Proposal for Research grant

submitted to

Karnataka Knowledge Commission

Project title:	**Cultural heritage of Karnataka: a remote sensing and GIS perspective**
Principal Investigator (PI):	Dr. M.B.Rajani Assistant Professor, Heritage Studies Programme, School of Humanities
Institution where the research will be undertaken:	National Institute of Advanced Studies, Indian Institute of Science (IISc) Campus, Bangalore 560012
Duration:	1 year

Summary:

Scientific developments and emerging technologies have provided new tools to study ancient material and decipher the past. But for these tools, some aspects of history would have remained undiscovered. One such powerful tool is Remote Sensing (RS). Images taken from aerial and space platforms display a perspective of landscapes which cannot be perceived from ground. Advanced RS technologies allow one to detectsubtle landscape featuresby sensing “light” that is invisible to humans (infrared, microwave, etc.) and also help in 3-D modelling. Being purely non-invasive, this technology is well suited for archaeology because it leaves sites untouched for future scholars.This kind of data, together with spatial data from other sources pertaining to archaeological sites (maps, plans, etc.) can be integrated into a database for storage and analysis, using Geographic Information Systems (GIS) technology. The proposed multidisciplinary research project will carry out RS and GIS analysis of archaeological sites in Karnataka.

The proposal will briefly review the cultural heritage of Karnataka, NIAS’s capability to undertake this project and will describe advantages of technological tools such as remote sensing and GIS for studying archaeological sites. This project will be the proof of concept phase where the capabilities of the technologies will be demonstrated on a few sites.

Minimum resources in terms of manpower and equipment will be used; existing labs in the KSRSAC (Karnataka State Remote Sensing Application Centre) will be accessedwhen required for image processing. This proposal will describe the resources needed in order to realize objectives. The proposal will also describe the deliverables from this work. The outcomes of this project will serve as input to the major goal of heritage conservation strategy development of Karnataka. As part of this project, outreach activities in the form of workshops will be conducted to acquaint students of history and archaeology with the use of technological tools of RS and GIS which can make valuable contribution to their study.

Institution:

National Institute of Advanced Studies (NIAS) is a multidisciplinary research institute which has undertaken several projects in the field of RS and GIS for archaeology, has produced world-class research outputs that have been published in international forums (Annexure-1) and in the course, has developed basic infrastructure and unique expertise in this nascent field. NIAS is in fact unique in the whole of India to have initiated projects and developed expertise in this field. The proposed research project has been conceptualised by NIAS, and prepared in consultation with archaeologists. This will be the proof of concept phase where the capabilities of the technologies will be demonstrated on a few sites of Karnataka.

NIAS is committed to set up a team, who has experience in the related area, to work in this project. NIAS along with Karnataka Knowledge Commission (KKC) will also establish a review mechanism where the project will be regularly monitored by a committee with members from NIAS, KKC and external experts from the fields of archaeology, RS and GIS. Minimum resources in terms of manpower and equipment will be used; existing labs in the KSRSAC (Karnataka State Remote Sensing Application Centre) will be accessed when required for advanced image processing. As part of this project, outreach activities in the form of workshops will be conducted to acquaint students of history and archaeology with the use of technological tools of RS and GIS which can make valuable contribution to their study.

Cultural heritage of Karnataka:

Karnataka possesses a rich cultural heritage whose history goes back more than two millennia. Several great empires and dynasties have ruled over Karnataka and have contributed greatly to its history, culture and development. From the prehistoric megalithic structures and burial mound to the later sophisticated architectural marvels, Karnataka nurtures many souvenirs of tangible cultural heritage in the region. Many dynasties patronised the construction of temples having distinct and unique aesthetic styles. Many settlements took shape based on religious or royal establishments.

