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SHORT NOTE

Multispectral Remote Sensing Data Analysis and Application for Detecting Moats Around Medieval Settlements in South India

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Abstract This work explores the potential of multispectral imagery in identifying dried and buried moats, and possibly any adjacent fortifications of medieval sites in South India. Vegetation marks in the form of geometrical patterns have been one of the key signatures indicating archaeological sites. To explore this three of well known sites from Karnataka in south India–Belur, Halebidu and Somanathapura–were chosen as their historical accounts mention that they were townships which had circumscribing artefacts such as fort/wall or moats that at present are not easily detected from conventional exploration. These three sites belong to Hoysala dynasty, a period when a systematic town planning was followed based on cultural aspects such as the religion or faith followed by the inhabitants of respective sites. Traces of specific configuration of moats can be detected around each of them. The present work investigates the possibility of identifying these artefacts on space imageries through spatial and spectral distinction along with synoptic views and use of appropriate image processing and analysis techniques.

Keywords Multispectral satellite image · Remote sensing · Wall · Fortification · Moat · Belur · Halebidu · Somanathapura

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Introduction

A defensive wall or fortification was used to protect a city or settlement from many kinds of attacks or encroachment. Generally, these are referred to as city walls or forts. Traditionally, moats were excavated around an outer wall and filled with water. They provided a preliminary barrier against attacks and made access to the walls difficult. With the decline of the ruling power and changing times, the defensive wall gets deserted. Over time, either they deteriorate or the material gets appropriated for fresh constructions. Some walls remain almost intact, some collapse into ruins and others get completely obliterated. But the underground remnants affect the land surface. These can be recognized when the area is viewed synoptically from air or space. The effect will be more conspicuous if the surface has vegetation because archaeological anomalies often present themselves as positive (healthy) or negative (weak) vegetation marks (Rajani 2007 and Agapiou and Hadjimitsis 2011). During the World Wars many archaeological sites were discovered in Europe by detecting such vegetation patterns in aerial reconnaissance photographs (Bradford 1957; Deuel 1969 and Brophy and Cowley 2005). These were black and white analogue photographs. In the present age sensors aboard satellites are able to take digital images of high radiometric resolution in panchromatic band covering 0.3 to 0.9 μm of the spectrum, which can make more sharp distinction between tones. But panchromatic image is a wide band covering the whole range of visible wavelengths in which features that are not vegetation also can show the same tone. The feature of interest has to be identified only on the basis of shape. With multispectral imagery observations can be made in bands that are sensitive to vegetation. Vegetation has high reflectance in green region, therefore human eye sees it as green colour, but the reflectance is at least 4 times more in infrared region (Joseph 2005). Therefore a multispectral image comprising infrared band has more potential to reveal subtle variations in vegetation tone, which could otherwise be elusive. Archaeological vegetation marks are often subtle.

Multispectral imaging has been used to analyse different kinds of archaeological data such as deciphering old manuscripts that are hardly legible (Chabries et al. 2003); details on murals that cannot be seen by naked eye (Kamal et al. 1999); composition of pigments in various layers of old paintings (Lau et al. 2008) and satellite images for detecting subsurface archaeological features (Lasaponara and Masini 2007, and Brivio et al. 2000). The present study has identified features on multispectral satellite imagery, indicating fortification and adjoining moat in three archaeological sites: Belur, Halebidu and Somanathapura in Karnataka, South India. Identification of these moats have been reported in Rajani et al. (2010), this paper will analyse the spectral and spatial nature of such signature. All these belong to the Hoysala period when a series of powerful kings ruled from the 12th to 14th centuries AD. The architecture of Hoysala settlements followed a pattern in which a temple formed the hub of a new township, both built simultaneously. The layout of the Hoysala township was influenced by the faith followed by the religious community. For example a village with dominant *Sri Vaishnava* community most often had the *Vishnu* temple located in its middle with *Siva* temples elsewhere and settlements with dominant *Siva* community had the main temple on the east. When temples were built in an existing village, a site was chosen either in the heart of the village or on the bank of a tank or river, or on the summit of a mound or hill. Generally temples of Saivaites, Vaishnavites and Jainas stand in localities where the followers of these respective cults were concentrated, but on as many occasions the foundation of the temple provided an incentive for the followers to settle around it (Settar 1992). Historical literature mention that these settlements had city wall and moat: currently it is difficult if not impossible to detect remnants of these on the ground.

