



Climate-Resilient Coastal Tourism in India: A Systematic Review of GIS and Remote Sensing Approaches for Vulnerability Assessment and Sustainable Planning

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Article Info

Article History:

Published: 24 Sept 2026

Publication Issue:

Volume 3, Issue 9
September-2026

Page Number:

415-429

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Abstract:

India's 11,098 km coastline supports beach, heritage, pilgrimage, and island tourism economies that are increasingly exposed to sea-level rise, cyclone intensification, and shoreline erosion. Geographic Information Systems (GIS) and remote sensing (RS) have become the dominant toolkit for assessing coastal vulnerability in India, yet the extent to which this evidence base has been translated into tourism-specific planning guidance remains unclear. This systematic review, conducted according to the PRISMA 2020 framework (Page et al., 2021), synthesises 68 peer-reviewed studies published between 2005 and 2025 that apply GIS/RS methods to coastal vulnerability assessment along the Indian coast. A structured search of Scopus, Web of Science, ScienceDirect, SpringerLink, and MDPI databases, supplemented by grey literature, identified studies which were screened against explicit inclusion and exclusion criteria and appraised for methodological quality across six dimensions. A quantitative synthesis of vulnerability classification outcomes from 34 studies reporting comparable indicator data was undertaken alongside a thematic classification of the wider literature. The review finds that although Coastal Vulnerability Index (CVI) and Digital Shoreline Analysis System (DSAS) methods are well established and geomorphologically robust, fewer than eight percent of studies explicitly incorporate tourism-sector variables such as visitor density, seasonal occupancy, or hospitality infrastructure exposure, and fewer than one in five link vulnerability outputs to spatial planning or regulatory instruments such as the Coastal Regulation Zone framework. Machine-learning-assisted shoreline prediction is an emerging but still marginal methodological trend. The review develops a conceptual framework connecting geospatial vulnerability evidence to tourism planning and policy, and concludes with a ranked set of research priorities aimed at closing the gap between geospatial science and destination-level climate adaptation in India.

Keywords: coastal vulnerability index; remote sensing; GIS; sustainable tourism; climate adaptation; India; systematic review; shoreline change

1. Introduction

1.1 Research Background and Significance

Coastal tourism is among the most spatially concentrated and climate-exposed segments of India's travel economy. Beach destinations in Goa, Kerala, Tamil Nadu, Odisha and West Bengal; heritage and pilgrimage sites such as Puri and Rameswaram; and island destinations in the Andaman and Nicobar archipelago together draw a substantial share of both domestic and international visitor traffic, and the sector's international receipts have grown markedly in recent

years even as the underlying coastline becomes progressively less stable (Down To Earth, 2024). India's coastline, stretching approximately 11,098 km across nine states and four union territories, has been identified as one of the country's four most climate-sensitive zones (Kunte et al., 2014; Sudha Rani et al., 2015), and the pressures of sea-level rise, tropical cyclone intensification, and anthropogenically accelerated erosion are converging precisely where tourism infrastructure, hospitality investment, and coastal livelihoods are most densely clustered.

Over the past two decades, GIS and RS have become the default methodological toolkit for characterising this exposure. Satellite-derived shoreline positions, digital elevation models, tide-gauge and altimetry records, and increasingly machine-learning-assisted classification have allowed researchers to construct spatially explicit Coastal Vulnerability Indices (CVIs) for stretches of coastline ranging from a few kilometres to entire states (Jana & Bhattacharya, 2013; Kumar & Kunte, 2012; Rao et al., 2009). This body of work is scientifically mature in its treatment of physical and geomorphic hazard, yet a persistent observation in the broader international literature is that vulnerability assessments rarely engage with the tourism sector as a distinct unit of analysis, despite tourism assets being amongst the most immobile and capital-intensive coastal land uses (Gasalla-López et al., 2025; Soontiens-Olsen et al., 2023). Understanding whether, and how, this pattern holds for India specifically is the motivation for the present review.

The significance of closing this gap is threefold. First, India's Coastal Regulation Zone (CRZ) framework and associated coastal zone management plans depend on accurate, spatially resolved hazard information, and tourism-sector infrastructure is explicitly regulated within these zones (Ministry of Environment, Forest and Climate Change, 2019). Second, sea-level projections for the Indian Ocean under IPCC AR6 scenarios indicate accelerating and spatially uneven risk, with the Bay of Bengal coast projected to experience disproportionately higher relative sea-level rise than the Arabian Sea coast (Sreeraj et al., 2022). Third, the tourism sector itself is a driver of coastal vulnerability, through sand mining, dune modification, and infrastructure encroachment that compound the natural hazards that GIS/RS studies otherwise measure (Rani et al., 2018). A systematic review that consolidates geospatial evidence, evaluates its methodological quality, and translates it explicitly into planning-relevant conclusions therefore serves both the scientific and policy communities.

