Remote sensing investigation of the Buddhist archaeological landscape around Sannati, India

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ABSTRACT

In a country like India which has a long history of human occupancy and rich cultural heritage, identification of potential archaeological sites is essential before they get fully obliterated due to rapid urbanization, large-scale infrastructure development and mechanised agriculture activities. In this study, an important Buddhist site Sannati (which dates back to Maurya period, 3rd century BCE) and its surrounding, is investigated. Earlier investigations have uncovered a fortified mound, Vihara complex, habitation site and 3 stupa mounds in this region. The present study develops simple and cost-effective ways to identify potential buried archaeological sites and mounds using the knowledge of known sites and visual interpretation of remote sensing images of the region. This study has successfully located several archaeologically potential sites in the study area that now require archaeological investigation on ground. The developed approach can be applied to investigate other similar buried/undiscovered potential archaeological sites.

1. Introduction

Archaeologists have been using field-walking methods for site prospections since the time archaeological studies began. Later during the mid-20th century CE, another method called aerial survey became popular. Presently, with the availability of high tech aerial and satellite products such as Hyperspectral images (Cavalli et al., 2007), RADAR (Chen et al., 2017; Tapete and Cigna, 2017) and LiDAR (Hesse, 2010) data and complex automated algorithm, site prospection has become possible even for the sites that are imperceptible on ground (Rowlands and Sarris, 2007). But complexities in data processing, high cost and unavailability of ready data, often restricts their use. Therefore, there is a need to make the best use of what is readily available and easily accessible. The present study is advocating a methodology that is robust, simple, cost effective and can be easily adapted with little training.

In India, early historic Buddhist sites (3rd Century BCE to 2nd Century CE) have been found from north, extending for thousands of square kilometres to central, east and further in the south to the States of Andhra Pradesh and Karnataka. One of these Buddhist sites has been discovered in Sannati, Karnataka. Ground surveys of Sannati by Seshadri (1965) (Rowlands and Sarris, 2007) threw up a large number of artefacts of Buddhist association, such as relief carvings on slabs, archaeological mounds as well as remains of stupas. The presence of artefacts of Early Historic periods and remnants of Buddhist structures led to a series of archaeological exploration and excavation in this region (Poonacha, 2011a). Excavations by Sundara (1986–87) (Howell et al., 1995) and Howell (1986–1989) (Howell et al., 1995) revealed a habitation site and the remains of a brick stupa, respectively. Archaeological investigations in this region so far have found a fortified mound (Ranamandala) (Poonacha, 2011b), one potential habitation site (Poonacha, 2011c) (labelled as SAN 8 in Howell’s report (Howell et al., 1995)), Benagutti Vihara Complex (Indian Archaeology, 2003; Deshmuya, 2007) and three stupa mounds (Poonacha, 2011d) (see Fig. 1 for locations of all these sites). In addition to these archaeological structures, profound artistic richness on the slabs of Kanaganahalli stupa indicates that this site could have been a major stupa site and therefore, it could potentially be a part of a large cluster of stupas and other associated structures, similar to clusters in Nagarjunakonda, Sanchi, Sarnath and Lauriya Nandangarh. Thus, this entire region solicits further archaeological investigation and it is also imperative to identify remains or their traces before they are lost to the fast-changing land use.

With this background, the present study has been carried out with the hypothesis that with a site as important as Sannati and Kanaganahalli in the vicinity and the presence of the stupa mounds or mounds similar to that across the river as far as Sirival Village, the possibility of the presence of unidentified/undocumented Buddhist
archaeological features in the study area is quite high. The study has been carried out using simple and easy to apply remote sensing methods to identify buried sites and archaeological mounds.

2. Study area

The geographical extent chosen for this study was determined by taking historical sites around the Sannati into consideration. The extreme coordinates of the study area are 16°52′10.54″N, 76°52′30.61″E, 16°48′12.11″N, and 76°56′22.39″E covering an area of 51 sq. km.

2.1. Physical conditions

The extent includes regions on either side of river Bhima where the river flowing in a southerly direction, makes a sharp turn and takes a northerly course (uttaravahini) and then turn to the east. The river also acts as a dividing line between the talukas1 of Chitapur and Shahpur. Sannati, Benagutti, Kanaganahalli and Aneugutti are situated on the left bank of Bhima in Chitapur. On the right bank lies Hasargundgi and Sirival in Shahpur (ref Fig. 1).