Belur: is one of the earliest townships created under the Hoysalas and represents the characteristics of their early town planning. It was established around the Chenna Kesava temple which stood in its middle. The temple was commissioned by Hoysala King Vishnuvardhana in 1117 AD. A total of 118 inscriptions have been recovered from the temple complex, covering the period between c. 1117 AD to 18th century, which give details of the artists employed, grants made to the temple and renovations. The site was dominated by the *Srivaishnavas* and all their temples are concentrated within an enclosure wall, which originally formed the heart of its settlement. The original plan has been considerably altered during the subsequent expansion of this township (Settar 1992). However the multispectral remote sensing images endorse the original layout showing a circular signature of positive vegetation mark surrounding the temple. This indicates existence of a moat which would have surrounded an enclosure wall.

The IRSP6 LISS-IV, date 31.12.2006 (Fig. 1b) multispectral image clearly shows the main temple (Chenna Kesava) located in the centre surrounded by a circular positive vegetation mark indicating that there was a moat earlier. This feature has been extracted and shown in Fig. 1a. Figure 1c shows the 2.5 m spatial resolution Cartosat1 Panchromatic data. The Panchromatic band (0.3–0.9 μm) covers the whole of visible band width as one layer and therefore is black and white. High resolution true colour composite images Fig. 2

