

# National-scale inventory and management of heritage sites and monuments: advantages and challenges of using geospatial technology

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**India is a vibrant and culturally diverse country with more than 3600 heritage sites and monuments of national importance, of which only 36 are recognized as World Heritage Sites by UNESCO. These heritage sites and monuments are precious and non-renewable resources which need to be conserved, protected and monitored. Conventional along with emerging geospatial techniques are required to prepare databases and action plans to manage them effectively and efficiently. This article discusses ISRO's efforts in the last decade in the field of archaeology using high-resolution remote sensing data in conjunction with GIS, GPS and other geospatial techniques in various applications like inventory and site management plans for a monument/site, cultural resources management plans for World Heritage Sites as well as in exploration archaeology and research for predictive location modelling in the identification of areas with high archaeological potential. Most of the projects have been executed in collaboration with major stakeholders involved in archaeology and in the process have institutionalized the use of geospatial technology to a large extent in operational and research activities.**

**Keywords:** Cultural resources management, geospatial techniques, heritage sites and monuments, predictive locational modelling.

## Introduction

INDIA is a vibrant and culturally diverse country with a vast geography and history. This diversity is seen in different forms of architecture, sites and traditions that are still visited, venerated and practised. Temples, mosques, tombs, churches, cemeteries, forts, palaces, step-wells, rock-cut caves, and secular architecture as well as ancient mounds and sites which represent the remains of ancient habitation belonging to different time periods constitute these heritage sites. Among these sites, some are given the status of national importance and managed by the Archaeological Survey of India (ASI) and a few are under

the protection and management of State Departments of Archaeology. Apart from these, there are few sites protected by NGOs; however, a large number of unprotected sites are present in the countryside. Depending upon the cultural value, uniqueness, vastness and global significance, only a select few are recognized by UNESCO as World Heritage Sites and many are on the tentative list. As these heritage sites and monuments are precious and non-renewable resources, in addition to conventional techniques, geospatial techniques can help to manage them effectively and efficiently.

## Remote Sensing and archaeology

Remote Sensing with its synoptic view offers many lead indicators for the location of archaeological sites such as vegetation marks, soil marks, anomalous structures, palaeochannels and coastal markings. The significant development in geospatial techniques and availability of very high-resolution images along with new digital technologies are useful tools in archaeological applications.

The important aspects of remote sensing are:

1. Improvements in spectral and spatial resolution which reveal increasing detailed information for archaeological purpose.
2. Synoptic view offered by satellite remote sensing data helps in understanding the complexity of archaeological investigations at a variety of different scales ranging from small to very large scale.
3. Satellite stereo data-derived Digital Elevation Model (DEM) improves the data analysis and interpretation efforts.
4. Availability of multi-temporal data allows periodic monitoring and management of sites.

## *Remote sensing and GIS applications in archaeology*

Archaeological research is interdisciplinary and its investigations range from synoptic views to small and

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site-specific details. Research indicates that in the global context, as early as the 1970s, aerial/satellite remote sensing data of both optical and microwave sensors of varied spatial resolution have been extensively used in archaeology for locating sites/artefacts in desert areas and thick forests, especially in the Sudanese deserts, Costa Rica, Cambodia and Guatemala as reported by Osicki<sup>1</sup>. In the Indian context, remote sensing data have been used to study distribution of archaeological sites in relation to the palaeochannels, river migration, coastal geomorphology and neotectonics by both geologists and archaeologists<sup>2-9</sup>. Satellite images have also been used to investigate ritual spaces and cultural landscapes<sup>10</sup>. Integrated applications of satellite imagery, GPS and GIS in India has been carried out for Nalanda<sup>11</sup>, Hampi<sup>12</sup> and Talakadu<sup>13</sup> as pilot case studies.

### *ISRO's efforts in archaeological applications*

Identification of archaeological sites has been carried out by the Indian Space Research Organisation (ISRO), Department of Space, Government of India (GoI) ever since the launch of IRS-1A satellite with its medium resolution spatial data since 1988. For example, studies on locating ancient cosmic sites<sup>14</sup>, potential archaeological sites in Gujarat using soil and vegetation marks<sup>14,15</sup>; palaeo river channels and remnants indicators establishing inter-relationships between palaeodrainage courses and archaeological sites in the Sarswati basin in western Rajasthan<sup>14</sup>, and a study of Hampi ruins<sup>14</sup>. With the launch of IRS-1C and easy availability of high-resolution data, technology development projects/case studies in archaeological applications were initiated in different centres/units of ISRO in collaboration with different stakeholders at the national and state level like ASI, Ministry of Culture (GoI), State Department of Archaeology, NGOs, etc. The feasibility and case studies have paved the way for collaborative projects with premier institutions dealing with archaeology and management of heritage sites and monuments.

ISRO has focused on three broad areas of application in the field of archaeology, viz. (i) inventory and mapping of heritage sites and monuments; (ii) cultural resources management plans and (iii) archaeological research in exploration and mapping of pre-historic sites using geospatial techniques. These three areas of application are briefly discussed below with the description of a few typical case studies taken up by ISRO with lead stakeholders.

*Inventory and heritage site management:* Systematic inventory of the heritage sites and monuments is the first and primary step in conservation, preservation and management. The inventory database allows for comparison

of heritage sites and monuments which can be the basis for prioritizing management interventions, whether for protection, conservation, reuse or maintenance. Based on the relative importance of the sites as seen from the heritage inventory database, management plans need to be generated which define the buffer zones of protection and conservation measures to be adopted. The heritage by-laws are formulated by the statutory bodies for a planned and regulated development to maintain the integrity around the heritage sites and monuments, which should become part of the local/regional development plans.

*Cultural resources management specific to World Heritage Sites:* Cultural resources management (CRM) is a document or a set of procedures or an action plan/master plan more often developed for a World Heritage Site. It has two important components, viz. geospatial database creation with a plan for monitoring and management of cultural resources as well as facilities management<sup>16</sup>. Protection of the heritage sites and monuments is carried out by providing guidelines and measures for conservation and protection of the sites by establishing different management zones which prescribe the areas of protection, public access and infrastructure development<sup>16</sup>.

Facility management includes documentation and management of all resources which not only includes the historical structures and archaeology of the site, but also other collateral infrastructure facilities of the site, viz. visitor service-related infrastructure, site transportation infrastructure and service supply<sup>16</sup>.

Geospatial inputs have been provided by ISRO for generating the CRM for Hampi world heritage area and the same model could be adopted for other important sites on the tentative list of World Heritage Sites by UNESCO for the preparation of CRM plans.

*Predictive locational modelling for exploration of new sites:* Predictive locational modelling is an important component of exploratory archaeological research and is used to identify locations with high archaeological potential. Predictive models are tools for projecting known patterns or relationships into unknown times or places which are of importance for documenting high-potential archaeological sites for future investigations that are under threat of destruction due to rapid urbanization and development<sup>9</sup>.

