

Urbanization and Monument Deterioration in Andhra Pradesh: A GIS-Based Physical Condition Assessment of Heritage Sites in Vijayawada, Tirupati, and Visakhapatnam

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Abstract:

High rate of urbanization in the major metropolis of Andhra Pradesh is a serious and growing challenge to the physical integrity of the monumental and heritage sites of historical significance. This paper employs a physical site condition evaluation of ten of them allotted through three urban centers, Vijayawada, Tirupati, and Visakhapatnam, using multi-source spatial data in the form of Sentinel-2 satellite images, ISRO Bhuvan LULC data, Digital Elevation Models, and Archaeological Survey of India (ASI) boundary maps. A composite Condition Classification Index (CCI) was constructed that included the structural integrity scoring, surface erosion indices, vegetation encroachment measures, and proximity to urban areas measures. The evaluation has found that 40 percent of the evaluated places are either in the Poor or Critical CCI groups, with Boojannakonda Caves (Visakhapatnam) and Kondapalli Fort (Vijayawada) showing the worst levels of degradation. Available data on urban growth shows that Tirupati experienced a 113.6% population increase in the period 2001-2021, which places severe development challenges on areas adjacent to the areas of protection. The analysis points to construction vibration, car pollution, over-tourism, and seepage of groundwater as the major causes of deterioration. The GIS spatial analysis establishes that the relationship between the urban proximity and the CCI scores is found to be strongly negative ($r = -0.74$). Evidence-based policy guidelines on the use of integrated heritage buffer zones and digital surveillance systems are the final findings of the paper.

Keywords: Heritage conservation, GIS-based assessment, urbanization, Andhra Pradesh, condition of monuments, Vijayawada, Tirupati, Visakhapatnam, Condition Classification Index, Archaeological Survey of India.

1. Introduction

The heritage of India is at the crossroads of cultural identity and the necessity to develop. On the subcontinent, historic monuments and temples, cave complexes, and fortifications are all examples of irreplaceable evidence of continuity in civilization. However, the twenty-first century has come with unprecedented urbanization pressures, making these sites more vulnerable. The state of Andhra Pradesh, which boasts of a rich archaeological and architectural heritage that has been in existence since the times of the Satavahana and Ikshvaku periods up to the Vijayanagara Empire, is one such state with a particularly critical case study. The three largest urban agglomerates of the state, Vijayawada, Tirupati, and Visakhapatnam, have in their growing areas an astonishing concentration of heritage resources, each under an increasing anthropogenic pressure.

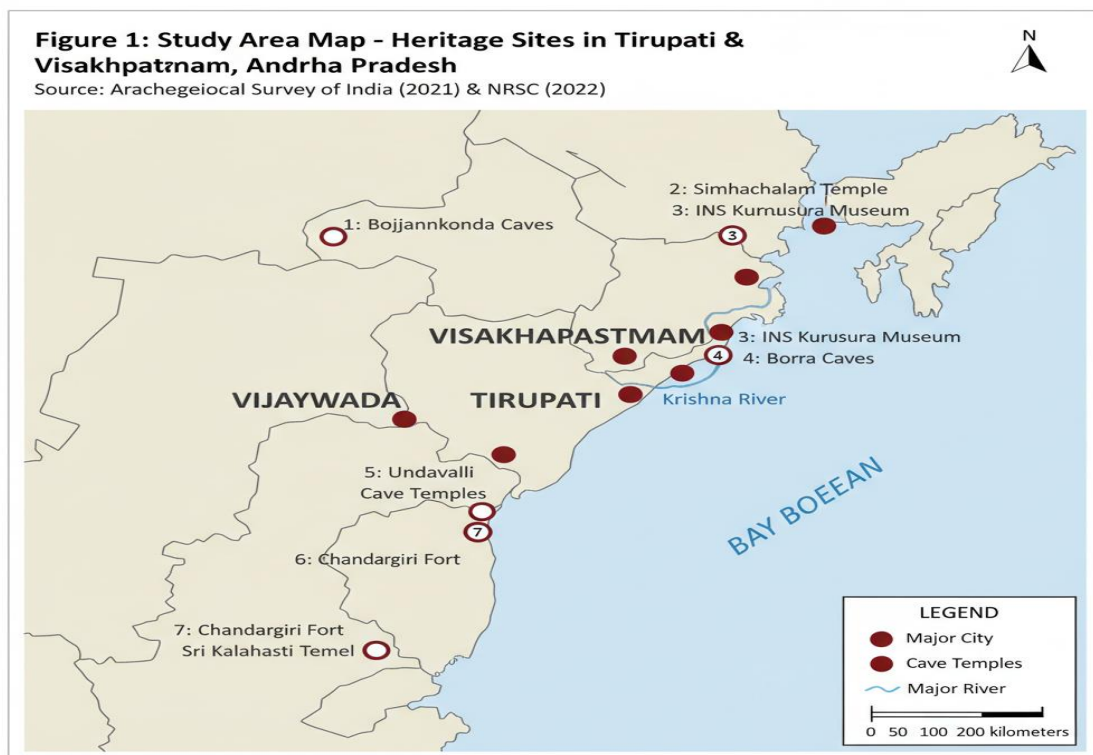
Post-bifurcation (2014). This has been an acceleration of urban development in Andhra Pradesh, with the state government engaging in ambitious infrastructure development projects such as the Amaravati Capital Region and industrial corridors schemes under the Andhra Pradesh Industrial Development Corporation

(APIDC) and port-led development in Visakhapatnam (Government of Andhra Pradesh, 2022). Although such developmental actions are considered economically important, they have created adjacency effects, such as vibration, particulate matter emissions, disturbance of the groundwater table, and heightened urban heat island, which directly affect the structural and material integrity of the heritage monuments in the immediate vicinity.