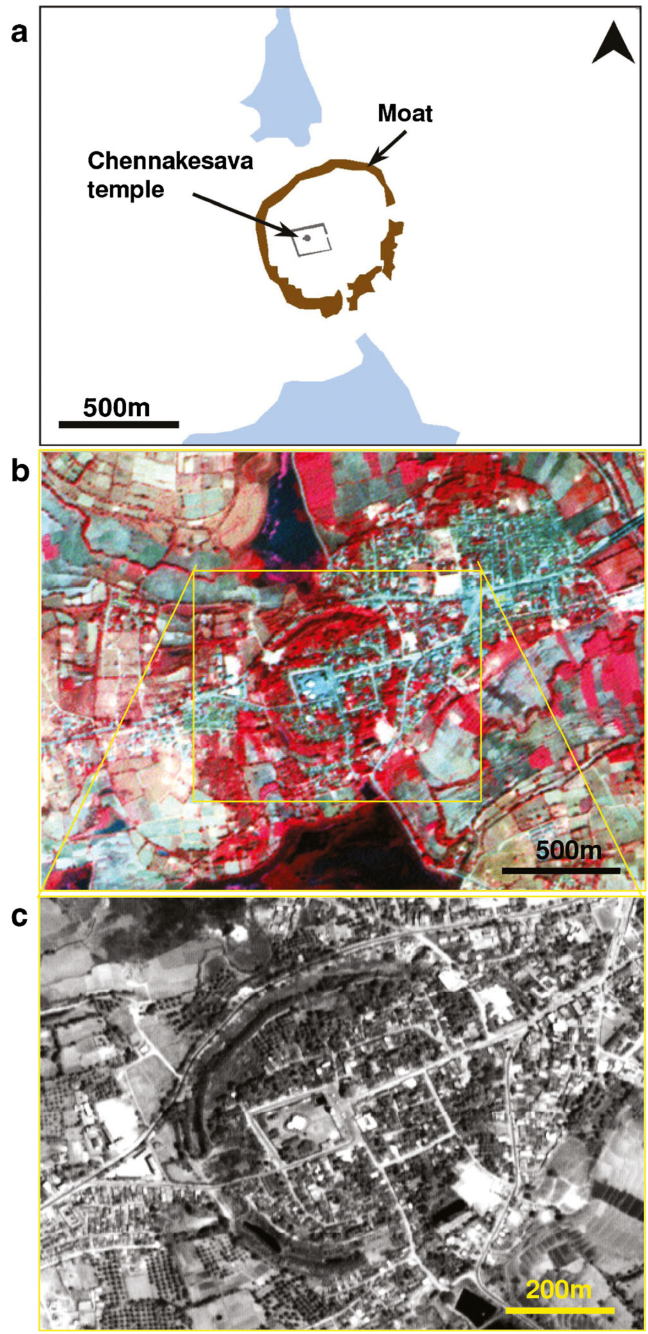
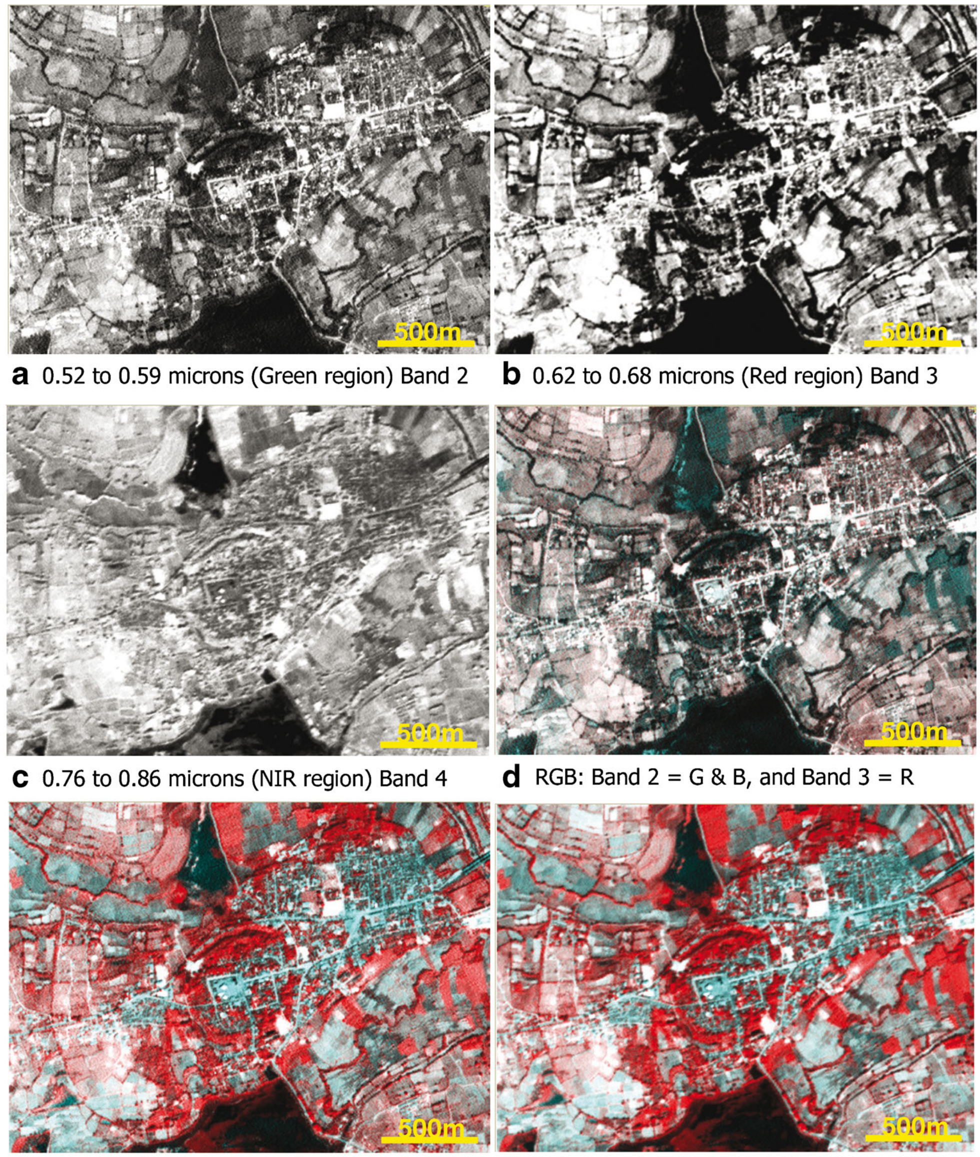


Fig. 1 Belur (**a**) Map extracted from then RS data showing layout of temple and moat, **b** Multispectral data (IRSP6 LISS-IV 31.12.2006; 5.8 m). **c** Panchromatic data (CARTOSAT-1 21.02.2008; 2.5 m)