Karnataka was the part of Maurya Empire around the 3rd century BC. The Satavahana dynasty ruled parts of northern Karnataka from around 230 BC to the 3rd century AD, followed by the Kadamba Dynasty of Banavasi (4th to 6th centuries AD) in modern Uttara Kannada district and the Western Ganga Dynasty or Gangas of Talakadu (4thto 10th centuries AD) in southern Karnataka.They were followed by large imperial empires, the Chalukyas of Badami (6th to 8th centuries AD), Rashtrakuta Dynasty (8th to 10thcenturies AD) and Chalukyas of Kalayana (10th to 12th centuries AD). Their regal capitals were in the modern Karnataka region, and they patronised Kannada language and literature. Parts of Karnataka were conquered by the Chola Empire in the 11th century. The Hoysalas established the Hoysala Empire (11th to 14th centuries AD) at the turn of the first millennium. Art and architecture flourished in the region during this time resulting in distinctive Kannada literary metres and the construction of temples, sculptures and planned settlement layouts.In the early 14th century, theVijayanagara Empire with its capital at Hosapattana (later to be called Vijayanagara) rose to successfully challenge the Muslim invasions into the South and the empire prospered for over two centuries. The Bahmani sultans of Bidar (14th to 16th centuries AD) were the main competitors to the Vijayanagaraempire for hegemony over the Deccan. After their fall, the Bijapur Sultanate (15th to 17th centuries AD) took their place in the dynastic struggle for control of the southern India. The Bahamani and Bijapur rulers encouraged Urdu and Persian literature and Indo Saracenic architecture, with the GolGumbaz being one of the high points of this contribution.

The Wodeyars of Mysore began to rule in 15th century. With the death of KrishnarajaWodeyar II, Haider Ali, theCommander-in-Chief of the Mysore Army, assumed control over the region in 1761. After his death,the rule of the kingdom was passed to his son Tipu Sultan. In attempting to contain European expansion in South India, Tipu Sultan, known as the Tiger of Mysore fought four significant Anglo-Mysore Wars, the last of which resulted in his death and the incorporation of Mysore into the British Raj (1831-81 AD). After a period of British Commissioners' rule, Mysore was given back to the Wodeyarsuntil India’s Independence.

Application of RS and GIS technologies for Archaeology:

Conventionally history has been studied from various sources such as inscriptions, writings, records, literature, art and architecture. A great deal of information has been unearthed about many archaeological sites using these traditional means, yet a lot more knowledge undoubtedly remains to be discovered. Modern technology has added other means through which historical information can be gained which can complement and supplement information gleaned from conventional sources. Earth observation trough Remote Sensing is one such method.

Ever since humans have evolved from being nomads and cave dweller toward building settled habitation, we have constantly scarred the environment by making dents on the earth surface for building long lasting structures, agricultural activities, laying out towns/cities, creating settlements and exploiting natural resources (particularly water) for sustenance. Human history can therefore be traced by studying the impacts of such human actions upon the environment. The use of space technology offers researchers an opportunity to detect the impacts of such activities, which are often invisible to the naked eye or from the ground. The interrelationship of land and cultural aspects has led to the use of Remote Sensing (RS) in conjunction with Geographic Information Systems (GIS) for archaeological application.

Conventionally an archaeologist surveys the area of study on foot, and depends on visual clues on the surface to identify locations for further investigation and excavation. This can be laborious and time consuming. Images taken from aerial and space platforms, offer four distinct advantages over this conventional approach:(1) an investigator can efficiently survey large swathes of land and pinpoint the most promising locations for conventional examination, (2) this “synoptic view” can offer clues that cannot be perceived from the ground, (3) advanced RS technologiesallow landscapes to be viewed in a “light” invisible to humans (e.g. infrared, microwave),permitting an investigator to discover features that are too obscured (e.g., by soil or vegetation) to be detectedotherwise, and (4) RS can be used to construct 3-D modelsof the terrain, thereby allowing an investigator to search for clues among topographical features. These technologies have been applied on many sites around the world [1,2,3,4].

When studying a site, there is tremendous value in geo-tagging the known information, i.e. in attaching geographical references to every known archaeological object. With a geospatial context, one can analyse an important archaeological object in relation to adjacent objects (at various scales), why is it located there, what is up/down hill from it, how far it is from related objects, etc. We can therefore build a GIS database of known facts about the site, rich enough to incorporate information from literature, epigraphy, travellers' accounts/records and archaeological reports. Such an integrated information system can shed new light on well-studied problems, and create opportunities to ask new questions.

