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Article

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Abstract

A major challenge in understanding the past is that it is not available for exploration at present. The sections of history that deal with geographical associates of human endeavours also pose a challenge to the readers and learners about the scale and experience of a past landscape. Despite the cognitive and reasoning capabilities of individuals, views of an entire landscape cannot be achieved by normal eye view. Geospatial technologies provide immense potential for accessing historical landscape and past realities. The tools are helpful in twin ways. Firstly, they enable learners to understand the existing information about landscape by providing synoptic and 3D views through interactive visualisation tools. Secondly, they enable researchers to look for clues to the past settlements in a landscape in ways that are not otherwise possible, i.e. "see" through infrared lens and integrate evidence gained from observations made across different times. The present paper discusses some of these advantages that we gain by applying gospatial technologies to normal human perceptions.

History is about understanding past events, their conditions and causes. Understanding realities of the past requires appreciation of the accounts and explanations of the ways and sequences through which the present came to be about. It requires finding and explaining commonalities and differences across time to understand the patterns. Appreciating the geographical and spatial conditions is a crucial aspect of engaging with the history, as they are linked with the cultural, economic and political activities of the past. The landscape influenced the way people navigated their space, constructed structures,

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resided and traded therein. History and geography are thus inseparable and fundamentally interdependent.[1]

The patterns in the historical phenomena have several physical and climatic conditions which indicate continuity and change in the events of history. The lasting social structures and the ones which have diminished may be related to the natural resources available for those societies. For example, why a specific region has been occupied by humans over historical intervals? Why were certain regions difficult to win over? Why did certain regions never flourish? All these questions and their answers indicate geographical conditions of terrains that have affected the course of history. However, the description of such geographical features is not easily grasped owing to the limitations of our mental structures. Remote sensing images and GIS techniques provide an augmented perception of such patterns and assist the understanding of the same in an effective way.

Satellite and aerial images have been used for understanding varied forms of built cultural heritage in many parts of the world.[2] One of the earliest applications of remote sensing to archaeology was the accidental discovery of the remains of ancient Samarra in Mesopotamia by Lieutenant-Colonel G A Beazeley (British Soldier during WWI) while conducting aerial reconnaissance in 1916.[3] In the 1980s, Earth Observation satellites began producing images that enabled the identification of ancient river courses (e.g., Sarasvati in NW India[4]), and riverine topography under the Sahara desert was revealed by radar images from Shuttle Radar Terrain Mission (SRTM).[5] More recent applications include space-based infrared imaging to identify the foundation of a previously unknown pyramid in Egypt[6] and aerial LiDAR scanning to identify Mayan remains under a thick tree canopy in the forests at Caracol in western Belize[7] and in deep jungles of Angkor in Cambodia[8]. In India, too, satellite imagery has provided new insights on many sites, including Nalanda[9] and Mahabalipuram[10].

Remote sensing and GIS as a cognitive-visual tool to visualise the past

Perception of landscape is not as simple as perception of smaller surfaces. The surfaces that we see with the naked eye can be viewed from a point in a single gaze. The bigger landscapes are different from the objects of our day-to-day perception, in that they do not render themselves to human visualization. Unlike the small-scale perceptions, one has to combine different cognitive processes to fathom the large-scale landscape reality. Spatial knowledge requires retrieval of information and representation of the same.[11] It requires memory, reasoning and/or use of miniature replicas of the same to cognise the spatio-temporal reality. The information such as, texture, terrain, turns, landmarks, mountain, hills, buildings, can be memorised and retrieved when desired. However, the representation of the same into a cognitive structure may not always correspond to reality.

For example, when we take records and notes of the landscape by indicating directions, verbally or by hand movements, it could be understood differently by different people. Even if the person is recording by himself, we cannot trust our memories of such a large set of information, as they tend to be subject to selective remembering.[12] For this purpose, the use of visual means such as maps, data charts and other representation techniques[13] and simple textual description[14] have proven to be a helpful aid. The dual coding theory in Psychology is particularly helpful in explaining the benefits of visual representation of spatial information. The theory proposes that there are two different systems of cognitive processing--one deals with verbal information processing and the other deals with non-verbal images. As per the studies done by A. Paivio[15], and replicated later, processing of any information entails activation of neural networks of both kinds, visual and audio. It implies that information which is processed at both the levels have better retention, mental representation and effective retrieval.