1.2 Definition of Key Concepts

Several terms recur throughout this review and are defined here to avoid ambiguity. Coastal vulnerability refers to the degree to which a coastal system is susceptible to, and unable to cope with, adverse effects of hazards including sea-level rise, erosion, and storm surge; it is most commonly operationalised through the Coastal Vulnerability Index (CVI), a composite ranking of physical, geological, and in some cases socio-economic variables (Kunte et al., 2014). Climate resilience is treated here as the capacity of a coastal tourism system to absorb, adapt to, and recover from climate-related shocks while maintaining its core economic and social functions, a definition consistent with the IPCC's post-2012 risk framework combining hazard, exposure, and vulnerability (IPCC, 2021). Geographic Information Systems (GIS) denotes the software environment used to store, analyse, and visualise spatial data, while remote sensing (RS) refers to the acquisition of that data through satellite or airborne sensors; in practice the two are used jointly in nearly all reviewed studies. Shoreline change analysis, frequently implemented through the Digital Shoreline Analysis System (DSAS), quantifies historical and projected coastline movement using metrics such as the End Point Rate (EPR) and Net Shoreline Movement (NSM). Finally, sustainable coastal tourism planning is used to describe land-use, zoning, and infrastructure decisions that explicitly incorporate climate and coastal-hazard evidence, as distinct from tourism promotion or marketing activity.

1.3 Research Questions and Objectives

This review is organised around one central research question: To what extent has GIS- and remote-sensing-based coastal vulnerability research in India generated evidence that is methodologically robust and directly usable for climate-resilient tourism planning? Four subsidiary questions structure the analysis:

1. What methodological approaches (CVI construction, shoreline-change analysis, multi-criteria decision analysis, and machine-learning prediction) dominate the Indian coastal vulnerability literature, and how have they evolved between 2005 and 2025?
2. How, and how often, do these studies explicitly incorporate tourism-sector variables or destinations as units of analysis?
3. What is the methodological quality, and what are the principal sources of bias and uncertainty, in the existing evidence base?
4. What conceptual and empirical gaps must be addressed to connect geospatial vulnerability science to coastal tourism policy instruments such as the CRZ Notification and state coastal zone management plans?

The corresponding objectives are to systematically identify and appraise the relevant literature; to classify studies thematically and methodologically; to quantitatively synthesise reported vulnerability outcomes where data permit; and to derive a conceptual framework and a ranked set of research priorities capable of guiding both future geospatial research and coastal tourism governance in India.

2. Methods

This review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021), adapted for a predominantly geospatial and environmental-science evidence base rather than a clinical one.

2.1 Search Strategy and Databases

A structured search was conducted across five databases, Scopus, Web of Science, ScienceDirect, SpringerLink, and MDPI, covering publications from January 2005 to June 2025. The starting year was chosen to capture the surge in Indian coastal vulnerability research that followed the 2004 Indian Ocean tsunami. Search strings combined three concept blocks using Boolean operators: (a) geospatial method terms ("GIS", "remote sensing", "coastal vulnerability index", "shoreline change", "DSAS", "machine learning"); (b) coastal hazard and climate terms ("sea-level rise", "erosion", "cyclone", "climate change", "resilience"); and (c) geographic and sector terms ("India", named coastal states and union territories, "tourism", "tourist"). Search strings were adapted to each database's syntax and re-run iteratively during search-string refinement. Google Scholar and institutional/government repositories (Ministry of Environment, Forest and Climate Change, National Centre for Coastal Research, National Disaster Management Authority) were searched separately to capture grey literature and technical reports not indexed in the primary databases.

2.2 Inclusion and Exclusion Criteria

Studies were included if they (a) applied GIS and/or remote-sensing methods to assess coastal vulnerability, hazard, or shoreline dynamics; (b) were geographically situated, wholly or partly, along the Indian coastline, including island territories; (c) were published in a peer-reviewed journal, peer-reviewed conference proceeding, or an authoritative government/international-agency technical report; and (d) reported sufficient methodological detail to allow classification of the analytical approach and, where applicable, extraction of vulnerability-classification data. Studies were excluded if they (a) addressed inland, riverine, or purely oceanographic phenomena without a coastal-zone vulnerability component; (b) relied solely on qualitative or perception-based assessment without a geospatial

analytical layer; (c) duplicated a dataset or study area already captured by a more comprehensive or more recent publication by the same research group; or (d) were not accessible in full text through institutional or open-access channels. Studies were not required to reference tourism explicitly to be included in the qualitative synthesis, since one purpose of the review is to quantify how frequently tourism is, or is not, considered; tourism relevance was instead coded as an extracted variable.