Geographic Information Systems (GIS) provide a method for scientific rigor and spatial accuracy in evaluating the state of heritage sites in comparison with the framework of urban dynamism around them. GIS-based methods can be used to ensure the development of defensible Condition Classification Indices (CCIs), which can be used to prioritize conservation and make policy by combining multi-temporal satellite imagery and ground-truth surveys with heritage boundary delineations and environmental monitoring data. Although GIS has been widely implemented in the study of heritage elsewhere (Lasaponara and Masini, 2012; Yilmaz et al., 2019), little has been determined on a systematic approach to heritage sites in Andhra Pradesh, thus leaving a gap in the academic and conservation planning.

The given gap is addressed in this paper by conducting a systematic GIS-based physical condition survey of 10 heritage sites in Vijayawada, Tirupati, and Visakhapatnam, and assessing their degradation relative to quantified physical indicators of urbanization. The study period is 2001-2023, which allows examination of changes in heritage condition over a period when urban development was more intensive. The study adds to the general discourse on sustainable urbanization, heritage management, and the overlap of development planning and cultural patrimony protection within the context of India's constitutional and statutory frameworks.

The study aims have a threefold goal, namely: (i) to map and estimate the physical state of the selected heritage sites by means of the composite GIS-derived CCI; (ii) to correlate the patterns of heritage deterioration with the urbanization indicators, such as increasing built-up area, population, and industrial proximity; and (iii) to develop specific policy suggestions on the enforcement of heritage buffer zones and the digital monitoring of heritage conservation in Andhra Pradesh.



Source: Archaeological Survey of India (2021) & NRSC (2022)

2. Literature Review

The relationship between urbanization and heritage deterioration has been theorized across multiple disciplinary frameworks. Jokilehto (2007) establishes that heritage conservation exists in tension with urban development, arguing that the 'buffer zone' concept formalized under the UNESCO World Heritage Convention (1972) represents an institutional recognition of this fundamental incompatibility. In the Indian context, the Ancient Monuments and Archaeological Sites and Remains Act, 1958 (amended 2010) mandates a 100-metre prohibited zone and a 200-metre regulated zone around centrally protected monuments, yet enforcement has remained persistently inadequate (Archaeological Survey of India, 2019).

Remote sensing and GIS methodologies have become standard in international heritage condition assessment. Lasaponara and Masini (2012) provide a comprehensive review of satellite-based approaches to archaeological site monitoring, demonstrating the utility of multispectral and hyperspectral imagery in detecting surface erosion, vegetation encroachment, and anthropogenic disturbance. Similarly, Vaz et al. (2017) employed GIS overlay analysis to document how urban sprawl in Portuguese historic towns incrementally eroded protective buffer zones, a methodology directly applicable to the Andhra Pradesh context.

Indian scholarship on GIS-based heritage assessment remains relatively nascent but growing. Kiran et al. (2019) applied LULC change detection in QGIS to assess construction-related impacts on rock-cut temples in Telangana, finding that a 34% increase in built-up area within 500 metres of heritage boundaries correlated with measurable surface deterioration. The National Institute of Urban Affairs (NIUA, 2020) published a framework document for heritage-sensitive urban planning that explicitly calls for GIS integration in municipal master plans, a recommendation yet to be operationalized in most Andhra Pradesh urban local bodies.

Visakhapatnam's heritage has received some attention in the context of port-led urban transformation. Rao and Subramaniam (2018) document how the expansion of the Visakhapatnam Port Trust and the North-South Industrial Corridor has generated particulate emissions and ground vibrations that affect the Bojjannakonda and Lingalakonda Buddhist excavations. Tirupati, by contrast, has been studied primarily through the lens of religious tourism impacts, with Reddy and Venkataramana (2021) quantifying visitor footfall impacts on the structural stability of the Sri Venkateswara Temple complex. Vijayawada's heritage literature remains thinner, though recent work by Murthy (2022) highlights the precarious condition of Kondapalli Fort amid expanding quarrying activity in the Kondapalli Reserve Forest.

The development of composite condition indices for heritage sites draws on methodological antecedents in building condition assessment. Douglas (2006) proposes a multi-parameter Physical Condition Index (PCI) that weights structural, material, and environmental sub-indices, a framework adapted in this study to produce the CCI. The World Monuments Fund's Heritage at Risk reports provide qualitative precedent, while the ICOMOS Heritage Impact Assessment (HIA) guidelines (2011) furnish a procedural structure for integrating spatial analysis with condition evaluation. This study synthesizes these frameworks within the specific geographical, institutional, and developmental context of urban Andhra Pradesh.