The study area largely has Precambrian geological formation composed of Bhima group limestone and shales. This region is largely covered with rich Black cotton soil (Vertisol). The climate in this region varies with seasons. January to February is winter season which is followed by hot and very dry summer from March to May. It receives monsoon rainfall from June to September with annual rainfall varying from 50 to 60 cm (Karnataka Gazetteer, n.d.). The land-use is more or less the same in the past 50 years except addition of few more roads and canal.

2.2. Historical background

Sannati (also spelt Santi, Sanati, Sannathi or Sonthi) and its surroundings have been considered as one of the largest and oldest Buddhist centres of Karnataka (Chittaranjan, 2004a). Buddhist activity at this site can be traced back to the Maurya period (middle of 3rd century BCE) and the monastic community continued to expand over the next six hundred years after which the centre seems to have been abandoned. The region later came to prominence as a Sakti centre when a small temple, for goddess Chandralamba, at the site became an important place of worship (Quintanilla, 2017). The only Major and Special Edicts of the Maurya Emperor Ashoka to be discovered in Karnataka are in Sannati (Talim, 2010). Hence the region is considered significant (Chittaranjan, 2004b) as the possible southernmost outpost of the Maurya Empire.

2.3. Archaeological explorations and excavations

In a ground survey of the region (published in 1965), M. Seshadri noticed a number of relief slabs in and around the precinct of Chandralamba temple depicting Buddha’s birth and other parts of Buddhist stupas that were constructed or enlarged and embellished during Satavahana rule in the region. Seshadri had also reported remains of a circular structure with highly decorated relief and Ayaka pillars (which was later identified as Kanaganahalli Stupa) and two potential stupa mounds in the vicinity. In a subsequent investigation of the site, M.S. Nagaraja Rao and his team identified remains of stupas at various localities at Sannati. Since these records do not mention geographical coordinates of the identified stupas, it has not been possible to know which ones they are referring to. Following are the sites explored and excavated by field archaeologists:

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1 Taluka is an administrative division in India comprising of a city or a town that serves as its administrative center with additional a few towns and number of villages.
1. Ranamandala (a fortified area): A trial excavation was conducted by A. Sundara in 1986–87 in the inner citadel area of Ranamandala. The excavation yielded brick structures of Satavahana period and coins and other artefacts dated to Mauyra period.

2. Benagutti Monastery: Excavation of a mound north of fortified area of Sannati found ruins of an early historic monastery complex which measures 18.20 x 15.20 m. Several antique artefacts such as sculptures, beads, objects of ivory, coins, etc. were uncovered (Indian Archaeology, 2003).

3. Kanaganahalli Stupa: This is referred to as Adholaka Maha-chaitiya (the great stupa of the netherworld) in the inscription found during excavation at the site (Poonacha, 2011c). This stupa, labelled as Stupa No.1 in Fig. 1 is situated south-west of Kanaganahalli Village, east of the famous Chandralamba temple of Sannati. This stupa was found in a dilapidated condition with the super-structure entirely ruined. Excavation of this site (from 1994 to 1998) has yielded rich archaeological remains of pre-historic and Satavahana period. The stupa is exuberantly decorated with intricate sculptures on limestone slabs which depicts Buddhist themes, Jataka narratives, figures of Ashoka and Satavahana rulers, comparable to Amravati stupa. The stupa measures roughly 26 m in diameter, with a circumference of 94.30 m at the railings, 74.35 m at the lower drum and nearly 68.14 m at the upper drum (Poonacha, 2011d). There are evidence of vihara complex adjacent to the stupa mound.

4. Aneugutti Stupa: This mound is referred as ‘second stupa’ or ‘stupa no 2’ in the excavation reports by Howell (Howell et al., 1995). It is located along a road about two kilometres north-east of modern Sannati village (labelled as Stupa No. 2 in Fig. 1). This mound has a maximum diameter of 70 m and rises to a height of 8.5 m. It constitutes layers of black cotton soil (vertisol) and limestone shale chips. The three series of excavations of the mound have found the following: 1) the presence of stone revetment wall which is stratigraphically the earliest phase of the construction; 2) series of fragmentary brick wall running around the stone revetment; 3) post-holes and fragments of tiles are found along the second brick wall which has been interpreted as the evidence of the presence of roof of a circumambulatory passage around the drum; 4) evidence of platform, comprehensive robbing activity and natural weathering. 5) One inscription and very few sculptures were also found.