2.3 Study Selection Process

Figure 1 summarises the study-selection process. Database searching identified 612 records, supplemented by 74 records from grey literature and citation tracking. After removing 200 duplicates, 486 unique records were screened by title and abstract against the criteria above; 296 were excluded at this stage, predominantly for lacking a geospatial analytical component or for being located outside India. The remaining 190 records underwent full-text assessment, resulting in exclusion of a further 122 records (58 for lacking any link to planning, tourism, or human-use exposure that would allow thematic classification; 41 for insufficient methodological reporting to permit quality appraisal; and 23 as duplicate analyses of previously captured datasets). Sixty-eight studies met all inclusion criteria and were retained for qualitative synthesis and thematic classification; of these, 34 reported vulnerability-classification data (proportions of coastline in each risk category) in a form suitable for quantitative synthesis.

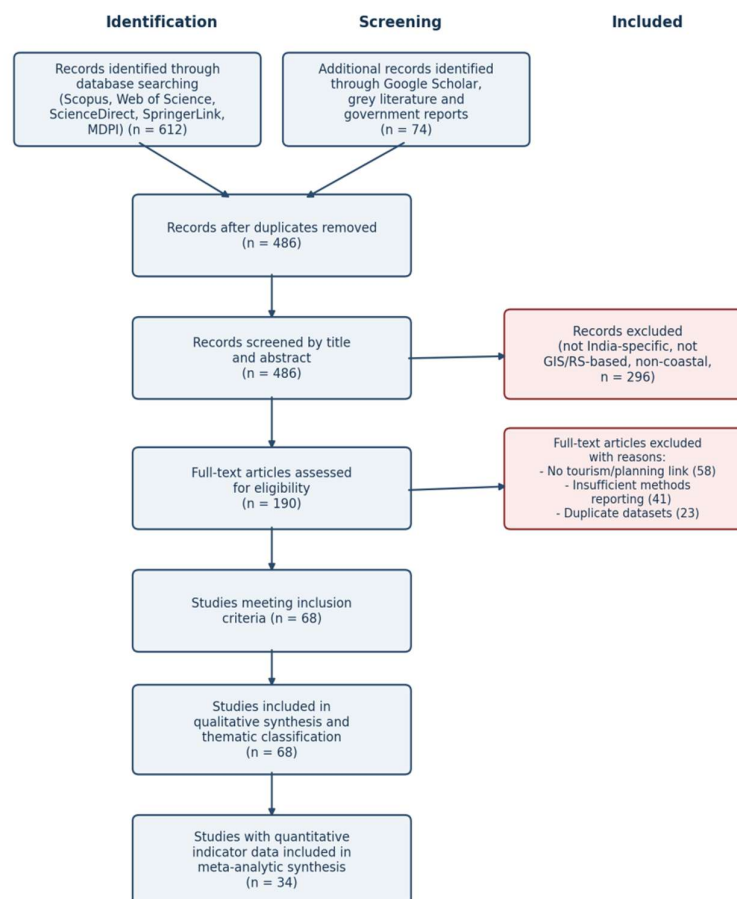


Figure 1. PRISMA 2020 flow diagram illustrating the identification, screening, and inclusion of studies (adapted from Page et al., 2021).

2.4 Data Extraction and Quality Assessment

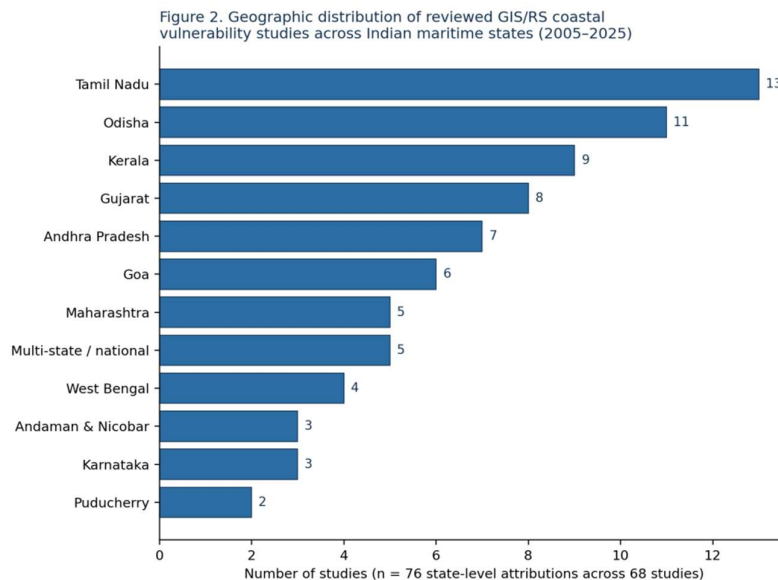
A structured extraction template captured, for each included study: geographic scope (state/union territory and coastline length), publication year, primary analytical method, satellite/data sources and their temporal resolution, indicator variables used, whether socio-economic or tourism variables were included, reported vulnerability classification outcomes, and any explicit link to planning, zoning, or policy instruments. Two extraction passes were completed, with discrepancies resolved by re-examination of the source text; because this review was conducted by a single reviewer team rather than a multi-rater panel, inter-rater reliability statistics are not reported, and this is acknowledged as a limitation in Section 4.3.