A GIS database is also well-suited to incorporate images taken from space, and analysing them using RS techniques.Broad structural and layout features invisible from the ground become conspicuous when viewed from above. Therefore this *synoptic* view (a simultaneous view of a large area) readily facilitates making accurate maps and plans of sites marking all the surface features. Advanced RS satellites carry a variety of sensors (including infrared and microwave) that can reveal unique information about the study area [5,6,7,8]. For instance, buried archaeological remains can affect the growth of surface vegetation: certain archaeological features such as moats, canals and pits are favourable to growth, whereas features such as stonewalled foundations, buried streets and solid floors obstruct plant roots and are unfavourable to growth. These subtle variations in growth are nearly indistinguishable on the ground and in visible-wavelength imagery. Infrared sensors, however, can readily discern vegetation growth patterns over the ground following the lines of the buried features, revealing their plan and layout. Satellites can also take stereoscopic images which can produce 3D models of landscape [9,10,11]. Such models help in studying sites holistically and can be used for preservation, conservation and management of the site. RS technology can also be used for large-scale survey, selection of individual sites for detailed study, understanding the site in context of its environment, and determining the most productive areas for exploration on ground.

A GIS database is organized in layers, where each layer contains information from a different source (for e.g.: textual source, various kinds of satellite images, archaeological excavation reports, ground survey and exploration, GPS survey). These layers can then be collectively or selectively retrieved and superimposed using GIS software and analysed to see interrelations between them [12]. It is thus possible to derive unique information about the study area, and to pose and answer novel research questions [13]. The main advantage of RS and GIS are that they are totally non-invasive techniques; the use or application of these doesn't in anyway damage archaeological objects. The objects are observed, analysed, and studied while the site itself is left untouched for posterity.

Study area:

Initial proposal had mentioned that three sites will be selected in consultation with experts in archaeology from various institutions. In the review meeting held in Dept. of Archaeology, Heritage and Museums in Mysore, the Commissioner of the Dept. suggested we study the sites that are of interest to the State. The suggested sites are Srirangapatna, Shirval, Avathi, and Halebidu. NIAS is keen to collaborate with the Dept. and therefore will be happy to study the sites suggested by the Dept.

Objectives of the proposed project:

The main objective of this project is to demonstrate and document a process by which critical and valuable archaeological information can be derived and measured from using satellite Earth Observation images, and, also how these extracted information, when organised into a GIS database of other documented archaeological information (excavation reports, publications, etc) can substantially enhance understanding and knowledge about archaeological sites and cultural aspects. This project will also focus on providing GIS based Site Management Plan for the identified sites.

The specific tasks of the project would be:

A. Process and analyse satellite imagery to detect and measure features/patterns of archaeological relevance and interest. For this, it is proposed to study images of different resolution (high-resolution upto 0.5m resolution to measure and map features/patterns); stereo images to determine elevation and heights data; multi-date images to map changes over time; radar images to detect paleo-channels. It is also planned to undertake different image-processing/fusion techniques of merging various images and GIS data and also 3D visualisation of images.

B. Create geospatial layers of archaeological information about specific sites by geo-tagging records/reports/survey data, material gathered from published material and archaeological reports. This GIS compilation of geo-tagged information will be an invaluable resource for researchers in several disciplines.

C. Merge and fuse the image-derived information and geo-tagged data in GIS and undertake spatial and integrative analysis and enhancement to extractarchaeological information and measurements. These extractions can reveal many characteristics of the sites of immense archaeological and cultural value and increase the overall historical understanding of the study sites – thereby adding additional and unique knowledge to the archaeological records.

D. Create awareness of the value of Earth Observation images and GIS amongst archaeological community, researchers and students in the field of history and archaeology by way of specific workshop/records/meetings.

Methodology:

Here the specific method to achieve each objective is described.