Unlike modern monuments or structures, the prehistoric sites do not exhibit any kind of distinctive structural features even on very high resolution remote sensing data, but are related to a set of physical characteristics<sup>9</sup>. Protection and conservation of these prehistoric sites are of vital importance as they throw light on the human adaptations to changing environmental and climatic conditions as well as behavioural changes associated with past cultures and linkages to modern human beings<sup>9</sup>.



**Case studies**

*Inventory and heritage site management of nationally important monuments*

ISRO has taken up a major initiative under a national project titled ‘Site Management and Inventory of Heritage Centres’ (SMARAC) in collaboration with the Ministry of Culture, GoI on the inventory and preparation of site management plans for nationally important monuments/sites in the country. SMARAC is implemented by the National Remote Sensing Centre (NRSC) in collaboration with ASI and the National Monument Authority (NMA), New Delhi.

*Scope and objectives*

The scope of the project is to develop a standard operating procedure for the creation of a comprehensive database on inventory and site management plans for nationally important heritage sites and monuments using geospatial technology along with conventional techniques and collateral data available with ASI. The specific objectives of the project are:

- Inventory of all the notified 3600-plus nationally important archaeological sites and monuments in the country by adopting geospatial techniques and use of high-resolution satellite images.
- Preparation of site management plans for all the heritage sites and monuments using web-enabled remote sensing and GIS tools along with the existing collateral data.

- Three-dimensional visualization of heritage sites and monuments for virtual reality applications.
- To integrate the geo-database with Bhuvan geo-platform for wide access to different stakeholders, including citizens, Government to Government (G2G) and Government to Citizen (G2C) activities.
- Capacity building in ASI and other stakeholder institutions to adopt and use operationally geospatial techniques in their areas of activity.

*Study area*

The study area constitutes more than 3600 monuments and archaeological sites of national importance, including a few world heritage sites spread across the country (Figure 1).

*Stakeholders*

Based on the work and responsibility of various activities in the project, the stakeholders are grouped into two categories, viz. (1) primary and (2) secondary. The primary stakeholders are ASI and NRSC, which are involved in the generation of geospatial database of heritage sites and monuments and in the preparation of site management plans for the protection and conservation of monuments. The secondary stakeholders are NMA and local planning bodies which use the database for their developmental planning exercise and implementation of heritage byelaws.

*Primary and collateral data sources*

Multi-resolution remote sensing data from CARTOSAT-1, RESOURCESAT-1 and KOMPSAT 2/3 sensors have been used in the study extensively as primary data sources in the inventory and site management plan preparation exercise. In a few instances, high-resolution data freely available on the internet and other sources are consulted to verify and validate the sites.

Collateral data from ASI include site plans, cadastral maps, historical sketches/historical maps, total station survey data, city/town ward maps, and high-definition field photographs and other tabular data which were used in inventory and delineation of the different management boundaries.

*Methodology*

Figure 2 shows a flow chart on the methodology adopted in the project.

*General data preparation:* Since the data are from multiple sources in different media and formats, they have been organized according to the project-specified

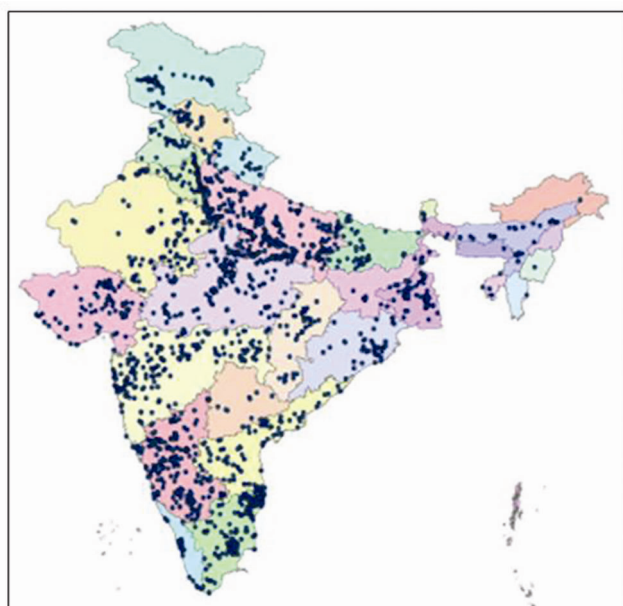


Figure 1. Study area.

database design, standards and specifications. Spatial and aspatial data (tabular) available on different media have been converted into digital format amenable for GIS processing.

*Satellite data processing:* Satellite datasets are processed and analysed using standard image processing and GIS techniques to ortho-correct, enhance and extract areas and objects of interest. DEM derived from CARTOSAT stereo data has been used for ortho-correction and deriving elevation information regarding the sites. The data have been suitably enhanced and fused to generate standard and natural colour composites for visualization, value-addition and interpretation.

*Georeferencing of collateral data:* Available collateral data, viz. total station survey, historical sketches, site plans, etc. have been georeferenced with respect to ortho images of the respective monuments/heritage sites for assigning real-world coordinates for spatial coincidence of satellite images and stacking the data in geo-database.

### Geospatial database organization

The geospatial database has been generated using standard norms with respect to projection and planimetric accuracy. It is organized to support a wide variety of geographic data, attribute data, metadata, raster/grid data, vector, CAD data with multi-user access and editing of the database. A unique code has been evolved for tagging

each monument for easy identification with respect to a state and the corresponding ASI circle to which the monument belongs. Standard file-naming convention has been evolved for both raster and vector files for each of the circles.

GIS tools have been used for creating the vector files for the preparation of inventory and site management plans. Satellite data and ancillary data along with the field knowledge of ASI officials are used for locating the heritage sites and monuments on the image. Most of the monuments are clearly seen in the satellite data. The geo-coordinates and delineation of the protection boundaries around the monuments/sites are achieved with the use of heritage site footprint on high-resolution satellite image and collateral data integration with the images. For example, in Figure 3 satellite images and the corresponding ground photographs are shown for two monuments belonging to East and West Champaran districts of Bihar in the Patna Circle. The footprints of the monuments are clearly seen in the satellite data. Simple-to-use GPS Aided GEO Augmented Navigation (GAGAN) enabled mobile apps on smartphones have been developed for collecting point and polygon data in the field for heritage sites not clearly interpretable from the high-resolution images.

The inventory database contains the geo-coordinates of the heritage sites, multi-temporal high resolution satellite image chips, ground photographs, sketches, maps, reports and other collateral documents of importance related to sites and monuments. Figure 4 a gives an example of each of these components.

### Site management plan

The site management plan (SMP) generation is an integrated planning exercise and action concept that provides guidelines and measures for conservation and protection of a site, and use and development of the area around the site without affecting its integrity.

Three management/buffer areas are delineated around every monument/heritage site using remote sensing and GIS tools. These buffer areas are defined according to the Ancient Monuments and Archaeological Site and Remains (AMASR 2010) Act of GoI.

*Protected area:* It is the management core zone enclosing the heritage site/monument with its various elements. The ownership of this area is generally with the ASI and is directly under its full administrative control. The protected zone has been delineated using the footprint of the heritage site seen clearly on the high-resolution satellite data or by superimposing the boundary derived from the collateral data onto the satellite data, or generating a vector from field surveys using customized mobile apps based on GPS and mobile GIS technology exclusively developed for this project.