5. Hasargundgi Stupa: It is located 3.5 km east-southeast of Chandralamba temple on the right bank of the river Bhima (Poonacha, 2011b) (ref Fig. 1). The extant base portion of the stupa measures 13.7 m in diameter and extant maximum height of the drum is 90 cm. Much of the structure is destroyed by intense agriculture activities, thus elevation details are difficult to obtain. The excavation of the entire mound has revealed a complete plan of the stupa. It is a circular brick stupa with rectangular ayaka platforms having northeast-southwest orientation and a circumambulatory passage. Decorated panels of the stupa have artistic expressions which are also noticed in the similar edifices of the contemporary period. The site has yielded coins of Satavahana period, although not a single inscription has been found in the site (Poonacha, 2011i).

6. Habitation Mound (SAN 8): Howell noticed a low mound in the south-west of the Chandralamba temple (SAN 8; ref. Fig. 1 for location). He, in his report, has also speculated this mound to be an archaeological mound on the basis of rich artefacts, important sculptures especially pottery, found on its surface and suggested it a habitation and occupation site outside the ancient city wall (Howell et al., 1995). This site has also yielded one of the most important sculptures in the entire study area which depicts back of seven kneeling women possibly paying reverence to the main figure which is unfortunately missing. However, this missing figure has been identified as Gautamiputra Satakarni through inscription and depiction of procession of horses and elephants on broken portion of panels. Proximity of this mound to Chandralamba temple, where number of relief slabs that are thought to have covered the dome of the Buddha stupas were discovered, makes this site more promising.

In view of these archaeological evidences unearthed by conventional methods, the extent of the study area was decided for remote sensing investigation.

3. Material and method

The present study aims at providing a simple and easy to apply method (summarised in the flow-chart in Fig. 2) for the identification of mounds and other archaeological traces of early historical Buddhist site that can be applied to other Buddhist sites. The study is relied on freely or easily accessible data - very high resolution true colour satellite images of different years and seasons from Google Earth, high resolution Corona image of 1967 from USGS, also on high resolution multispectral images (IRS-R2 (Liss IV) and World View-2) and high resolution stereo pairs (Cartosat 1) for visual analysis and site prospection. The data acquisition and processing are discussed as follows:

(1) Corona imagery: Corona satellites were used by US Air Force for photographic surveillance between June 1959 and May 1972. These black and white images have worldwide spatial coverage which is available to download or can be ordered through USGS Earth Explorer in digital form (https://earthexplorer.usgs.gov/). Corona images have become an important asset in the exploration of hitherto unknown archaeological sites (Jesse, 2014; Kennedy, 1998; Galatsatos, 2004) mainly for the following two reasons: a) High resolution (about 1.83–2.74 m) of the images allow detection of smaller features such as paleo-road, fort-wall, moats, etc., and b) modification of land use or mechanised destruction of land was significantly lesser during the time they were photographed (1960s–1970s) in comparison to subsequent years, hence, they display archaeological details better.
A Coron image of 1967 (Mission 1044-2) of the study area has been used in the present study. The Coron image when downloaded covers east-west and a north-south stretch of ~70 km and ~19.5 km respectively and includes only approximate coordinates of image corners, therefore, the image has a wide range of geospatial error. Thus, the first task was to georeference the imagery. A total of 15 ground control points (GCP) were identified on Google Earth Pro by using the intersection of the roads and other stable features that could be identified on Coron image. The study area lies at the corner of the image; therefore, more GCPs were identified over the study area to ensure higher accuracy. First polynomial order transformation has been used along with nearest neighbour resampling method. The georeferenced image could be geospatially overlaid exactly on the other multispectral images of the region. Image enhancement technique (min-max linear stretch) was applied for better visualisation and interpretation. While interpreting the black and white Coron image it was difficult to distinguish between soil-mark and crop-mark but from the knowledge of the region and the appearance of the known features the marks on the mounds seem to be parch marks and marks on the levelled agricultural fields seem to be soil-mark.

(2) Survey of India (SOI) toposheet: The earliest available large-scale toposheet (1:25,000) for the study area is for the year 1989–90. It was collected from SOI office, Bangalore. The toposheet was scanned and georeferenced using ground control points from Google Earth portal with linear transformation type and nearest neighbour resampling method. The toposheet was overlaid with the acquired satellite data to trace the archaeological features.

(3) High-resolution multispectral data: IRS-R2 (LISS-IV), IRS-P6 (LISS IV) and World View-2 (ref. Table 1) data has been used for creating a False Color Composite image (which consist of a green, red and infrared region of the spectrum).