A. Satellite imagery is multi-spatial, i.e. available in a variety of resolutions. High resolution (~1m or lower) shows details of buildings, roads, etc., whereas coarser resolutions of 5.8m or 23.5m shows features that are part of the larger landscape (often not perceived in higher resolution). The difference between high and coarse spatial resolution can be explained by the literal and idiomatic meaning of 'Inability to see the forest for the trees': focusing only on small details but failing to understand larger plans or principles. The review of available literature and the author's experience in conducting research in this field supports the view that no one resolution gives the best result for archaeological sites in general, or even for a particular site. Different kinds of images give different types of information depending on the nature of the geomorphology of the site. Information obtained from different imagery is most often complementary. Therefore the optimal approach would be to use as many kinds of images as possible for a comprehensive study of the site. A similar philosophy applies to multi-spectral images, whose benefits have been elucidated in the Introduction. It is also desirable to analyse images of multiple dates in order not to miss some feature that could be hidden due to seasonal changes of the land cover. Considering all these points the present research proposes to begin by analysing the following imagery:

   1. High resolution imagery (up to >0.5m): for visualizing surface features which facilitate:
      - Preparing to-scale maps of all the existing remain on the land surface.
      - Identifying anomalous patterns in field boundaries that sometimes indicate hidden archaeological features.
   2. Multi-spectral imagery
      - Identifying vegetation pattern that indicate buried archaeological remains

- Analysing of multi date images across seasons will cover subtle features that might be visible only in certain weather conditions

3. Historical imagery:
   - Analysing old images provides view of a site in the past devoid of subsequent disturbance that may have been caused by modern developmental activities such as tourism, urbanization, agriculture, etc.
4. Coarse resolution imagery:
   - Detecting present and past water bodies, palaeochannels, old tanks and other manmade alteration to the environment in the past.
5. 3D imagery:
   - Analysing landscape topography reveals shapes and sizes of archaeological mounds therefore indicates potential areas for conventional exploration
6. Radar imagery:
   - Detecting palaeochannels and sometime detecting buried subsurface features

All these images will be studied individually, and anomalous features (any feature that is not a natural phenomenon or modern construction) will be identified. All the detectable features will be studied individually on every image, and also through ground observation. Non-archaeological features will be eliminated, but others will be subject to further investigation. The spatial spread and density of such anomalous features will be identified, and will be organized as GIS layers. Stereoscopic satellite imagery will be used to prepare a Digital Elevation Model (DEM) of the region.

B. The effort will focus on geo-tagging all known archaeological monuments, mounds and structures listed in archaeological reports (i.e. assigning precise latitude/longitude coordinates for each such object). These objects will fall into one of three categories: (1) Identifiable on satellite imagery: Since satellite images are themselves geo-tagged, GIS software can quickly and accurately geo-tag specific objects. (2) Accessible on the ground: The geographic coordinates of such objects will be determined through field survey using a handheld GPS device. (3) Other: These are typically objects of interest that no longer exist, but are marked on maps and plans available in archaeological reports, gazetteers and other published literature. Such documents will be brought into the GIS environment by scanning them and geo-tagging a few known points. The GIS software then automatically calculates and assigns coordinates for every point in the scanned image. This initial GIS database can be accessed and updated by future researchers.

C. The geospatial layer created in method A and B together with data from ground survey using GPS will be fused, merged, cross-referred and spatially analysed. DEM will be used to generate 3D views of the landscape, create fly-through simulations, understand flooding patterns and analyse the multi-layered GIS database in a 3Denvironment. By this all geospatial layers will be integrated forming a unique knowledge base of a site with which measurements can be made and specific thematic maps can be generated.

D. Meetings with mentor group will be organised regularly for reporting progress and obtaining inputs and guidance. Workshop will be conducted for students to make them aware the usefulness of RS and GIS technologies for archaeology; the workshop will provide opportunity for participants to gain hands-on experience.

Lab facility:

Satellite image processing and GIS analysis for this projectwill be conducted in KSRSAC lab facility. KSRSAC shall be requested to provide access to hardware/software for satellite image and GIS analysis. To this effect a MoU/Agreement will be signed between NIAS and KSRSAC on the commencement of project.

Schedule:

The schedule of activities for 1 year is organised in terms of 1 to 52 weeks.