The tools available under the larger umbrella of geospatial technologies goes farther than just providing visual images. They provide detailed cartographic representation and diverse visualisations of the landscape. They can help a person not just visualise a region or landscape but allows him to navigate the terrain virtually. By allowing the visualisation and virtual navigation of the space it reduces the cognitive load on human beings in understanding and developing new knowledge about the same. There are many more sophisticated functions performed by geospatial technology which are not possible by bare human means. We provide instances of such educational and knowledge-building potential of geospatial tools in the remaining sections of this paper.

Investigating historical sites using remote sensing and GIS

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 the past of a landscape by studying the impacts of such human actions upon the environment. Space technology can be used to detect the impact of such activities that are not always visible to the naked eye or from the ground. This is because images taken from aerial and space platforms display a perspective of landscapes which cannot be perceived from the ground.

Conventionally we have learnt about locations of historical sites or their spatial expanse from sources such as inscriptions, writings, records, literature, or art and architectural remnants at the site. But, with the advent of new technologies, historical sites

render themselves for analysis using various techniques available under the large umbrella of geospatial technologies. This is because of the nature of such heritage. Structure(s) were necessarily built in particular geographical and cultural settings, originally based on appropriate site selection in order to suitably locate the structure(s) and its components. Furthermore, the initially planned layout and subsequent additions would have a spatial spread, together with the subsequent changes in the land use (agricultural, settlement or affected by disasters like floods), which are also spatial in nature. These factors combined with the locational permanence of the structure(s) make built heritage well-disposed for geospatial analysis.

Advanced remote sensing technologies allow detecting subtle landscape features by sensing "light" that is invisible to humans (infrared, microwave, etc.). This non-invasive technology is most suitable for archaeology since it leaves sites unscathed. Remote sensing image data, along with other spatial data (maps, plans) regarding archaeological sites can be integrated into a database for storage, retrieval 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 remote sensing, GIS, 3D visualization together with sat-nav for positioning and ground truthing can collectively be called Geospatial Technology.

Four distinct ways of enhancing perception of the past:

Images taken from aerial and space platforms, enable four distinct ways of enhancing perception which is not otherwise possible: (i) they provide a synoptic view of larger landscape; (ii) they allow viewing of landscapes in the "light" invisible to humans (e.g. infrared, microwave); (iii) they facilitate visualising virtual 3-D models of the terrain; and (iv) they allow integrated visualisation of information from multiple sources - such as maps, plans and satellite imagery of various dates, seasons and technologies, as well as non-spatial data (such as data from field and excavation reports).

We elaborate each of these advantages with examples in the following section.

(i) **Synoptic view:** It was only with the advent of aviation that archaeologists had access to an entirely new perspective of a site under study, the synoptic view. Observations from aerial and, more recently, space platforms provide an overall view of a site. When viewed from an elevated platform, seemingly scattered features can sometimes be recognized as part of overall patterns, which we do not see from the eye-level view. As we are walking on a countryside road, all we can see is the immediate surrounding, the vegetation, texture, colour of the soil and humps on the road. In simple terms, we can view the eye

level perspective. The eye-level perspective allows us to organise our perception in a unified way, ignoring the details. Psychologically, it can be called a Gestalt view.[16] It means that we impose completeness in an image or view, even if they are in parts. Thus, if there are different formations in the land structure or vegetation, we do not notice it with the normal vision because of our tendency to see complete pictures. However, the same principle of Gestalt psychology allows humans to see the unified whole in the scattered landscape when viewed from above. For example, the picture below shows the view of the historical site of Nalanda (Fig.1).

