhancement

A specialized Conflict Incident Database was created by extracting and geocoding data from the South Asia Terrorism Portal (SATP) and the Armed Conflict Location & Event Data Project (ACLED), covering 2015-2024, classifying incidents into IED explosions, ambushes and confrontations (Map-4.2.2(c)).



Map 4.2.2 (C): The conflict database

3.2.3 Database management

All datasets were standardized to WGS 84 / UTM Zone 44N (EPSG: 32644) for accurate metric calculations. The study employed the OGC GeoPackage (.gpkg) standard for unified storage. Data organization followed a hierarchical structure: Raw Data, Pre-Processing, Analysis and Final Product. Pre-processing included atmospheric correction via Sen2Cor, geometric co-registration using Ground Control Points (bridges and road intersections) with RMSE less than 0.5 pixels, cloud masking with temporal median compositing and hydrological conditioning of DEM datasets.

3.3 The Four-layer geospatial blueprint methodology

The analytical framework is organized around the sequential construction of four interconnected geospatial layers, transitioning from physical reality to strategic modeling. All geospatial analysis was conducted using QGIS 3.34 (Prizren) for vector and raster manipulation and Google Earth Engine (GEE) for cloud-based computational tasks, particularly Random Forest classification (Fig-4.2.12).

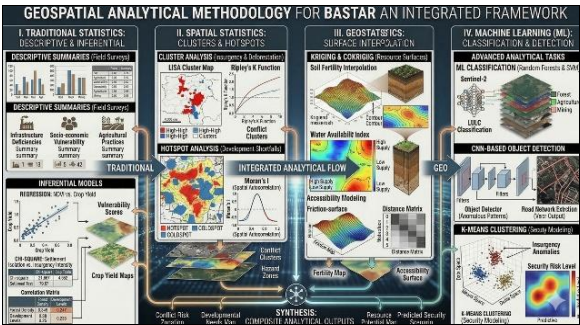


Fig 4.2.12: Geospatial analytical methodology

3.3.1 Layer 1: The physical baseline

The Random Forest (RF) algorithm within Google Earth Engine was employed for Land Use/Land Cover classification. RF was selected over Maximum Likelihood Classification due to its non-parametric nature, enabling handling of high-dimensional data and complex, non-linear relationships. A 'Feature Stack' was created comprising: (i) Optical Bands: Sentinel-2 Blue, Green, Red, NIR, SWIR1, SWIR2; (ii) Spectral Indices: NDVI (Vegetation), NDWI (Water), NDBI (Built-up); (iii) Radar Backscatter: Sentinel-1 VV and VH bands (smoothed with Lee Speckle Filter); and (iv) Topographic Variables: Elevation, Slope and Aspect from ALOS PALSAR DEM. In the absence of field GPS points, 'virtual ground-truthing' was conducted using high-resolution Google Earth imagery. Over 600 Regions of Interest (ROIs) were digitized across eight classes: Dense Forest, Open Forest, Scrubland, Agriculture (Kharif/Rabi), Mining/Barren, Water Bodies and Built-up. A split-sample validation approach (70% training, 30% validation) generated a Confusion Matrix calculating Kappa Coefficient and Overall Accuracy, targeting the academic standard of exceeding 85%. Advanced terrain modeling derived the Topographic Ruggedness Index (TRI) from the ALOS PALSAR DEM. Unlike slope, which measures steepness, TRI measures elevation difference between a central pixel and its eight neighbors, a crucial variable for security modeling as insurgents utilize rugged terrain for concealment and movement.

3.3.2 Layer 2: The human terrain

Systematic grid-based manual digitization was employed to map 'unmapped' settlements. A 5km x 5km vector grid covered the entire study area and each cell was systematically scanned at 1:5,000 scale using high-resolution base imagery. Every visible cluster of three or more structures was digitized as a polygon, ensuring capture of subtle visual signatures of tribal hamlets that automated algorithms often misclassify. These polygons were joined with Census 2011 attributes where spatial correspondence existed. Zonal Statistics for electrification modeling employed VIIRS Night-Time Lights data overlaid on the settlement layer. The algorithm calculated mean radiance values within each settlement polygon. A threshold based on known electrified control points (Jagdalpur peri-urban areas) classified settlements as 'Dark/Un-electrified' or 'Light/Electrified,' creating a binary map of state connectivity.

3.3.3 Layer 3: the connectivity matrix

A Weighted Friction Model was developed to quantify infrastructure gaps. In conflict zones, Euclidean distance is

insufficient; accessibility is defined by terrain 'friction' and network quality. A Cost Raster was generated where every pixel value represents time cost to traverse it: Paved National Highway (Base Cost = 1), Unpaved District Road (5), Open Scrubland (15), Dense Forest (50), Steep Slope >30 degrees (100) and River without Bridge (500). Using the QGIS Network Analysis toolkit, isochrones (contours of equal travel time) were calculated from key service nodes (Primary Health Centers and Police Stations). A spatial difference operation identified settlements outside the 60-minute travel time isochrone of any health center as 'Critical Infrastructure Gap Zones.'