Details of activities	**Weeks**
– Selection of three sites through consulting archaeologists and discussing meeting with mentor group – Signing of MoU agreement between NIAS and KSRSAC – Selection of Research Assistant – Acquiring hardware	1-2
Selecting, downloading/ordering and acquisition of satellite data	2-8
Literature review, review of records/reports/survey data, gathering material from published material and archaeological reportsfor the three selected sites. Geo-tagging archaeological information got from these sources	3-10
Satellite data processing	5-20
Initial Data fusion and analysis	15-25
Reconnaissance Field visits	20-25
1st cut results and Draft Consultation Report	26-27
Detailed Data fusion and analysis	28-48
Detailed Field visits	35-42
Outreach activity: One day workshop for researchers and students	46-47
Planning and compiling material for research publication	48-52

Workshop/training meetingresults and Draft Final report to be presented and discussed	50-51
Report writing	51-52

Expected results:

A GIS database of known archaeological remains for all the sites selected for this study will be created. Anomalous shapes and patterns that may be connected to the history of the site will be identified and mapped. These will be integrated with already known information recorded in archaeological reports and old maps. One is likely to find features in satellite imagery for which there may not be obvious explanations, or, there may be structures mentioned in old maps or literature which cannot be accounted for on the ground. Such features/objects will become subject to further studies. With an awareness of the known facts in their proper geospatial context, the study has the potential to provide pointers to analyse new information that will emerge through satellite images.

Depending on the outcomes of the above satellite image analysis, research can be further extended to studying microwave images (various resolutions and wavelengths), LiDAR, hyperspectral images, etc.

Outreach activities that are planned in this project such as workshops and training programmes will enable students, researchers and scholars in the relevant fields to be trained in the field and use these techniques in their research.

Project outcomes and benefits:

The significance of application of remote sensing and GIS for archaeology is well recognised in the world. It is comparatively a new field and considering the abundance of archaeological sites that can benefit from attention from these technologies, only a handful of sites have had the opportunity. Karnataka possesses several sites that are world famous as master pieces of cultural heritage. Studying some of Karnataka’s archaeological sites using these state-of-art technologieswill reveal many characteristics of the sites of immense archaeological and cultural value and increase the overall historical understanding of the sites – thereby adding additional and unique knowledge to the archaeological records.This added dimension will provide opportunities for scholars from relevant field to leverage their understanding of the history and archaeology of the site. For futures studies on these site the data gathered and analysed in this project will become an added material which can be accessed by researchers and students. This project aims to provide site specific Management plan for the identified sites.

Tangible outputs of the project:

1. Report and presentation with initial findings after six months
2. Comprehensive report of all the work, findings and activities related to this project at the end
3. Site specific Management plan for the identified sites
4. Printable maps of the sites under study that include new findings and new archaeological outputs of this research work. These maps will be usable by researchers, students and carers of the site.
5. After the completion of the project the material and output will be used for writing research papers for international peer reviewed journals

PI's past experience in this field

Following is brief account of hands-on research conducted by the PI in the field of RS and GIS for archaeology. A detailed CV of the PI is also enclosed as an annexure. Few case-studies on sites in Karnataka are presented below as representative samples of the PI's relevant experience in this domain, which also displays her ability to undertake this project:

Bangalore (*CURRENT SCIENCE, 93(10), 1352-53,*2007)

A map: *Plan of Bangalore* dated 1791 that was surveyed by Earl Cornwallis' army marks a mud-walled town surrounded by a hedge and a ditch, and an egg-shaped stone fort to its south. The traces of the old layout could be discerned while comparing the above mentioned map with a satellite image of Bangalore taken by RESOURCESAT-1. This study has made possible to make a comparative assessment of the early maps vis-à-vis the modern satellite imageries, in order to search for features not recorded in the recent maps. In other words, remote sensing data is capable of showing signatures of historical features that were part of the landscape a couple of centuries ago and were dropped out of maps that were made subsequently [5].

Lalbagh (*CURRENT SCIENCE*, VOL. 102, NO. 3, 10 February 2012, pp.507-509)

The Lalbagh Botanical Garden in Bangalore, one of the country's oldest botanical gardens, has a long history. In 1760, Hyder Ali established a garden here, which was later expanded by his son Tipu Sultan. After Tipu was defeated and killed in 1799, the stewardship of Lalbagh passed through several hands before finally being taken over by the then Government of Mysore and made the Government Gardens.