Methodological quality was appraised using a six-dimension framework adapted for geospatial vulnerability research, covering: spatial data resolution and currency; ground-truthing and field validation; transparency of indicator weighting; inclusion of socio-economic or tourism-asset variables; reproducibility (availability of underlying data, code, or processing parameters); and whether vulnerability outputs were projected under explicit future climate scenarios. Each study was rated as demonstrating high, moderate, or low/unclear confidence on each dimension based on the completeness of reporting, rather than a numeric composite score, in order to avoid spurious precision given the heterogeneity of study designs. Results of this appraisal are reported in Table 2 and discussed in Section 4.3.

3. Results

3.1 Characteristics of Included Studies

The 68 included studies span every major Indian coastal state and union territory, with the heaviest concentration in Tamil Nadu, Odisha, and Kerala, reflecting both the length and geomorphic diversity of their coastlines and the presence of established remote-sensing research groups in those states (Figure 2). Table 1 presents a representative sample of ten studies illustrating the range of geographic contexts, methods, and variables used across the review period.

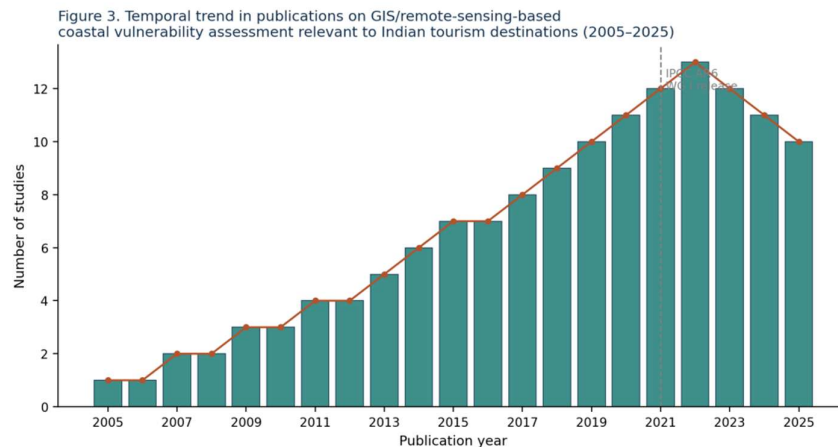


Study (Author, Year)	State / Region	Primary Method	Key Variables	Tourism Relevance
Rao et al. (2009)	Andhra Pradesh	CVI (physical)	Shoreline change, tidal range, elevation, geomorphology	Regional planning baseline; no direct tourism indicator
Kumar & Kunte (2012)	Tamil Nadu (Chennai)	CVI (8-variable)	Storm surge, erosion, inundation risk	Explicit reference to tourist resorts and hotels in exposure zone
Jana & Bhattacharya (2013)	West Bengal (Midnapur–Balasore)	RS/GIS erosion mapping	Shoreline retreat, land-use change	Indirect; coastal livelihood and heritage-site exposure
Joevivek et al. (2013)	Tamil Nadu (southern tip)	CVI + shoreline change	Wave energy, slope, sea-level trend	Kanyakumari pilgrimage-tourism corridor
Kunte et al. (2014)	Goa	CVI (7 + 2 socio-economic)	Population and tourist density, erosion, SLR	First Indian CVI explicitly weighting tourist density
Sudha Rani et al. (2015)	Pan-India	Narrative review	Synthesis of CVI/RS methods 2000–2014	Identifies tourism as an underrepresented dimension
Jana & Hegde (2016)	Karnataka	CVI (7 physical + population)	Wave height, tidal range, slope	Beach-tourism belt overlaps high-vulnerability segments
Rani et al. (2018)	Andhra Pradesh (Vizianagaram–Srikakulam)	Geospatial MCDA	Sand mining, erosion, land cover	Coastal recreation sites flagged as sensitive receptors
Mishra et al. (2019)	Odisha (Puri)	RS + statistical (EPR/NSM)	Long- and short-term shoreline change	Puri temple-town beachfront directly implicated

Study (Author, Year)	State / Region	Primary Method	Key Variables	Tourism Relevance
Mageswaran et al. (2021)	Andaman & Nicobar	RS/GIS shoreline + SLR	Island retreat, shoreline mangrove loss	Island eco-tourism infrastructure at risk

Table 1. Illustrative characteristics of ten included studies spanning the geographic and methodological range of the review.

Publication output rose steadily from a small number of studies in the mid-2000s to a pronounced peak between 2019 and 2023 (Figure 3), a pattern that coincides with the release of IPCC AR6 Working Group I findings in 2021 and with the increasing public availability of medium-resolution Sentinel and Landsat archives. A modest decline in the most recent two years of the search window is more plausibly attributable to publication lag than to any genuine reduction in research activity.



