Applications of geospatial technology in the management of cultural heritage sites – potentials and challenges for the Indian region

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Cultural heritage management can be defined as all the processes in understanding (through knowing and identifying), conserving and managing various expressions of cultural heritage. These expressions could be intangible like traditional skills, crafts, folklore, rituals, etc. or tangible like objects or places. Objects including artefacts, murals and sculptures are defined as movable cultural property, while structures, monuments, precincts, water bodies and canals are called sites and also termed as immovable cultural property. Emerging technologies and scientific developments are increasingly being used in the management of these different expressions of cultural heritage. For example, heritage object databases that link source, provenance and current location are proving useful in museum contexts, predictive technologies are being used to fill in partially missing sections of murals/inscriptions or aid virtual reconstruction of object remains or even something as basic as mapping indigenous processional routes. However, the expression of cultural heritage as immovable cultural property or heritage sites appears to render itself most to analysis through various techniques available under the large umbrella of geospatial technology. This is because of the nature of such heritage – structures are necessarily built in particular geographical and cultural settings, presumably based on appropriate site selection in order to suitably locate them and their components, and the initially planned layout and subsequent additions would have a spatial spread – these factors combined with the locational permanence of the structures relative to movable property make built heritage well-disposed for geospatial analysis. This review article therefore explores the use and applicability of geospatial technology for the management of built cultural heritage, including its context and environment.

Keywords: Cultural heritage management, geospatial technology, heritage practice, potentials and challenges.

Introduction

CONVENTIONALLY we learn about the history and development of cultural heritage sites from sources such as inscriptions, writings, records, literature, art and architecture. Scientific developments and emerging technologies provide us new tools to study ancient material remains and decipher the past, in ways that both complement and supplement the information we derive from conventional sources. But for these tools, some aspects of history would remain undiscovered.

Ever since humankind has evolved from being nomads and cave dwellers and moved towards building settled habitation, we have constantly scarred our environment by making dents on the earth's surface – for agricultural activities, building structures, laying out towns/cities, creating settlements and exploiting natural resources (particularly water) for our sustenance. We can therefore trace our history and development by studying the impacts of such human actions upon the environment. Space technology offers researchers an opportunity to detect the impacts of such activities that are often invisible to the naked eye or from the ground. For example, declassified satellite images of the 1960s and 70s from the spy satellite CORONA are proving useful in advancing our understanding of historical settlements prior to large-scale industrialization[1–3]. This is because images taken from aerial and space platforms display a perspective of landscapes which cannot be perceived from the ground.

Such inter-relationship between the earth's surface/land and human intervention has led to the use of remote sensing (RS) and geographical information system (GIS) for archaeological applications. Advanced RS technologies allow one to detect subtle landscape features by sensing 'light' that is invisible to humans (infrared, microwave, etc.). Being purely non-invasive, this technology is well suited for archaeology because it leaves sites untouched. Such RS data, together with other spatial data (maps, plans, and the like) pertaining to archaeological sites can be integrated into a database for storage and analysis through GIS technology. Even historical narratives pertaining to past landscape conditions can be revisited and understood better using 3D visualization. The set of technologies that include RS, GIS, 3D visualization

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together with sat-nav (satellite navigation) for positioning and ground truthing can be collectively called geospatial technology (GT). Increasingly, GT is being used in new kinds of application that bring its versatile potential to the fore; for example, Gillespie *et al.*[4] have used predictive modelling with eight environmental parameters to identify 121 possible locations in the Indian subcontinent where edicts of the Ashoka era may be looked for. At the other end of the spectrum, GT is more commonly being used in the interpretation and presentation of cultural heritage sites to visitors or general public, e.g. making augmented reality images available at specific locations at a site, digital inpainting of missing sections of monuments. For example, various projects of the India Digital Heritage initiative by the Department of Science and Technology, Government of India[5]. However, in this article we mainly address the applications of RS, GIS, sat-nav and 3D visualization to heritage practice and processes. These are referred to variously in different countries – UK and India tend to use heritage conservation, Australia uses cultural heritage management (CHM), while USA prefers historic preservation. Broadly they are synonymous. More recently, India is veering towards use of the term 'cultural heritage management' as a way to distinguish the larger process from the physical act of conserving a site or monument[6–8].

This article posits that the use of GT in understanding and identifying sites both worldwide and in the Indian region is fairly well established, but its application in conservation and management of cultural heritage sites appears to be less common worldwide while in the Indian region it appears to have not been exploited. Hence this article not only reviews the ways in which GT has been used in cultural heritage identification and understanding, but also explores how it can be effectively used in various other aspects of CHM in the Indian region. Through case studies this article demonstrates the potential of GT across the vast range and scale of built cultural heritage, including, but not limited to archaeological remains, monuments, structures/complexes and areas like archaeological parks and/or cultural landscapes. The first half of the article presents a typical sequence of CHM processes and the use of GT in each of these steps – starting with understanding, then conserving and finally in managing heritage sites. Having established the potential of GT, the article then discusses the challenges in its application in the heritage sector.

Finally, the case studies demonstrate that the use of GT in various CHM processes is largely dependent on the particular site under consideration and cannot be applied in a prescriptive manner across all sites. As with any tool, the extent of its applicability and interpretations from it depend largely on the skills, knowledge and experience of the user. Lastly, we reiterate that GT complements and/or supplements other methods and CHM processes; we do not advocate replacing them with GT.

Understanding cultural heritage sites

Built cultural heritage sites range from single stones like the Ashokan inscriptions at different locations or individual monuments such as Kempegowda Tower (9 m^2), small complexes like Belur (0.02 km^2) or large areas like the archaeological site of Nalanda Mahavihara (0.23 km^2 core zone), forts such as Srirangapattana (5.2 km perimeter; 1.38 km^2 area), or Hampi World Heritage Site (236 km^2) which encompasses several smaller complexes within it besides 30 villages along with their revenue boundaries.

Satellite and aerial images have been used for understanding such varied forms of built cultural heritage in many parts of the world[9–12]. Images taken from aerial and space platforms offer four distinct advantages over conventional approaches like writings, records or even on-site archaeological investigations, in understanding such heritage: (1) using such technology researchers can efficiently survey large swathes of land and pinpoint the most promising locations for conventional examination; (2) this 'synoptic view' can offer clues that cannot be perceived from the ground; (3) advanced RS technologies allow landscapes to be viewed in a 'light' invisible to humans (e.g. infrared, microwave), permitting investigators to discover features that are too obscure (e.g. by soil or vegetation) to be detected otherwise, and (4) RS can be used to construct 3D models of the terrain, thereby allowing investigators to search for clues among topographical features.

The case studies in this section, reiterate the four points mentioned above, in identifying components of site(s)/structure(s) and at the level of landscape/site context. The section closes with a brief note on the potential of GT in understanding site morphology.