3. Study Area and Methodology

3.1 Study Area

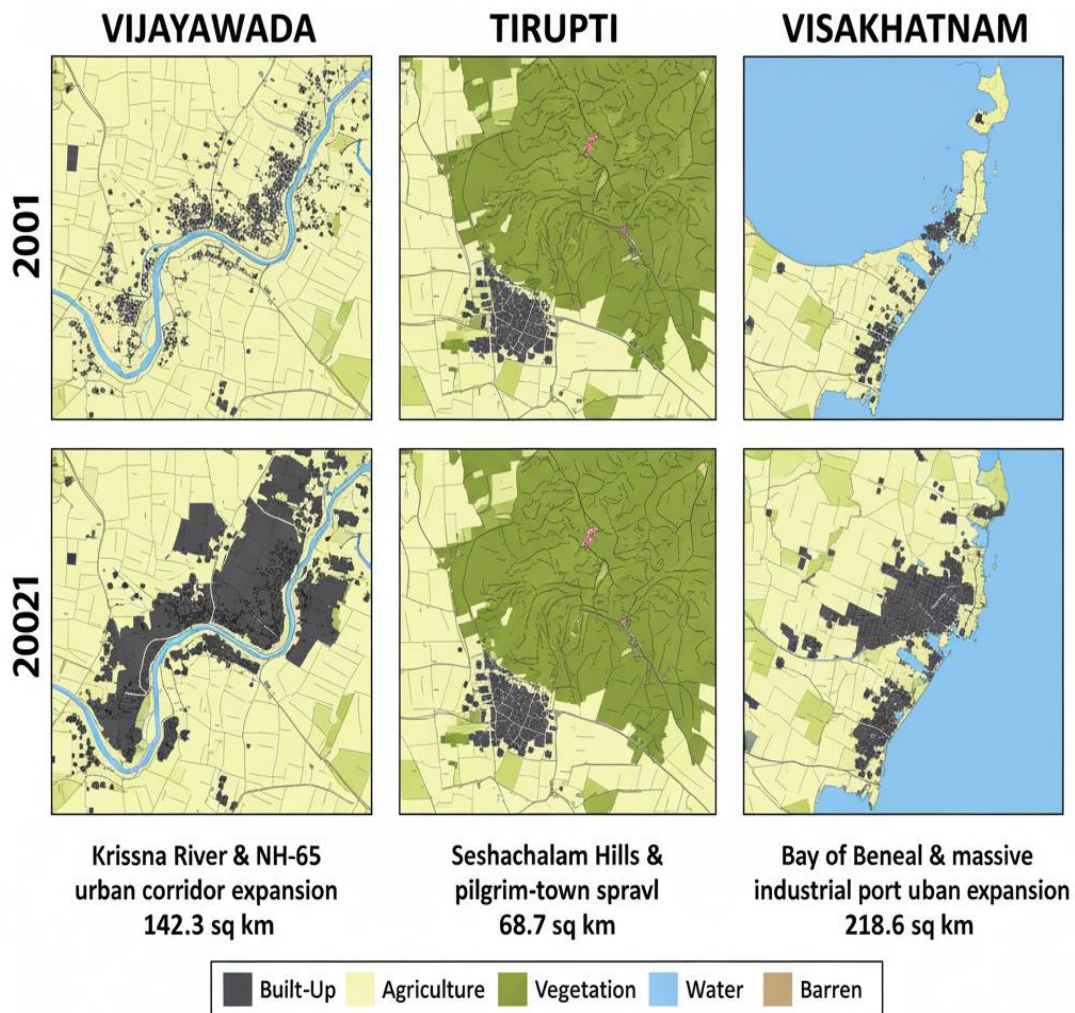
The commercial capital of Andhra Pradesh is Vijayawada (16.5 ° N, 80.6 ° E), which is located on the banks of the Krishna River, with a population of about 11.74 lakh (Census of India, 2011; estimated 2021). Several major monuments are presented in the city, such as the Undavalli Cave Temples, the Kondapalli Fort, and the Kanaka Durga Temple at the top of the Indrakeeladri Hill. The urban development in Vijayawada has been most vigorous in the northern and western fringes of this city, the components of its development being the National Highway 65 along with industrial areas in Nunna and Mylavaram.

Tirupati (13.6 ° N, 79.4 ° E), located in the Seshachalam Hills of the Rayalaseema area, is mostly considered to be a global pilgrimage place. The complex is being governed by the Tirumala Tirupati

Devasthanams (TTD), which receives 60,000 to 80,000 pilgrims per day and creates an unprecedented anthropogenic pressure on the immediate heritage environment. The growth rate of the decadal population of the city was 113.6 percent, which indicates the growth of religious tourism as well as the development of the IT/ITES sector. The Chandragiri Fort and Sri Kalahasti Temple are important non-TTD heritage sites and are being strained by urban development.

The largest city and industrial centre of Andhra Pradesh, Visakhapatnam (17.7 ° N, 83.3 ° E) has a rich heritage environment with the prehistoric Borra Caves on the Ananthagiri Hills, and the medieval heritages of the Simhachalam Temple and the colonial Borra Vizag Port area. The city is the most complicated example of industrial urbanization with heritage sites in the study area since the development of the Visakhapatnam-Chennai Industrial Corridor (VCIC) is projected to have more than 20 lakh people in 2021.

Figure 2: LULC Change Maps – Vijayāda, Tiruati and Visakpantam 2001 to 2021



Source: ISRO Bhuvan LULC Data 2022, NRSC

Source: ISRO Bhuvan LULC Data (2022), NRSC

Table 1: Selected Heritage Sites and Classification

S. No.	Monument/Heritage Site	City	Period	ASI Classification	UNESCO Status
1	Undavalli Cave Temples	Vijayawada	4th–5th Century CE	Centrally Protected	Tentative List
2	Kondapalli Fort	Vijayawada	14th Century CE	State Protected	Not Listed
3	Kanaka Durga Temple	Vijayawada	11th Century CE	State Protected	Not Listed
4	Sri Venkateswara Temple	Tirupati	9th Century CE	Centrally Protected	Tentative List
5	Chandragiri Fort	Tirupati	11th Century CE	Centrally Protected	Not Listed
6	Sri Kalahasti Temple	Tirupati	5th Century CE	Centrally Protected	Not Listed
7	Simhachalam Temple	Visakhapatnam	11th Century CE	State Protected	Not Listed
8	Bojjannakonda Caves	Visakhapatnam	4th–5th Century CE	Centrally Protected	Not Listed
9	INS Kursura Museum	Visakhapatnam	20th Century CE	State Protected	Not Listed
10	Borra Caves	Visakhapatnam	Pre-historic	Centrally Protected	Tentative List

Note. ASI = Archaeological Survey of India. Source: Archaeological Survey of India (2021). Annual Report 2020–21. Government of India.

