

# A view on Greater Angkor: a multi-scalar approach for investigating the Khmer forests

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Keywords: Angkor (Cambodia), multispectral analysis, Vegetation Indices, PCA, ASTER, Quickbird, Ikonos

## ABSTRACT

This paper will focus on the results of a joint international project (a partnership between the University of Sydney and the University of Venice) that develops and applies satellite remote sensing methodologies for finding and mapping unknown archaeological sites in the surroundings of Angkor, in Cambodia. Long famous for its temples, this World Heritage site is now increasingly recognized as a vast, low-density urban landscape.

The project consists of using the spectral content of remotely sensed images to reveal the presence of buried sites and structures of the ancient Khmer landscape on the basis of the different spectral characteristics of the terrain and vegetation. By applying spectral analysis, the current research aims to scan vegetated and bare soil areas in order to clarify features that are ambiguous in existing maps and reveal features which would otherwise remain undetected

## 1. INTRODUCTION

With the aim of supporting sustainable development of the Cambodian regional ecosystem and the management of Angkor as a national and an international cultural resource, the University of Sydney has been collaborating for an extended period with the Cambodian authorities in a number of innovative, multidisciplinary projects in the social sciences related to the ancient town of Angkor and its countryside, namely Living with Heritage (LWH) and Greater Angkor (GAP) projects, both receiving major funding from the Australian Research Council through 2009 and operating in partnership with international institutions and authorities.

The research presented here forms a part of the GAP project and aims to contribute to the work already done by exploiting acquired and newly acquired remotely sensed data. Based on the diverse experience of the participants, the project intends to develop and apply mature strategies of satellite RS for detection of archaeological unknown or not otherwise detectable features and monuments, integrating past and future research and international heritage best-practises.

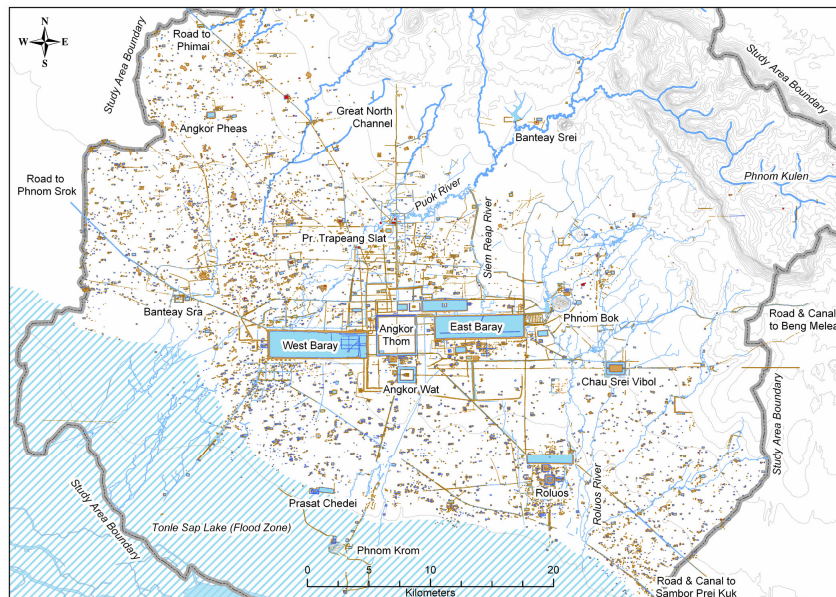


Figure 1. The Greater Angkor, after Evans-Pottier 2007 (image courtesy of PNAS)

<sup>1</sup> “Mapping the past using advanced technologies: Satellite applications for uncovering archaeological remains at Angkor”, ARC International Linkage funded project.

### 1.1 *The Greater Angkor Project (GAP): 10 years of USYD research on Angkor.*

The GAP is a collaborative project between the University of Sydney (Dir. R. Fletcher), the Ecole française d'Extrême-Orient (EFEO) and Authority for the Protection and Management of Angkor (APSARA). Since 1999, GAP worked for mapping and analyzing the urban layout of Angkor with an aim to understanding the role of the water management system in Angkor's demise.

The project focuses on northern reaches of the ancient town, where radar images taken from a NASA Space Shuttle in 1994 indicated that a vast and complex extension to Angkor's water management system might be found. New radar data JPL AirSAR data (2000) and other remote sensing data provided the foundation for a seven-year study by Dr. D. Evans (University of Sydney) on mapping the further reaches of Angkor's urban complex (Evans *et al.*, 2007). In August 2007 the publication of the results of this long project revealed the entirety of Angkor's extremely complex water management system. Although the precise boundaries of Angkor's urban sprawl are still difficult to define, the new map discloses Angkor as probably the largest integrated network of known urban space (fig. 1).

