Spatial analyses and Maya cultural landscape

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Abstract

The objective of this paper is to apply geographical information systems (GIS) in the analysis and interpretation of a large corpus of archaeological field data pertaining to the Maya culture and collected in central parts of the Yucatan Peninsula in Mexico. Since the area has so far been practically unexplored, the expected final results should represent a significant contribution to the understanding of the Maya culture in central lowlands of the Yucatan peninsula. In this study we have used basic and advanced processing methods to determine some locational properties of Maya sites. This was the first step towards a model that could predict possible locations of unknown sites and thus simplify field surveys. The paper is focused to two of (partially independent) objectives. First, we have tried to observe characteristics of archaeological sites with respect to relief. Next, visibility studies have been performed and intervisibility between centres has been determined. The results of the study show that the sites frequently occur in prominent areas, being characterized with light slopes, higher curvature and roughness of the terrain and higher relative heights. Viewsheds from all of the sites, with different offsets of heights for observation and observed (target) points, helped us to understand the terrain characteristics, possible visual communications between different centres, reasons for the chosen centres locations, etc. We have proven that positions of the centres chosen by the Maya lie significantly in the areas that are more visible than the average (random) study area.

Keywords: GIS, spatial analysis, cultural landscape, Maya Lowlands

Introduction

The purpose of the project is to apply geographical information systems and remote sensing in the analysis and interpretation of a large corpus of archaeological field data pertaining to the Maya culture and collected in central parts of the Yucatan peninsula in Mexico. The case study area lies approximately between 90°00'W and 89°09'W, and between 17°49'N and 18°20'N (Figure 1). Due to the amount and nature of the available information, and considering the experiences we have already acquired using this methodology, the study is expected to lead to important novel results in the particular field of research, but should also have wider implications, both for the development of specific methods and techniques applicable to anthropological research and for the identification and formulation of the problems that can be most adequately solved through their application.

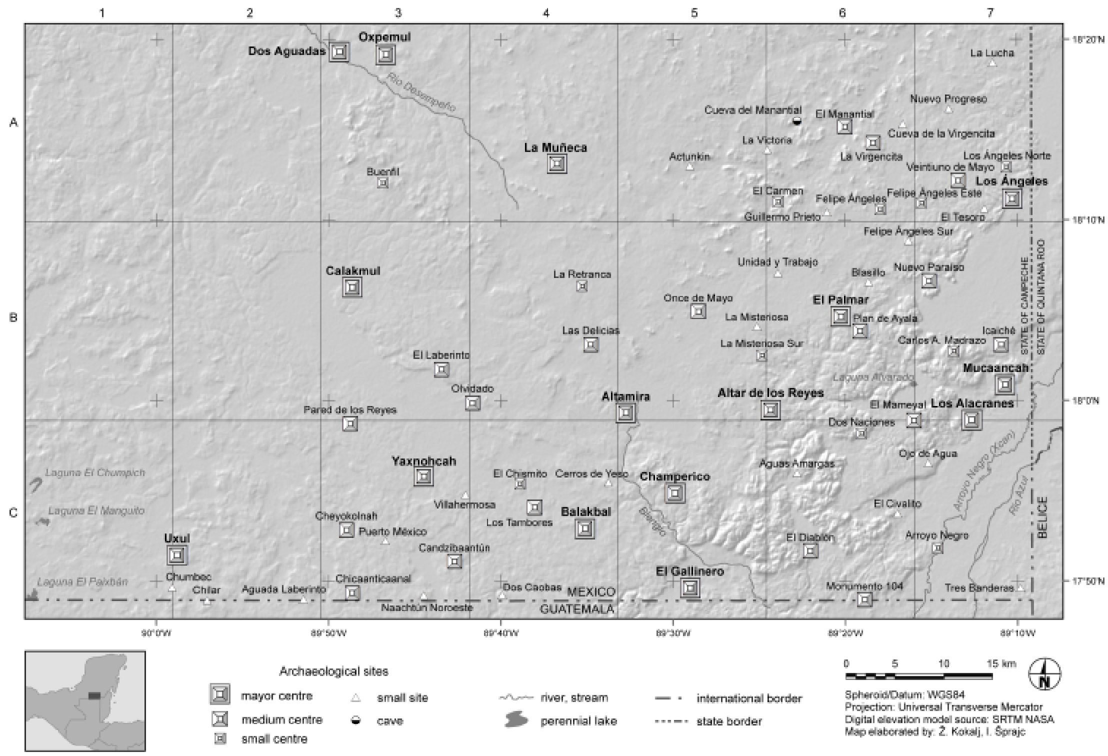


Figure 1: Research study area on Yucatan peninsula.