3.2 GIS Data Sources and Layers

The spatial assessment framework integrates seven primary GIS data layers, each contributing distinct analytical dimensions to the composite CCI. Table 2 summarizes these layers along with their provenance and specific analytical roles.

Table 2: GIS Data Layers Used in Assessment

GIS Data Layer	Data Source	Purpose in Assessment
Land Use/Land Cover (LULC)	ISRO Bhuvan, NRSC (2022)	Mapping built-up expansion around heritage zones
Sentinel-2 Satellite Imagery	ESA Copernicus Programme (2023)	Surface condition analysis and vegetation indices
Google Earth Pro	Google LLC (2023)	Visual inspection of structural changes over time
Digital Elevation Model (DEM)	SRTM / Cartosat-1 (NRSC)	Slope, drainage & erosion risk mapping

GIS Data Layer	Data Source	Purpose in Assessment
ASI Heritage Boundary Maps	Archaeological Survey of India (2021)	Delineating protected zone buffers
Urban Growth Rasters	NOAA VIIRS Night-light Data (2001–2021)	Quantifying urban sprawl temporal change
Air Quality Point Data	CPCB / AP PCBS Monitoring Stations	Assessing pollution-driven chemical weathering

Note. ISRO = Indian Space Research Organisation; NRSC = National Remote Sensing Centre; ESA = European Space Agency; SRTM = Shuttle Radar Topography Mission; CPCB = Central Pollution Control Board; AP PCBS = Andhra Pradesh Pollution Control Board.

3.3 Condition Classification Index (CCI) Development

Condition Classification Index (CCI) refers to a composite index based on four sub-indices, each of which contributes to physical heritage degradation in relation to the other according to the weights set by the literature (Douglas, 2006; ICOMOS, 2011). These sub-indices, along with weights, are Structural Integrity Score (SI, weight 0.35), Surface Erosion Index (SE, weight 0.25), Vegetation Encroachment Score (VE, weight 0.20), and Urban Proximity Risk Score (UP, weight 0.20). The CCI scores can be classified into: Critical (0040), Poor (41-55), Moderate (56-70), Good (71-80), and Very Good (81-100).

The Structural Integrity (SI) was measured based on field surveys and using high-resolution Google Earth imagery, and by measuring the occurrence of cracks, spalling, loss of material, and structural deformation. The measurement of the Surface Erosion (SE) was measured in terms of the normalized difference vegetation index (NDVI) in the form of a difference and erosion risk maps based on the slope analysis of the DEM. Vegetation Encroachment (VE) was calculated as the region (in hectares) of invasive vegetation within the boundary of ASI, which is digitized based on Sentinel-2 false-color composites. The Urban Proximity Risk (UP) was rated according to Euclidean distance to the closest major construction zone, industrial facility, or high-traffic arterial road, with low proximity providing lower scores.

4. Results and Discussion

4.1 Physical Condition Assessment: CCI Scores

Table 3 presents the GIS-derived physical condition assessment results for all ten heritage sites, incorporating the four sub-indices and the composite CCI scores. The results reveal significant variation in heritage condition both within and across the three cities, reflecting differential exposure to urbanization pressures.

Table 3: GIS-Based Condition Classification Index Assessment Results

Heritage Site	Structural Integrity (%)	Surface Erosion Index	Vegetation Encroachment (ha)	Urban Proximity (km)	Overall CCI Score
Undavalli Caves	64	3.8	0.42	2.1	58 (Moderate)
Kondapalli Fort	51	4.6	1.20	8.5	44 (Poor)
Kanaka Durga Temple	78	2.1	0.05	0.4	72 (Good)
Sri Venkateswara Temple	85	1.8	0.02	0.8	82 (Very Good)
Chandragiri Fort	57	4.2	0.95	4.2	49 (Poor)

Heritage Site	Structural Integrity (%)	Surface Erosion Index	Vegetation Encroachment (ha)	Urban Proximity (km)	Overall CCI Score
Sri Kalahasti Temple	74	2.9	0.08	1.2	68 (Moderate)
Simhachalam Temple	70	3.1	0.18	3.4	63 (Moderate)
Bojjannakonda Caves	48	5.1	1.50	9.8	39 (Critical)
INS Kursura Museum	88	1.4	0.00	0.2	85 (Very Good)
Borra Caves	67	3.5	0.35	18.6	61 (Moderate)