3.3.4 Layer 4: The strategic synthesis

Multi-Criteria Decision Analysis (MCDA) using Weighted Linear Combination (WLC) integrated preceding layers into two predictive models. The Security Risk Model defines risk as geographic favorability for insurgent operations. Variables normalized on a 1-10 scale included: Forest Cover Density (Weight: 0.35), Topographic Ruggedness TRI (0.25), Proximity to Paved Roads (0.20) and Proximity to State Borders (0.20). Risk Index equals the sum of each variable multiplied by its weight. The Development Suitability Model identifies optimal locations for infrastructure expansion based on: Slope (Weight: 0.30), Infrastructure Gap Index (0.40) and Population Density (0.30). The final Policy Blueprint employed Bivariate Mapping through a 2x2 Policy Matrix: Quadrant I (High Suitability/Low Risk) represents the 'Golden Zone' for immediate investment; Quadrant II (High Suitability/High Risk) represents 'Contested Zones' requiring security saturation; Quadrant III (Low Suitability/Low Risk) represents 'Stable Zones' for maintenance; and Quadrant IV (Low Suitability/High Risk) represents 'No-Go Zones' requiring containment strategies.

3.3.5 Statistical validation

A Chi-Square test was employed to validate the Security Risk Model by testing the correlation between modeled 'High Risk' zones and actual geolocated incidents of IED blasts and ambushes (2015-2024). A statistically significant correlation ($p < 0.05$) confirms the predictive power of the model.

3.4 Qualitative methods

Fieldwork was structured in phased, adaptable modules including: (i) access preparation with administrative permissions and police coordination; (ii) ground truthing for LULC validation, NDVI verification and terrain model refinement; (iii) participatory spatial inquiry through Focused Group Discussions (FGDs) with tribal students and internally displaced persons in peri-urban safe zones using PRA tools including Timeline Analysis and Mobility Mapping and (iv) validation-refinement cycles integrating field observations with GIS outputs. Weather data analysis utilized 10-year historical precipitation data from the CHIRPS satellite dataset, with Ombrothermic Diagrams prepared to correlate rainfall peaks with conflict hotspots, revealing the 'monsoon pause' phenomenon of reduced logistical mobility and insurgent activity during July-August (Fig-4.2.6).

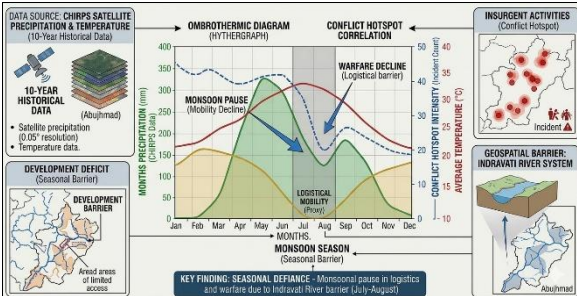
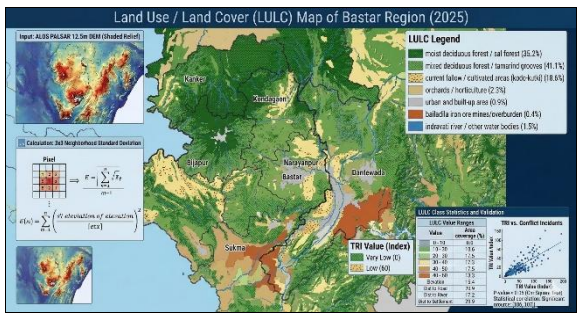


Fig 4.2.6: Weather data capture & seasonal barrier diagram

4. Results

4.1 Physical geography and environmental landscape: Layer 1

The canopy-compensated digital twin of Bastar was successfully constructed using multi-sensor data fusion, revealing the profound influence of natural geography on regional development and security trajectories (Map-5.2.2).



Map 5.2.2: LULC Map of Bastar

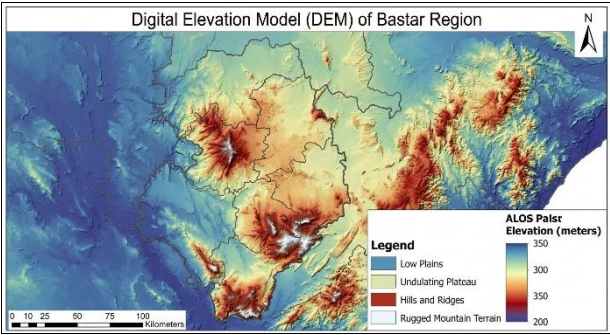
4.1.1 Terrain morphology

Analysis of the ALOS PALSAR 12.5m DEM revealed complex plateau-forested landscapes of the Deccan shield. The Terrain Ruggedness Index analysis demonstrated that large portions of southern Bastar exhibit high ruggedness values, significantly influencing both insurgency dynamics and infrastructure development (Map-5.2.1-a and Map-5.2.1-b)

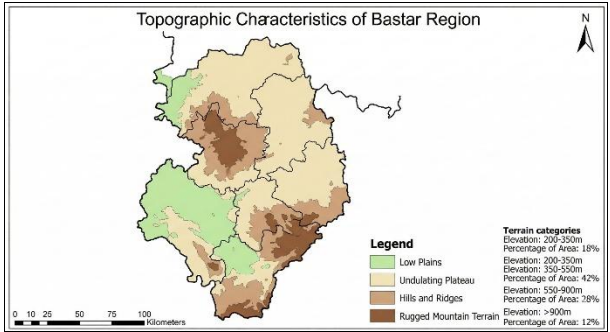
Table 1: Topographic characteristics of the Bastar region.