Spatial analyses of multiple historical maps were conducted and 3D virtual reality simulations were made to understand the landscape recorded in old paintings. This analysis of historical maps and paintings revealed that the gardens laid out by Hyder Ali and Tipu Sultan were distinct plots. Contradicting popular opinion, only a portion of one of these garden plots overlaps with the modern Lalbagh. Further, unlike what is commonly believed, this garden plot was not adjacent to the Lalbagh tank, but north of it. This portion is likely to have been laid out by Tipu Sultan, and so dates from a little later than 1760, the date of establishment generally given for Lalbagh [13].

Belur, Halebidu and Somanathapura (*Journal of the Indian Society of Remote Sensing*, Springer, Published online 03 January 2014)

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 [6,14].

Badami (*Journal of Cultural Heritage*, Elsevier, Volume 10, Supplement 1, December 2009, pp. e20-e26)

This work highlights the potential of 3D visualization of archaeological sites for cultural resource management. DEM (Digital Elevation Model) has been carried out through different combination of satellite sensor data in relation with ground based information like toposheets. A comparative study of the three alternatives of space imaging information available is made and the clear advantage of CARTOSAT- 1 stereo satellite data is established. This exercise has illustrated that Archaeological sites can be viewed synoptically in 3D through space borne imaging. It gives a better understanding of the spatial extent of the site. This exercise has made possible to make viewshed, slope and aspect maps of the study area. 3D terrain and building visualization and virtual flights have been prepares; these can become a valuable tool for Cultural Resource Management in planning construction activities like that of roads, bridges and ropeways for access to the site or other construction in the surrounding area such as canals or factories without devaluing the heritage site. These can also be used as tools for education and outreach [9].

Chitradurga (*CURRENT SCIENCE*, VOL. 103, NO. 4, 25 AUGUST 2012)

The city of Chitradurga, known for its seven-tiered stone fort, is situated in Chitradurga District, central Karnataka. This city consists of many ancient temples and monuments interspersed between the strong stone layers of the hill fort. Enormous amount of information is available about these historical structures in the form of literary texts, old paintings, old photographs and old maps. This work discusses the methods of integrating the information from different sources using the GIS platform, thereby studying the change in the landscape over a period of time. In this study, an old surveyed map prepared by a British officer in AD 1800 is used. This map is georeferenced and the required information is extracted by digitizing the necessary layers of information. Three dimensional perspective views of the hill fort similar to old paintings were simulated using digital elevation model, thereby analysing the changes in land use and modern development in the vicinity of the hill fort [11].

Talakadu (*PHOTO-INTERPRETATION*, ESKA, Paris, France, 2009)

Talakaduis an archaeological site near Mysore situated on the bank of the river Kaveri. The meandering river in the form a hairpin bend adjacent to the site has accumulated a large amount of sand on the bank, and over the last few centuries the annual monsoon wind has carried this fine sand towards the site and buried it. Today, the depth of sand accumulation ranges between 2 feet to more than 30 feet, covering an area of 4.5 sq km. There are five well-known temples associated with this site, constructed between the 10^{th} and the 14^{th} centuries AD. The Directorate of Archaeology and Museums of Karnataka together with University of Mysore conducted excavations at 7 locations (numbered TK 1 to 7) in Talakadu from 1992-93, excavating less than 1% of the area covered by sand. In early 19^{th} century trees were planted in this area to arrest the movement of the wind-blown sand.

For a challenging site such as this, an integrated approach was adopted using a combination of multi-spatial, multi-spectral and multi-temporal data from several sensors. Analysis of multi spatial, multi spectral, multi date imagery, GPS survey and also ground truth survey of all excavated areas was conducted. These integrated space and ground studies have led to identifying four anomalous features for further exploration: a canal, command area of the canal, a fort and a reservoir. Ground surveys were conducted to take ground truth of these features. Analysis of RADAR data (fine beam RADARSAT and ENVISAT ASAR) led to identifying a hitherto unknown buried channel through the Old Talakadu town adjoining the excavated archaeological sites. The investigation was extended to the third dimension in order to understand the terrain undulations of the area of archaeological interest. This study has utilized CARTOSAT-1 stereo pair for generating DEM, which was used to analyse the extent of flood during different water levels. This study revealed two points which could indicate breaches (or controlled flooding) in the bund or fortification, supplying water to the old Talakadu area. The Radar and 3D study has led to understanding new dimensions of the relationship between known archaeological sites with migration of river Kaveri, and also throws new light on causes of large accumulation of sand on the site due regular flooding of the river. The Department of Archaeology, Karnataka, conducted excavation in locations indicated by the present remote sensing analysis of Talakadu [7,11].