Fig. 2 Digital Globe image date 17.11.2011 extracted from Google earth on 08.05.2013

(Digital globe), is also of higher spatial resolution compared to the multispectral FCC image. The ring-like circular feature is more prominent and readily visible in the 5.8 m multispectral image FCC (Fig. 1b). Once the feature is detected, then it can be identified in higher or coarser resolution by visual association. The feature is visible on PAN data (Fig. 1c) but it is not as striking as the multispectral data of 5.8 m spatial resolution. On the PAN data it looks like a round dark patch rather than a circumscribing ring. The tone of the vegetation on the circular feature is indistinguishable from the other vegetation and urban features that have the same tone. Similarly in the true colour Google Earth imagery (Fig. 2) the tone of the vegetation on the circular ring is not distinguishable from other vegetation. In fact the circular shape is less distinguishable even when compared to PAN (Fig. 1c); this may be due to the seasonal variation in the vegetation between the dates of the imagery. PAN is of February 21st, which is a dryer season compared to Fig. 2 which is November 17th, post monsoon. However the multispectral image, in which the circular shape is most visible, is of December 31st. Once the boundary of the moat is detected using multispectral image, high resolution image can be overlaid using GIS and taking advantage of the higher spatial resolution image thematic layers with higher definition can be prepared.

In order to investigate the reason for such a prominent signature to be formed on multispectral image, each band was separately studied and various combinations of two bands were analysed. Figure 3a is only Band 2 (0.52 to 0.59 μm) showing Belur area as observed only in the green region of electromagnetic spectrum. The grey levels in the image indicate the intensity of reflectance of this bandwidth; white areas have high reflectance and black areas are where the energy of this bandwidth gets absorbed. The circular vegetation mark indicating moat does not display any distinctive tone though the shape is somewhat distinguishable. Figure 3b shows the same area as observed in red band (0.62 to 0.68 μm). In this band the circular feature looks very dark, almost black which means the energy of this bandwidth gets totally absorbed, and is not distinct from other dark features in the image. Figure 3c is the Infrared band (0.76 to 0.86 μm) and the magnitude of reflectance of this bandwidth is very high along the circular feature, but the shape is not distinguishable from other regions of similar reflectance. This shows that the circular feature is not seen in any single band, therefore it is the combination of bands that make the feature conspicuous. To identify the pair that contribute maximum for such a feature, various combinations of two bands were analysed. Figure 3d is a colour composite image where Band2 (green region) is projected in green and blue colours; and Band3 (red region) is projected in red. The resulting image is very close to a natural colour composite as two bands are projected in their respective natural colours. In Fig. 3e Band2 (green region) is projected in green and blue colours; and Band4 (infrared) is projected in red; and in Fig. 3f Band3 (red region) is projected in green and blue colours; and Band4 (infrared) is projected in red. The circular feature is most prominent in the last combination (Red and Infrared bands); it is quite distinctive in the pairing of green and infrared bands also but not so conspicuous in the combination of red and green bands. This shows that a combination which includes infrared makes the feature's tone and shape very distinctive though the infrared band by itself does not show such a pattern. However the feature is not as prominent in coarser resolution (23.5 m) multispectral image. In



a 0.52 to 0.59 microns (Green region) Band 2 **b** 0.62 to 0.68 microns (Red region) Band 3

c 0.76 to 0.86 microns (NIR region) Band 4 **d** RGB: Band 2 = G & B, and Band 3 = R

e RGB: Band 2 = G & B, and Band 4 = R **f** RGB: Band 3 = G & B, and Band 4 = R

Fig. 3 Band combinations, using multispectral images of Belur

that scale the shape of the feature is not as conspicuous as in Fig. 1b which is multispectral but 5.8 m spatial resolution. This illustrates that identifiability of a feature is sensitive to both spatial and spectral resolutions.

The present work on Belur has established the existence of the moat by the approach adopted here. Further, no single band makes the feature as conspicuous as a combination that includes IR. For a site of this size, medium (5.8 m) resolution multispectral data is optimal for the detection of the moat. However, higher and coarser resolution imagery can provide complementary information, such as buildings, roads and other built up structures (in case of high resolutions) and landcover features of contiguous areas including agricultural fields and drainage system (using coarser resolution). These will add onto the knowledge base of the site.