Identifying individual entities: ruins/buildings, mounds and their components

When studying a site, there is tremendous value in first geo-tagging known information, i.e. attaching geographical references to every known archaeological object. This can be done either by identifying the object on a satellite image of the site, or recording its location at site using Global Positioning System (GPS) or such other sat-nav systems. With such a geospatial context in place, one can then analyse the archaeological object in relation to adjacent ones (at various scales), by querying why it is located there, what is up/downhill from it, how far is it from related objects, and so on. We can thus build a GIS database of known facts about the site, rich enough to incorporate information from literature, epigraphy, travellers' accounts/records and archaeological reports. Such an integrated information system can shed new light on well-studied problems, and create opportunities to ask new questions. For example, the customized 3D web-based GIS platform, Heritage Information Management Package (HIMP), which was broadly conceptualized as an Enterprise Resource Package for large, geographically dispersed heritage organizations like the Archaeological Survey of India (ASI), Government of India and various State Departments of Archaeology in order to aid resource planning and allocation across their sites[13].

GIS databases are also well-suited to incorporate images taken from space, providing a platform to analyse them using RS techniques. Broad structural and layout features invisible from the ground become conspicuous when viewed from above. Therefore, this synoptic view (a simultaneous view of a large area) readily facilitates making accurate maps and plans of sites marking all the surface features. Advanced RS satellites carry a variety of sensors (including infrared and microwave) that have helped reveal unique information about cultural heritage sites/components being studied[14–17]. For instance, buried archaeological remains can affect the growth of surface vegetation: certain archaeological features such as moats, canals and pits are favourable to growth, whereas features such as stonewalled foundations, buried streets and solid floors obstruct plant roots and are unfavourable to growth. These subtle variations in growth are nearly indistinguishable on the ground and in visible-wavelength imagery. Infrared sensors, however, can readily discern vegetation growth patterns over the ground following the lines of the buried features, revealing their plan and layout. Satellites can also take stereoscopic images which are helpful in producing 3D models of settled landscapes[18–20].

Identifying landscape features (water bodies, palaeochannels, canals, roads, routes, etc.)

Apart from features in the immediate vicinity of a site, RS technology can also be used in large-scale survey, selection of individual sites for detailed study, understanding the site in context to its environment, and determining the most productive areas for ground exploration. Any historical settlement, whether it existed for a few decades or centuries, would have depended on its local environment for resources for existence and sustenance; water being the most essential resource. Communities may settle close to flowing water sources such as river banks, or conserve rainwater by constructing tanks, ponds and wells, or draw water by diverting it from nearby drainage channels by building canals. Such features are all man-made alterations to the geomorphological setting, and they often leave scars (of typical shapes) on the earth's surface, usually at specific locations vis-à-vis the rest of the settlement. It is sometimes possible to delineate such scars when the overall region is observed synoptically using satellite imagery. For such purposes, coarser resolution (5.8/23.5/30 m/pixel) is useful to show features that are part of the larger landscape; such features may not be perceivable in higher resolution images (~1 m/pixel) that show details of buildings and roads.

For the former purpose, LANDSAT images of the region at 30 m resolution have proved useful. LandsatLook Viewer is an on-line interface for viewing LANDSAT images in natural colour taken during different seasons spread over the past few decades. For example, a careful examination of its images of the region in and around Nalanda World Heritage Site shows a series of water bodies surrounding the site. While south Bihar has several scattered water bodies, the ones clustered around Nalanda form a pattern not seen elsewhere in the vicinity. Their spread with respect to the geographical context of the site, suggests their association with the site, and may therefore also indicate the full extent of the site[21,22]. Among the many water bodies that surround the site, the layout of the largest tank – Dighi Pokhar – is in sharp contrast to the others as it stretches out eastward rather than tightly framing the site. RS image analysis has also revealed a 10 km palaeochannel that connects the east end of this tank to a nearby river (Figure 1). Therefore, in historical times, this tank could well have been the reservoir for water drawn from the river through this channel towards the site[21].

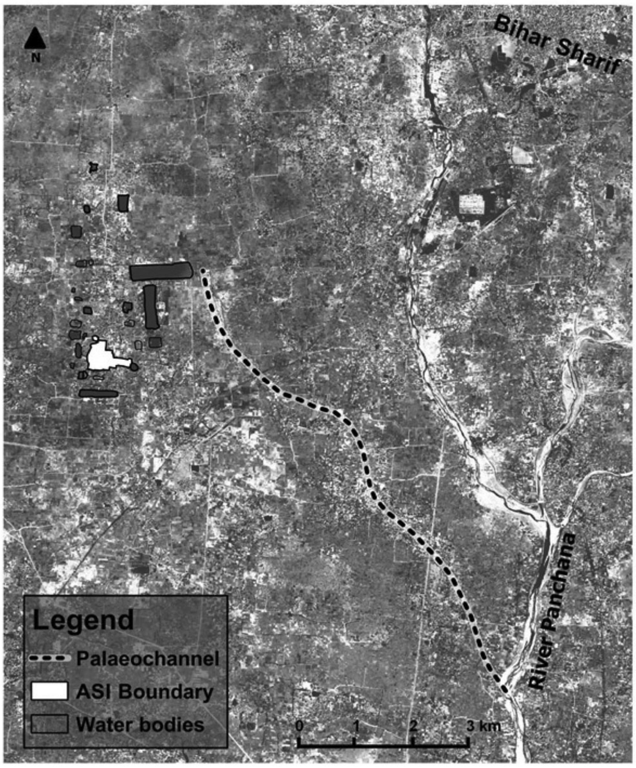

Figure 1. The excavated site of Nalanda and environs, along with 10 km long palaeochannel that drew water from River Panchana to the site, as seen on CARTOSAT1 Aft image of 9 February 2008.