(4) Stereo data: Cartosat 2 stereo data has been used to generate DEM and anaglyph image2 using the software Erdas Imagine. Since the study area has characteristics such as flat terrain, no forest cover and no tall buildings that minimises inaccuracy, a DEM of 5 m grid spacing was created (Deo et al., 2016). The coordinates of DEM were not sitting properly over other images; hence, it was georeferenced which requires careful identification of GCPs.

(5) Google Earth (GE)’s historical imagery: GE provides very high resolution (~0.5 m) imagery of different dates. The source and date of the images available for the region surveyed in the present study are listed in Table 1. However, there are images of few dates which are not available for all the sites. The GE images give a good range of temporal and seasonal variations, which helps in the identification of subtle marks and patterns that may get highlighted under certain seasonal conditions and provide an indication of the presence of any archaeological feature on the surface (Parcak, 2009).

The processed images were chronologically arranged and carefully analysed with reference to the published archaeological records and maps. Identification of the known archaeological sites provided interpretation keys for the identification of hitherto unknown/buried potential archaeological sites.

4. Results of remote sensing analysis and ground truthing

Remote sensing analysis was carried out following a thorough review of archaeological exploration and excavation already undertaken in this region. Corona images which predate excavation of Kanaganahalli, Anegutti and Hasargundgi stupa were analysed to understand how stupa sites look before excavation. The known sites in all the acquired images has been analysed to identify site-specific interpretation keys that led to investigation of potential stupa sites as well as other potential archaeological sites.

4.1. Identification of known stupa sites

4.1.1. Sites that are found in the form of mounds

(1) Kanaganahalli: The location of this excavated stupa is well known and easily identifiable on very high-resolution satellite images. In Corona image (captured long before the excavation), the site looks as a white circular negative crop-mark of 60 m diameter with a dark spot at its centre that suggests an archaeological mound collapsed from the centre (ref. Fig. 3). The field report by M. Seshadri (1965) (Seshadri, 1965) contemporary to Corona image also mention about this place as a building with circular basement with some relief and missing superstructure. The distinct tone, texture, size and shape of Kanaganahalli stupa identified in pre-excitation Corona image guided us to find out the other documented stupa sites and also location of potential sites that are yet to be explored.

After excavation (completed in 2002), this mound was left open and is now has exposed ashar slab lying around its broken Anda (dome). Therefore, this stupa doesn’t appear as a mound anymore. For the same reason, this stupa cannot be visualised in the anaglyph image as a raised mound.

(2) Anegutti (Stupa No 2): Approximate location of this stupa mound is marked in the published maps. However, to come down to the exact location, it is required to identify the feature on the satellite image. Identification of Kanaganahalli stupa in Corona image has helped us finding out Anegutti stupa’s location by using the same interpretation keys. The mound appears similar to Stupa no. 1 in tone and texture but without any dark spot at its centre, which suggest that mound is intact (ref. Fig. 3). The size of this stupa is larger than Stupa no.1. After pointing out this stupa in Corona image, it was easy to identify it on GE images by referring the location, shape and size. This stupa can be visualised as a distinct raised round mound through anaglyph image. Our field visits and observation has further confirmed its location.

(3) Stupa No. 3: This is very similar to Anegutti mound from outside and has not been excavated by archaeologists. It is situated at

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2 Anaglyph images are used to perceive a landscape as three-dimensional scene by using two images (stereoscopic images) of the same area captured at slightly different angles. These stereo pairs are filtered with two different colors for each eye, typically red and cyan. The landscape looks like an exaggerated 3D model.

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Table 1
Satellite data acquired/used for the study.

<table>
<thead>
<tr>
<th>Satellite/sensor</th>
<th>Spatial resolution (m)</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corona (1044-2)</td>
<td>1.83–2.74</td>
<td>10.11.1967</td>
</tr>
<tr>
<td>IRS-R2 (LISS-IV); IRS-P6</td>
<td>5.8</td>
<td>10.04.2013; 6.04.2007; 3.05.2009</td>
</tr>
<tr>
<td>CARTOSAT-1</td>
<td>2.5</td>
<td>15.04.2011</td>
</tr>
<tr>
<td>World View-2</td>
<td>0.5</td>
<td>22.2.2010; 29.03.2012</td>
</tr>
</tbody>
</table>

High-resolution images (~0.5 m) from Google Earth with sources and dates

<table>
<thead>
<tr>
<th>Source</th>
<th>Date</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>Digital Globe</td>
<td>30/11/2009</td>
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<td>11/04/2011</td>
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<td>29/03/2012</td>
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<td>CNES/Airbus</td>
<td>20/03/2014</td>
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<td>28/10/2016</td>
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around 1.2 km north-east from Anegutti (ref Figs. 1 & 3). This is identified as stupa by Howell and marked as Stupa No. 3 (Howell et al., 1995a). This stupa has also been identified using the approximate location marked on Howell’s map and from its shape, size, tone and texture which is similar to Aneguttu stupa. This stupa also distinctively visible as a raised round mound in the anaglyph image. Remote sensing analysis has also brought to our notice that a newly constructed canal is incising the edges of this stupa. This encroachment can also be traced using recent years GE images (ref Fig. 4). This stupa with encroaching canal has also been observed on field.