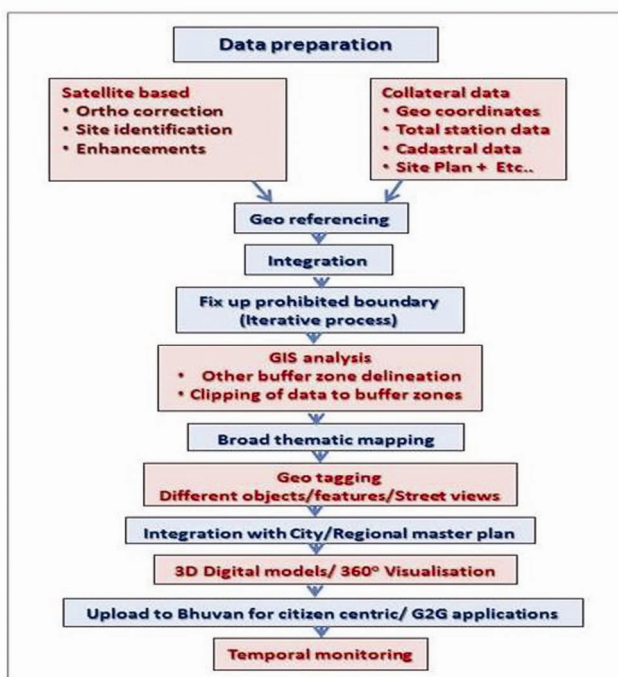


Figure 2. Broad methodology flow chart.



Figure 3. Monuments as seen on satellite images.

*Prohibited area:* It is a 100 m buffer area around the designated protected area of a heritage site/monument.

*Regulated area:* It is a 200 m buffer area around the prohibited area.

These three management buffer zones define the protection status of the monuments and also the conservation strategy to be adopted. The protected area prescribes the zone of no development and complete conservation of all the elements within its jurisdiction. The prohibited area prescribes development within its jurisdiction with strict adherence to heritage bye-laws which describe the kind of building materials to be used, the number of floors a building can have, the type of land uses in the surroundings, etc.

Lastly, the regulated area, prescribes the heritage bye-laws to be implemented within this zone which are slightly relaxed with respect to building materials, height of buildings, etc. Figure 4 b depicts site management plans of four important sites respectively. The red-

coloured line indicates protected area, yellow-coloured line indicates prohibited area and green-coloured line indicates regulated area.

At present, the entire SMP is being incorporated as the area of conservation in the master plan/regional plans of the towns/cities in which they are located. SMP database contains the vectors of management boundaries, cadastral-level details with ownership and other relevant information.

*Three-dimensional buildings models:* These play an important role in archaeology, wherein photorealistic 3D models of the monuments are constructed to get a three-dimensional perspective of the monuments in their natural environment. COTS packages are used in generating 3D digital model using the footprint of the building from high-resolution satellite data as reference points and to scale. Very high-definition field photographs of the monuments are taken in different perspectives and are draped on the 3D mesh of the buildings to create existing



textures for near real look and feel of the heritage sites. Figure 5 shows a step-by-step procedure for generating the 3D models.

The 3D models are useful in conservation activity. The 3D models of buildings, especially iconic ones present within the site management zones, viz. prohibited and regulated areas, facilitate in making informed decisions with respect to maintaining clear line-of-sight, avoiding obstructions and conflict of designs, construction material used, etc. in the designated management zones (Figure 6 a-c).

*Decision support system:* On-line decision support system (DSS) has been developed to enhance the operation

efficiency of augmenting inventory, SMP preparation and other scientific activities of ASI and other stakeholders. Customized mobile applications have been developed exclusively for empowering the stakeholders in augmenting

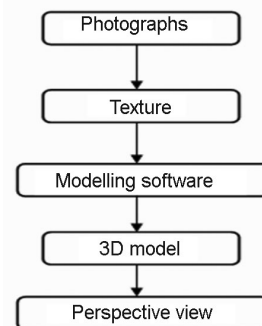


Figure 5. Steps for generating 3D models.

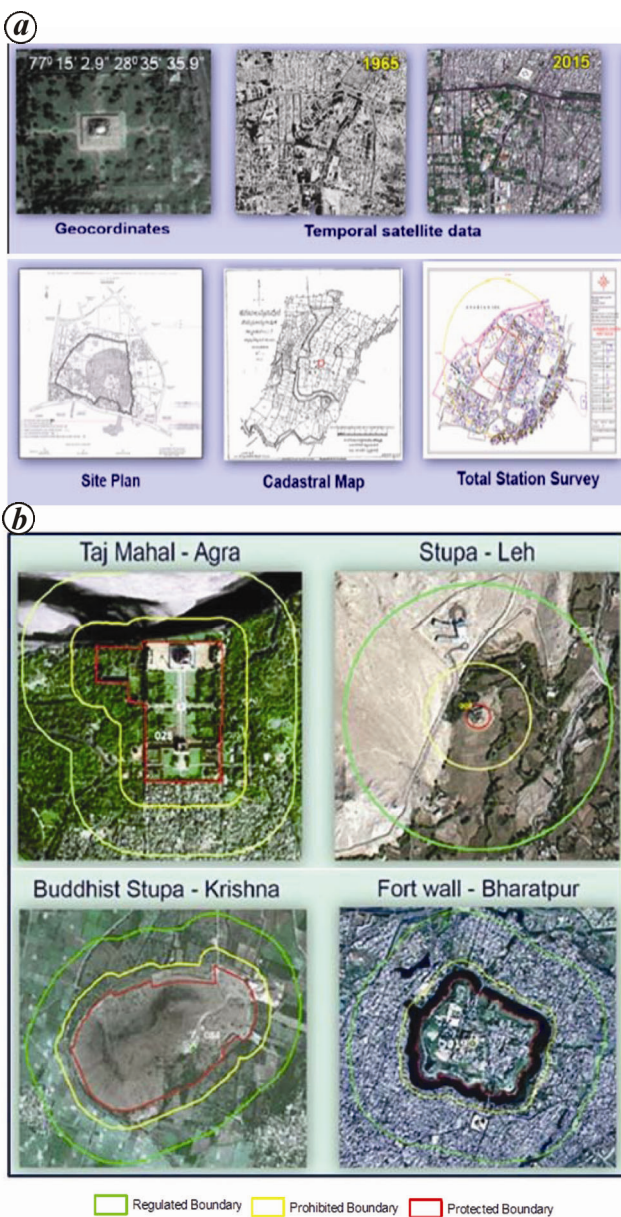


Figure 4. a, Inventory geo-database inputs. b, Site management plans.