Figure 1: Photographs from ground of some of the structures at Nalanda

The picture shows the archaeological remains of the site of Nalanda monastery, situated to the southwest of the town of Bihar Sharif in the State of Bihar. What we can see are some structures. However, viewed with a satellite image we can see the overall landscape at different scales as shown in the Figures 2 and 3.
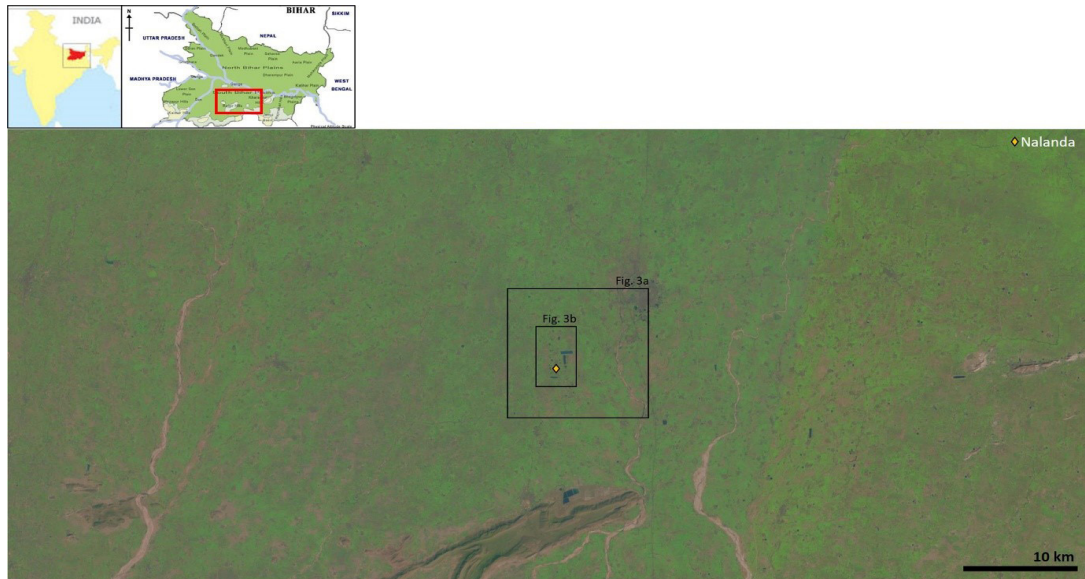
Figure 2: An image showing a large swathe of south Bihar (image date Landsat 08 Feb 2009)
together with the cluster of waterbodies around Nalanda

Figure 2 shows views from Landsat satellite which produces images of spatial resolution 30m per pixel. Landsat Viewer is an online interface for viewing Landsat images in natural colour. A careful examination of these shows a series of water bodies surrounding Nalanda. South Bihar has several scattered water bodies, but the ones clustered around Nalanda form a pattern that was not seen elsewhere in the vicinity (see Fig.2). As we zoom in (Fig.3b), we observe something further: most of these water bodies are rectangular and their sides face the cardinal directions, which suggests that they are man-made tanks. They frame not only the area protected by the Archaeological Survey of India (ASI), but a larger expanse extending much farther to the north and a bit to the south. Therefore, these tanks mark the full extent of Nalanda, and this corroborates the textual evidence stating Nalanda to have been a Mahavihara, a large monastery. While most of the water bodies in the cluster are compactly framing the area around the site, there is one odd-looking tank stretching far out to the east (see the tank 'Dighi' in Fig 3b). This tank was laid out stretching so far to the east to connect to a palaeo-channel that once drew water from a nearby river. This channel is now dry, but its scars are still visible (Fig 3a).
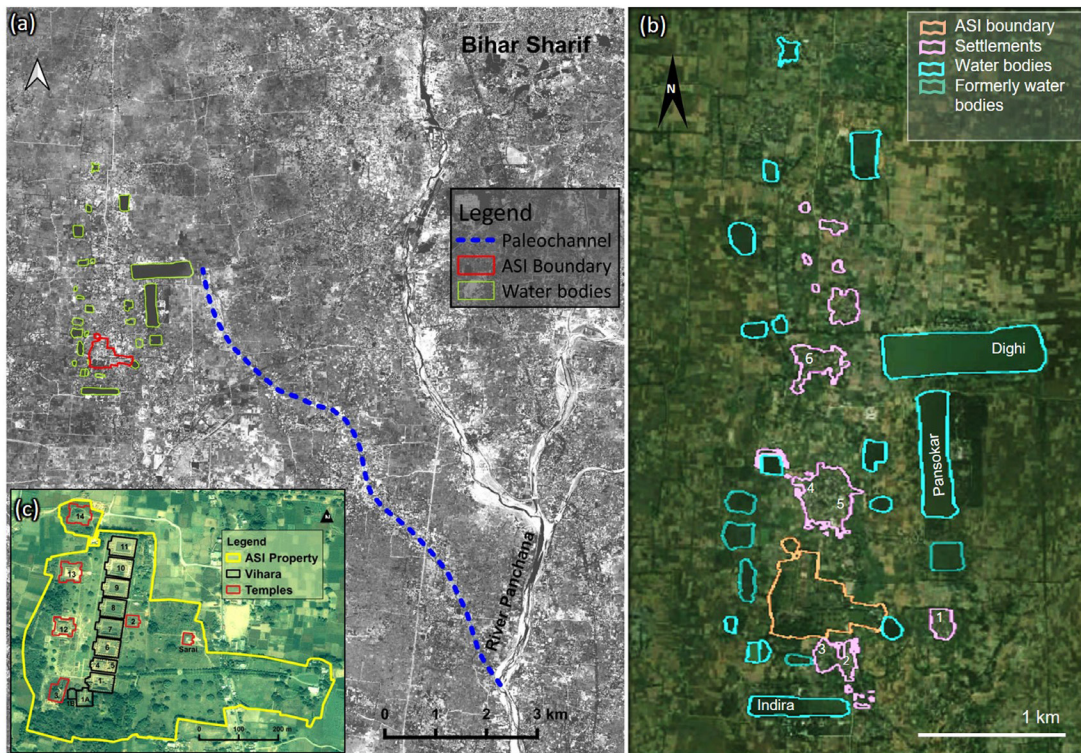
Figure 3: (a) Regional view of environs of Nalanda showing the palaeo-channel; (b) The larger landscape around protected site showing the cluster of past and present water bodies; (c) The excavated site of Nalanda showing the large structures (6 Temples and 11 Monasteries) together with boundary of area protected by ASI