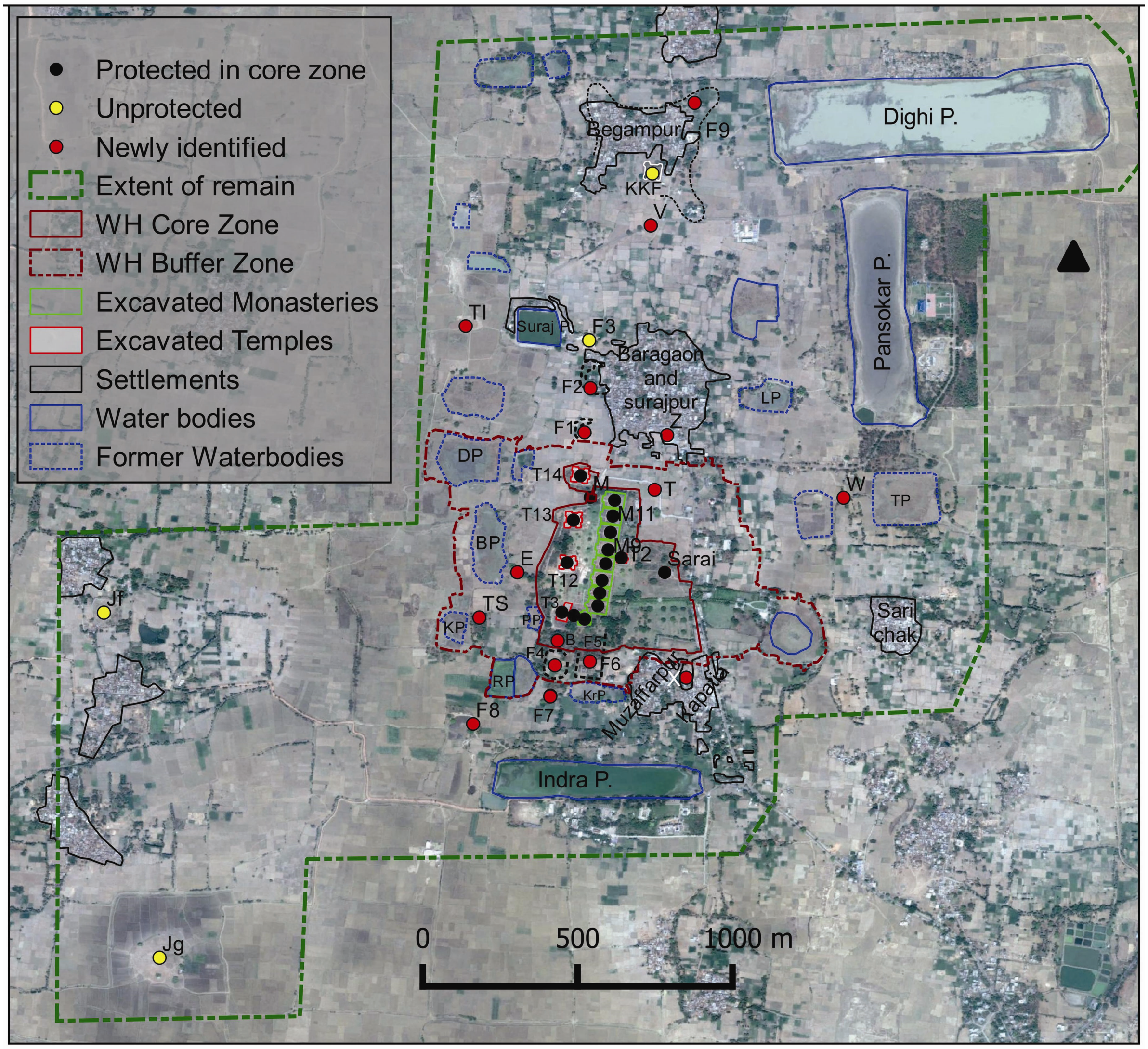

Figure 2. The spread of identified archaeological remains around Nalanda in the context of the core and buffer zones of the archaeological site of Nalanda Mahavihara inscribed as World Heritage property by UNESCO.

Understanding site morphology and/or transformation over time

With regard to built cultural heritage sites, most often what we see or visit is just the extent of the protected monument(s) and its surroundings, whether at central or state or regional level. Whereas if we go by historical records (where available) or even early archaeological reports made when the site was comparatively untouched, we find instances where the surveyor was able to observe and has recorded expressions of cultural heritage spread over a far larger area. For example, Francis Buchanan visited Nalanda in 1812 and left a detailed description of the ruins together with a hand-drawn sketch of the spread of ruins. Alexander Cunningham, the first Director General of ASI, explored and excavated few Mounds at Nalanda (1861–1864) and made detailed reports, including a plan of the site. Alexander Broadley, a District Magistrate of Patna and Gaya also conducted excavations and made a sketch of the scattered ruins. Recent RS analyses have revealed traces of ruins mentioned in such reports, set within the larger landscape of the site[21], and subsequently integrated all these maps onto a GIS platform together with textual information of the accompanying reports. This overlay made it possible to identify locations of every feature noticed by the three 19th century explorers. Site visits were then made to each identified feature for on-ground verification and the extent of the spread of ruins that still remain in the environs of the site was graphically illustrated. It spans approximately 7.25 km^2, while the currently protected area boundary stands at 0.23 km^2 as core zone and 0.58 km^2 as buffer zone (Figure 2), that was inscribed as world heritage[23].

If in future there is a possibility to amend the protected area to include the larger extent of the site, then it becomes necessary to not only identify the overall spread of

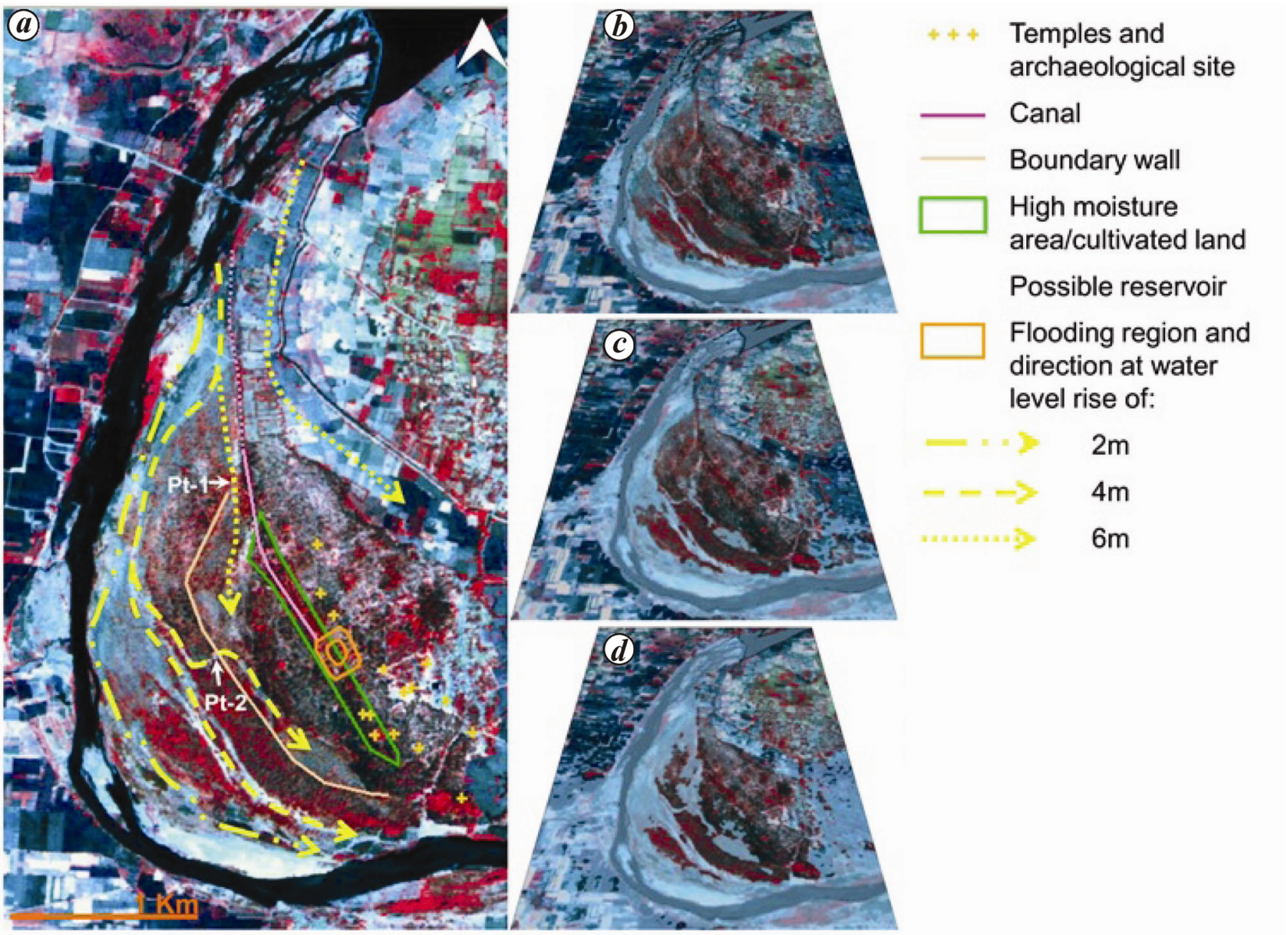

Figure 3. ***a***, IRS-P6 LISS-IV, 23 March 2007, showing the extent and direction of floods near Old Talakadu. ***b–d***, Simulated 3D perspective views with water levels during floods.