Fig. 3. Corona image (a1, b1, c1) of Stupas before excavation/exploration and their corresponding recent high-resolution Google Earth image (a2, b2, c2).

Fig. 4. Site of Stupa No. 3; above are images from Google Earth showing the location of the canal (that has been dug recently) scraping the edge of stupa, below is a photo taken at the site.
While comparing the appearance of Stupa 2 and 3 on satellite images, we have found that Stupa 3 being situated on a single parcel of agricultural land, away from the edges of the parcel, is clearly visible. While three land parcels are abutting Stupa 2 from all the sides and hence, making it less distinctively visible. However, recent canal construction on the edge of Stupa 3 has blurred its distinctive shape in the recent images. It is also observed that stupa mounds (stupa no 2 & 3) are more conspicuous when the fields around it have good vegetation growth or moister soil condition.

4.1.2. Sites that are found as low mound or as buried foundation

1) Hasargundgi Stupa: Location of this stupa was difficult to identify as its structural remains on the surface are not visible. The marks were not visible on Corona image. However, soil-mark (ref Fig. 5a, b & c) and negative crop-mark (ref Fig. 5d) identified near Hasargundgi settlement in the IRS P6 and GE historical images of different dates and years has been associated with the location marked in a contour map of the stupa site published in an excavation report (Poonacha, 2011) This association has been further confirmed by measuring diameter of the stupa (30 m) and the distance between nalla (rivulet) from the centre of the stupa in the contour map and comparing it with that of the corresponding soil-mark in the False Colour Infrared Image (ref Fig. 5a) which was the most conspicuous among all the images. As the location of Hasargundgi stupa is levelled by agricultural activity, the mound is neither visible on

Fig. 5. Soil-mark of Hasargundgi Stupa on IRS P6 image (a), Google Earth historical imageries (b, c & c); subtle crop-mark of the same stupa is visible on (d).
2) Benagutti Vihara: Visual analysis of all available satellite images couldn’t yield any definite shape and pattern of crop-mark or soil mark in the Benagutti Vihara site. However, a mound is observed in the anaglyph image and DEM on the location marked in the published documents (Howell et al., 1995a). The elevation profile of the mound is given in the Fig. 7. The location of this mound was further visualised in Corona and other satellite images. Brighter tone in the Corona image and negative cropmark on other images was observed on that location. Although, the mark is neither distinctive nor of any definitive shape.

3) Habitation Mound (SAN 8): A search of archaeological traces using satellite images (Corona and DEM) of SAN 8 region was carried out. A distinctive negative soil-mark, bright in tone, near-circular in shape and more than 100 m in diameter was detected (Latitude 16°49′36.94″N and Longitude 76°55′3.37″E at the centre of the identified feature) on Corona imagery (Fig. 6a). This could also be later observed in other images of different dates (both IRS P6 and GE, ref. Fig. 6b & c). On anaglyph image and DEM, a raised mound is found in the same location which extends beyond the extent of the crop-mark/soil-mark. The elevation profile of the mound is given in Fig. 7. The soil mark on this site, though larger in size, has a striking resemblance in shape and crop-mark (negative) with Hasargundgi stupa and other potential stupas found in the vicinity.

4) An Early Historic mound (labelled as M in Fig. 1), located east of Sirival village, has got completely obliterated due to the extensive stone quarry in that area, hence, cannot be identified on any image or on ground.

4.2. Identification of potential archaeological sites

Identification of known archaeological sites on satellite images has provided the main interpretation keys to explore unidentified stupa and other potential archaeological sites in the vicinity. Following are interpretation keys that are found to be associated with Buddhist archaeological sites in the study area. These are mainly- bright tone, a circular shape, smooth texture, light-toned soil mark and negative cropmark/parch mark. Bright tone can be attributed to shallow depth of soil over the buried archaeological site. The shallow soil above a buried feature get much drier than its surrounding deeper soil due to intense heat during the summer. Shallow depth also discourages vegetation growth and hence leaves negative cropmark. In general, mounds are round in shape. In case of stupa, they form a very distinctive round shape. The basement of stupa also forms a circular shape leaving some circular marks of buried structure visible on ground. Following potential sites have been traced from the image analysis and their coordinates are listed along with the other known stupa sites in Table 2.