Terrain Category	Elevation Range (m)	Percentage of Area	Spatial Distribution
Low Plains	200-350	18%	River valleys and agriculture zones
Undulating Plateau	350-550	42%	Central Bastar
Hills and Ridges	550-900	28%	Abhujmad and Bailadila
Rugged Mountain Terrain	>900	12%	Southern Dantewada and Sukma

Rugged terrains create natural barriers for road construction, administrative access and security patrol mobility while simultaneously providing natural cover for insurgency operations and enabling guerrilla warfare strategies.



Map 5.2.1-A: Digital elevation model of bastar



Map 5.2.1-b: Topographic characteristics of bastar

4.1.2 Land use and land cover classification

Integrated classification using Sentinel-1 (Radar) and Sentinel-2 (Optical) data fusion produced a high-precision LULC baseline. The Random Forest classifier achieved acceptable accuracy standards with the inclusion of radar and topographic variables enabling distinction between classes based on texture and position.

Table 2: Land use/land cover classification of the Bastar region.

LULC Class	Area (Sq. Km)	Percentage (%)	Description/Significance
Dense Forest	12,450	32.7	Core habitat; high volume scattering; primary insurgent cover
Open Forest	9,820	25.8	Transition zones; secondary growth; movement corridors
Scrubland	5,140	13.5	Degraded lands; often bordering tribal hamlets
Agriculture (Kharif/Rabi)	7,680	20.2	Primary tribal livelihood; mostly rain-fed
Mining/Barren	1,240	3.3	Focused on Bailadila; high-grade iron ore deposits
Built-up/Settlement	950	2.5	Urban centres (Jagdalpur) and rural paras
Water Bodies	720	2.0	Including Indravati river and seasonal streams

Forests dominate over 70% of the landscape, agricultural land is highly fragmented and largely rain-fed and settlement footprints remain extremely sparse. The 'Structural Penetrator' (SAR) enabled differentiation of dense Sal forests from open scrubland, a distinction often obscured in standard optical imagery (Map-5.2.2).

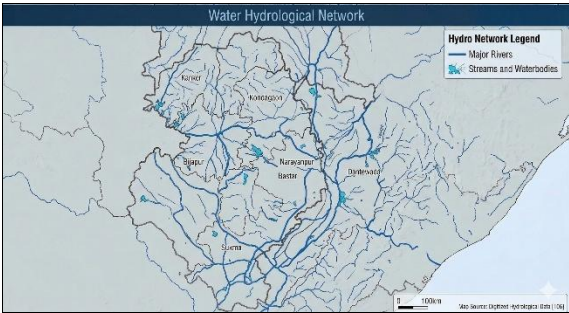
4.1.3 Hydrological networks

Hydrological analysis identified major river systems including the Indravati, Sabari, Shankini and Dankini, with 112 seasonal streams and 14 reservoirs mapped across the

study area (Map-5.2.3). Rivers serve dual roles: providing irrigation potential and ecosystem services while acting as physical barriers for connectivity and causing seasonal isolation during monsoon periods.

Table 3: Hydrological features of the Bastar region.

Features	Number/Length
Major Rivers	4
Seasonal Streams	112
Reservoirs	14



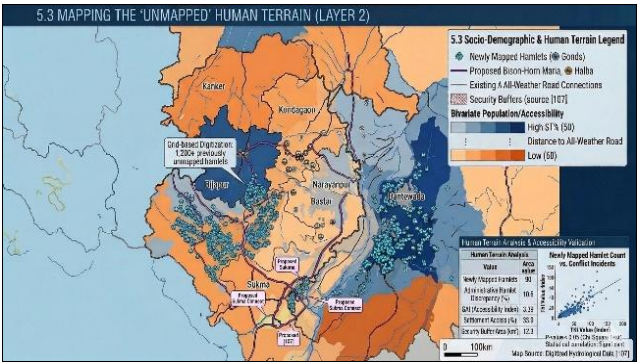
4.2 Mapping the human terrain: Layer 2

A central finding of this research is the critical inconsistency between official administrative claims and the objective reality visible from space. Systematic grid-based manual digitization identified over 1,200 previously unmapped or inaccurately geolocated hamlets (paras), revealing a severe spatial data gap in governance records (Map-5.3).

Table 4: Settlement distribution in the Bastar region.