archaeological remains connected to the site but also understand subsequent changes to this larger area. For example, modern villages might have cropped up, or hotels, industries or other such transformations may have occurred. GT is useful in visualizing and understanding such transformations. The main advantage of RS and GIS is that they are totally non-invasive techniques; their use or application does not in any way damage archaeological objects or site components. Objects are observed, analysed and studied, while the site itself is left untouched for posterity. This aspect is also useful because often the physical boundary delineating the protected area of a site is disconnected from its surrounding context – wherein on ground one is unable to access the surroundings or understand the relation of the protected site to its larger context.

The GIS platform also allows one to simulate plausible landscape conditions. For instance, we can create virtual 3D models and simulate situations of floods or rise in the sea level of coastal landscapes, and visualize the effects on built heritage in such environments. Flood-layer analysis of the Talakadu landscape was carried out for different levels of flooding. The results have shown the extent and direction of water entry into Old Talakadu (Figure 3). This has made it possible to locate two points which could have been breaches in the bund or fortification leading to flooding of Old Talakadu area (Pt-1 and Pt-2 in Figure 3). Ground truthing at these locations on a day following heavy rainfall did indicate water accumulation. This study has enabled better understanding of topography and, flood levels and flood direction of Talakadu region. Similar GIS analysis of the Mahabalipuram site and adjoining coastline compared a 17th century Portolan chart (maritime map) and recent remote sensing data, particularly digital elevation model (DEM) of the site. The analysis simulated a coastline similar to that depicted in the old Portolan chart which had a higher sea level that revealed the erstwhile coastline and corresponding extent of flooding based on site topography. This enabled the researchers to study its effects on the monuments thereof and identify the seven monuments that could possibly have constituted the historical toponym ‘Seven Pagodas’ for the site[19].

The analysis above was made possible only by integrating multiple layers of geographical information on a GIS platform. A GIS database is typically organized in layers, where each layer contains information from a different source: for example, in the case of the Mahabalipuram information from textual sources and archaeological excavation reports on one side and geospatial features – identified from various kinds of satellite images, ground survey and GPS surveys – were all arranged in independent layers. These layers could then be collectively or selectively retrieved and superimposed using GIS software and analysed to note inter-relations between them[24]. It was thus possible to derive unique information about the study area, and pose and answer novel research questions[25].

As demonstrated in this section, GT has proven its application potential in identifying unknown aspects of cultural heritage sites and extending our understanding of such sites. However, as elaborated in the next sections, it also has potential in conserving and managing existing heritage sites or resources.

Conserving cultural heritage sites

Typically, managing existing cultural heritage sites first necessitates physical or structural conservation, which can be briefly defined as all the steps taken to ensure that the cultural significance of the site is retained[1,2,26]. This could involve some or all aspects of conservation ranging from preservation, i.e. maintaining sites as is, restoration, i.e. rebuilding structure(s) using existing material only and/or reconstruction, i.e. rebuilding using new material as well. In any case the conservation process commences with the heritage inventory or documentation as it is also called, which is creating a record of the current state of the site through a combination of drawings, assessments of its physical or structural condition, studying its evolution and morphology to understand possible causes of distress and/or deterioration.

GT has potential in the heritage inventory, particularly for organizations dedicated to heritage conservation like ASI or State Departments of Archaeology, given the numbers and range of heritage sites under their guardianship. For example, Historic England's (equivalent organisation to ASI) Pastscape is a comprehensive GIS database on the country's cultural heritage sites. It is a digital archive comprising various kinds of data ranging from photographs, satellite imagery, 3D imagery, reports detailing past conservation works at the site – in other words, a heritage inventory[27]. GIS software lends itself to incorporating such different forms of data. CyArk, one of the larger non-profits to use digital technology in cultural heritage applications, promotes itself as a digital archive of cultural heritage sites. It presents geo-tagged 3D imagery of endangered cultural sites for public consumption[28]. The Arches Project is an open-source GIS platform that was developed for use in heritage inventory and documentation, not just by heritage officials and organizations, but also community groups or general public[28,29]. The project's website talks about its potential use in site management as well.

Such GIS databases currently appear to be the exception rather than the norm in the Indian region, though some basic information is available on monuments protected by the ASI[30]. The Hampi World Heritage Area Management Authority (HWHAMA), a quango constituted by an Act of the Karnataka State Assembly, the first such heritage management entity in the country, has developed a GIS database for the entire World Heritage Site of Hampi (UNESCO maintains and invites applications at country level to its list of 'World Heritage Sites' – they are supposed to have universal value for all of mankind[31]). The HWHAMA database includes information on not just monuments but also land records, revenue, public infrastructure, irrigation systems, tree cover and on all 30 villages within the World Heritage Site boundary. However, it is not open to public and appears to be limited to inventory – its potential for analysis does not seem to have been explored. Currently, the HIMP platform mentioned earlier, appears to be the only one to have built upon the idea of a GIS based heritage inventory and extended it to resource optimization to aid physical or structural conservation.

To demonstrate using one feature of HIMP – conservation professionals or heritage practitioners generally assess monuments and sites in order to prioritize conservation works. This usually takes the form of grading. For example, Urgent (6 months to 1 year), Necessary (1–2 years) and Desirable (within 5 years). In parallel they also classify type of works, typically including items like flagging, flooring, waterproofing, dismantling, re-erecting and so on. HIMP users can accurately geo-tag the location of such works, including labels for nature and type (Figure 4). This may not seem to be very effective in smaller isolated monuments like the Kempegowda Tower, for example, but can be of immense value in the case of say, Srirangapattana Fort, which though covering a perimeter of 5.2 km and area of 1.38 km^2, encompassing other structures within, is also classified as a monument. HIMP provides a search platform to locate the nature and type of works within and across monuments, thus making it useful for heritage authorities to both plan and allocate resources, including manpower and budgets. Innovative overlays include site IP (internet protocol), camera images, information on past works, instructions up and down organizational hierarchy and hierarchical log-ins. Since it is a web-based platform, general public can easily access the public interface of HIMP to view monument information like photographs, drawings and visitor facilities, in other words, the heritage inventory.