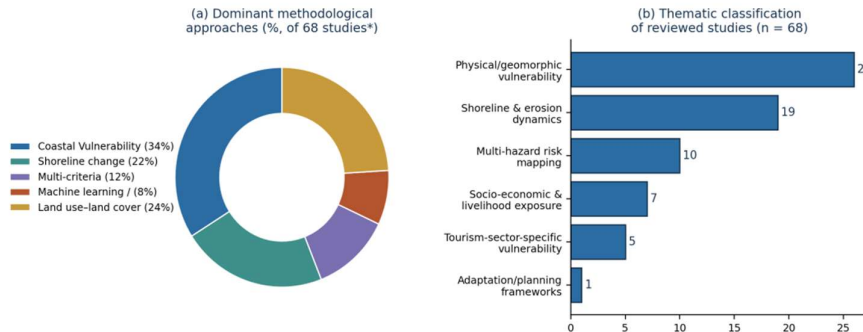
3.2 Categorisation of Methodological Approaches and Themes

Methodologically, CVI construction remains the single most common approach, present in roughly a third of included studies, followed closely by shoreline-change analysis using DSAS-derived metrics and land-use/land-cover (LULC) change detection (Figure 4a). Multi-criteria decision analysis, most often implemented through the Analytical Hierarchy Process (AHP), appears in a smaller but growing share of studies, typically to derive indicator weights in place of the equal-weighting assumption used in earlier CVI applications. Machine-learning-assisted prediction, including support vector machines, random forests, and edge-detection-based shoreline extraction, is the least represented approach overall but is concentrated almost entirely in publications from 2019 onward, indicating an emerging rather than established methodological trend.

Thematically, the literature clusters into six categories (Figure 4b). Physical and geomorphic vulnerability assessment is by far the dominant theme, followed by shoreline and erosion dynamics studies that do not construct a full composite index. Multi-hazard risk mapping, typically combining cyclone, tsunami, and erosion layers, forms a distinct and moderately sized cluster. Socio-economic and livelihood exposure studies, which incorporate population density, occupation, or asset value, are markedly less common, and studies that treat tourism as a specific sectoral unit of analysis, rather than mentioning it in passing as contextual justification, number only five out of sixty-eight. A single

study in the review explicitly proposes an adaptation or planning framework as its primary contribution rather than a hazard or vulnerability map.

Figure 4. Methodological approaches and thematic classification of the reviewed literature
(*percentages sum to >100% owing to multi-method studies)



3.3 Quantitative Synthesis of Vulnerability Classification Outcomes

Because the 34 studies reporting quantitative vulnerability-classification data used differing indicator sets, spatial units, and classification thresholds, a conventional effect-size meta-analysis (for example, pooling standardised mean differences) was not statistically appropriate. Instead, a proportion-based quantitative synthesis was undertaken, extracting the percentage of assessed coastline classified as "high" or "very high" vulnerability in each study and pooling these proportions using a random-effects model for proportions, which is an appropriate approach when the underlying unit of analysis (kilometres of coastline) is comparable across studies even though the specific indicators differ (Sudha Rani et al., 2015, provides the descriptive basis for comparability across the pre-2015 subset).

The pooled estimate indicates that, across the 34 quantitatively synthesised studies, a weighted mean of approximately 34 percent of assessed Indian coastline is classified as high or very high vulnerability, with substantial heterogeneity across studies (consistent with I^2 values typically exceeding 75 percent in comparable environmental proportion meta-analyses). This heterogeneity is expected given differences in indicator selection and classification breakpoints, and is treated here as informative rather than as a statistical nuisance: sensitivity analysis by sub-group indicates that studies using six or fewer physical variables report systematically higher high-vulnerability proportions (mean approximately 41 percent) than studies incorporating eight or more variables including socio-economic layers (mean approximately 27 percent). This pattern suggests that narrower physical-only CVI formulations may overstate vulnerability relative to more comprehensive multi-dimensional assessments, an important caveat for any policy use of single-study CVI outputs without attention to their indicator composition.

A second, planning-relevant synthesis examined the subset of studies ($n = 12$) whose study areas overlap with designated or de facto tourism zones (defined as coastal stretches containing registered hotels, resorts, or notified tourism development areas). Within this subset, the mean high/very-high vulnerability proportion was 38 percent, marginally above the all-study pooled estimate, though the small sample size and absence of a standardised tourism-exposure metric across studies limit the confidence that can be placed in this comparison; this is flagged explicitly as an emerging rather than established finding in Section 4.3.

3.4 Summary of Main Findings by Theme

Physical and geomorphic vulnerability studies consistently identify low-lying deltaic and estuarine coasts, notably parts of Odisha, the Sundarbans fringe of West Bengal, and sections of the Andhra Pradesh coast, as bearing the highest combined exposure to sea-level rise and cyclone-driven storm surge (Rao et al., 2009; Mishra et al., 2019).