Settlement Category	Number
Major Towns	7
Large Villages	168
Medium Villages	541
Small Hamlets	1,132
TOTAL	1,848

Many settlements remain unrecorded in official government databases, confirming the presence of a severe spatial data gap that directly affects development planning and service delivery.



Map 5.3: Layer2 human terrain

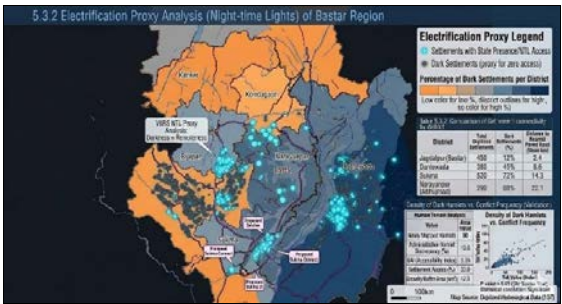
4.2.1 Electrification proxy analysis

Overlaying VIIRS Night-Time Lights data on settlement footprints revealed stark disparities in state connectivity across districts:

Table 5: Comparison of settlement connectivity by district.

District	Total Settlements	Dark Settlements (%)	Mean Distance to Paved Road (km)
Jagdalpur (Bastar)	450	12%	2.4
Dantewada	380	45%	8.6
Sukma	520	72%	14.3
Narayanpur (Abhujmad)	290	88%	22.1

A direct spatial correlation exists between excessive ruggedness and dark settlements, suggesting that the state's reach diminishes where terrain becomes complex. Dark settlements are predominantly located in dense forests, high ruggedness zones and far-flung administrative regions, areas that also correspond strongly with insurgency influence (Map-5.3.2).



Map 5.3.2: Electrification proxy

4.3 Infrastructure accessibility: Layer 3

The Weighted Friction Model demonstrates that Euclidean distance is insufficient for measuring accessibility in Bastar. A 10km distance in the Abujhmad forest represents a significantly higher traversal 'cost' than 10km on the plains of Jagdalpur (Map-5.4).

4.3.1 Road network analysis

The integrated road network model classified roads into four categories, revealing severe last-mile connectivity deficits

Table 6: Road infrastructure in the Bastar region.

Road Type	Length (km)
National Highways	246
State Highways	512
District Highways	780
Unpaved Roads	2,340

Nearly 60% of transportation routes consist of unpaved or seasonal tracks. High-resolution imagery revealed that many 'official' roads in the Local Government Directory are overgrown with vegetation or breached by seasonal streams, rendering them non-functional for medical emergencies.

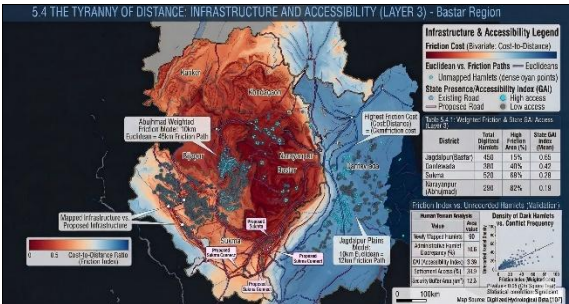
4.3.2 Healthcare accessibility

Network analysis of Primary Health Centre (PHC) accessibility revealed critical healthcare gaps

Table 7: Distance to nearest primary health centre.

Distance to Nearest PHC	Percentage of Settlements
< 5 km	28%
5-10 km	32%
10-20 km	25%
> 20 km	15%

Sixty-four percent of identified interior settlements fall outside the 60-minute travel time isochrone for any PHC, representing operationally disconnected populations. This spatial inequality directly affects infant mortality, maternal health outcomes and disease outbreak response.



Map 5.4: Distance to Infrastructure and Accessibility- Layer3

4.4 Security landscape and spatial risk modeling: Layer 4

The final phase of analysis integrated physical, human and infrastructural layers into two Multi-Criteria Decision Analysis models: the Security Risk Surface and the Development Suitability Model.

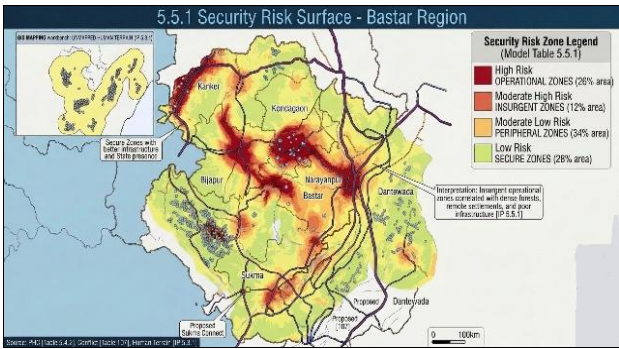
4.4.1 Security Risk Surface

The model identified 'high-risk corridors' by correlating forest density (0.35 weight) and ruggedness (0.25 weight) with the Conflict Incident Database. Statistical validation using a Chi-Square test confirmed a significant correlation ($p < 0.05$) between modeled surfaces and actual geolocated incidents of IED blasts and ambushes (2015-2024).