Halebidu: Also known as Dorasamudra (entrance from ocean) is in Hassan District, Karnataka. Dorasamudra, with a fortified area, was the capital of the Hoysala kingdom. Its history begins in the middle of the 11th century with the excavation of a tank on the bank of which the Hoysalesvara temple was later located. Hoysalesvara temple (dating from 1121 AD) is dedicated to the Hindu God Siva and is one of the best examples of Hoysala architecture. It is the dominant temple of the city and occupied the eastern section thereof. Halebidu was dominated by Saivas, but Jains also held a position of importance here. Though the construction of the principal temple was initiated and financed by wealthy Saiva citizens of the city, prominent among whom were Ketamalla and Kesarasetti, its twin shrines named Siva as Hoysalesvara and Santaleshvara, acknowledging the god as patron both of

Vishnuvardhana (Hoysala) and his queen, Santala. The temple building activity was taken up in competition with the construction of the Chennakesava Temple at Belur, a Vaishnava temple (Settar 1992). Halebidu was sacked by the armies of Malik Kafur in the early 14th century, after which it fell into a state of disrepair and neglect.

Halebidu had an asymmetric shaped fort covering a large area and attached with a deep moat. The archaeological report for the year 1930 (1934) records that this moat was 50 ft deep. It states that the fort wall had bastions at interval of every 100 yards, and several gateways. This report also published a “rough sketch map” indicating the fort, temples and tanks. An accurate map can now be prepared through the present study using multispectral imagery. The outline of the fort can be identified following the traces of the moat which can be detected on multispectral imagery.

However, certain parts of the moat are more prominent than other parts and application of few image processing and enhancement tools further assist in tracing the feature. For example, the west boundary is easily distinguishable as it is broad (width ranging from 20 to 50 m) and forms a separate patch of land with texture distinct from the adjacent cultivated fields on either side, which have a homogeneous texture. This portion is further highlighted by applying ratioing, PCA and IHS to the image. The southern boundary is fairly discernable because of the difference in colour and texture of vegetation between the inside and outside. The latter has more moisture, being on the slope that drains water into the tank on the east,