Managing cultural heritage sites

Site management typically follows from physical/structural conservation. It includes day to day issues like maintenance to long-term plans and strategies like

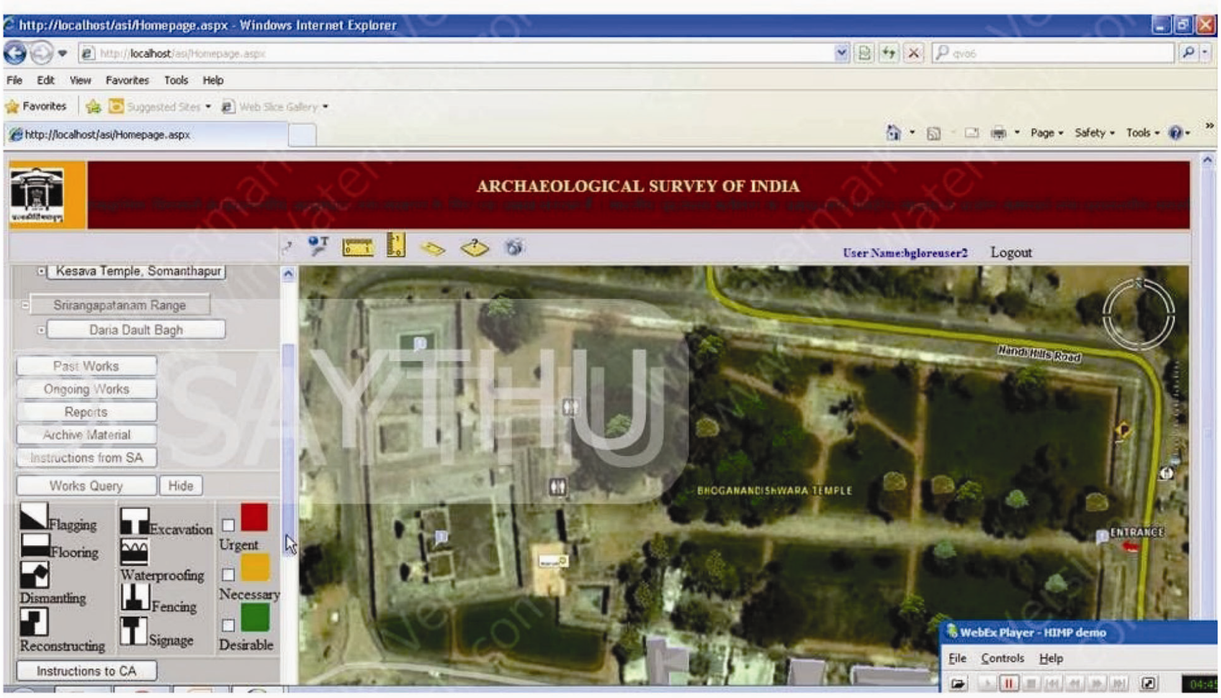

Figure 4. Screenshot of the HIMP interface showing icons for nature and type of work (left) and satellite image of the site (right).

handling tourism and development pressures or issues of legislation and regulation related to the site.

Rationalizing heritage site boundaries for day-to-day management and in dispute resolution

At a basic level GT is useful in CHM by aiding the development of rational site boundaries. One way could be by overlaying historical and current administrative boundaries in the GIS environment. Such an overlay would make it easier to visualize gaps and or inconsistencies between both, with implications for site management.

For example, the historic Lalbagh Botanical Gardens in Bengaluru – analysis of old maps together with paintings that depict the layout of the garden in the late 18th century in comparison with the current boundary revealed that only a fraction of the original gardens is part of its current boundary; the remaining has been irreversibly urbanized[25]. The Lalbagh case usefully demonstrates loss of integrity due to urbanization. Whereas in the environs of Nalanda heritage site, similar analysis showed a number of archaeological mounds dotted around the surrounding landscape which could potentially be retrieved. This is because unlike Lalbagh, the area is largely agricultural with a few villages scattered in between (Figure 2)[21]. Heritage authorities could work towards a long-term plan at this site to incorporate such areas within their purview to ensure that the cultural significance of the site is maintained and not lost.

Such landscape visualizations could also prove extremely useful while engaging with other stakeholders of a site like resident communities, Panchayat bodies and district officials, in order to explain the need to acquire land for example, or to clarify why particular development controls are in place at some locations and not others, or even to plan monument zones and boundaries.

For example, at Hampi World Heritage Site villagers were relocated some years ago from the bazaar area in Hampi village to near Kaddirampura village. Both villages lie within the core zone of the World Heritage Site. After relocation, local authorities and resident communities realized that the new settlement falls within the Panchayat revenue boundary of a third village, viz. Malappanagudi. So a peculiar situation ensued where displaced residents continued to vote for Hampi Panchayat but resources allocated to them had to come from the budget of Malappanagudi Panchayat. This led to their needs being sidelined. Adding to the administrative layers the line demarcating the core zone of the World Heritage Site cuts through the revenue boundary of Kaddirampura village such that the relocation site falls outside the core zone, while the existing village or settlement falls within the core zone (i.e. stricter development controls). This led to existing residents of Kaddirampura becoming unhappy over the ease of development permissions to relocated residents. Taking another example, when the ASI introduced the concept of monument zones in the 1990s, it created a certain amount of confusion among communities settled in and around protected monuments. This is