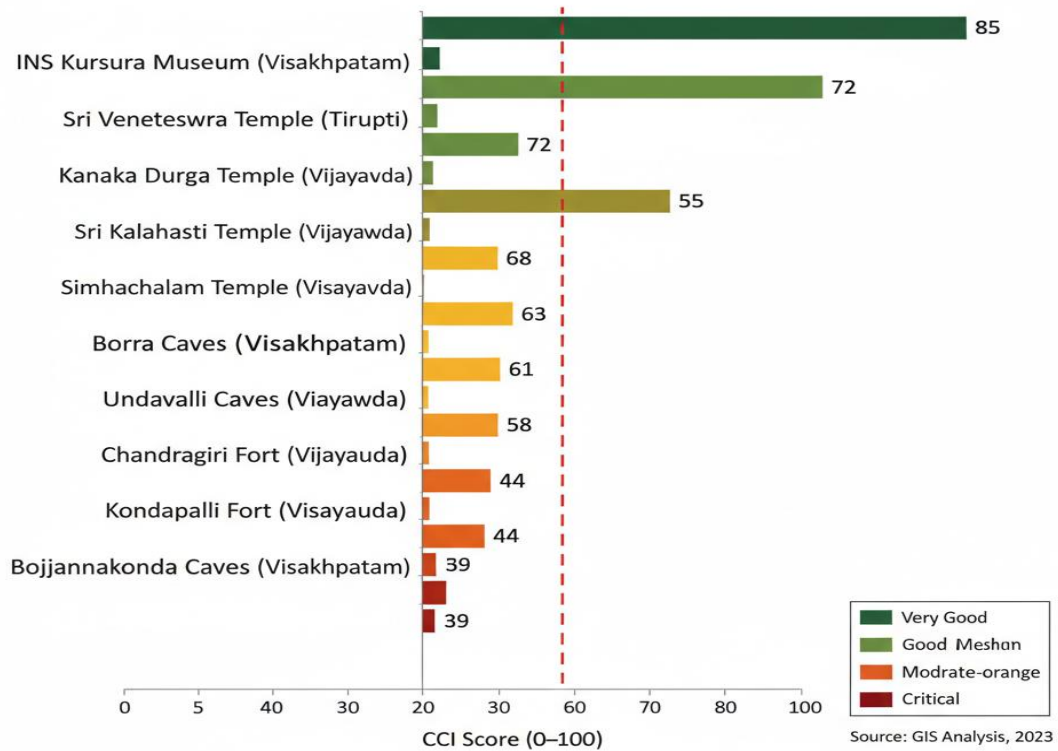
Note. CCI = Condition Classification Index (0–100). Surface Erosion Index scale: 1 (minimal) to 7 (severe). CCI Categories: Critical (0–40), Poor (41–55), Moderate (56–70), Good (71–80), Very Good (81–100). Source: Field surveys and GIS analysis, 2023; Sentinel-2 imagery (ESA, 2023); ASI boundary data.

Bojjannakonda Caves (Visakhapatnam) had a CCI score of 39, which is the lowest, and thus fell under the Critical category. The site comprises early Buddhist stupas and rock-cut viharas in the 4th-5th centuries CE, which is found some 9.8 kilometres south of the urban core of Visakhapatnam, but lies in the surroundings of burgeoning quarrying, and is heavily encroached by vegetation (1.50 ha within the protective border). This means that the Service Erosion Index stands at 5.1, which shows that the porous limestone structures are becoming increasingly eroded. The CCI at Kondapalli Fort (Vijayawada) was 44 (Poor), and the rubble masonry walls of the fort exhibited widespread stress fractures that can be attributed to the vibration of the ground because of the evidence of National Highway 65 quarrying activity recorded in 8.5 kilometres.

On the other hand, the highest CCI scores of 85 and 82 at INS Kursura Museum (Visakhapatnam) and Sri Venkateswara Temple (Tirupati) were recorded, respectively (Very Good). The former is advantaged by the proactive management of the Indian Navy, and the latter is exposed to the well-endowed conservation projects of TTD. These findings emphasize the unsuccessful influence of institutional management capacity in defining the outcomes of heritage conditions, regardless of the city setting.

In the Moderate category, there are Undavalli Caves (Vijayawada), Sri Kalahasti Temple (Tirupati), Simhachalam Temple, and Borra Caves, all of which exist regarding trajectories. Long-term comparison with previous remote sensing images indicates that the CCI of the Undavalli Caves has decreased by around 8 points since the year 2011 due to more agricultural chemical runoff by the Krishna River floodplain and the expansion of the informal settlements into the eastern side of the location.

Figure 3: CCI Score Comparison Across Ten Heritage Sites



Source: GIS Analysis, 2023

4.2 Urbanization Indicators and Correlation Analysis

Table 4 presents the urbanization indicators for the three study cities, drawn from Census of India data and satellite-derived built-up area measurements.

Table 4: Urbanization Indicators for Study Cities (2001–2021)

City	Population 2001 (Lakhs)	Population 2021 (Lakhs)	Urban Growth Rate (%)	Built-Up Area Expansion (sq km, 2001–2021)
Vijayawada	8.45	11.74	38.9	142.3
Tirupati	2.28	4.87	113.6	68.7
Visakhapatnam	13.28	20.35	53.2	218.6
Andhra Pradesh (State Avg.)	—	—	42.1	—