Table 8: Security risk zone distribution

Risk Category	Area Coverage
Low Risk	28%
Moderate Risk	34%
High Risk	26%
Very High Risk	12%

High-risk areas demonstrate strong correlation with dense forests, remote settlements and poor infrastructure connectivity, zones that function as insurgent operational areas (Map-5.5.1).



Map 5.5.1: Security Risk Zones

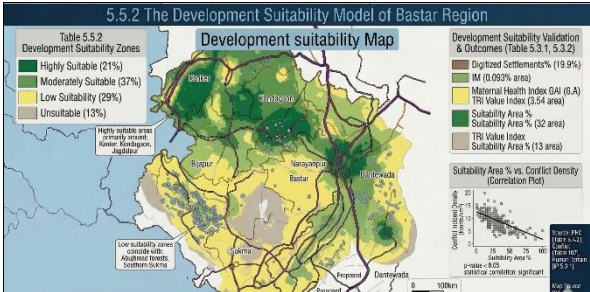
4.4.2 Development suitability model

The Development Suitability Model integrates terrain slope, distance to roads, settlement density, land cover and water availability to identify optimal locations for infrastructure expansion:

Table 9: Development suitability zone distribution

Suitability level	Area coverage
Highly Suitable	21%
Moderately Suitable	37%
Low Suitability	29%
Unsuitable	13%

Highly suitable areas are located primarily around Jagdalpur, Kondagaon and Kanker, while low suitability zones coincide with Abhujmad forests and southern Sukma (Map-5.5.2).



Map 5.5.2: Development suitability map

4.4.3 The integrated policy matrix

Overlaying the Security Risk Surface and Development Suitability Model produced a 2x2 Policy Matrix classifying every pixel into strategic intervention categories:

Table 10: The 2x2 Policy Matrix for strategic intervention.

Quadrant	Risk Profile	Suitability Profile	Strategic Recommendation
Golden Zone	Low	High	Immediate, high-impact development and market intervention
Contested Zone	High	High	High social need; requires security saturation before infrastructure
Stable Zone	Low	Low	Maintenance of existing services; forest conservation focus
No-Go Zone	High	Low	Core forest; focus on containment and tribal forest rights (FRA)

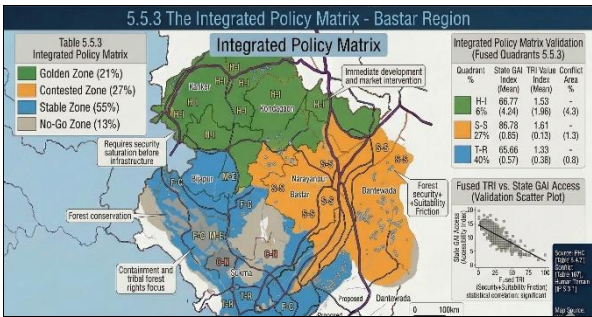
This matrix provides spatially explicit guidance for differentiated governance strategies across the entire Bastar landscape (Map-5.5.3).

4.5 Environmental and resource management findings

Satellite image analysis indicates increasing pressures on Bastar's ecosystems. Mining activity is particularly concentrated in the Bailadila iron ore region, raising concerns regarding ecological sustainability (Map-5.6).

Table 11: Environmental change indicators

Indicator	Trend
Forest Loss	Moderate Localized
Mining Expansion	Increasing
Water Body Shrinkage	Seasonal
Soil Erosion	Moderate



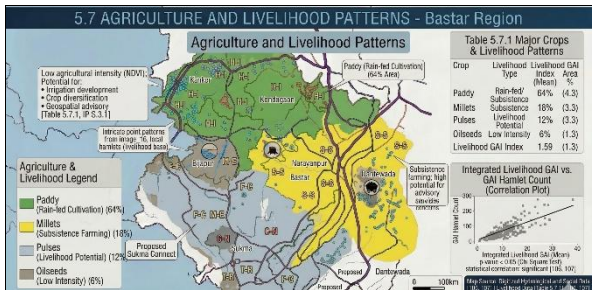
Map 5.5.3: Integrated policy matrix

4.6 Agriculture and livelihood patterns

Agriculture in Bastar is characterized by rain-fed cultivation, low productivity and subsistence farming. NDVI analysis indicates low agricultural intensity, highlighting potential for irrigation development, crop diversification and geospatial advisory services (Map-5.7).

Table 12: Major crop distribution by area share

Crop	Area Share
Paddy	64%
Millets	18%
Pulses	12%
Oilseeds	6%



Map 5.7: Agriculture and Livelihood Patterns

4.7 Qualitative insights

Focus Group Discussions with internally displaced persons from Bijapur interior confirmed the GIS friction values through mobility mapping exercises. An IDP participant validated that the 'data vacuum' is not merely about absent cartographic features but about the failure of existing traces to represent the lived experience of physical barriers. The FGDs revealed dimensions not captured in government records, including situations experienced by the local indigenous population, highlighting the need for two-way pathways: reducing insurgency while simultaneously providing accessibility, infrastructure and awareness to local populations.