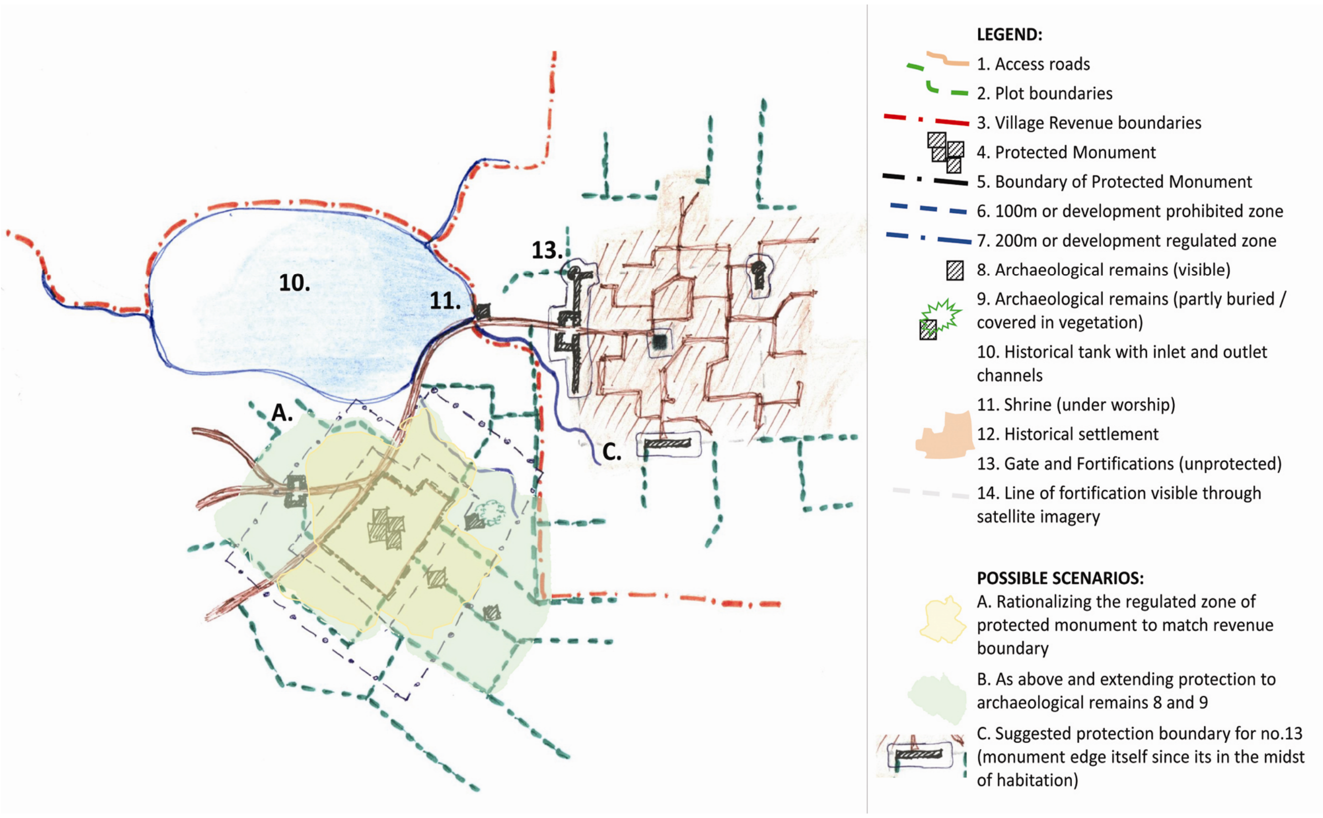

Figure 5. A simulated map showing possible legislative and regulated zones for protected/unprotected monuments in the context of a historical settlement.

because a distance of 100 m from the monument was declared a prohibited or no development zone, while further 200 m from this zone was declared a regulated or development controlled zone. Typically the 100 and 200 m were drawn as circles from the monument leading to their cutting through property lines and creating confusion over applicable controls. Nor was there clarity initially on whether distances were to be measured from the edge of the monument structure or fencing/boundary.

In both instances above the use of a GIS platform would have considerably eased the task of heritage authorities in a fairly simple manner by making it possible to create accurate overlays of different monument zones, revenue and other administrative boundaries. It would be a laborious process to undertake such a task manually as it would necessitate physically overlaying different kinds of administrative maps which would typically be in different scales. Conversion of these maps to a common scale would also lead to issues of accuracy. Figure 5 is a simulated map showing possible legislative and regulated zones for protected/unprotected monuments in the context of a historical settlement. A recent positive development in this context is the tie-up between ASI and ISRO for the SMARAC project that is nearing completion. It involves geo-locating all ASI monuments on BHUVAN portal and marking the protected, prohibited and regulated zones around each[32]. This information is available to public (for more details readers can refer to the article by Raj *et al.* in this Special Section). The project demonstrates application of GT not just in the identification of heritage site boundaries, but also different protection zones like the no-development and development-controlled zones mentioned above at individual monument locations. Heritage authorities could extend such applications to help identify core, buffer and peripheral zones of sites proposed for inclusion in the World Heritage list. Over the years UNESCO World Heritage Centre (WHC) has become strict about such applications and all ‘nomination dossiers’ are required to contain maps indicating monument zones, protection boundaries, core/buffer zones and habitation sites as overlays. Without such information sites are not accepted to the Tentative list of UNESCO WHC (Figures 6 and 7; 1980s map of Hampi when it was first proposed for World Heritage and 2012 map of the site which was developed in a GIS environment. The overlay indicates the earlier and current core zones of the site. Based on documents available on UNESCO’s portal, considering Indian World Heritage Sites, besides Hampi, currently only Champaner appears to have such geospatial maps).

As a corollary of the above, i.e. rationalizing heritage site boundaries, GT has the potential to aid resolution of

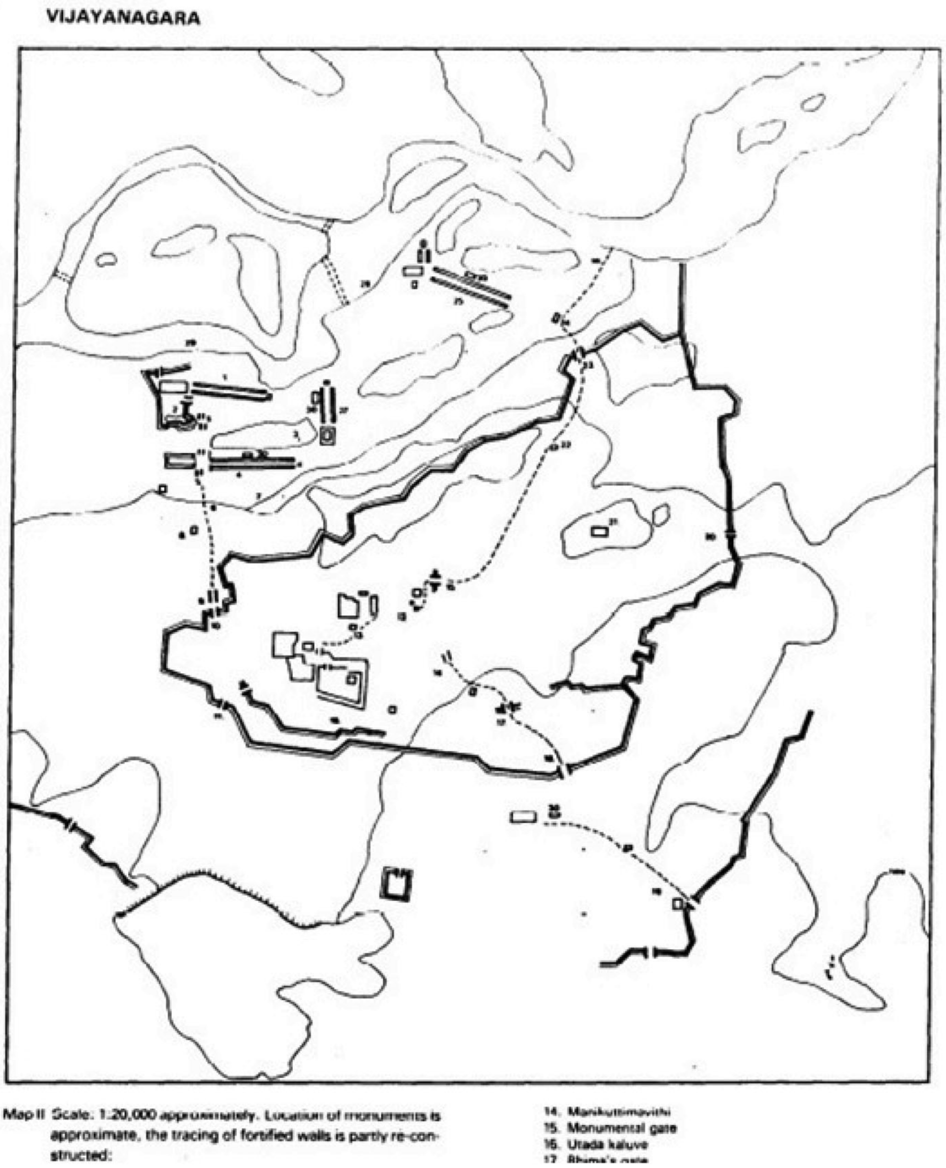

Figure 6. The 1982 proposed world heritage boundary for the Hampi site. Source: UNESCO and ICOMOS.

disputes arising out of heritage legislation and regulation being implemented on ground. For example, in case of conflicting ownership claims related to land acquisition and compensation mechanisms (heritage authorities generally acquire land only when absolutely essential for setting up monument zones) having a GIS overlay which features not just revenue boundaries and proposed monument zones, but also ownership would make it easier to verify the validity or otherwise of such claims. The timeline feature of freely available on-line portals like BHUVAN or Google Earth is useful in land disputes related to proposed/existing monument zones. This is because satellite images are a permanent visual record of the earth's surface features with respect to a particular date and time. Going back to an earlier date using the timeline feature or accessing earlier high-resolution satellite images like CORONA imagery could make it possible to verify generational claims of cultivation/farming activity at particular locations with archaeological mounds and/or remains. Satellite images have been used as evidence against encroachments[33]. Figure 8 *a* and *b* shows CORONA and Google Earth images of Hospet near Hampi clearly indicating the extent of development.