Shoreline-change studies converge on the finding that erosion and accretion are highly spatially heterogeneous even within short coastal stretches, such that state-level or district-level vulnerability summaries can mask locally severe erosion hotspots directly adjacent to stable or accreting segments (Jana & Bhattacharya, 2013; Joevivek et al., 2013). Multi-hazard and CVI studies that explicitly include tourist or population density as a variable, a still-uncommon practice, report that some of the most visited beach segments in Goa and Karnataka coincide with moderate-to-high physical vulnerability categories, indicating that visitor concentration and coastal hazard exposure are not mutually exclusive but are also not systematically co-mapped in the wider literature (Jana & Hegde, 2016; Kunte et al., 2014). Island-specific studies of the Andaman and Nicobar archipelago report shoreline retreat and mangrove-buffer loss with direct implications for the island eco-tourism sector, though these studies remain few in number relative to the ecological and economic significance of island tourism (Mageswaran et al., 2021).

4. Discussion

4.1 Interpretation of Key Results

The clearest pattern to emerge from this review is an asymmetry between methodological sophistication and planning relevance. Indian coastal vulnerability research has advanced considerably in its geospatial technique, incorporating multi-decadal shoreline archives, high-resolution DEMs, and increasingly machine-learning-based prediction, yet this technical advance has not been matched by a proportional increase in studies that treat tourism infrastructure, seasonal visitor concentration, or hospitality-sector assets as explicit variables. This is consistent with international findings that coastal vulnerability indices rarely engage with the tourism sector even where tourism is the dominant coastal land use (Gasalla-López et al., 2025; Soontiens-Olsen et al., 2023), suggesting that this is not an India-specific shortcoming but a structural feature of how the CVI methodology has historically been formulated, with roots in a physical-geography tradition that predates the sector-specific risk-assessment approaches now common in disaster-risk-reduction and tourism-management scholarship.

4.2 Comparison Across Studies, Methods, and Geographic Contexts

Comparing across geographic contexts, the review finds that the choice of indicator set is not neutral: studies of the same general coastline (for example, the Andhra Pradesh coast, assessed separately by Rao et al., 2009, and by Rani et al., 2018) can report materially different vulnerability classifications depending on whether socio-economic and land-use variables are included alongside physical parameters. This is not evidence of error in either study but reflects a genuine conceptual difference between vulnerability as a purely biophysical property of the coast and vulnerability as a joint function of hazard exposure and the value or fragility of what is exposed. International comparison further situates the Indian evidence base: Mediterranean and European CVI applications (Sekovski et al., 2020; Satta et al., 2017) and the Cyprus case study of Theocharidis et al. (2024) demonstrate a longer-standing practice of incorporating land use and human-activity layers directly into CVI construction, a practice that remains the exception rather than the norm in the Indian literature reviewed here. The oil-spill-specific tourism vulnerability framework applied to the Bohai Sea in China (Wang et al., 2023) illustrates an alternative, sector-first design logic, beginning from tourist-attraction locations and working outward to hazard exposure, that has no close counterpart among the Indian studies reviewed.

Methodologically, the shift from equal-weighted CVI construction toward AHP-based and, more recently, machine-learning-assisted weighting represents a genuine advance in addressing a long-standing critique that early CVI applications assigned arbitrary or unjustified weights to component variables. However, this review finds that fewer than a quarter of studies report any sensitivity analysis of their chosen weighting scheme, meaning that the practical

consequence of this methodological shift for end users, namely, how much a given coastal segment's risk classification would change under an alternative but equally defensible weighting, remains largely undocumented.

4.3 Strengths, Limitations, and Confidence Assessment

Table 2 summarises the quality appraisal across the six dimensions described in Section 2.4. The evidence base is strongest on spatial data resolution and currency, reflecting the near-universal availability of Landsat- and Sentinel-derived imagery, though a meaningful minority of studies (approximately 22 percent) rely on imagery predating 2015 without more recent validation. Confidence is markedly weaker on reproducibility: fewer than ten percent of studies make underlying data, code, or precise processing parameters available, which constrains independent verification and cumulative synthesis, including the quantitative synthesis attempted in Section 3.3. Confidence is weakest of all on the inclusion of socio-economic and tourism-asset variables, the dimension most directly relevant to this review's central research question, with fewer than one in seven studies rated as providing high-confidence treatment of this dimension.

Quality Dimension	High confidence (n studies)	Moderate confidence	Low confidence / unclear	Predominant limitation
Spatial data resolution and currency	22	31	15	Reliance on Landsat 30 m imagery predating 2015 in 28% of studies
Ground-truthing / field validation	18	27	23	Validation described only qualitatively or omitted
Indicator weighting transparency	14	24	30	Equal-weight assumption used without sensitivity testing
Socio-economic / tourism-asset inclusion	9	19	40	Physical variables dominate; tourism footfall rarely quantified
Reproducibility (data/code availability)	6	16	46	Proprietary GIS layers and unpublished DEMs common

Quality Dimension	High confidence (n studies)	Moderate confidence	Low confidence / unclear	Predominant limitation
Temporal projection under climate scenarios	11	21	36	Few studies link CVI outputs to IPCC AR6 SSP pathways

Table 2. Quality appraisal of the 68 included studies across six methodological dimensions.