In this way, synoptic views at various scales from a variety of satellite imagery can render different kinds of information for, firstly, understanding the long-standing legend that Nalanda was the site of a large monastery, and secondly, developing the historical knowledge about the site further by enabling us to see the size, shape, and arrangement of the water bodies and the palaeo-channel in the context of the site. We are well aware of the painstaking ways maps were created in earlier days. Even if we keep recording while we walk through the space, we may not be sure if we end up representing the landscape with the same spatial accuracy. It takes a huge amount of time and effort, as our perceptive abilities are not programmed to take such cognitive load. Nevertheless, geospatial technologies provide a view that enables such perceptions.

Synoptic view can also aid in visualising buried features. Most buried features are of two types: those created by scarring the earth's surface (i.e., removal of surface/sub-surface soil for making ditches, pits, canals, moats, tanks, ponds, etc.), and those where foundations are laid to support larger structures above. In both cases, the buried features

have typical shapes, they are linked/aligned to the rest of the settlement and the main water sources. Once these structures fall into disuse, they are affected by decay (natural decay and deterioration from exposure to the elements, and anthropogenic decay caused by the removal of building material for reuse or clearance). This decay can reduce structures to ruins, thereby transforming their surface appearance. Such scattered vestiges can sometimes only be identified synoptically. A settlement's outer defences (moats and fort walls) can often be identified in this manner. When fort walls collapse, their material is often deposited into their surrounding moats. Source of water to moats may also dry up for various reasons, and the remains may be difficult to recognize at ground level. However, in synoptic views from satellite images, excess water/moisture is usually present in areas where the moat existed. This is either detectable directly, or indirectly when it is covered by comparatively healthy vegetation, in tell-tale patterns (circular, oval, rectangular, etc.). Figure 4 illustrates two of the many different ways in which a pair of typical archaeological features (a fort with a surrounding moat) could manifest.
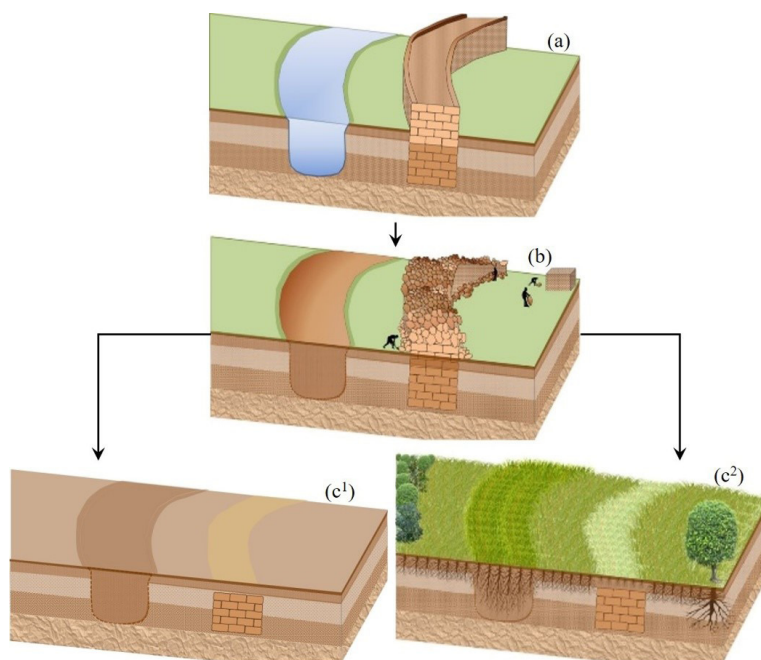
Figure 4: Diagram showing two ways in which a pair of typical archaeological features (a fort with a surrounding moat) could decay.