5. Discussion

The findings of this study demonstrate that security and development in the Bastar region constitute a coupled socio-spatial system where geography, insurgency, governance and development interact dynamically. The Four-Layer Geospatial Blueprint provides evidence for several critical interrelationships that have implications for both theory and practice.

5.1 Geography as a strategic variable

The terrain morphology analysis reveals that Bastar's physical geography is not merely an environmental context

but an active strategic factor shaping patterns of governance and conflict. The rugged terrain and extensive forest cover offer decisive advantages to insurgent groups, enabling mobility and concealment in remote areas that remain difficult for security forces to access (Fearon & Laitin, 2003; Berman & Laitin, 2008) ^[4, 14]. The Topographic Ruggedness Index (TRI) analysis quantifies this relationship, demonstrating that high-ruggedness zones coincide with both insurgent operational areas and infrastructure development challenges. This finding aligns with the conflict geography literature, which establishes that terrain complexity, forest density and remoteness are systematically exploited by guerrilla movements (Hoelscher *et al.* 2012; Mukherjee, 2017) ^[23, 32].

The 'weaponization of geography' observed in Bastar, where insurgents have systematically exploited the dense triple-canopy tropical moist deciduous forests and rugged undulating terrain, confirms the theoretical framework proposed by conflict geographers. The natural barriers created by hills, plateaus and rivers have been transformed into military assets, making the construction and protection of roads a high-risk endeavor. This finding has direct implications for counterinsurgency strategy, suggesting that terrain-informed geospatial intelligence must precede operational planning.

5.2 The Resource paradox

The Bailadila iron ore belt, while economically critical, exhibits high Security Risk rankings due to the rugged terrain and the weaponization of geography by insurgents. This paradox, where mineral wealth coexists with security vulnerability, reflects the broader 'resource curse' dynamics observed in conflict-affected resource-rich regions globally (Homer-Dixon, 1991) ^[24]. The LULC classification reveals that mining areas constitute only 3.3% of the landscape yet generate disproportionate economic and security attention, highlighting the need for balanced approaches that consider both extraction potential and ecological and social sustainability.

The environmental monitoring findings indicate moderate localized forest loss and increasing mining expansion. Mining activity concentrated in the Bailadila region raises significant ecological sustainability concerns that geospatial monitoring can help address through real-time detection of boundary breaches, illegal extraction and land degradation. The integration of sustainable extraction practices with ecological impact tracking, as enabled by the Four-Layer Blueprint, offers a pathway toward resolving this paradox.

5.3 The human terrain and governance deficits

The identification of over 1,200 previously unmapped settlements represents a critical finding with profound governance implications. When settlements are not accurately mapped, they are systematically excluded from development schemes, infrastructure planning and welfare programs. This administrative invisibility perpetuates cycles of marginalization and, as the FGDs confirmed, fuels the insurgent narrative that the state is absent or indifferent to tribal welfare.

The electrification proxy analysis reveals a direct spatial correlation between state absence and insurgency influence. Districts such as Narayanpur (Abhujmad), where 88% of settlements are classified as 'Dark,' represent zones where the state's reach has effectively ceased, creating governance

vacuums that insurgents fill. This finding validates the theoretical proposition that insurgency thrives not merely in poor areas but in areas where the state is spatially absent.

5.4 The tyranny of distance and infrastructure gaps

The finding that 64% of interior settlements fall outside the 60-minute travel time isochrone for any Primary Health Center quantifies the spatial dimension of healthcare inequality in Bastar. This is not merely a matter of distance but of terrain complexity, road quality and security conditions that compound to create effective isolation. The weighted friction model demonstrates that standard Euclidean distance metrics significantly underestimate the true accessibility challenges in this terrain.

The discrepancy between official road maps and ground reality, where many 'official' roads are overgrown or breached, reveals a critical data quality issue. Government datasets that do not reflect actual traversability lead to flawed planning assumptions and resource misallocation. The systematic digitization and quality assessment of the road network performed in this study addresses this gap, providing a more realistic foundation for infrastructure planning.

5.5 The agriculture-security nexus

NDVI analysis indicates that agricultural productivity is lowest in 'dark settlements' far from paved roads, establishing a direct link between connectivity and livelihood security. Agriculture in Bastar remains predominantly rain-fed and subsistence-oriented, with paddy occupying 64% of cultivated area. The correlation between low agricultural intensity, settlement isolation and insurgency presence suggests that livelihood insecurity is both a consequence and a driver of conflict. This finding supports the argument that development interventions targeting agricultural productivity, irrigation infrastructure and market connectivity can serve dual security-development objectives.

5.6 Integrated framework performance

The statistical validation of the Security Risk Model, confirming significant correlation ($p < 0.05$) between modeled high-risk zones and actual geolocated conflict incidents, demonstrates that an integrated geospatial framework using exclusively unclassified, open-source data can produce actionable security intelligence. This finding addresses a critical gap in the literature, where military GEOINT methods are typically classified and inaccessible to civilian researchers and development planners (Coorey, 2018; Clarke, 2001) ^[8, 9].