## 2. MULTISPECTRAL REMOTE SENSING ON THE ANGKORIAN LANDSCAPES

Starting from the results so far achieved from the GAP this project seeks to exploit the spectral characteristics of the relevant amount of RS data collected over Angkor landscape in the past years. The spectral content of remotely sensed images is being used to reveal the presence of buried sites and structures of the ancient Khmer landscape on the basis of the different spectral characteristics of the terrain and vegetation.

As previously stated, multispectral and radar data have already been adopted in the GAP team to detect and draw maps of archaeological monuments or possible archaeological features like village ponds, canals, roadways and temples (Fletcher *et al.*, 2002). Landsat TM data were used in an attempt to locate a possible boundary for the distribution of surface artifacts which define the Angkorian settlement landscape in 2002. An Ikonos scene acquired over Angkor was also available for the analysis; however, its spatial coverage was relatively limited. A complete coverage of ASTER scenes was available during the analysis due to an archaeological research being carried out by Dr. M. Hendrickson (2006). AirSAR airborne radar system has been used from 2002 as a method of archaeological data collection (Fletcher *et al.*, 2004).

The outcomes of the use of remotely sensed data so far have been satisfactory, leading to detection and mapping of a large number of features with different levels of certainty about their origins, but the process is still partially incomplete as regards specific areas. Deficiencies within the existing maps are ascribed to particular environmental conditions: for example, a large part of the investigated area is strongly forested. Previous shortcomings with the multispectral data are due to the fact that the analysis was mainly performed through a simple on-screen visual investigation of the raw data. Significant results can now be achieved exploiting the spectral characteristics of the satellite images through image processing. Consequently various satellites images (ASTER, Landsat TM, Ikonos, Quickbird) have already been or will be soon submitted to image processing techniques, accordingly to the type of natural environment of the target area they represent. The ambiguity caused by vegetation cover, for example, can be at least partially overcome using spectral content of the images. For this reason particular emphasis is given in our research to Vegetation Indices (VI): the vegetation covering archaeological features and hiding them to a pedestrian, aerial or radar survey have in fact specific spectral signatures that can be detected through image processing, possibly leading to the identification of subsurface archaeological structures.

Here only the first results of spectral analysis achieved so far using ASTER data will be presented, since the Quickbird and Ikonos data are still under process and results consequently under evaluation.

### 2.1 *ASTER data: previous and current use*

Forty ASTER tiles (ASTER L1A reconstructed unprocessed instrument data v003) have been acquired for GAP in the past years; the data were collected in different periods of the year between 2002 and 2003. On screen visual analysis have been performed in the past on all of them (Dr. M. Hendrickson – University of Sydney), leading to the identification of the location, the mapping and the analysis of the extant remains of the Angkorian road network across northern Cambodia and southern Laos.

In the current project, investigation exploiting the spectral content of ASTER data are being performed and tested. While evaluation of the outcomes and new processing are still in progress, what will be discussed next are the first results of the application of Vegetation Indices and Principal Component Analysis (PCA).

### 2.2 *Mapping vegetation: quality assessment Indices (VI)*

The primary limitation of the mapping work previously carried out by using radar and satellite data was the forest cover, which tended to obscure the settlement artifacts in large tracts of the study area. Additionally, a

portion of the study area was covered by light vegetation, including scrubland and sparse forest presenting some problems for detection of archaeological objects. In this type of environment features can be identified by slight differences in the biomass of the vegetation cover detectable in the spectral imagery. Consequently wide application is being given in this research to Vegetation Indices, since studies about the quality of the vegetation, monitoring variations in its vigor, can enable the detection of subterranean archaeological deposits that allow or limit the growth of the vegetation. Heterogeneity of the texture of the subsoil has in fact a strong impact on the growth of the vegetation, creating the manifestation of “marks” over the vegetation canopy. Calculation of different types of VIs can achieve different results for archaeological purposes, depending on the vegetation coverage type and the density of the canopy, both being primary factors to keep in consideration when selecting the appropriate process to evaluate the biomass of a certain area, since they can strongly affect the results of the process itself. The most suitable procedure to follow is to perform and test different vegetation indices after a careful consideration of the environmental and morphological study case area characteristics (Traviglia, 2006). The results gained are first being compared among themselves to determine the best method for evaluating vegetation health in the target spot and secondarily with the original images in order to verify the improvement of the visibility of traces they offer. So far 2 VIs have been calculated and tested, whose the formulas are well known:

$$\text{DVI (Difference Vegetation Index): } DVI = NIR - R \quad (1)$$

$$\text{NDVI (Normalized Difference Vegetation Index): } NDVI = \frac{(NIR - R)}{(NIR + R)} \quad (2)$$



Figure 2. NDVI of ASTER data.