Fig.4 is a diagram, where (a) illustrates a typical fort and adjacent moat as they would have existed when in use. Note the cross-section indicating the subsurface – the moat has a channel filled with water, and the fort has a tightly packed foundation; and (b) illustrates a subsequent condition where the disused moat is filled with silt and the fort is

dilapidated, parts of which have collapsed (due to natural decay, human destruction during conflicts, or due to removal of material for reuse/clearance).

Beyond this stage, the landscape can undergo different kinds of transformation depending on subsequent activities in the landscape. Two possibilities are explained here.[17]

a. Soil Marks (Fig.4c1): Arid lands with little or no plant cover normally show bare soil with uniform colour. However, sometimes soil does show different colour marks in an otherwise homogeneous land parcel. Such variations are caused by differences in the mineral and organic content of the soil. In addition, buried ditch fillings can sometimes show distinct marks because of differences in moisture content.

b. Crop marks (Fig.4c2): Crop marks are difference in tone/shade in vegetation cover from its immediate surroundings creating an observable pattern. Negative crop marks indicate that the vegetation is stressed, in contrast to surrounding growth that is healthier. At such places, there is a possibility of buried structures that prevent roots of surface vegetation from reaching water and nutrients adequately. These clearly manifest as lighter tones. Positive crop marks correspond to areas with richer soils and/or enhanced moisture content, which allows vegetation to prosper.

Taking example of the colour and texture of vegetation, if we are viewing from the ground, we may see vegetation as a continuous stretch. If a large space is covered with vegetation, we may not see the difference from a close proximity. An aerial view allows swift recognition of such changes in the patterns.

Ability to detect such features across large swaths of land facilitates exploration of large area with less cost and labour and enables pinpointing at the most promising locations for visiting on ground for further study. Therefore, these technologies help in optimising time, effort and cost for survey of large areas.

(ii) **"See" with light invisible to humans:** People have a tendency to perceive the views of their surroundings in a predisposed way. As a result of inherent and learnt predispositions, people attend to certain sensory stimulations and filter others from their perceptual field. It is an example of top-down processing of information, which proposes that people's past experiences and expectations guide the understanding of information presented to them.[18] In the case of perceiving visual fields, it may be visible in forms of camouflaged patterns. For example, if we see Figure 5b, the picture shows the settlement of Belur in Karnataka. The town and surrounding vegetation seem as a continuous formation as seen with normal colours or wavelengths visible to the human eye. However, as we see in the infrared image in Figure 5c, it highlights a circular formation of the vegetation which was not visible with

the normal wavelength or at eye-level view as in Figure 5a. The circular pattern seen as a cropmark is more conspicuous in the false colour infrared image in Fig.5c than in the higher-resolution natural colour image from Google Earth Fig.5b[19]. The addition of the infrared image here has a crucial role in perceiving beyond human limitations. It allows us to break the normal perceptual set and trace the untraceable.
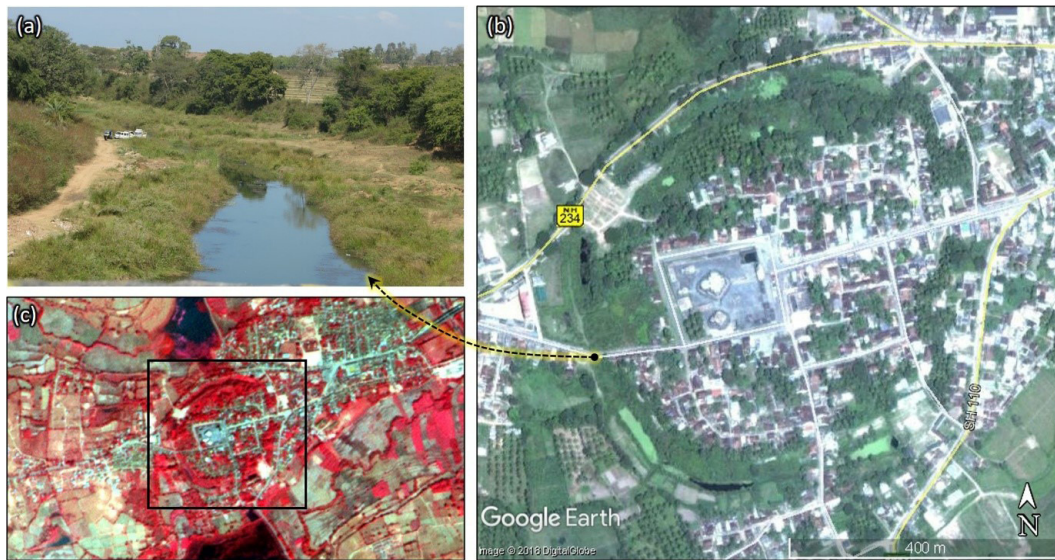