The 2x2 Policy Matrix represents a novel contribution by simultaneously visualizing security risk and development potential, enabling policymakers to move beyond binary security-or-development approaches toward integrated strategies tailored to specific landscape conditions. The identification of 'Golden Zones' (Low Risk, High Suitability), 'Contested Zones' (High Risk, High Suitability), 'Stable Zones' (Low Risk, Low Suitability) and 'No-Go Zones' (High Risk, Low Suitability) provides a spatially explicit decision-support tool.

5.7 Methodological innovation

This study demonstrates that the 'data vacuum' of an inaccessible conflict zone can be overcome through multi-

sensor data fusion, virtual ground-truthing and secondary data triangulation. The fusion of Sentinel-1 SAR (structural information) with Sentinel-2 optical (spectral information) and ALOS PALSAR DEM (topographic information) enabled canopy-compensated LULC classification that would be impossible with any single sensor. The 'remote ground-truthing' methodology, using high-resolution reference imagery and systematic virtual digitization, provides a replicable approach for other inaccessible regions.

The Participatory GIS component, involving Screen-Based Participatory Mapping with NGO workers and district planners, demonstrated that geospatial outputs can be validated and enriched through local knowledge integration even when physical access is restricted. This approach addresses ethical concerns about top-down surveillance by incorporating community perspectives into the analytical framework.

6. Policy implications

The Four-Layer Geospatial Blueprint generates actionable implications across multiple domains of governance, security planning and sustainable development. The spatially explicit outputs provide evidence-based foundations for targeted interventions that acknowledge the heterogeneity of the Bastar landscape.

6.1 Security planning

The Security Risk Surface enables predictive deployment of security resources based on geographic favorability for insurgent operations rather than reactive response to incidents. High-risk corridors identified through the MCDA model, validated against historical conflict data, can inform patrol route optimization, outpost siting and vulnerability assessment for critical infrastructure. The integration of terrain analysis (line-of-sight, least-cost path modeling) with forest density and proximity variables provides a comprehensive operational picture. The framework also supports ethical security planning by identifying civilian settlement patterns within risk zones, enabling measures to minimize collateral impact.

6.2 Infrastructure planning

The Development Suitability Model and Infrastructure Gap Analysis provide quantitative foundations for prioritizing road construction, healthcare facility placement and communication tower deployment. The finding that 64% of settlements are outside the 60-minute PHC isochrone establishes a measurable target for healthcare infrastructure investment. The weighted friction model identifies optimal route alignments that minimize terrain cost while maximizing population connectivity. The 'Golden Zone' classification enables phased development strategies that begin with low-risk, high-impact investments and progressively expand into contested areas as security conditions improve.

6.3 Tribal development

The settlement mapping database, identifying over 1,200 previously unmapped hamlets, provides the foundational data required for inclusive development planning. The Night-Time Lights electrification analysis enables targeted prioritization of solar micro-grid installations in 'Dark Settlements,' which are harder for insurgents to disrupt than

traditional high-tension lines. Participatory GIS (PGIS) frameworks should be institutionalized to enable tribal communities to map traditional territories, document Non-Timber Forest Produce (NTFP) zones and support claims under the Forest Rights Act. This approach aligns geospatial technology with social justice and indigenous rights, addressing community distrust in surveillance technologies.

6.4 Environmental monitoring

The LULC classification and change detection capabilities provide foundations for continuous forest monitoring, illegal logging detection and mining impact assessment. The identification of moderate localized forest loss and increasing mining expansion in the Bailadila region establishes baselines for environmental regulation enforcement. Satellite-based forest surveillance systems should be integrated into routine administrative operations, complemented by community-based forest management programs. The hydrological analysis supports watershed management and flood vulnerability assessment, particularly important given the seasonal barrier effects of the Indravati river system.

6.5 Resource management

Geospatial monitoring ensures that mining boundaries are not breached, illegal extraction is detected and critical infrastructure remains secured. The framework supports sustainable extraction practices by tracking ecological effects, identifying patterns of land degradation and assessing socio-environmental impacts of mining operations. Integration of mineral resource mapping with environmental sensitivity indices enables balanced resource governance that considers both economic potential and ecological constraints.

6.6 Governance enhancement

The Four-Layer Blueprint demonstrates that the 'Security Vacuum' is frequently a 'Data Vacuum' first. Without the ability to map settlements and infrastructure gaps, the state cannot provide services that would undermine insurgent recruitment through improved livelihoods and awareness. The establishment of an Integrated Geospatial Data Infrastructure at the state level, consolidating spatial datasets from multiple departments into a centralized platform accessible to planners, administrators and researchers, would significantly improve interdepartmental coordination and evidence-based decision-making.

6.7 Disaster preparedness

The DEM-based terrain analysis, hydrological modeling and weather data integration (CHIRPS dataset) provide foundations for flood, landslide and forest fire early warning systems. The identification of the 'monsoon pause' phenomenon, where reduced mobility during July-August affects both development logistics and insurgent activity, has operational implications for timing of development interventions and security operations.