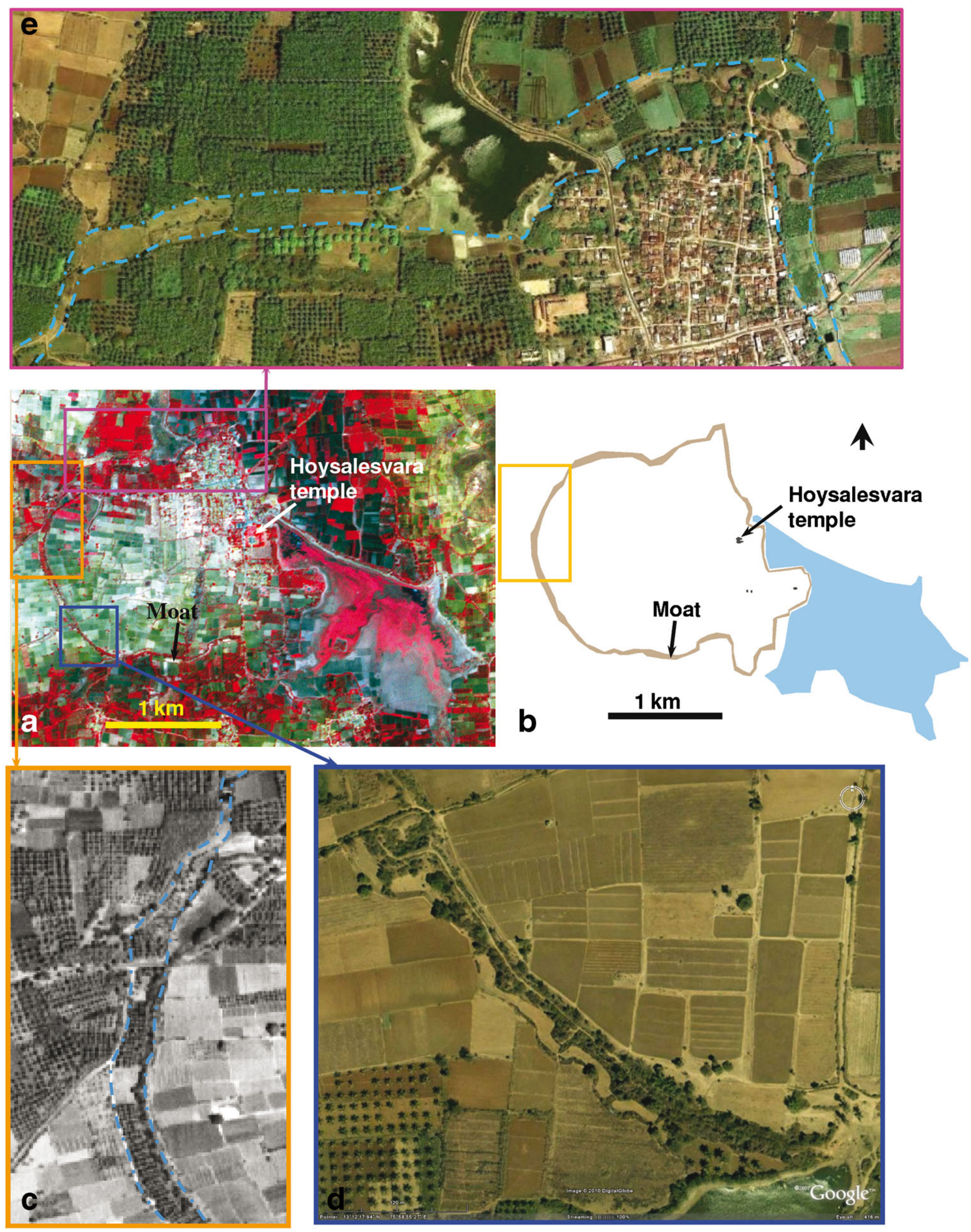


Fig. 4 Halebidu: **a** IRS-P6 LISS-IV multispectral image; **b** Map showing the complete outline of the moat; **c** CARTOSAT-1 image of a portion of the moat; **d** and **e** Google Earth image showing two different portions of the fort

and therefore the vegetation has more chlorophyll content as reflected by the high infrared signature, whereas the inside of the boundary has drier looking cultivated fields (enhanced by ratioing and IHS). On the east side the boundary can be traced because of the contrast created between land and water of the adjacent lake (enhanced by NDVI). The north portion is the most inconspicuous one as the boundary merges with a mixed heterogeneous texture of fields and human habitation. With the help of the rough sketch map from the annual report of 1930, (1934) and the images and enhancements (NDVI particularly) the north boundary also can be mapped fairly accurately. Halebidu is a case in point to demonstrate that multispectral imagery is better than high resolution panchromatic (PAN) or true colour imagery for detection of a continuous and near-complete moat through circumscribing vegetation signature. Once the moat is detected through difference in vegetation colour, higher resolution imagery can be used for high definition of spatial characteristics such as shape of the boundaries. The pattern indicated by the multispectral image is due to the subsurface composition of the area and the pattern that can be seen on high resolution PAN is the surface condition. Both these are useful and are complementary to each other. With this, one can map the exact shape of the moat using GIS. Figure 4 shows the whole area produced by multispectral LISS-IV (Fig. 4a) sensor and a section of the moat on the image (Fig. 4c) produced by panchromatic camera aboard CARTOSAT-1 (2.5 m spatial resolution). The moat is marked with a blue dotted line. A well-preserved portion of the moat is shown in Fig. 4d. This is from Digital Globe image date 23.2.2006 extracted from Google Earth; the spatial resolution of this image is ~60 cm. With this resolution the detailed spatial characteristics can be mapped. As can be seen in the figure, the shapes of the bastions of the fort is very clear through the vegetation anomaly, though there is no evidence of the structure itself. The contrast is also because of the dry season. The same area when observed with another Digital Globe image date 17.11.2011 (available on google earth on 11.05.2013) the shapes of this feature were not as distinct as the vegetation thereof had filled out and also the tone of the feature was not as distinct from the surrounding because of the overall vegetation growth in that season. In the northern portion the shape of the moat can be identified using land cover and field boundary pattern seen on Google Earth's Digital Globe image (Fig. 4e).