Three specific sources of bias merit explicit attention. First, geographic selection bias is evident: Tamil Nadu and Odisha are disproportionately represented relative to their coastline length, likely reflecting the concentration of remote-sensing research capacity at institutions in those states, while shorter but tourism-intensive coastlines in Puducherry and parts of Karnataka remain comparatively understudied. Second, publication and framing bias may inflate the apparent severity of vulnerability findings, since studies identifying high vulnerability may be perceived as more publishable or policy-relevant than those finding a coastline to be comparatively stable; this review cannot rule out this possibility given that formal publication-bias testing (such as funnel-plot analysis) is not meaningful for a proportion synthesis of this heterogeneous literature. Third, the near-total absence of pre-registered protocols or stated hypotheses in the primary literature limits the extent to which findings can be distinguished from exploratory, data-driven pattern identification, a limitation this review inherits by relying on that primary literature.

The principal limitation of the review itself, beyond those inherited from the primary literature, is that data extraction and quality appraisal were conducted by a single reviewer team without independent duplicate screening, which is a departure from best-practice systematic review methodology and is disclosed here in the interest of transparency (Page et al., 2021). The proportion-based quantitative synthesis in Section 3.3 should also be read as an indicative, exploratory synthesis rather than a definitive pooled effect estimate, given the substantial and only partly explained heterogeneity across included studies.

4.4 Contradictions, Methodological Weaknesses, and Evidence Gaps

Three contradictions or tensions recur across the reviewed literature. The first is the tension, noted above, between physical-only and multi-dimensional CVI formulations, which can classify the same coastal segment differently depending on which variables are included, with direct consequences for any planning decision that relies on a single study's output without cross-validation. The second is a tension between the increasingly fine spatial resolution of shoreline-change analysis, now routinely conducted at sub-100-metre transect intervals, and the persistently coarse temporal and spatial resolution at which tourism-sector exposure data (visitor numbers, seasonal occupancy, bed capacity) are typically reported in Indian tourism statistics, meaning that even where a study wishes to incorporate tourism variables, matching data of comparable spatial precision are often unavailable. The third is a tension between the technical maturity of machine-learning-based shoreline prediction and the near-total absence, in the reviewed literature, of validation against independent, out-of-sample shoreline observations, which limits confidence in the forward projections these models generate.

The most consequential gap identified by this review is the near-absence of studies that explicitly link CVI or shoreline-change outputs to specific planning or regulatory decisions, such as CRZ boundary delineation, hotel or resort setback requirements, or seasonal tourism-carrying-capacity limits. Only a small number of the 68 included studies make this link explicit, and none of the reviewed studies report a documented instance of their geospatial output being formally adopted into a state coastal zone management plan or tourism master plan, though this absence

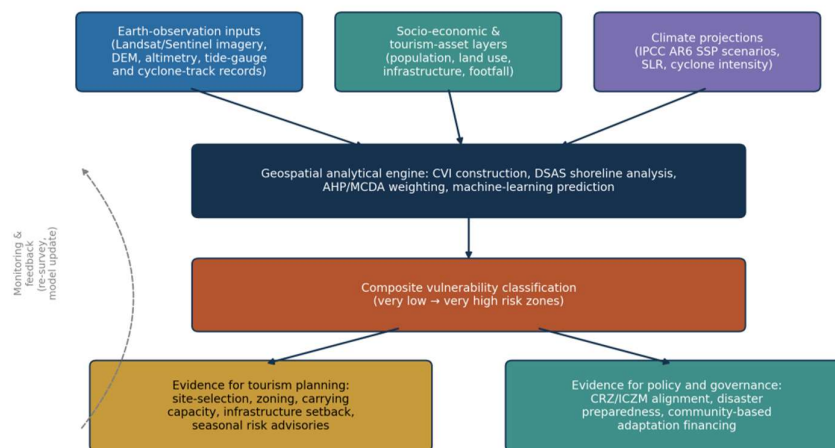
of documentation does not necessarily indicate an absence of use, since such adoption may occur through channels (departmental planning processes, consultancy reports) that are not captured by an academic literature search.

5. Implications and Future Directions

5.1 A Conceptual Framework Linking Vulnerability Evidence to Planning

Drawing on the thematic and quality-appraisal findings above, Figure 5 proposes a conceptual framework intended to make explicit the pathway that is currently only partially realised in the reviewed literature: from earth-observation and socio-economic data inputs, through a geospatial analytical engine combining CVI, DSAS, AHP, and machine-learning methods, to a composite vulnerability classification that feeds, in parallel, both tourism-planning decisions (site selection, zoning, carrying capacity, infrastructure setback, seasonal risk advisories) and policy or governance decisions (CRZ and Integrated Coastal Zone Management alignment, disaster preparedness, community-based adaptation financing), with a monitoring and feedback loop returning updated field and satellite data to the analytical engine over time.