7. Conclusion

This research has demonstrated the transformative capacity of an integrated Four-Layer Geospatial Intelligence Framework for addressing the security, development and governance challenges of the Naxal-affected Bastar region. By constructing a comprehensive 'Digital Twin' of an

inaccessible conflict zone using exclusively unclassified, open-source geospatial data, this study has overcome the 'data vacuum' that has historically impeded evidence-based planning in the region.

The framework generates several conclusive findings. First, Bastar's physical geography, specifically the dense forest cover (58.5% combined dense and open forest) and rugged terrain (12% mountainous, 28% hilly), functions as a strategic variable that simultaneously enables insurgent operations and impedes development. The canopy-compensated LULC classification, enabled by Sentinel-1 SAR and Sentinel-2 optical fusion, quantifies this relationship with unprecedented precision.

Second, the identification of over 1,200 unmapped settlements reveals a severe administrative data gap that perpetuates cycles of marginalization and exclusion from development schemes. The electrification proxy analysis confirms that state presence, measured through Night-Time Lights, is inversely correlated with terrain complexity and directly correlated with insurgency influence.

Third, the Weighted Friction Model quantifies the 'tyranny of distance' in Bastar, demonstrating that 64% of settlements are operationally disconnected from healthcare services and that official road maps significantly overestimate actual accessibility.

Fourth, the Security Risk Model, validated through Chi-Square testing against geolocated conflict incidents ($p < 0.05$), confirms that geographic variables (forest density, ruggedness, road proximity) are significant predictors of insurgent activity. The Development Suitability Model identifies 21% of the landscape as highly suitable for infrastructure development.

Fifth, the integration of these models through the 2x2 Policy Matrix provides a spatially explicit decision-support tool that classifies the landscape into Golden Zones, Contested Zones, Stable Zones and No-Go Zones, enabling differentiated governance strategies.

This research contributes a replicable, open-source methodological framework for studying inaccessible conflict-affected regions globally. By integrating AI-driven spectral analysis with local qualitative validation through Focused Group Discussions, the framework bridges the gap between 'peacetime' GIS methodologies and military-centric intelligence approaches. The ultimate objective is to transform Bastar from 'Terra Incognita' to 'Terra Cognita,' ensuring that every pixel of geospatial data contributes to saving lives, protecting the environment and fostering inclusive governance.

8. Limitations

1. Several limitations of this study should be acknowledged. First, the absence of physical ground-truthing due to security constraints introduces unavoidable uncertainty into the LULC classification. While virtual ground-truthing using high-resolution reference imagery and split-sample validation were employed, the lack of field GPS points limits the accuracy assessment to internal validation rather than independent verification.
2. Second, the 2011 Census data, while the most comprehensive demographic reference available, is significantly outdated. Population dynamics, including displacement due to conflict and seasonal migration patterns, are not captured in this static dataset.

3. Third, the Night-Time Lights electrification proxy, while useful for large-scale assessment, cannot distinguish between grid electricity, solar micro-grids and other off-grid lighting sources. This binary classification (electrified versus un-electrified) oversimplifies the complex energy access landscape of Bastar.
4. Fourth, the Weighted Friction Model relies on assigned cost values that, while informed by terrain characteristics and qualitative FGD validation, remain somewhat arbitrary. Actual traversal times may vary based on seasonal conditions, security situations and individual mobility capacities.
5. Fifth, the Security Risk Model, while statistically validated, relies on historical conflict incident data that may be incomplete due to underreporting in remote areas. The model predicts geographic favorability for insurgent activity rather than actual insurgent presence or intent.
6. Sixth, ethical concerns regarding the potential dual-use nature of geospatial data in conflict zones remain. While this research prioritizes development applications, the same data could theoretically be used for surveillance purposes that raise privacy and community trust concerns.

9. Future scope

1. Several directions for future research emerge from this study. The integration of high-resolution drone imagery, as the Earth surface and anthropogenic activities are dynamic in nature, would significantly enhance the spatial resolution and temporal currency of the digital twin. Machine learning-based land-cover classification, particularly Convolutional Neural Network (CNN) approaches, could automate the settlement detection process that was manually performed in this study.
2. Longitudinal studies tracking environmental change and infrastructure development over time would enhance understanding of the region's evolving dynamics. The incorporation of additional datasets including high-resolution commercial satellite imagery, LiDAR data for forest structure modeling and real-time IoT sensor networks for environmental monitoring would expand the analytical capabilities of the framework.
3. Collaboration between academic institutions, government agencies and local communities, particularly tribal and indigenous populations, will be essential for sustaining research initiatives and policy implementation. The development of mobile-based geospatial advisory platforms for agricultural extension, building on the NDVI and soil suitability analysis conducted in this study, represents a promising application domain.
4. Future research should also address the ethical dimensions of geospatial surveillance in conflict zones more comprehensively, developing community-centered frameworks for data governance that ensure tribal populations benefit from and have agency over geospatial technologies deployed in their territories.

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