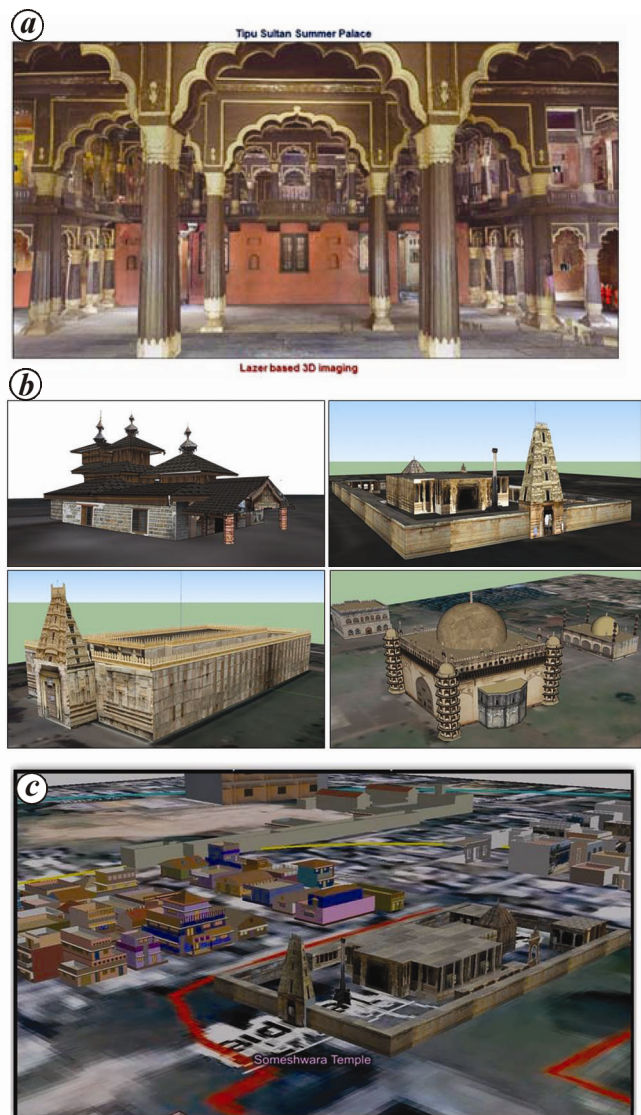


Figure 6. a, Laser-based 3D imaging. b, Three-dimensional building models. c, Digital city model of a heritage site with management boundaries.

geospatial database and citizens in on-line building plan approval towards ease of doing business efforts. DSS is a collaborative effort of NRSC and National Informatics Centre (NIC), where web services are exchanged between the NIC server and BHUVAN geo-server. Figure 7 shows the broad framework of DSS.

The DSS for on-line no objection certificate (NOC) processing for NMA involves the development of two mobile apps, namely SMARAC-G2G and SMARAC-CITIZEN, an auto geo-processing system and a web application. SMARAC-G2G is used for the creation of reference boundaries around protected monuments in a more efficient manner using GPS or GAGAN-based receivers. SMARAC-CITIZEN facilitates collection of geospatial data by the user/citizen of a location for which the NOC

is sought. With these two inputs on geo-coordinates and the vectors of different management boundaries, DSS facilitates the decision-making process for NOC. The geo-processing module performs the proximity analysis and provides proximity status of the target feature (polygon, line or point) from the reference boundary (protected boundary). The output of the geo-processing module is used as the criterion to decide whether approval has to be given for an activity sought by the user such as construction near a heritage site. Checks and balances are built in auto geo-processor module based on the accuracy of the geo-coordinates provided by the user and relative location of the coordinates with respect to the management boundaries. If the coordinates fall too close to any management boundary, recommendation for NOC will be suitably decided by the NMA officials.

The mobile applications developed use the native features of the smartphone (viz. GPS, camera, etc.) as well as external GAGAN dongle to create monument boundaries along with attributes and geo-tagged photographs. GAGAN receiver interface has been established with an Android-based smartphone through Bluetooth for better position accuracy (<3 m); <https://developer.android.com/index.html>.

Figure 8 shows screenshots of the mobile apps with major functionality.

*Ease of doing business:* For transparency and faster processing of NOC requests, SMARAC-CITIZEN app is operationally used by some local planning authorities like the New Delhi Municipal Corporation (NDMC) and Greater Mumbai Municipal Corporation (GMMC) for processing NOC applications on-line within a stipulated time. With the successful implementation in two municipalities, NMA proposes to soon extend the usage to all cities with million + population.

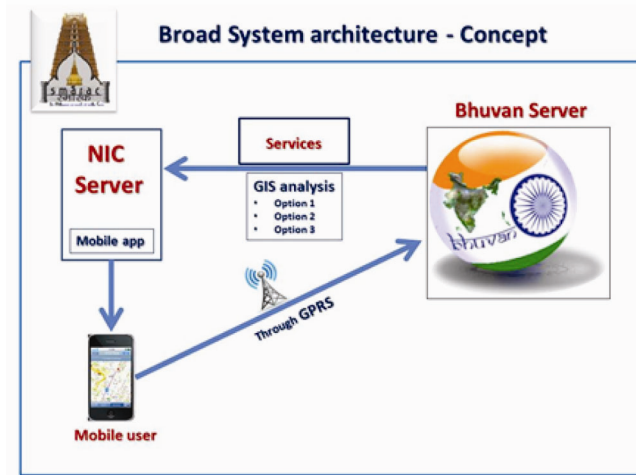


Figure 7. On-line data processing steps.

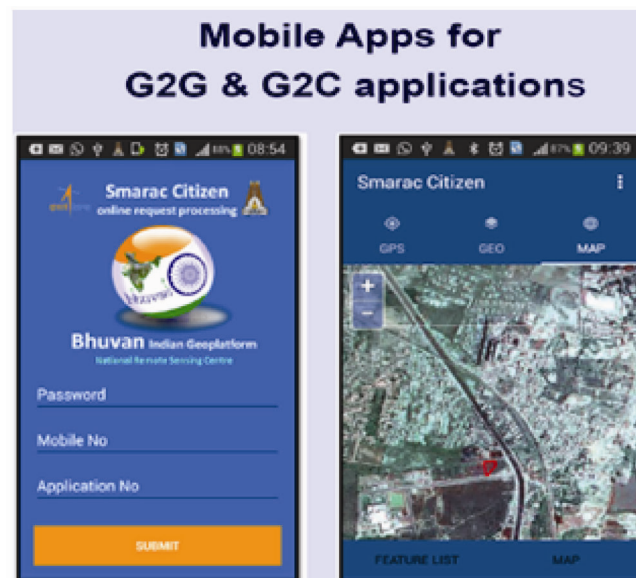


Figure 8. Mobile apps Graphical User Interface.

*Outreach through BHUVAN*

BHUVAN is a geoportal platform of ISRO, hosted presently through the URL <http://bhuvan.nrsc.gov.in>, with a host of wide-ranging services that cover visualization of multi-date, multi-sensor satellite data, thematic map display, query and analysis, free data downloads and products, near real-time disaster services, apps for crowd sourcing and diverse geospatial applications.

The entire database generated under the SMARAC project is currently hosted on a separate webpage titled 'Monuments', wherein both the inventory and SMPs have been hosted along with field photographs. On-line access to the database is possible based on any administrative boundary, including the ASI Circle Office or even based on the notified heritage site/monument. The entire database is in the public domain for larger outreach.