Figure 5: (a) A ground photo of a portion of what was the moat surrounding the settlement of Belur;
(b) Google Earth image showing the Chennakeshava temple complex in the centre of the settlement of Belur; (c) the circular moat is more visible in the multispectral image from IRS P6 LISS-4

Remote sensing satellites carry a variety of sensors (including infrared and microwave) that have helped reveal unique information about historical sites or parts of sites.[20] For instance, the effect of buried archaeological remains are very subtle on the surface, often not distinguishable even in satellite images of the natural colour and are nearly indistinguishable on the ground. Images from infrared (having higher reflectance from vegetation) sensors, can display patterns in vegetation growth following the lines of the buried features, revealing their plan and layout.

Although more variation in the shades of vegetation can be seen in infrared imagery, patterns indicating subsurface historical remains may be visible only under certain weather/moisture conditions. Therefore, vegetation cover should be analysed across seasons in order to isolate all potential archaeological features, which should then be analysed in the context of the layout of known archaeological remains. Satellites can also take stereoscopic images which are helpful in producing 3D models of archaeological landscapes.[21]

(iii) **3-D models of the terrain :** To analyse and appreciate historical situations effectively, historians as well as the readers of history take the help of imagination. Historians imagine people and events in the past along with geographical settings that provide the backdrop for such graphical imagination, while readers imagine the minds of historians as well as the narration. As E H Carr writes, the "past is dead but it is still alive in the minds of historians. He must re-enact the thought that might have gone in the minds of people in the past, and the reader in turn must re-enact what goes in the mind of historian."[22] To get a feel of the past historians have to traverse the time between themselves and the past. Most of the time, historians get primary sources unexplained and raw partial facts. They require the human interface, interpretations and explanations of the stories around them. For example, for centuries before the early 19th century the structural remains of Nalanda were just some ruins, in fact, large portions of the site was used as a free source of bricks for constructing houses and paving roads in neighbouring villages.[23] The first English translations of the accounts of the Chinese monk Xuanzang (596-664 AD), who had visited Nalanda[24], provided impetus to the growing interest in the discovery of Indian historical places among British explorers. Aided by the translation, Alexander Cunningham identified the remains as the ruins of the famous Nalanda that Xuanzang had visited.[25] Following this, later historians and archaeologists have explored the site further.

It requires historians to weave the shreds of evidence along with the formulated narratives about the place. Without this attempt to evoke the past and refurbish it for present consumption the structures are dead. They are waiting for a historian to visualise the conditions and possibilities of the happenings in the past to rebuild the narratives about it. At such times imagination is a part and parcel of the historical investigation, not only because the primary sources are to be explained but also for visualising all the happenings, their causes and the minds of the people involved. Historians and readers of history have to compile and organize facts. Very frequently, the historical narratives include descriptions of the landscape of the past and the subsequent changes in them, as it did also in establishing the location of Nalanda using descriptions of its context among other known places like Rajgir in the south and Patna in the north. Narratives entail intertwining and describing the possible human conditions and navigation of spaces in past. In doing so, it is crucial to envisage and understand the space in terms of distances and terrains. It also requires perceiving the depth in the given pictures (if available). All these perceptions of geographies and landscapes that had to previously depend on imagination can now be evocatively studied and presented using objective geospatial data and analysis.

The brain processes pictures to form the 3D image from a 2D image. Research has confirmed that presenting 3D images eases the speed and accuracy of the object and space

perception.[26] 3D models allow a landscape to be perceived in much more detail than paper maps due to the three dimensionality of the data layers. When a landscape is visualized in an interactive mode moving through a 3D model, different perspectives of the landscape are presented.[27] Virtual 3D models are especially helpful when complementing rather than replacing archaeological fieldwork as they help in planning field work and also allow certain details of the study region to be reviewed during analysis back in the laboratory. They can become a starting point for a GIS-based analysis of spatial patterns and relations.[28] At the same time, their visual attractiveness makes virtual 3D models a valuable means of presenting results of historical and archaeological research to a wider public.