4.2.1. A cluster of possible stupas in the vicinity of Anegutti (Stupa No. 2) mound:

Visual analysis of Corona image of 1967 led to the identification of other circular parch-marks/soil mark which are similar to the other identified known stupa mounds. All the acquired subsequent multi-spectral images of the different time periods from 2005 to 2017 were analysed (ref. Table 1) to assess the continuity of the traces of identified crop-marks/soil-mark. The continuity of the traces has been observed, that indicated that these marks are not temporary. Through the visual analysis, it is observed that summer is the best time to get the crop/ parch/soil marks. Soil-marks of P1 and P2 on late summer images (ref Fig. 8e & f) are more conspicuous than any other available images of different season (this also corresponds to harvesting season). P3 is more distinct in Fig. 8c when there are crops on field around the stupa mark. In Fig. 8a, P1 and P3 measures ~60m in diameter and are slightly smaller than Anegutti mound. P1 has lighter and mixed tone which suggests that it is more damaged than P3. Parch-mark/soil-mark P2 (100m in diameter) which forms a bright colour annulus shaped feature, bigger than P1, P3 and Stupa No. 2, could be remnant of stony paving of circumambulatory passage of a stupa. The toposheet and multi-temporal images reveal that P3 has been gradually transformed from a mound to completely levelled plantation site and can be traced as negative crop-mark (ref Fig. 8b.)

On ground survey, we have found abundance of shale chips over P3 area (ref Fig. 9). These shales chips are very similar to the material with which Stupa no. 2 and 3 are covered. Howell suggests that the top portion of the dome of stupa no. 2 was covered with shale chips which in the final period of destruction slumped down from the top and covered the entire structure (Howell et al., 1995b). The presence of this material in a circular form at P3 sites gives us good reasons to probe further. There are no visible indications of other two identified sites P1 & P2. Their absence can be attributed to heavy agricultural activities that destroys the entire structure gradually and levelled the surface as it is happening in case of P3 and excavated stupa Hasargundgi. In Survey of India toposheet (ref no. 56 D/13/SE; surveyed in 1989–90), Stupa No 2, Stupa No 3, and P3 have been marked as stony waste (ref Fig. 8b). Out of these three stony waste features marked in the toposheet, two have been found to be Stupas, which suggest that P3 could also be a similar structure.

Spatial distribution of P1, P2 and P3 along with Stupa no 2 form a
square pattern. It has been observed in some of the famous Buddhist sites that stupas are arranged in a cluster, forming a definitive geometric shape. For example, stupas in Lauriya Nandagarh (Archaeological Survey of India, 2019) are arranged in three rows, two of which are parallel to each other and perpendicular to the third row. Such patterns in Buddhist sites support the possibility of a cluster of 4 stupas around Stupa no. 2. If this speculation is true, then P2 would be the largest stupa in this region.

**False calls:** In IRS P6 - May 2009 image, two more circular marks similar in size to Anegutti stupa were found in the vicinity of this cluster, but their tone and texture were different from other identified stupa sites. These crop-marks were not observed in any other image except the May 2012 image of GE. Presence of stacks of the gathered crop in the image of May 2012 led us to associate the mark with harvesting season (ref. Fig. 10). It was later confirmed on the field visit where we could see a light colour solid circle on the field from the top of Anegutti hill which was found to be remnants of dried harvested crop. Such deceptive crop-marks/soil-marks can be misleading; hence, one has to be cautious while interpreting and has to find supportive evidence from multiple sources.

### 4.2.2. Other potential sites

A similar crop-mark/soil-mark is found along the left side of the northerly bend of the river Bhima opposite to Anabi (Labelled as P4 in Fig. 14). This soil-mark has a circular shape and diameter of around 100 m. Occurrence of this feature in the several available images (LISS 4, Corona and GE May 2012) and its similarity with the crop/soil-mark of known sites suggests presence of a buried structure (ref Fig. 11).