Compared to Belur, Halebidu posed higher degree of complexity in the interpretation of the satellite imagery for identifying the moat. Techniques such as NDVI, ratioing, PCA, IHS, had to be employed to detect and delineate configurational details of the moat. This work also demonstrated that the different spatial and spectral resolutions provide complementary information. It also shows that an archaeological feature is more conspicuous in a homogenous land cover of lower spatial frequency; in a high spatial frequency or heterogeneous land cover situation identification becomes more challenging. The present work on Halebidu has made an exhaustive assessment of the details of moat, beyond what conventional archaeology and mapping could provide earlier.

Somanathapura: is located 30 km from Mysore, Karnataka, India. This town is famous for Kesava temple built in the second half of 13th century during the reign of the Hoysala king Narasimha III. The Kesava temple is a good example of Hoysala architecture built in schist; it is fairly well preserved. Historical records mention that the temple was once surrounded by a protective wall and a moat (Settar 2008). At present it is difficult if not impossible to find vestiges of this wall or moat. But a remotely-sensed image taken from space reveals the temple and its alignments with the surrounding land cover features displaying a pattern that befits a boundary wall. Figure 5 is a multispectral FCC image taken by IRSP-6 LISS-IV on 24th March 2005; offers an overall perspective of the landscape including the main temple, the river course, canal, roads and the subtle signature of the buried defensive wall. The features that are almost black are water bodies, with river Kaveri on the left and a lake on the right. A canal skirts Somanathapura; the land between canal and river formed the command area and is showing a high NIR reflectance because of intense cultivation there. A small grey rectangular feature in the centre of the image is the Kesava temple. Synoptic view from satellite imagery reveals a much larger rectangle, the proportions of which are nearly similar to that of the temple.

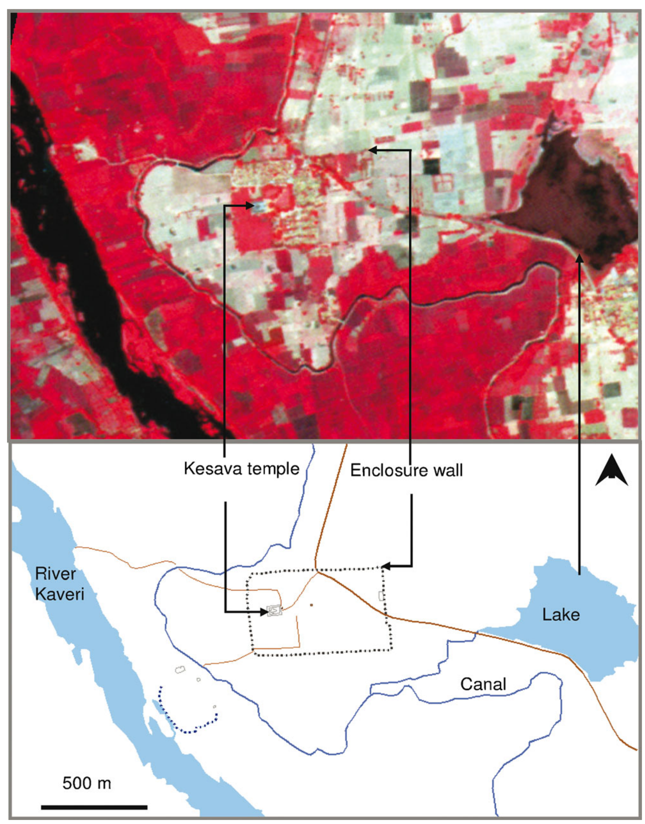


Fig. 5 IRSP-6 LISS-IV (24 March 2005) showing Somanathapura and environs

The band combinations analysis (similar to the analysis done on Belur) was performed on multispectral image of Somanathapura. This also shows that signatures indicating circumscribing moat/fortification are most clearly seen on image produced by a combination that includes infrared band. The temple is in a position that suggests some symmetry and harmonious arrangement of the whole layout. Most of the outer rectangle is indicated by a positive vegetation-mark, which is probably due to the moisture retained in the buried moat. The rest of the rectangle is connected with boundaries of the fields and settlement. Probably the hard remnants of the stone fort hindered vegetation and obstructed fresh construction. These lines become separators between two fields or two types of land cover. These lines together with vegetation marks collectively reveal the shape of a near complete rectangle. This pattern also suggests that the planning of the outer rectangle was in harmony with the plan of the temple or vice versa, which suggests that both belong to the same period.