To view a terrain feature in a three-dimensional space, it is necessary to generate digital model of the terrain and drape a surface image over it - as though draping a fabric over furniture where the furniture is analogous to a terrain model and the cloth to the image, where a viewer sees the 3D shape of the furniture but the surface features are the prints/ colour of the cloth. Digital Elevation Model (DEM) is the topographical model of the terrain showing undulations and synoptic satellite image draped over the DEM shows the surface colour and features. Once such a 3D model is generated one can visualise the landscape in 3D from all directions.
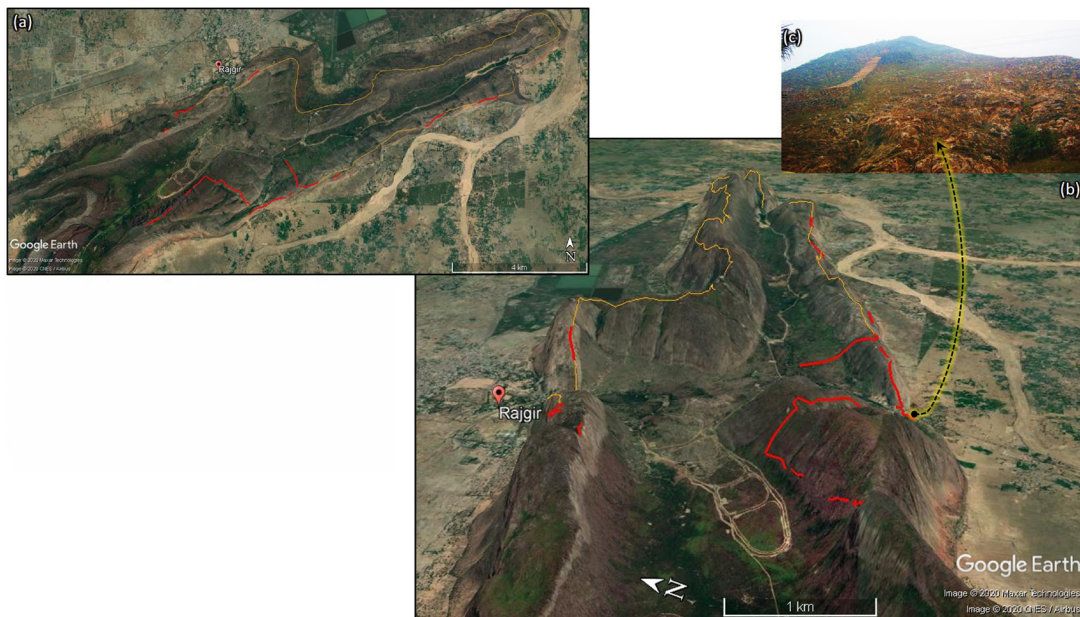

Figure 6: (a) Synoptic view of Rajgir hill with cyclopean wall. Red lines are stretches where remnants of the wall are visible, orange stretch is the ridge of the hill where the wall would have been but is not visible in satellite images; (b) 3D view of the same; (c) View from the ground of a portion of the hill and wall

Figure 6a shows the Rajgir hill in synoptic view and Fig.6b shows a virtual 3D model of the same. The Rajgir hills, also known as "Rajghara" hills, is near the city of Rajgir in Bihar. These hills form two parallel ridges—southern one stretching around 60 km and northern one about 35 km—and other smaller hills forming folds in between them. The ridges provided natural fortification for the central area and hence has been a strategic location historically. Between these two ridges lie a number of places of historical importance, dating from the period of Gautam Buddha, Mahavira, the Mauryas and the Guptas.