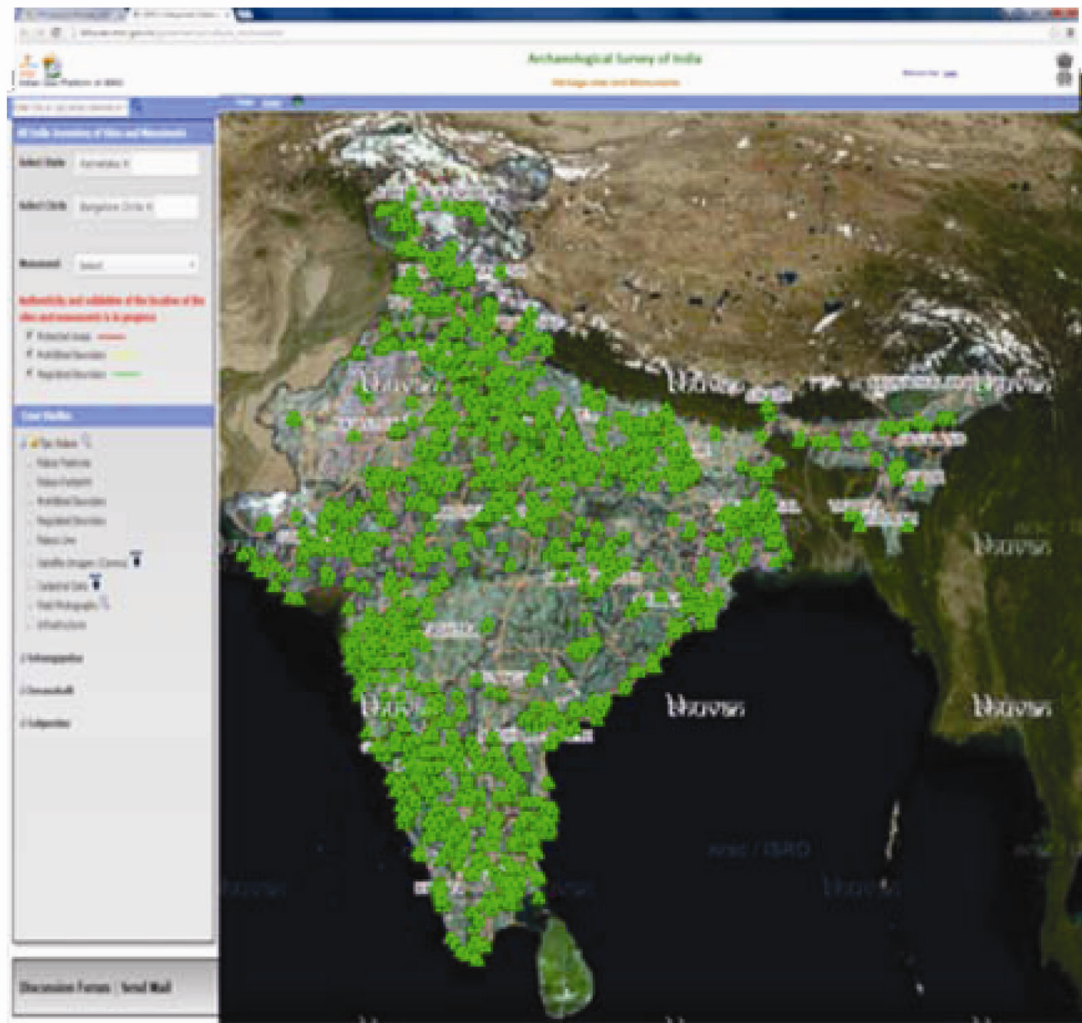


Figure 9. Archaeology webpage in BHUVAN.

### Cultural resources management for Hampi World Heritage Site

There are 36 World Heritage Sites in India recognized by UNESCO. Twenty-eight of them are under 'Cultural' category, seven under 'Natural' category and one under 'Mixed' category. As World Heritage Sites, they are expected to maintain the geodatabase according to the UNESCO guidelines for proper protection, conservation and management, and also provide minimum level of tourist facilities to international and local visitors.

#### Background

In 1986, the group of monuments at Hampi attained the status of World Heritage Site. In 1999, Hampi World Heritage Site was placed as endangered in the world heritage list after unplanned construction commenced on two suspension bridges on the Tungabhadra river near Ane-

gundi that threatened the integrity of the site with heavy traffic flow leading to damage of the structures. The Government of Karnataka in consultations with ASI, formed a regulatory authority, viz. Hampi World Heritage Area Management Authority (HWHAMA) to manage and implement the CRM system. ISRO was approached to assist the Authority for providing inputs and integration of collateral data useful in preparing a database and a CRM for regulating the development in the area of Hampi heritage site in 2006–2007.

The scope and objectives of the project were to prepare:

- Baseline resources information at 1 : 10,000 scale using high-resolution satellite data for an area of 236 km<sup>2</sup> and very high-resolution satellite data for the core Hampi area.
- Inputs to prepare CRM integrating the resources information, cadastral boundaries and other collateral data.

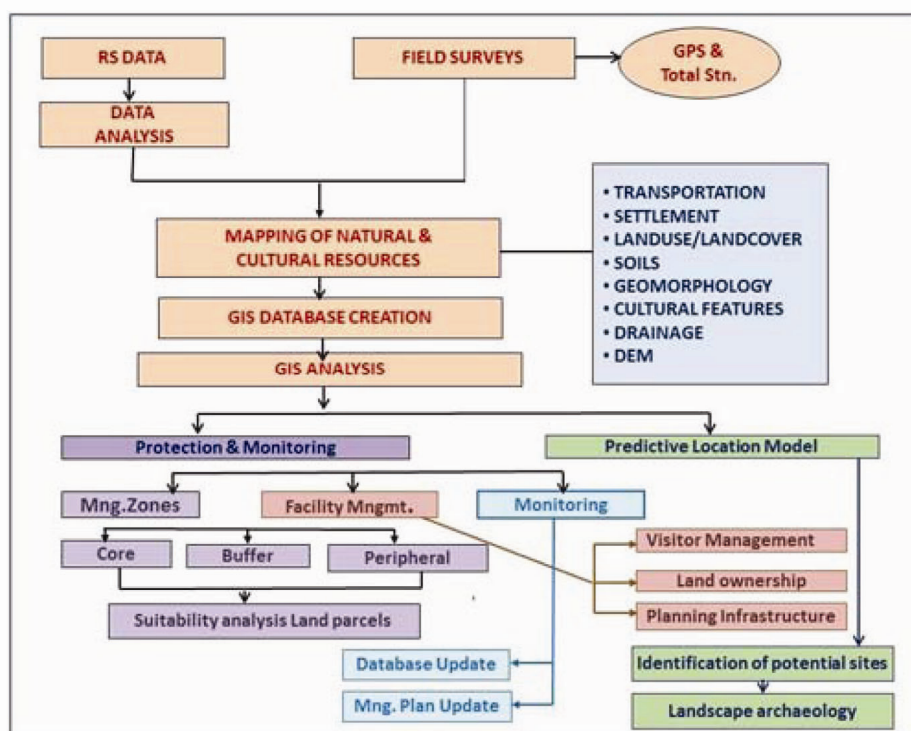


Figure 10. Cultural Resources Management (CRM) methodology flow chart.