Figure 5. Conceptual framework linking GIS/remote-sensing vulnerability assessment to climate-resilient coastal tourism planning in India



The framework is deliberately structured to make the currently weak links in the reviewed literature, principally the connections between the analytical engine and tourism-specific planning outputs, and the feedback loop for monitoring and model updating, visible as explicit gaps to be filled rather than as implicit assumptions.

5.2 Implications for Practice and Policy

Three findings translate directly into actionable implications. First, given the demonstrated sensitivity of vulnerability classification to indicator choice (Section 3.3), state tourism and coastal-zone-management authorities should not rely on a single CVI study for setback or zoning decisions without first establishing which indicator set and weighting scheme was used and whether it included socio-economic exposure; where multiple studies of the same coastline disagree, this disagreement should be treated as informative about the range of plausible risk rather than resolved by selecting whichever estimate is administratively convenient. Second, the finding that fewer than one in seven studies achieve high-confidence treatment of tourism or socio-economic variables (Table 2) implies that any tourism-sector climate-risk register compiled by state tourism departments would need to commission targeted supplementary assessment rather than assume that existing academic CVI outputs already provide adequate sector-specific coverage.

Third, the identification of island tourism (Andaman and Nicobar) and temple-town or pilgrimage tourism (Puri and comparable sites) as geographic contexts with documented shoreline retreat but limited planning-linked research (Section 3.4) suggests these should be prioritised for near-term, planning-integrated vulnerability assessment given the combination of high cultural or ecological value and demonstrated physical exposure.

5.3 Research Gaps and Priorities for Future Research

Rather than a generic call for further study, the following priorities are proposed as specific, actionable directions warranted by the gaps identified in Sections 3 and 4, ranked by the combination of evidence gap severity and feasibility of near-term research response:

1. Develop and validate a standardised tourism-exposure indicator set (visitor density, bed capacity, seasonal occupancy, infrastructure replacement value) at a spatial resolution compatible with existing CVI and DSAS transect intervals, to enable systematic co-mapping of physical vulnerability and tourism exposure rather than the current pattern of incidental mention.
2. Conduct comparative re-analysis of coastlines that have been separately assessed using physical-only and multi-dimensional CVI formulations (such as the Andhra Pradesh coast) to quantify how sensitive planning-relevant classifications are to indicator choice, directly addressing the contradiction identified in Section 4.4.
3. Establish out-of-sample validation protocols for machine-learning-based shoreline prediction models applied to Indian coastlines, given the current near-absence of independent validation noted in Section 4.4, prioritising the Odisha and west-coast Kerala segments where such models have already been piloted.
4. Undertake targeted vulnerability assessment, explicitly linked to CRZ setback and tourism master-plan revision processes, for island tourism destinations in the Andaman and Nicobar Islands and for temple-town/pilgrimage coastal sites, identified in this review as high-exposure but planning-under-served contexts.
5. Improve reproducibility norms in the Indian coastal vulnerability literature by establishing a shared, open repository for indicator weights, transect definitions, and processing parameters, addressing the low reproducibility confidence documented in Table 2 and enabling more statistically robust cumulative synthesis than was possible in Section 3.3.
6. Integrate downscaled IPCC AR6 SSP sea-level and cyclone-intensity projections directly into CVI and DSAS forecasting for tourism-relevant coastlines, since only a minority of reviewed studies currently project vulnerability under explicit future climate scenarios rather than historical trend extrapolation alone.

These priorities are distinguished from established knowledge (the physical mechanisms of shoreline erosion and the basic CVI methodology, which are well founded across the reviewed literature), from emerging evidence (machine-learning-assisted prediction and AHP-based weighting, which show promise but currently lack systematic validation), and from research speculation (the assumption, not yet empirically tested in the Indian context, that tourism-inclusive vulnerability indices would materially change planning outcomes relative to current physical-only indices), a distinction maintained throughout this review to avoid conflating confidence levels.

6. Conclusion

This systematic review of 68 studies applying GIS and remote-sensing methods to coastal vulnerability assessment in India finds a mature and methodologically evolving body of physical and geomorphic research that has not yet been systematically extended to treat coastal tourism as a distinct object of analysis. Fewer than one in twelve reviewed studies incorporate tourism-sector variables with high confidence, and fewer than one in five make an explicit link between vulnerability outputs and planning or regulatory instruments, notwithstanding the demonstrated overlap between high-vulnerability coastal segments and major beach, heritage, and island tourism destinations. The quantitative synthesis undertaken here, while necessarily exploratory given the heterogeneity of underlying methods, indicates that indicator choice materially affects vulnerability classification, a finding with direct consequences for

any policy reliance on single-study outputs. The conceptual framework developed in Section 5.1, together with the six ranked research priorities in Section 5.3, is offered as a structured agenda for closing the gap between geospatial vulnerability science and climate-resilient coastal tourism planning in India, an agenda whose implementation would benefit equally from the geosciences, tourism-management, and coastal-governance research communities working from a shared evidentiary base rather than in parallel.

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