Towards site development

At the other end of the heritage management spectrum are issues related to site development, including infrastructure for visitors and development activities in surrounding

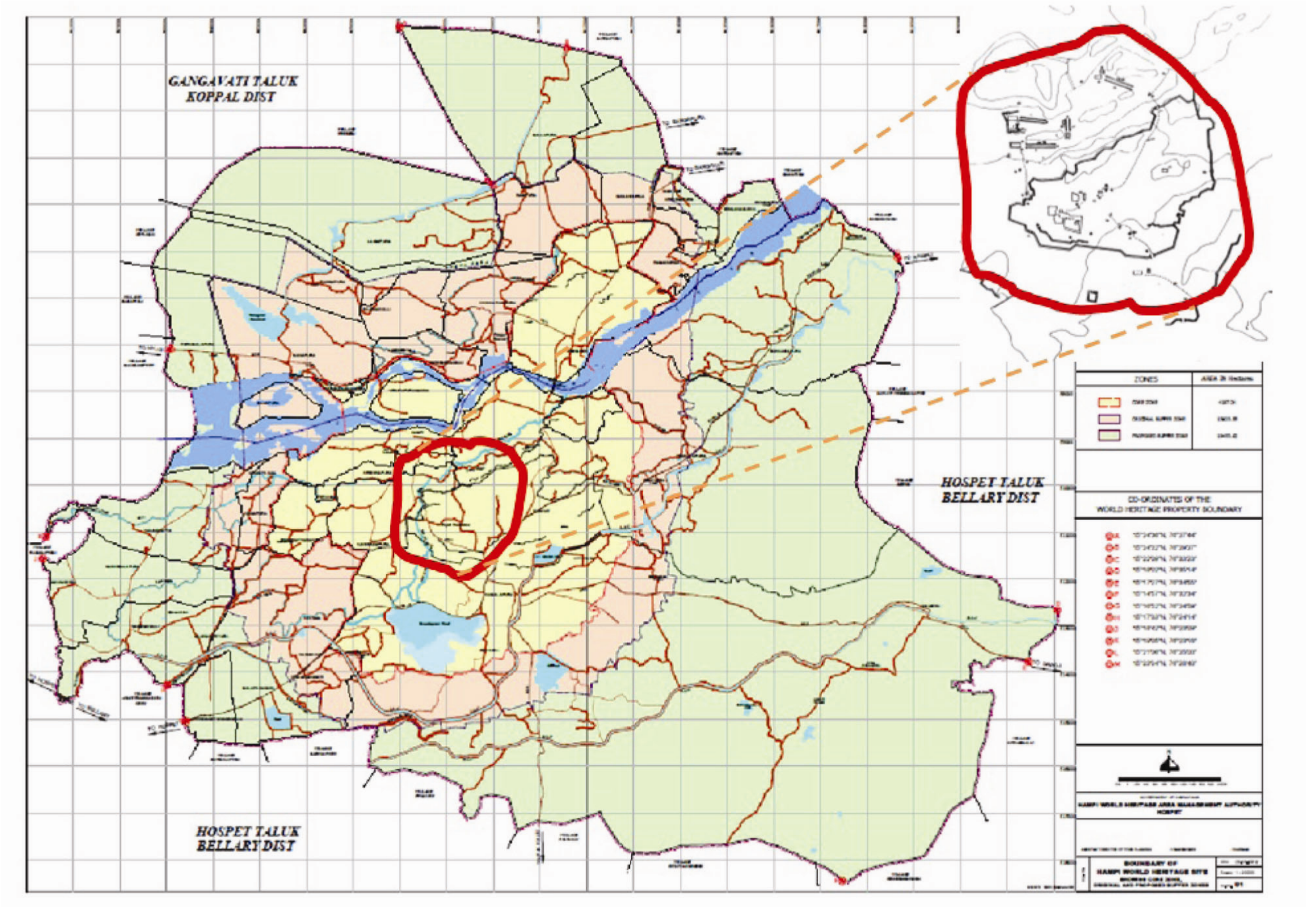

Figure 7. Current core and buffer zones of Hampi World Heritage Site (yellow and green colours) with overlay of the 1982 proposed core zone (area within the red circle). Base images: UNESCO and ICOMOS.

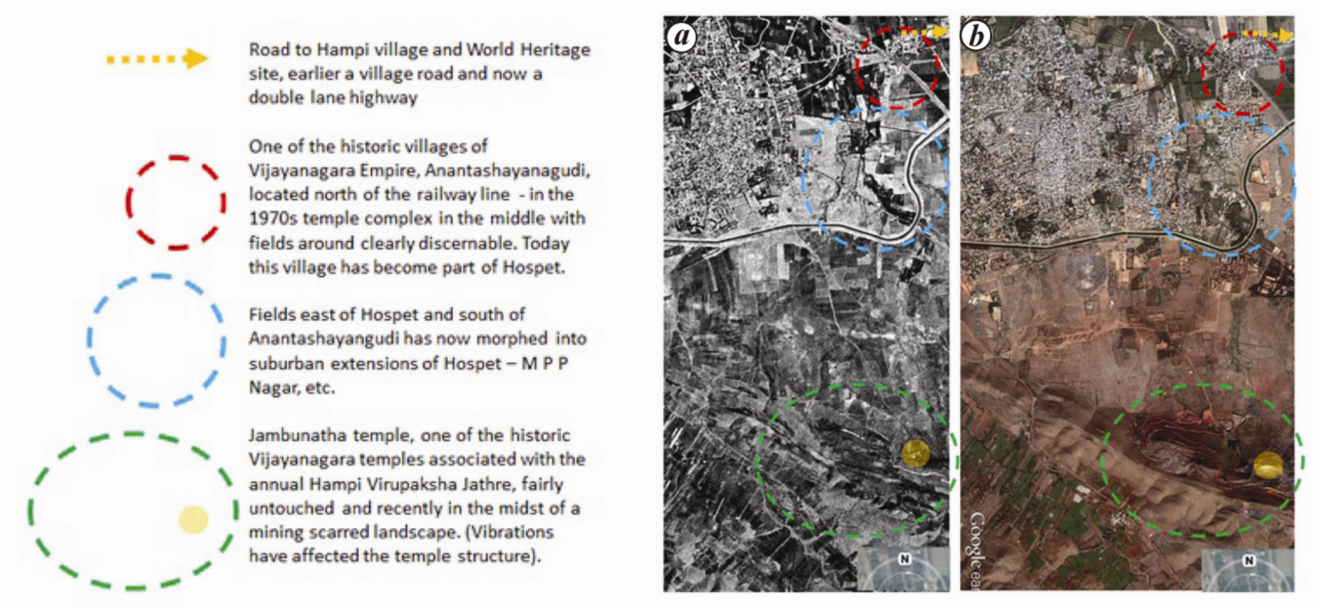

Figure 8. ***a***, A 1970s Corona image of Hospet town (gateway to Hampi World Heritage Site – where all the hotels, main bus stand, and railway station are located. ***b***, A 2012 Google Earth image of Hospet.