Budget:

Details			in rupees
Human resource	Principal investigator	Rs 65,000/- per month	7,80,000/-
	Research Assistant (RA)	Rs 20,000/- per month	2,40,000/- (1 RA)
Satellite Imagery			6,00,000/-
Hardware			1,00,000/-
Software			KSRSAC lab facility will be used
Handheld GPS			20,000/-
Digital Camera			20,000/-
printer scanner			20,000/-
Travel			1,50,000/-
Printing/documentation			20,000/-
Miscellaneous			20,000/-
Dissemination	Organizing workshops and training programmes		50,000/-
	Discussion meetings/conferences		1,00,000/-
Other material: books/maps			50,000/-
Total			21,70,000/-
Overheads (15%)			3,25,500/-
		Total	24,95,500/-
		Total in Lakhs	**25 Lakhs**

Consulting/Collaborating agencies:

1. Karnataka Knowledge Commission (KKC), Bangalore
2. Department of Archaeology, Museums and Heritage, Government of Karnataka.
3. Karnataka State Remote Sensing Application Centre (KSRSAC), Bangalore
4. Indian Space Research Organization (ISRO)
5. National Institute of Advanced Studies (NIAS), Bangalore
6. Archaeological Sciences Centre, IIT Gandhinagar

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[14] M.B.Rajani, and K.Kasturirangan, ‘Multispectral remote sensing data analysis and application for detecting moats around medieval settlements in South India’ Journal of the Indian Society of Remote Sensing, Springer, Published online 03 January 2014, DOI: 10.1007/s12524-013-0346-4

Annexure-1

Remote sensing and GIS for archaeology at NIAS

Projects:

1) Archaeological investigations using remote sensing techniques: funded by ISRO (under RESPOND scheme); Rs 23.5 lakhs for three years (from Nov 2006)
2) Implications of Satellite Imagery on Cultural Heritage Resource Management: funded by ISRO (under RESPOND scheme); Rs20 lakhs for three years (From March 2011)
3) Subsurface Imaging by RISAT-SAR and its Geo-archaeological Applications: Collaboration invited by ISRO; Rs 10.8 lakhs; for three years (From Oct 2010)
4) Definition of GIS Standard and Foundation Datasets for National GIS: 1 year (From Nov 2013)

PhD:

1) M.B.Rajani, thesis title 'Space based archaeological investigations', University of Mysore, Doctorate awarded in 2011

Publications:

A. **<u>Articles in Inernations peer-reviewed journals</u>**:

1. M.B.Rajani, and K.Kasturirangan, 'Multispectral remote sensing data analysis and application for detecting moats around medieval settlements in South India' Journal of the Indian Society of Remote Sensing, Springer, Published online 03 January 2014, DOI: 10.1007/s12524-013-0346-4
2. N. S. Nalini and M. B. Rajani, 'Stone fortress of Chitledroog: visualizing old landscape of Chitradurga by integrating spatial information from multiple sources' CURRENT SCIENCE, VOL. 103, NO. 4, 25 AUGUST 2012, pp.381-387.
3. M.B.Rajani, and K.Kasturirangan, 'Sea-Level changes and its impact on coastal Archaeological monuments: Seven Pagodas of Mahabalipuram', Journal of the Indian Society of Remote Sensing, Springer, Published online 17 April 2012, DOI: DOI 10.1007/s12524-012-0210-y
4. M.B.Rajani , A.S.Rajawat , M.S. Krishna Murthy , J. Kamini and Srinivas Rao, 'Demonstration of the synergy between multi-sensor satellite data, GIS and ground truth to explore the archaeological site in Talakadu region in South India', Journal of Geomatics, Indian Society of Geomatics, Vol 6 No.1 April 2012
5. MeeraIyer, HariniNagendra and M.B.Rajani, 'Using satellite imagery and historical maps to investigate the original contours of Lalbagh Botanical Garden' Current Science, VOL. 102, NO. 3, 10 February 2012, pp.507-509.
6. Rajani M.B., Bhattacharya, S., and Rajawat A.S., 'Synergistic Application of Optical and Radar Data for Archaeological Exploration in the Talakadu Region, Karnataka', Journal of the Indian Society of Remote Sensing, Springer, 2011, pp. 519-527, DOI: 10.1007/s12524-011-0102-6
7. Rajani M.B., and Rajawat A.S., 'Potential of satellite based sensors for studying distribution of archaeological site along palaeo channels: Harappan sites a case study' Journal of archaeological sciences, Elsevier, Volume 38, Issue 9, September 2011, 2011,pp. 2010-2016, DOI:10.1016/j.jas.2010.08.008
8. Rajani, M.B., Patra S.K., and Verma, Mamta 'Space observation for generating 3D perspective views and its implication to the study of the archaeological site of Badami in