### Study area

Hampi is situated in an exceptionally beautiful landscape covering a vast area of 46.8 sq. km on the southern banks of the Tungabhadra in Hosapete taluk, Bellari district, Karnataka. Hampi includes major archaeological remains of a famous medieval capital city of Vijayanagara founded in AD 1336. Today, it is a living site, with 29 villages and widespread agricultural activity. An area of 236 sq. km around Hampi is considered as its local planning area.

### Data sources and methodology

IRS-P5 CARTOSAT-1 data with spatial resolution of 2.5 m and multi-spectral data from LISS-IV were used to derive all the required spatial layers at 1 : 10,000 scale. DEM from CARTOSAT stereo and Ground Control Points (GCPs) collected from an exclusive Differential Global Positioning System (DGPS)-survey conducted was used for ortho image generation which formed the image base for preparation of base map, interpretation, analysis and information extraction.

Figure 10 shows the methodology adopted for the preparation of CRM of Hampi.

### Geospatial database creation

Different thematic maps such as detailed land use/land cover, canal network, transportation and settlements,

inventory and spatial distribution of monuments were prepared from merged product of CARTOSAT-1 PAN with multi-spectral LISS-IV data. Very high-resolution satellite data from IKONOS satellite were used for mapping the monuments and their extents within the core area. Figure 11 shows some of the resource layers generated.

One of the most challenging tasks was geo-referencing of cadastral maps from different sources ranging from the Nizam of Hyderabad regime to British regime on different scales and units. A near-seamless mosaic of all the georeferenced village cadastral databases for 29 villages falling within Hosapete taluk, Bellari district and Ganga-vathi taluk, Koppala district has been created and integrated as part of the comprehensive geospatial database of HWHAMA. The village cadastral database contains survey numbers (Figure 12) and the village names which are further updated with other attributes like ownership details by HWHAMA.

*Protection and monitoring:* Three management zones, viz. the core, buffer and peripheral zones (Figure 13) have been delineated using inputs on the monument density and spread, resources information, cadastral survey details and other ancillary data. Detailed heritage bye-laws for each of the zones were prepared with specific prescriptions on the use of building materials, type and height of the buildings, etc. and periodic monitoring of the area using multi-temporal satellite data for suspected violations.



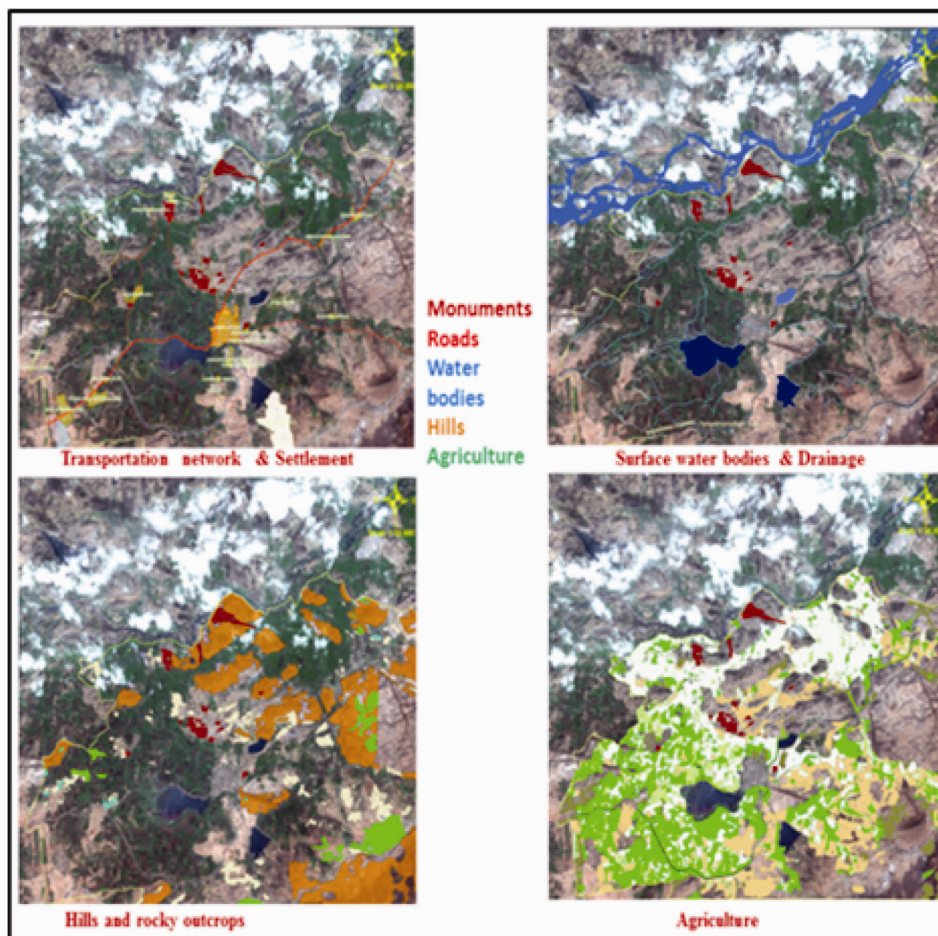


Figure 11. Baseline resource information generated using satellite data.

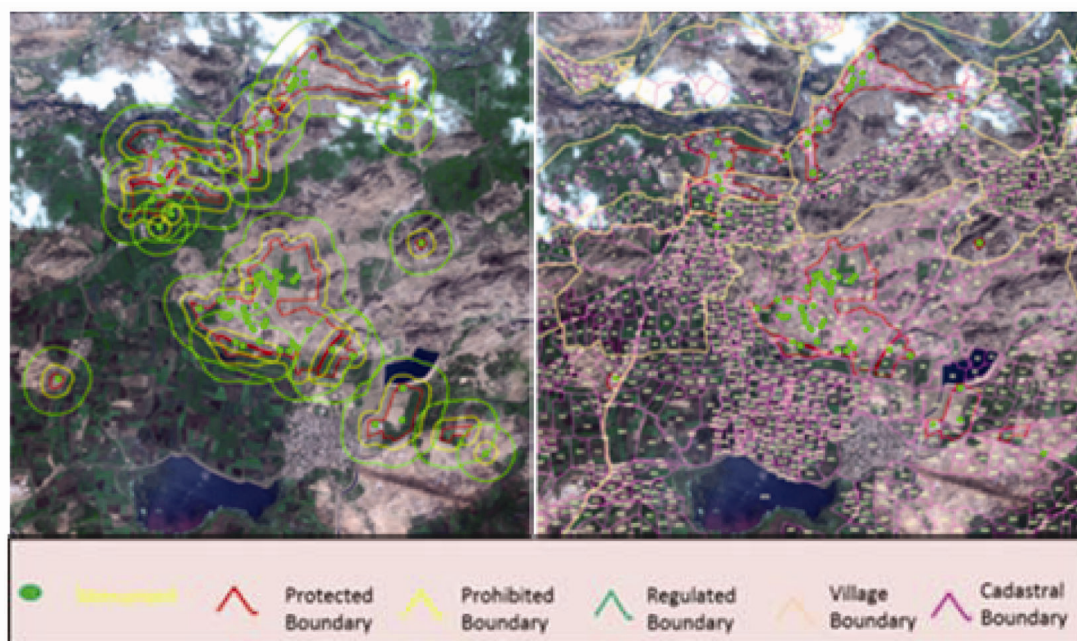


Figure 12. Site management zones with cadastral overlay of all the Archaeological Survey of India monuments.