areas, which could affect the monument context. GT has the potential in helping heritage authorities identify development zones/pockets which would cause minimum impact on visible and below-ground archaeological remains/monuments. For example, with GT one could identify visible and/or below-ground features like fort walls, moat locations, palaeochannels and mounds, and thus identity zones of minimum impact within a site, areas that are more suitable for construction of visitor kiosks, information centres and parking, i.e. areas where construction would not disturb the archaeological record, of course subject to other on-ground considerations/restrictions.

Surrounding development could and has impacted heritage sites, which may not be visible on ground. For example, at Avati historical landscape satellite imagery makes it clear that the national highway and railway line cut through the larger extent of the site (as indicated by the canal), possibly destroying buried archaeological remains. Future such development/infrastructure projects could be planned more sensitively by overlaying such proposal over RS images of the site, and its context to immediately visualize and understand their potential impact on the cultural significance of the site. Specific techniques could be used at appropriate locations for the ease of such visualizations. For example, visibility maps – also called viewshed – are useful at sites like Badami or Chitradurga fort by virtue of such built heritage being embedded in dramatically undulating rocky terrain intermingled with open rural landscape[20,25]. At such locations one could create 3D models of the proposed development, like a ropeway or mobile towers, embed them in virtual 3D landscape models and visualize the site from various angles to analyse their impact on the heritage setting. Such visualizations are useful empirical tools to convince stakeholders like development authorities, of visible impact of the proposed development on the cultural significance of the site.

The sections above make it clear that GT does indeed have tremendous potential in CHM. However, there are certain challenges that need to be addressed before its potential can be harnessed, which is discussed in the next section.

Challenges

We find a number of challenges to the wider use and adoption of GT in regular heritage conservation and management processes.

Technological

First, is a need to keep up with technology upgrades – GIS software on-line portals are constantly introducing newer tools and interfaces, or newer resolution or types of RS images. As such technology is not static, one needs to be constantly in touch in order to utilize its full potential. In addition, a wide range of technology is available for use, therefore, resultant data are available in different software or formats (that are often not interoperable), media (such as print, analogue, digital), cartographic scales and projections. Combining data from multiple sources can become challenging and induce errors, if not attempted carefully. The article by Gupta *et al.* (see page 1961) in this Special Section has discussed methods to overcome such challenges by following national standards set up by national GIS (N-GIS).

Social

Second is a general lack of awareness. A large proportion of the user community that plays an active role in conservation and management of built cultural heritage is unaware of such technological-cum-cultural resources at its disposal. It is clear from the preceding sections that even minor tools like the timeline feature mentioned earlier can improve accuracy, cut down time and 'red tapism' in day-to-day functioning of heritage authorities, e.g. files being passed back and forth between offices of heritage authorities, Panchayat and revenue departments. Even when there is awareness, there is not enough familiarity or appreciation among user communities about the wide variety of uses that GT can be put to in heritage conservation and management. For example, while enterprise packages like HIMP may be installed, they need regular review in order to update information and keep up with technology upgrades, which may not be feasible for most user communities.

Even if awareness is created or is present, there is a pragmatic challenge that staff/personnel often lack basic training in using such software/interfaces. There is a general lack of expertise, which could be because GT is not part of their training curriculum. For example, the issue of no-objection certificate (NoC) is now a day-to-day affair for heritage authorities. NoC is required in order to undertake development activities in the regulated zone and repairs in the prohibited zone of protected monuments. Whether a piece of land in a request for NoC falls within the monument zone is something that can be easily ascertained using free on-line geoportals like Google Earth or BHUVAN – one only needs to know to use a computer and be aware of certain minimal functions of these portals. However, a related challenge is whether a lay practitioner/officer, apart from being able to operate computers and geo-portals, would be able to locate the monument on the RS image and decide from where to measure 100/200 m. Experts might know, but they would also benefit by having access to RS images with monument protected area outlines clearly marked. For example, the SMARAC project mentioned above, which is a good example of geospatial inventory of monuments, could be emulated more widely to encompass state/regional monuments and unprotected monuments as well. However, while it is helpful to have monument zones identified for dispensing NoC applications speedily, this is not sufficient to address other site management issues. The latter need more involved mapping where core and buffer can be drawn taking revenue boundaries into consideration. The need for such consideration has been elaborated earlier in the text. Such initiatives necessitate increased cooperation and acceptance of GT across different government departments like revenue, land records, heritage and so on, which may not be feasible currently.

A third issue is that the staff appear to dislike technological solutions like HIMP, as it makes them accountable – use of such enterprise resource packages necessarily makes their work processes transparent. There is also a lack of trust, which is likely a consequence of lack of awareness, knowledge and precedence, and hence unwillingness to change. This could be overcome by wider usage. However, a larger issue observed by the authors is the real fear of technology and its potential/capability, which might be difficult to overcome.

Conclusion

It is clear from the discussion on challenges that the use of GT presumes some knowledge and access to GT. This ought to not detract from the versatile potential of GT, wherein one can attempt to understand the heritage site at one's desk even before physically visiting and inspecting it. Where earlier being prepared for the field might mean putting together survey kits and equipment, now with free geo-portals like Google Earth or BHUVAN one can prepare for a field visit by undertaking basic tasks like viewing the site in relation to its surroundings – to understand the terrain, obtain a sense of whether it sits in the midst of habitation or cultivation and locate nearby features. For example, the sectional profile feature of Google Earth makes it possible for one to obtain a sense of the contours and slopes around a site. One is thus able to visit the site with a certain amount of pre-preparedness.

Given that satellite imagery is a permanent record of the earth's features at a particular date and time and general lack of site management plans for individual sites, GT could be used to prepare base maps of monument zones, including mapping of all legislative, regulatory and revenue/administrative boundaries, e.g. the BHUVAN portal mentioned above, which is restricted to national monuments alone and 100/200 m zones.

Attempts could also be made towards increasing the ease of access to existing monument databases, using them and integrating them with other development plans. There could even be a Central Government policy to develop and maintain a national-level GIS-based cultural heritage site database, with content developed by experts or crowd-sourced or both, encompassing protected and unprotected sites nationwide.

In conclusion, the case studies demonstrate the application potential of GT in all stages of CHM. They also make a good case for not being prescriptive in developing site management plans for built cultural heritage. For example, what might be applicable in the case of Nalanda site may not apply in the case of Lalbagh or Hampi. The examples clearly demonstrate the need for context-based understanding and individual plans for each site, rather than a generic one without much merit to be applied uniformly across all sites.

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