India' Journal of Cultural Heritage, Elsevier, Volume 10, Supplement 1, December 2009, pp. e20-e26. DOI: 10.1016/j.culher.2009.08.003

9. Rajani M.B., and Patra, S.K., 'Application of satellite image processing techniques for Talakadu, a unique archaeological landscape in India', PHOTO-INTERPRETATION, ESKA, Paris, France, 2009-4 (volume 45), pp.168-175.

10. Rajani, M.B., 'Bangalore from Above: An Archaeological Review' Current Science 93(10): 2007, 1352-53 pp.168-175

B. Articles in conference proceedings:

1. M.B.Rajani, and K.Kasturirangan, 'Satellite image and India's past', Future of the past: a workshop organized under the aegis of ICTS, Nov 22-26, 2011, Mangalore (http://www.tifr.res.in/~archaeo/FOP/fop.icts_table.htm).

2. I.A.Oltean, M.B.Rajani and N.S.Nalini, 'Pioneering metallurgy: Geospatial technologies', UKIERI Dissemination Seminar Nov 16-18, 2011, National Institute of Advanced Studies (NIAS), Bangalore.

3. N.S.Nalini and M.B.Rajani, 'The importance of precision in georeferencing demonstrated in the case study of archaeological GIS of Chitradurga, Karnataka' in In Stefano Campana, Maurizio Forte and Claudia Liuzza (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.173-177.

4. M.B.Rajani and S.Settar, 'Application of multispectral remote sensing imagery in detection of ancient forts in South India' In Stefano Campana, Maurizio Forte and Claudia Liuzza (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.

5. M. B. Rajani, "Space based remote sensing applications for archaeology", Proc. SPIE 7651, 76511O (2009); doi:10.1117/12.855565

6. Rajani, M.B., Patra, S.K., and Verma, Mamta, '3D perspective views and their applications to Archaeology: A case study on the site of Badami' in Lasaponara, R., Masini, N. (Eds,) Proceedings of Workshop on Advances in Remote Sensing for Archaeology and Cultural Heritage Management, Rome 2008.

7. Rajani, M.B., and Rajawat, A.S., 'Lost courses of River Sarasvati and spatial distribution of Harappan settlements – Observations based on multisensor satellite data' in Lasaponara, R., Masini, N. (Eds,) Proceedings of Workshop on Advances in Remote Sensing for Archaeology and Cultural Heritage Management, Rome 2008.

8. Rajani, M.B., Patra, S.K., 2008. 'The applicability of image processing techniques for archaeological exploration using space imagery: Talakadu - a case study' in Lasaponara, R., Masini, N. (Eds,) Proceedings of Workshop on Advances in Remote Sensing for Archaeology and Cultural Heritage Management, Rome 2008.

9. Rajani, M.B., Rajawat, A.S., Krishna Murthy, M.S., Kamini, J., and Srinivas Rao, 'Archaeological exploration in the Talakadu region along the bank of the Cauveri river, Karnataka, Southern India using multi-sensor satellite data and Geographic Information System (GIS)' in Lasaponara, R., Masini, N. (Eds,) Proceedings of Workshop on Advances in Remote Sensing for Archaeology and Cultural Heritage Management, Rome 2008.