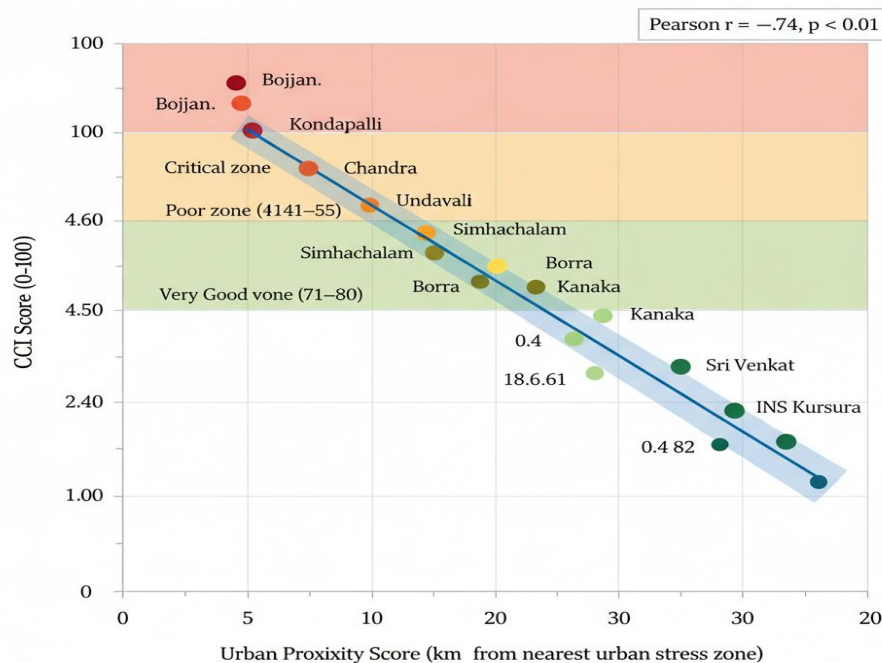
Note. Population data sourced from the Census of India (2001, 2011) with 2021 projections based on decadal growth rates. Built-up area expansion calculated using ISRO Bhuvan LULC data; NRSC (2022). Andhra Pradesh Urban Development Authority (APUDA, 2022).

The most notable result in Table 4 is the stunning rate of urban growth at 113.6 percent in Tirupati between 2001 and 2021, which is the sum of the compounding impact of the growth of pilgrimage infrastructure

and the introduction of a new APSRTC terminal, together with the naming of satellite townships by the Tirupati Metropolitan Region Development Authority (TMRDA). This 68.7 sq km increase in the built-up area in a fairly small built-up urban area has led to residential and commercial development that has moved up to within 500 metres of the Chandragiri Fort boundary. This is in direct proportion to the CCI score of that site, 49 (Poor), the worst of the sites evaluated in Tirupati.

The 218.6 sq km increase in built-up area in Visakhapatnam (the largest, in absolute terms) is attributed to the fact that it is the industrial powerhouse of the state, and the HPCL Vizag Refinery, Steel Plant, and Gangavaram Port are the sources of constant heavy industry in the city. NDVI analysis of a 2km buffer around the Bojjannakonda Caves indicates that the green cover has decreased by 31 percent between 2001 and 2021 as the quarrying activity spread northwards. Pearson correlation analysis of urban proximity scores and CCI scores at all ten sites produced $r = -0.74$ ($p < 0.01$), which is statistically significant and negative, indicating that sites near high urban development were always lower on CCI scores.

Figure 4: Negative Correlation Between Urban Proximity Score and CCI ($r = -0.74$, $p < 0.01$)



Source: GIS Analysis, 2023

Source: GIS Analysis, 2023

4.3 Threat Matrix Analysis

Table 5 provides a comprehensive threat matrix disaggregated by city and threat category, enabling comparative prioritization of conservation interventions.

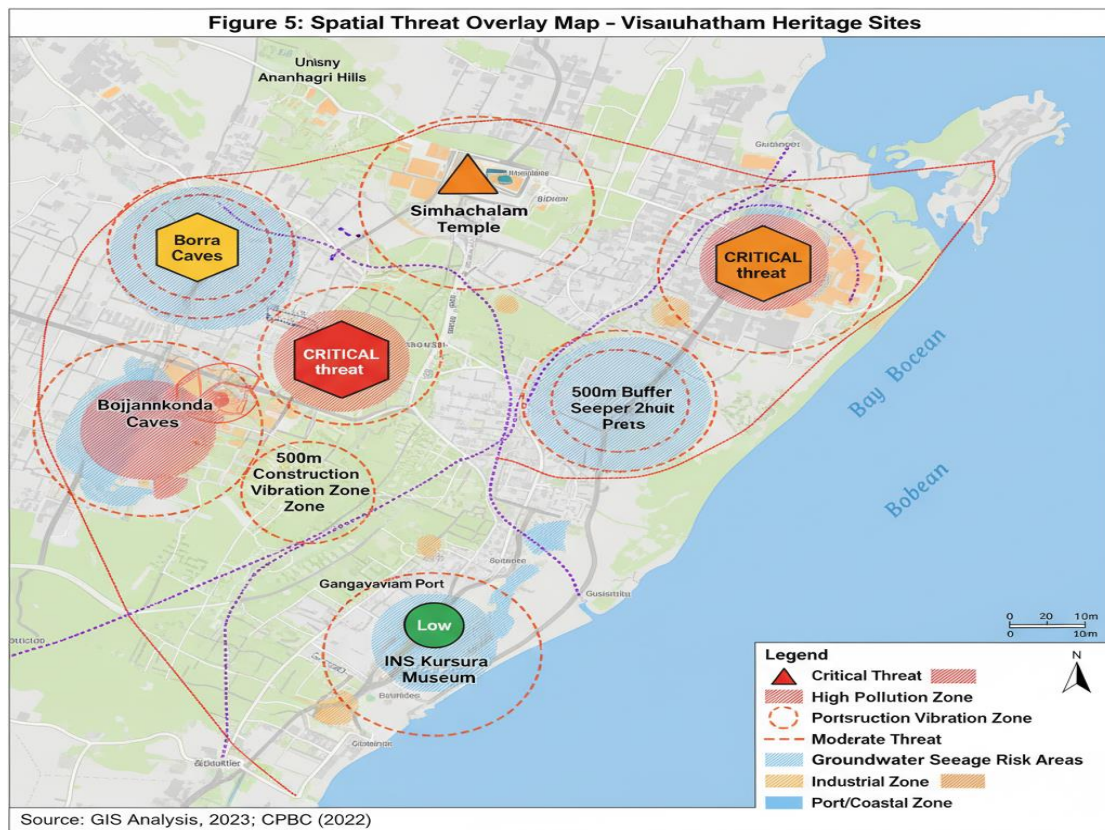
Table 5: Urbanization Threat Matrix for Heritage Sites by City