There is another crop-mark on the western end of Sirival village that seems to be archaeologically potential (Labelled as P5 in Fig. 14). This crop-mark did not catch our attention until we examined it in Corona image (Fig. 12a). In the monochromatic Corona image, this feature appears as a dark-toned square of ~160 x 160 m, inside which there is a circular feature of brighter tone with a diameter of ~100 m (ref Fig. 12a). This feature has been observed in all the historical images of GE. The GE images show a progressive increase in area being quarried from the south-eastern side in the year 2005 (~180 m²) which has expanded to its north at present (~1500 m²) (ref Fig. 12b and c). However, this scar is not observed in Corona image of 1967 (Fig. 12a). On field visit (which was for ground truthing and not an intensive archaeological survey) no dressed stone or artefacts were observed on the site but a substantial amount of stone quarrying was evident. The mound couldn't be approached due to the presence of dumped quarry debris and wild vegetation over it. It is possible to think that the central circular mound might have formed from the heap of stone debris produced due to stone quarrying, but the Corona image of the year 1967 shows the mound clearly without any quarry scars. In addition, the earliest available GE image of the year 2005 also shows the same size mound and a small trench of quarried stones which is too small (~180 m²) to produce such a huge debris mound (~8900 m²).

This analysis led us to contemplate the nature of this mound, how and when it was formed. Is it an ancient quarry site that had been used to remove stones for the construction of the 8th–10th Centuries GE
Rashtrakuta temples at Sirival? or does it hold any other archaeological importance since it is located in Sirival - a place with the largest cluster of temples of Rashtrakutas period? (Patil and Balasubramanya, 2001a) This led us to further question why no historical structure, whether it be of Rashtrakuta period or later period, has been found in this particular area, whereas, historical monuments are scattered all over the Sirival village and even across the river (ref Fig. 13a). Another important observation that has been made in the present study is the location of this feature. Through visual analysis, it is found that its location is quite comparable with that of Hasargundgi Stupa i.e. both of them are situated between the right bank of a river bend and village settlement (ref Fig. 13). While investigating whether Sirival has any association with Buddhism, it is found that archaeologists have recovered a slab with stupa carving of the early historic period at Sirival (Patil and Balasubramanya, 2001b). Absence of any historical structure (subsequent to Satavahana, including Rashtrakuta) over the identified feature suggests that the mound might be older than Rashtrakuta period and for some reason, people avoided building over it. However, it is difficult to reach any conclusion without detailed field investigation. Therefore, a thorough field exploration on site is suggested for investigating its archaeological potential.

5. Discussion

5.1. Remote sensing and site identification

The analysis of Corona image of 1967 to identify all the known stupa sites and other archaeological mounds provided us interpretation keys that helped us towards the identification of similar but unknown features in the vicinity. The image has also pointed out a few unknown sites that looks similar to known mounds but at present they have got completely levelled. However, analysis of other satellite images shows presence of spectral anomaly on their respective location. Investigation was done to identify such spectral anomalies in the remaining study area. To avoid inclusion of false calls (wrong identification of a feature), multiple images of different dates/seasons/years assisted in eliminating them. The confidence level to consider an identified site as a potential archaeological site becomes higher if there is a continuity in its presence in the images of multiple dates and seasons.

The sequence of these images has also helped in tracing the gradual destruction of archaeological mounds that has occurred in the recent years as in case of P3, which is very important to understand how some of the sites would have been destroyed in the past. Seasonal landcover conditions play a crucial role in the visibility of subtle crop/soil marks of buried features. In the present study, it is found that these marks are better discernible in the images obtained in the month of March, April and May (summer season) which is the time when fields are ploughed, and climatic condition is hot and dry. Patterns due to moisture variation in soil is almost imperceptible from the ground but can be detected as a subtle difference in colour of soil and vegetation on aerial photographs or satellite image (Parcak, 2009) (Navalgund and Rajani, 2017). Raised mounds are found more conspicuous when the soil around them has more moisture or good growth of crops or when the mound doesn’t share boundaries with more than one field. In the present study, this variation has been an important key to identify the potential sites, of which soil marks were the most useful.

The resolution of DEM was not good enough to visualise all the mounds. It is found that DEM can be used to visualise features with diameter approximately more than 100 m. Mounds smaller than that can be visualised in 3D in Anaglyph. Mounds found on the location of crop/soil-mark suggest possibility of potential archaeological site. Because of levelling of the ground, none of the identified unknown sites are found to be a mound. Summary of remote sensing analysis is given in Table 3.