As preliminary results we have noticed that the NDVI (fig. 2) has proved to have better sensitivity than DVI to changes in vegetation cover and compensating for changing illumination conditions and other extraneous factors like areas where there is a shadow effect. This is particularly true in determined environmental circumstances, like in case of high vegetation cover, while the index showed its sensitivity to canopy background variations when applied in areas of low or sparse vegetation. Based on previous experience with these vegetation indexes, the aim in the prosecution of the research is to test a larger number of indices to identify those that can better fit specific situations not investigated before, like, for example, partially submerged vegetation.

### 2.3 Highlighting surface changes: the Principal Component Analysis (PCA)

Supplementary information compared to the original bands and a better discrimination of different surfaces rendered more distinguishable for visual analysis have been obtained through the application of the Principal Component Analysis (PCA), a process aiming to reduce the redundancy in data by transforming a set of correlated variables into a new set of uncorrelated ones. Through this process the information previously contained in the original  $n$ -band data set is reduced into a smaller number of new bands that can be used in place of the original ones. This is particularly useful when dealing with images like ASTER composed by an elevated number of bands.

Several surface features in areas of bare soil or low and sparse vegetation have been highlighted when applying this process to the Khmer landscape. Other tests will be soon executed and ground truthing

conducted in order to define the level of improvement in quality of the image trace visibility.

A particular type of PCA, a Selective Principal Component Analysis (SPCA) has been tested in order to magnify the results already obtained with PCA. The SPCA is a Principal Component Analysis computed for spectral subsets, that is to say groups of bands, e.g. belonging the same spectral region. As an output, better results in terms of recognizable features compared to normal PCA can be obtained (fig. 3).

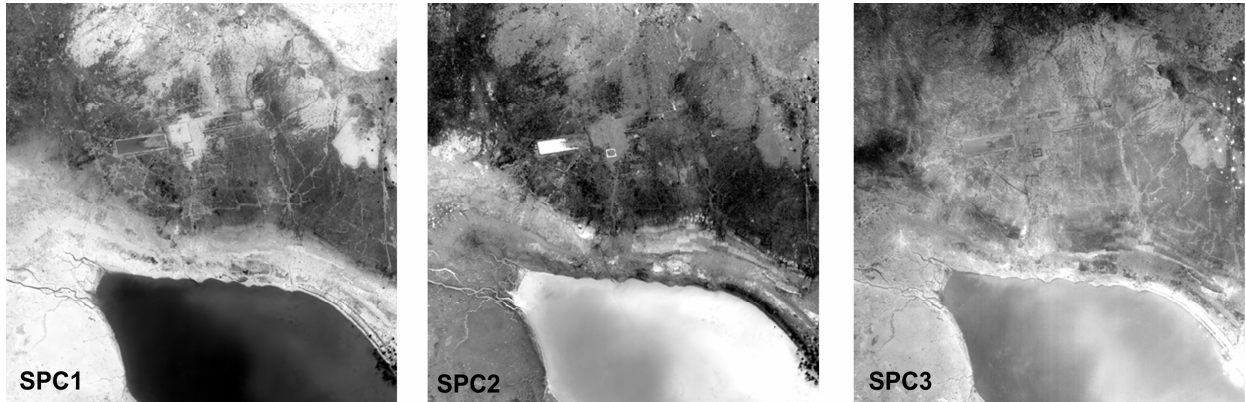


Figure 3. First 3 Components of a SPCA performed on VNIR bands.

### 3. ACHIEVEMENTS AND FURTHER DEVELOPMENTS

The availability of many remotely sensed data for the needs of the project allows a multi-scalar and multi-temporal approach for the detection of archaeological features and will permit the identification of a larger set of typologies of features. While, for example, ASTER data proved to be useful in the detection of large hydrological systems of which the landscape is rich, higher resolution data like Quickbird currently under examination promise to permit the detection of small features and recognize a pattern in their location; currently the Quickbird data led to the detection of a temple area and traces of a palaeo-riverbed. Thus far also Ikonos data are showing a great potential for the investigation of highly vegetated areas, where a red band intensively highlighted different typologies of vegetation. The results of the investigation of the treated images augment the current map of greater Angkor and are crucial for a correct understanding of the extension of the Khmer settlement and of the processes which led to its decline and abandonment.

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