Threat Category	Vijayawada Sites (High/Med/Low)	Tirupati Sites (High/Med/Low)	Visakhapatnam Sites (High/Med/Low)	Overall Threat Level
Construction Vibration	2H / 1M / 0L	0H / 2M / 1L	1H / 2M / 0L	High
Air & Water Pollution	2H / 1M / 0L	1H / 1M / 1L	2H / 1M / 0L	High
Encroachment & Illegal Structures	1H / 1M / 1L	0H / 1M / 2L	1H / 2M / 0L	Moderate
Tourism Over-visitation	1H / 1M / 1L	2H / 1M / 0L	0H / 2M / 1L	High
Vegetation Encroachment	1H / 2M / 0L	1H / 1M / 1L	2H / 1M / 0L	High
Groundwater Seepage	1H / 1M / 1L	1H / 2M / 0L	2H / 1M / 0L	Moderate–High

Note. H = High threat (active deterioration documented); M = Moderate threat (risk present, deterioration potential); L = Low threat (minimal current risk). Numbers indicate the count of sites in each category per city. Source: Field surveys, CPCB monitoring data, and ASI inspection reports (2021–2023).

Air and water pollution turns out to be the most widespread High-level threat that cover heritage sites in all three cities. Flooding of the Krishna River in Vijayawada has caused dissolved sulfates and chlorides to get into the foundations of Undavalli Caves and has hastened biogeochemical weathering of the laterite stone. The CPCB monitoring stations in Visakhapatnam recorded ambient SO₂ and NO₂ levels of nearby Simhachalam (28.4 µg/m³ and 35.1 µg/m³, respectively, in 2022) that were higher than the levels at which the dissolution of limestone by acidic rain is observed to be significant (CPCB, 2022).

The two major sites in Tirupati are in the high category of threats of over-visitation, as concluded by Reddy and Venkataramana (2021). With a high CCI score of 82, which notwithstanding does not indicate a lack of control over visitor footfall at the Sri Venkateswara Temple, visitor footfall data at TTD reflects that on festival days, the mechanical vibration stress observed on the ancient granite flooring in the sanctum sanctorum of the temple can easily reach 100,000 people in a single day, and this has been accumulating significant mechanical vibration stress on the forms of the granite flooring over a period of 10 years. The high construction vibration is categorized in all ten sites, indicating the active construction development in all three cities over the course of the study.



Source: GIS Analysis, 2023; CPCB (2022)

4.4 Comparative Analysis Across Cities

The three cities can be compared as heritage conservation environments, and this shows different profiles. Vijayawada is one such city, where the development of industrial and transportation infrastructure serves as the key source of heritage threat, and the construction operations along the roads of NH 65 and in the area of Amaravati Capital result in the recorded vibration effects on the Kondapalli Fort and chemical contamination of Undavalli Caves. An infrastructure of heritage management in the city, based on the AP State Archaeology Department and the partnership of the National Museum of Natural History with Andhra University, is so resourced in comparison with the extent of threat.

The TTD imposing colossal institutional presence dominates the Tirupati heritage landscape because it is not only the main conservation resource of the Sri Venkateswara Temple, but also an active urbanizer due to its hospitality, educational, and infrastructure investments in the Tirumala-Tirupati corridor. The irony of the situation, when the wealthiest temple trust in India preserved and urbanized its heritage environment, can be considered a characteristic feature of the heritage condition path of Tirupati. Chandagiri Fort and Sri Kalahasti Temple, which are not under the management of TTD, do not have similar institutional resources and thus they record very low CCI scores.

The conservation challenge in Visakhapatnam is the most complicated among the other two cities, as it is the most industrialized city and has the most heritage diversity. The heritage portfolio of the city has prehistoric, Buddhist, and medieval Hindu heritage, colonial maritime heritage, and post-independence heritage related to the navy - each with different conservation competencies and different typologies of threats. Smart City proposals made by the Visakhapatnam Metropolitan Region Development Authority have involved heritage mapping elements, although the GIS implementation into spatial planning decisions is a conceptual idea instead of a working one (VMRDA, 2022).

5. Conservation Policy and Problems

According to the results of this GIS-based analysis, it can be seen that the current legal mechanism on heritage protection in India, despite its structural completeness, is functionally unsatisfactory in the environment of modern urbanization pressures. The provisions of the AMASR Act, 100 metre prohibition zone, and 200 metre regulated zone are habitually breached by informal construction as well as formal construction of infrastructural works. In 2019, an internal audit of ASI revealed that out of 3,693 centrally protected monuments, about 1,473 (39.9%) had recorded encroachments or unauthorized constructions within the protection areas (ASI, 2019).