*Facility management*

Suitable location for visitor lounge, transportation routes for operating battery-operated vehicles taking into consideration the spatial spread of important monuments, tourist convenience points, etc. have also been planned using the geospatial database.

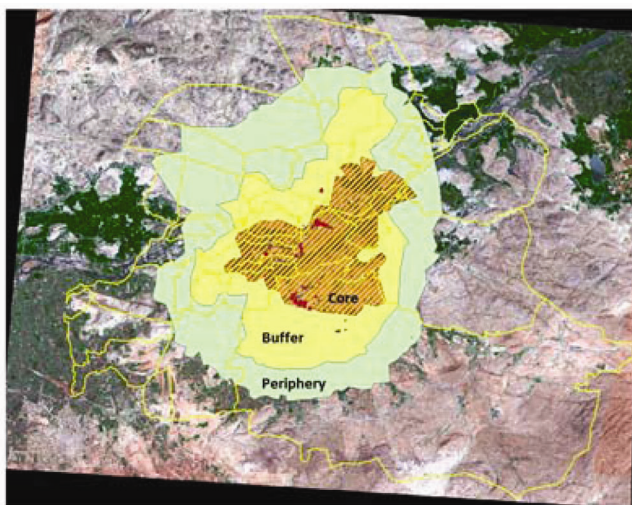
*Institutionalizing effort at HWHAMA*

The geospatial database and CRM inputs are institutionalized at HWHAMA for day-to-day use and as management DSS. All the developmental activities in the Hampi local planning area are now bound by the management zones bye-laws for proper implementation and monitoring.

**Predictive location modelling – study of prehistoric sites in the Palar River Basin, Tamil Nadu, east Coast of India**

*Background*

A joint collaborative project under ISRO Geosphere Biosphere Project (IGBP) programme was initiated by Sharma Centre for Heritage Education and RC-South, NRSC during the 2006–2008 time-frame on ‘Satellite remote sensing in archaeology: prehistoric landuse patterns and culture resource management in the Palar River Basin, Tamil Nadu’, to study the Paleolithic sites using high-resolution data and geospatial techniques. Details of the study with some of the major findings of the project with respect to impact assessment and heritage management component are well documented in the publications of the project<sup>7-9</sup>.



**Figure 13.** CRM zones – core, buffer and periphery.

*Scope and objectives:* The main objective of the project has been to detect and locate archaeological sites as well as features in relation to palaeo landforms within the study area as well as to study the impact of modern land-use patterns on them and prepare CRMs for selected sites<sup>7</sup>. Using predictive modelling techniques, identifying new prehistoric sites has also been attempted as part of the project.

*Study area*

The total project area surveyed was of 8000 sq. km in the districts of Thiruvallur, Kanchipuram and Chennai covering the basins of rivers Arani, Kortallaiyyar, Cooum, Adyar, Palar and Cheyyar.

*Data sources*

IRS-1D PAN and LISS-III data of November 2004 were used for carrying out the regional data analysis and deriving resources information on 1 : 10000 scale. IKONOS data of April 2005 covering Attirampakkam and surrounding areas have been used for generating cadastral-level information (Figure 14). DEM derived from SRTM has been used to derive the elevation data. Extensive field surveys were conducted and other ancillary data from published sources were used.

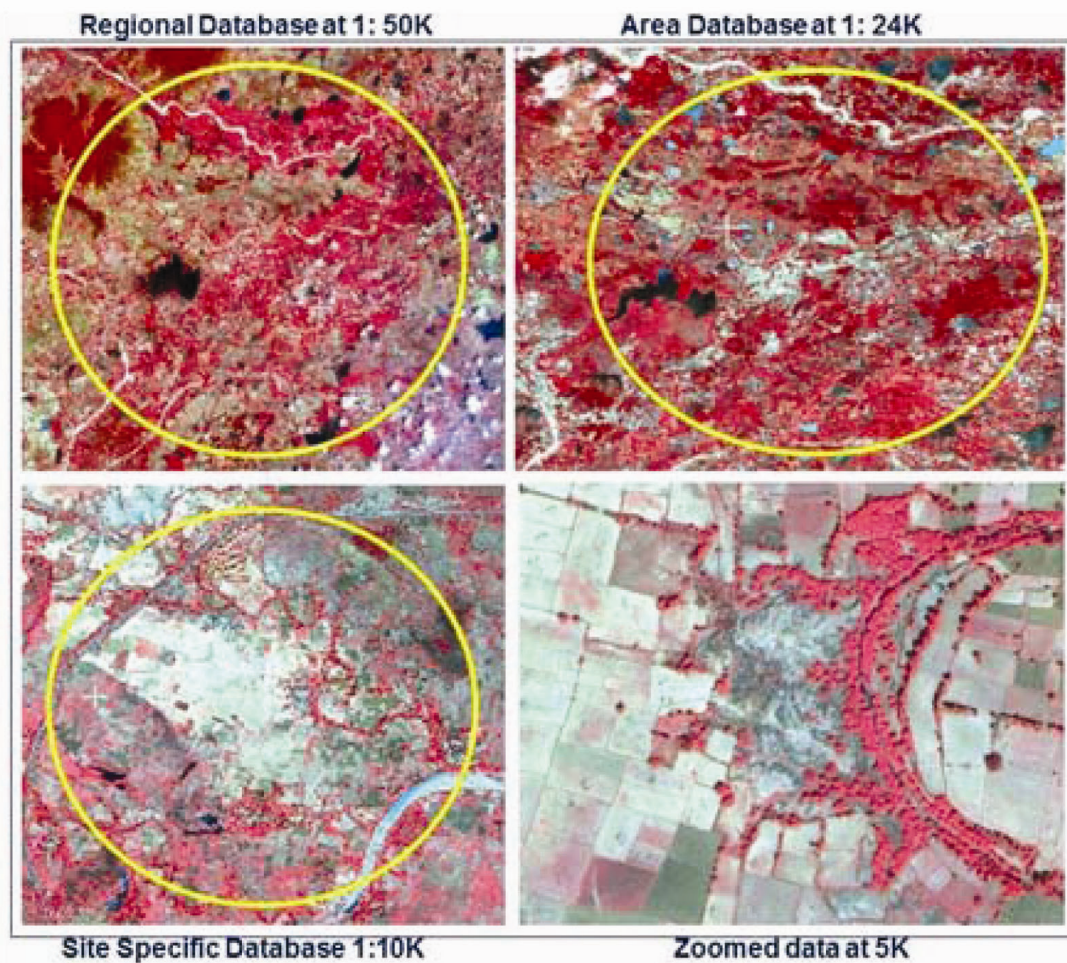
*Methodology*

*Satellite data preparation:* Satellite data of varied spatial resolution have been used for preparing the geodata-base at different scales, as indicated in Figure 14.