The present study on Somanathapura has provided a holistic understanding of the spatial relationship between different landforms both natural and anthropogenic. This in turn has enabled the actual identification of the existence of the moat besides characterising the adjacent landforms in relation to the moat.

Conclusions

The ancient city walls and fortifications were generally surrounded by moats, which constituted the defence system of the settlement. Even if the fort/wall has gone into ruins, the buried moat affects the surface vegetation, which can be detected on remote sensing imagery. These effects can be better detected on multispectral imagery as the signature is determined by varying vegetation colour and texture.

This work has demonstrated detection of moats in three historical sites (Belur, Halebidu and Somanathapura) of the Hoysala period and has also illustrated the extent of identifiability of such signature on higher resolution PAN and true colour composite compared to medium resolution multispectral image. This work has also discussed the geometric pattern and layout of the sites based on cultural and community factors. This combination of cultural information and associated geometrical patterns can be used for detecting moats and other buried historical sites. This further reiterates the importance of creation of GIS data base to facilitate preservation of heritage sites.

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References

1934. *Annual Report of the Mysore Archaeological Department for the Year 1930*. Bangalore, India: The Government Press.

Agapiou, A., & Hadjimitsis, D. G. (2011). Vegetation indices and field spectro-radiometric measurements for validation of buried architectural remains: verification under area surveyed with geophysical campaigns. *Journal of Applied Remote Sensing, 5*(1), 053554. doi: 10.1117/1.3645590.

Bradford, J. (1957). *Ancient landscapes: Studies in field archaeology*. London: G. Bell and Sons, Ltd.

Brivio, P. A., Pepe, M., & Tomasoni, R. (2000). Multispectral and multiscale remote sensing data for archaeological prospecting in an alpine alluvial plain. *Journal of Cultural Heritage, 1*(2), 155–164.

Brophy, K., & Cowley, D. (2005). *From the air: Understanding aerial archaeology*. Tempus, Stroud, Glos.

Chabries, D. M., Booras, S. W., Bearman, G. H. 'Imaging the past: recent applications of multispectral imaging technology to deciphering manuscripts'. *Antiqity*, June 2003.

Deuel, L. (1969). *Flights into yesterday: The story of aerial archaeology*. Middlesex: Pelican.

Joseph, G. (2005). *Fundamentals of remote sensing*. Hyderabad: University Press.

Kamal, O. S., Ware, G. A., Houston, S., Chabries, D. M., Christiansen, R. W., Brady, J., & Graham, I. (1999). Multispectral image processing for detail reconstruction and enhancement of Maya murals from La Pasadita, Guatemala. *Journal of Archaeological Science, 26*(11), 1391–1407.

Lasaponara, R., & Masini, N. (2007). Detection of archaeological crop marks by using satellite Quickbird multispectral imagery. *Journal of Archaeological Science, 34*(2), 214–221.

Lau, D., Villis, C., Furman, S., & Livett, M. (2008). Multispectral and hyperspectral image analysis of elemental and micro-Roman maps of cross-sections from a 16th century painting. *Analytica Chimica Acta, 610*(1), 15–24.

Rajani, M. B. (2007). Bangalore from above: an archaeological review. *Current Science, 93*(10), 1352–1353.

Rajani, M. B., & Settar, S. 'Application of multispectral remote sensing imagery in detection of ancient forts in South India'. In: Campana, S., Forte, M., Liuzza, C. (Eds.), *BAR–S2118, 2010 Space, Time, Place Third International Conference on Remote Sensing in Archaeology, 17th–21st August 2009, Tiruchirappalli, Tamil Nadu, India*. ISBN 978 1 4073 0659 9, pp. 123–127.

Settar, S. (1992). *The Hoysala temples*. Bangalore: Karnatak University and Kala Yatra Publications.

Settar, S. (2008). *Somanathapura*. Bangalore: Ruvari.