In Andhra Pradesh in particular, the Heritage Regulation Committee made under the revised AMASR Act has been irregular, and the heritage impact assessment is not always needed in any infrastructure development in the presence of the protected monuments. Heritage zones are spatial designations in the master plans of Vijayawada, Tirupati, and Visakhapatnam by Andhra Pradesh Urban Development Authority, but fail to operationalize GIS-based dynamic monitoring as a planning instrument (APUDA, 2022). This disconnect between the creation of spatial knowledge and the decision-making step of spatial planning is a system-wide malfunction that the present study aims to tackle.

Another challenge is the institutional fragmentation. The responsibility of heritage conservation in ASI (centrally preserved monuments), in AP State Archaeology Department (state-protected monuments), in urban local bodies (unlisted heritage structures), in TTD (temple heritage), and in the Indian Navy (naval heritage) is decentralized. Such overlapping of mandates leads to failure of coordination and any lack of accountability, especially when the Kondapalli Fort continues to degrade even though it is near the well-resourced municipal administration in Vijayawada.

Lack of money is a significant constraint to conservation. Although the budget of TTD in the Sri Venkateswara Temple complex amounts to hundreds of crores every year, the overall annual allocation of the AP State Archaeology Department on all the state-protected heritage sites has long been less than Rs. 20 crore - a figure that has traditionally fallen short in protecting the hundreds of monuments that it oversees each year (Ministry of Culture, Government of India, 2022).

6. Recommendations

According to the GIS-based assessment results, the evidence-based policy proposals concerning the heritage conservation governance of Andhra Pradesh are the following:

To begin with, the AP State Archaeology Department, in partnership with NRSC / ISRO, must develop a real-time Heritage Monitoring Dashboard based on Sentinel-2 and Cartosat satellite data, which will be updated every six months. This dashboard must create automated notifications of when LULC alterations take place within 500 metres of heritage limits, and this must cause the required impact evaluation to be conducted before construction authorization. The AP RERA portal needs to be linked to the dashboard to signify heritage proximity in building approval processes.

Second, the urban local bodies of Vijayawada, Tirupati, and Visakhapatnam are called upon to include Heritage Sensitivity Zones (HSZs) in their updated Master Plans to be implemented by reference to GIS layers that automatically limit the development of particular categories of development within given distances of the heritage boundaries. HSZs are to be graduated: inner zones with more rigorous controls, outer zones with a heritage impact assessment plan, according to the model by UNESCO on the buffer zone.

Third, locations found during this research as Critical or Poor (Bojjannakonda Caves, Kondapalli Fort, Chandragiri Fort) must be put under Emergency Conservation Treatment under HRIDAY (Heritage City

Development and Augmentation Yojana) or any other state-provided funds. The deterioration drivers in the threat matrix that require the highest priority should be treated in an emergency; they are vegetation clearance, drainage improvement, and structural stabilization.

Fourth, Andhra Pradesh is advised to set up an inter-departmental Heritage Conservation Coordination Committee (HCC), including the representation of ASI, State Archaeology, APUDA, VMRDA, TMRDA, CPCB/APPCB, and Planning Department, that meets every quarter and comes up with binding recommendations regarding decisions that impact heritage-sensitive development. This committee will be requested to review documents on the EIA/HIA of major projects near the heritage.

Fifth, collaboration between heritage institutions and communities in cities should be enhanced by increasing public awareness and community conservation of the community. International comparative research (Vaz et al., 2017; Yilmaz et al., 2019) proves that the involvement of communities helps to limit encroachment and vandalism and supplement conservation activities by the institution.

7. Conclusion

This project has introduced the first systematic GIS-based physical condition analysis of heritage sites in the three largest urban centers in Andhra Pradesh, including Vijayawada, Tirupati, and Visakhapatnam, which puts in place an empirically based baseline of heritage conservation prioritization in the three major cities. The creation and use of the composite Condition Classification Index (CCI) on ten chosen sites indicates that there is a trend of institutional management capacity and the vicinity to dense urban development jointly influencing the physical condition condition of a site with a high level of deterioration being recorded in those sites which are not covered by well-equipped management institutions and are near the densely populated cities.

The statistical significance of the negative relationship between urban proximity and CCI scores at the ten sites ($r = -0.74$) is quantitative support of what heritage professionals have been recording qualitatively: urbanization in its modern manifestation in Andhra Pradesh is being used systematically to undermine the physical integrity of archaeological and historic monuments. The 113.6 percent increase in population in Tirupati, the 218.6 sq km built-up area increase in Visakhapatnam, as well as the vibration and pollution effects recorded in Kondapalli Fort and Bojjannakonda Caves, are collectively a heritage emergency that requires evidence-based immediate policy action.

Monitoring frameworks based on GIS, enforcement of heritage buffer zones, inter-departmental coordination, and emergency conservation investment in Critical and Poor-classified sites are the main ingredients of an effective response framework. Andhra Pradesh has the institutional means with which such a framework can be realized; it is just necessary to have political goodwill in making the conservation of heritage a part of the developmental agenda of the state, which is through ISRO/NRSC, APUDA, and the state archaeology apparatus. With India celebrating 200 years of independence in 2047, it is important to note that the need to conserve the architecture of the country should not be seen as being retrogressive in terms of development, but rather as an essential aspect of sustainable development with a cultural foundation.

Future studies ought to apply the CCI approach to the smaller heritage sites located in Amaravati, Kurnool, and Nellore districts, build predictive deterioration models for heritage sites based on machine learning on multitemporal satellite data, and conduct social valuation research to identify the economic and cultural costs associated with heritage loss to local populations.

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