*Field investigations:* An area of 8000 sq. km was field-surveyed and a systematic database of over 200 locations of interest for both archaeological and quaternary environmental studies has been generated (Figure 15). A detailed analysis of the artefacts, number, workmanship including the raw materials collected at these sites has been carried out with the help of experts’ knowledge<sup>7-9</sup>.

*Predictive location modelling parameters:* In this study, an inductive approach from known to unknown with the main assumption that locations of Palaeolithic sites in India are largely conditioned by a range of factors, including geomorphology, geology, soils, erosional features, water bodies, elevation and access to sources of raw material has been adopted.

*Weightages:* A weighted value method was adopted for each parameter on a scale of 0 to 1, with 0 indicating no possibility and 1 the highest possibility. This has been based on the experts’ field knowledge and site context obtained over a decade-long study of the region<sup>7</sup>.



**Figure 14.** Satellite images of the study area falling in parts of Thiruvallur, Kanchipuram and Chennai districts.

*Geospatial database creation:* Using satellite data and ground information, thematic maps were generated on drainage, surface water bodies, transportation network, settlement locations, land use/land cover, geomorphology, geology, lithology and elevation. Other details pertaining to each site were generated based on field-collected data, viz., area, artifact density, stratigraphy, cultural phases, assemblage composition, etc.

#### *Predictive location modelling*

All the thematic data, collateral data and field data on artefacts collected were reclassified with certain weighting factors applied to each cell of the raster layer. The weighting and rating factors were specified based on the statistical analysis of specific parameters in relation to their correlation with known sites in terms of the locations. All raster layers were rated and final predictive model maps were constructed to identify areas with high probability of artifact occurrence. Broad combinations of variables were evolved which were fine-tuned based on

experts' knowledge. The model was applied with different variables for sites of different cultural phases and tested in the field accordingly<sup>7-9,17</sup>.

#### *Results*

Maps were generated for all prehistoric sites and for each cultural phase, determining areas with high or low probability. In Figure 15, the highly probable areas of locating Achuelian (Phase 1) sites have been depicted, which fall on the pediplains or denudation surfaces, related to Satyavedu Formations, or in context of proximity to raw material sources related to the Cretaceous formations. Shifts in site location were seen over the Middle to late Palaeolithic periods. Areas with negligible probability occurred in alluvial contexts<sup>7-9</sup>.

A significant outcome of the present study is that an urgent survey and sampling of the regions demarcated as high potential areas can be taken up to ensure rapid conservation of the sites as well as documentation in particular under constraints of time and funding. The same



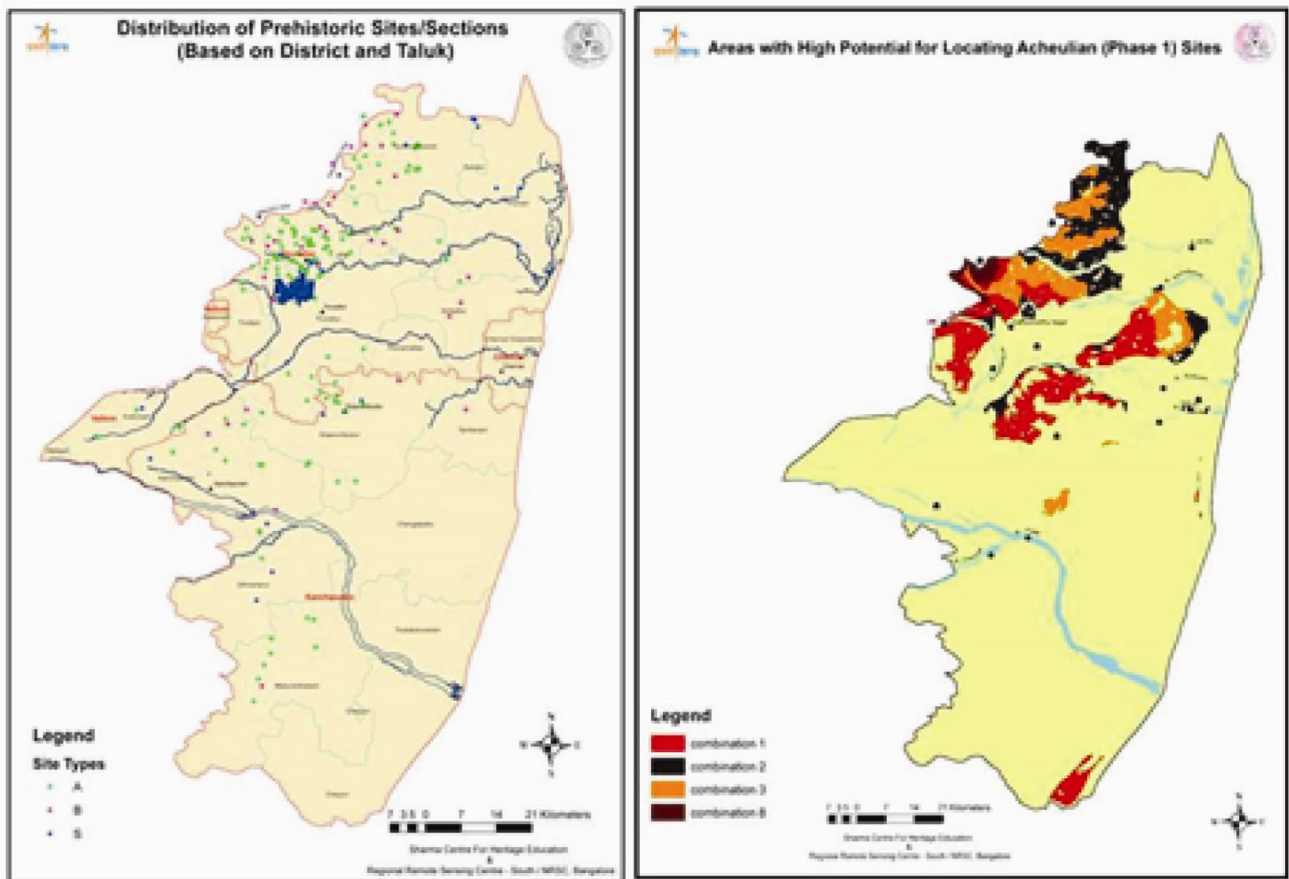


Figure 15. Distribution of sites and predictive modelling output of potential areas.

parameters can be applied to archaeologically rich areas extending from Tamil Nadu to Odisha, or in regions bearing similar geomorphological features, while modifications of this model may be applied to extend to sites of different time-periods and in other regions of the country.

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