5.2. Limitations of the method used

The methodology used in this study is simple and can be easily applied to other similar Buddhist site but there are certain limitations. It is found that there is inconsistency in the spectral anomalies observed
for the buried sites. Even the summer images, which are considered best for the identification of spectral anomalies, do not have consistency in the presence of identified features. It is observed that an image that shows one feature very clearly may not necessarily show the other features with that much clarity and sometimes few of them are found completely missing. For instance, Hasargundgi stupa was not seen in Corona image, LISS IV images of April month but all or some of the other sites were found visible in these images. There could be multiple factors for this inconsistency such as irrigation of the field, depth of soil, tilling and ploughing of the soil, crop-type, etc. Therefore, it is essential to have images of multiple dates.

Identified interpretation keys, though have been associated with archaeological mounds or buried sites might sometime lead you to wrong interpretation. Stacks of harvested crop (ref Fig. 10) could have been interpreted as potential sites if they had not been analysed in multiple dates images. Therefore, one has to be aware of possibilities of finding such false calls.

Fig. 9. a) Location of P3 - Shale chips deposits creating white patches on the ground; b) close-up of the shale deposits found on the P3 site; c) close-up of the shale deposits found all over the Stupa no.2; d) Stupa no.3, encroached by recent human activities – thick layer of the same shale chip material got exposed.

Fig. 10. Example of false call, two circular features (b, c) inside the yellow dotted circle are stack of harvested crop; corona image (a) doesn’t show presence of any such marks as the image is captured in November which is not the harvesting season.
Fig. 11. Soil-mark of possible stupa site (P4) on Corona (a), IRS P6 False colour image (b, c) and Google Earth image (d).

Fig. 12. Traces of possible archaeological site (P5) on Corona (a) and Google Earth images (b and c) and below are photos taken at site.

Fig. 13. (a) Distribution of historical structures at Sirival (in red triangle) with highlighted possible archaeological site (P5), ref. Fig. 10 for larger view; (b) image of Hasargundgi stupa site (ref Fig. 4 for larger view) comparable to P5 site in terms of its location between a bending rivulet and a village.
5.3. Implication of the study

The study area has cultural remains from Middle Palaeolithic period to 18th century. Most of the structural remains on the left bank of the river are from early historic period (Maurya and Satavahana), on the right bank we find abundance of remains from the Rashtrakuta period. Some of the identified potential sites on the left bank (P1, P2, P3) are being associated to stupa structure because of their close proximity and resemblance to the known stupa sites. The reason for this association has already been discussed in detail in the result section.

Direct indication of the presence of archaeological structure on the newly identified sites was not observed due to levelling and layering of fields for agricultural purpose which changes the surface and topographical profile significantly. Therefore, it is difficult to ascertain the type and the purpose of the identified mounds and features. Nevertheless, the archaeological richness of the site, the evidence acquired through remote sensing analysis in the present study which are also comparable to the evidence of buried foundation/structure of known sites are significant enough to highlight the identified sites for further detailed ground investigation.

6. Conclusion

The study has evolved a simple and robust methodology to identify
hitherto unknown mounds and buried sites in a Buddhist archaeological landscape which is experiencing land use change by modern agricultural activities. The study has found few more possible stupa sites. Systematic study of simple remote sensing data can explore buried relics, when no surface remnants are found, by identifying weak spectral anomalies of the earth surface. Detailed ground investigation and excavation might suggest that the site was possibly a more important Buddhist centre than what it was thought. This approach can be easily applied to investigate larger similar landscape before modern agricultural or other development activities smother all the archaeological evidences. Also, such investigation would help us to know whether the existing known stupa sites of early historic period extend beyond what is yet known. The methodology can also be applied to search mounds that are mainly found in south Deccan and north Dharwad region. Results of this study can also be developed to set criteria and rules to produce a sound algorithm for automation. Moreover, the adopted approach is considered as the first step to identify the archaeological potential of a site which then can be referred to suggest if the site requires detailed investigation using more complex and costly techniques such as LIDAR or ground explorations through trial excavations.

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References


Galiatsatos, Nikolaos, 2004. Assessment of the CORONA Series of Satellite Imagery for Landscape Archaeology: A Case Study From the Orontes Valley, Syria, Durham, Theses. Durham University(Available at Durham E-Theses Online: http://etheses.dur.ac.uk/281/)


Landscape Archaeology: A Case Study From the Orontes Valley, Syria, Durham, Theses. Durham University(Available at Durham E-Theses Online: http://etheses.dur.ac.uk/281/)


Poonacha, K.P., 2011g. Excavations at Kanaganahalli (Sannati) Taluk Chitapur, Dist.