There are many occasions in historical analysis where historians need to take the help of imagination. One such case is for drawing inferences, for understanding the mental frame of the people in the past and for understanding the values and ethos of the then societies. It could be as simple as getting the feel of the space that a person or group of people used in the past. Why did they choose a location? How did they choose it? What purpose did it serve? How long did the place serve that purpose? It is not easy for us to recollect our own thoughts and experiences and consequent decisions we made a couple of decades ago. At the most, what one can do is to recollect certain behaviour and prominent feelings of the time. Nevertheless, the 3D visualizations facilitated by geospatial technology enable a virtual entry to historical landscapes from various heights and angles. We can see that Figure 6.b is more impactful than Figure 6a in giving a feel to the viewer almost like physically being above the Rajgir hills and looking down at the Cyclopean Wall and estimating the effort it could take to navigate through it. While physically moving around among the hills on ground, one can easily lose the sense of direction and feel lost. But by virtually navigating the hills from above and from different directions we see why this location was chosen, what advantages the hills provided and how a wall could augment the existing natural setting to protect the interiors. The Cyclopean Wall of Rajgir is among the world's oldest specimens of cyclopean masonry. It was a stone wall that encircled the entire ancient city of Rajgriha. It is believed to be around 40 km long. Figure 6a shows portions of the wall that can be identified using satellite imagery; Fig.6b is a 3D view showing how the wall traces the summit of the ridge. By allowing such historical imagination through 3D visualization, geospatial analyses bring immense value to historical pursuits.

(iv) **Incorporating multiple layers of spatial information:** GIS is a software system that provides a framework for gathering, integrating, managing, and analysing spatial data. It is often useful to look at multiple satellite images for a given site. These could be images taken by the same sensor on different dates, or from different sensors. This is because some parts of the target area may be visible in natural colour images, while other parts may be traceable through images of infrared or other wavelengths. There could be further variations in visibility of features in images taken at different times of the year due to

seasonal differences in land cover (for example, post rainfall there could be lush vegetation growth; in contrast, in summer it could be relatively barren). It is also possible that some features representing a historical layout were visible decades ago and the subsequent land use changes have made them obscure in images taken recently. Hence considering images taken a few decades ago is also important. To represent the entire historical landscape, all the sources are combined to make the complete picture. An example of such a representation is given in Figure 7. GIS organizes information into layers based on geospatial location, allowing the analyst to integrate data from multiple images, as well as spatial data from other sources such as ground truthing, field observations, old maps and other historical spatial records. In order to integrate spatial data, it is necessary to ensure that all this data is georeferenced so that features in one layer are as accurately aligned as possible to their footprint in other layers. GIS allows such an integration of images to be placed on its respective latitude and longitude. It allows an analyst to pin his selected narratives – textual as in the case of reports or accounts, or graphical as in the case of maps or images – of the landscape to its appropriate location (georeference) and visualise the resulting picture, thereby representing his/her analysis in a concrete and holistic form.

Figure 7: Map of fort wall and moat surrounding the Hoysala capital Halebidu made from multiple layers; (a) Corona satellite image of 1978; (b) Multispectral (with infrared band) satellite image from World View 2 of 2013; (c) A map made by Colin Mackenzie in 1806; (d) Natural colour Google Earth image of 2016; 1 and 2 are ground photos of location marked on the map with respective numbers

Figure 7 shows synoptic views of the landscape of the fortified settlement of Halebidu in Karnataka, which was the 12th century Capital of Hoysala dynasty. It shows the locations of the fort wall and moat that bound the settlement. The whole perimeter of the fort wall

and moat was not identifiable in any one image. As Figure 7 illustrates, four different layers of spatial data were used to identify various portions of the fort wall and the moat, which could be overlaid using GIS to map the overall extent of these features and the ruins that could be seen on ground could be accordingly contextualised. The land cover within the fort is predominantly agricultural – except for the settlement on the northeastern corner. When the northern portion is visualised with recent images (for example Google Earth image of 2016) it shows a sequence of several land parcels that reveal the curvilinear shape of the moat, even though almost no structural material of the fort survives there at present[29] but when we use Corona image of 1978 we do see ruins and traces of the fort on the north too (Fig. 7a).

Summary

Identifying and knowing the impressions of past settlements in the present landscape can immensely enhance our understanding of historical sites and their landscapes. The past has a strong connection with space and location. For people who study the history of regions and locations, geospatial tools provide them an evocative access to those spaces. Surpassing the human capacities and range, remote sensing and GIS technologies enable visualisation and navigation of present and past historical sites. By allowing virtual access to the past, with several visualisations and navigation tools, these technologies create a unique cognitive experience in learning about the past. The close approximation of the past through such technological tools also enables sharing it objectively with others. They enable cognition, comprehension and knowledge generation about the same. In the above sections we have illustrated that geospatial technologies can enhance our perception of the past visually in at least four different ways. There could be many more applications of each of these kinds of visual perceptions than what we have listed in this paper. These enhanced means of seeing the past not only assist a historian to impart the history of a landscape he has been able to imagine, but also to see realities of landscapes that are blocked or not perceivable by limitations and biases of his/her imagination.

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