The location and surface characteristics of a number of formerly unknown archaeological sites were recorded, samples of surface material were collected and topographic surveys were carried out at major sites. The remains of settlements of different types are largely from the 1st millenium A.D., when the Maya culture attained its peak; the material vestiges observable on the surface are therefore rich and diverse, including architectural structures of different sizes, functions and types, sculpted monuments, some with hieroglyphic inscriptions, and multiple small finds. The problems we intend to solve, using geographical information systems (GIS), concern subsistence activities and land use, communication, sociopolitical organization and dependence of site location on environmental and related economic factors. Since the area has so far been practically unexplored, the expected results should represent a significant contribution to the understanding of the Maya culture in central lowlands of the Yucatan Peninsula, and of the nature of relations between this and the neighboring regions.

Theoretical background

Any population living in a particular environment wants to improve its recognition and understanding of the landscape. A population's specific cultural response also influences its behaviour, including beliefs, taboos, rituals, etc. which can deviate greatly from the "common" rules. Additional rules can thus play an important social role although they may be difficult to understand. The geographical information system (GIS) includes effective tools for resolving spatially related tasks. Archaeological information and actual hypotheses can be explored by applying GIS analyses that consider different data layers, especially digital elevation models and remotely sensed images (Podobnikar and Oštir 2007). With various data sources, natural and social factors of colonization and use of the environment can be modelled (Wheatley 1993). In this study we are attempting to improve our understanding of the past by analysing the patterns of ancient settlements, and by using the discovered and confirmed rules to model the derived indicators and variables. The procedure applied here is iterative, because the process or its parts can be repeated; the model is being improved step by step. The model can also be advanced by deepening the understanding of the problems, working interactively, applying different views to the problems, etc. In general, our work is based on an inductive approach to the analyses and is aimed at developing a holistic knowledge, although it is a very time-consuming process.

One of the first steps could be to find the rules concerning past settlement patterns using a cognitive mapping approach, i.e. producing mental maps. This is an intuitive and psychological procedure based on an opinion survey using the graphical response of individuals (Weiner and Harris 2003, Podobnikar et al. 2004). With mental maps one wants to map links between ancient cultures and the environment and tries to better understand possible patterns by means of visualisations. Several maps reflecting different hypotheses or different authors, primarily specialists for the relevant spatial problems, can be produced and presented as an integration of different layers in the GIS environment. Interpretation and synthesis of the mental maps is significantly more difficult and could be supported by expert evaluation models using a set of GIS tools. Information in the mental maps is therefore multicriterial and synthetic.

Using other approaches we try to obtain better insight into and understanding of settlement patterns. Sufficient data sources and the expert knowledge of archaeologists and historians allow one to produce a computer-based model that can explain spatial patterns and at the same time predict spatial structures, e.g. settlements, paths, and economic units that would be explored in the natural environment in the future. Predictive modelling, though it represents one of the final tasks of this project, is not discussed in this chapter. It requires deep knowledge and complex testing of the possible spatial indicators and complex techniques of modelling. Some indicators are described in this chapter and analysed step by step, with the purpose of discovering their archaeological potential. They should be used for predicting archaeological sites in future research.

Predictive modelling might be described as an attempt to recognise the behaviour of an unobservable phenomenon. It involves figuring out what environmental and social variables affect people's choice of where to live, then using that information to predict where archaeological sites might be. Predictive modelling may be also used in the field of archaeological cultural resource management in terms of potential. Thus, a map of the archaeological potential in a given landscape, developed through predictive modelling, could play a valuable role, not only for archaeologists, but for environmental planners such as landscape managers as well. As the quality of predictive modelling increases, terrain survey and its cost will decrease. Traditionally, there are two main approaches to predictive modelling. An inductive model, also called a "bottom up" approach, usually starts with the basic archaeological data and then builds its conclusions based on all the biases inherent in the original data set (Dalla Bona 1994). It employs known site locations, derived from either extant inventories or through sample surveys, as a guide for predicting additional site locations (observation → pattern → tentative hypothesis → theory). In the deductive approach, also called "top-down" approach, one starts with the theoretical knowledge and understanding of archaeological data on the synthetic level and tries to deduce some conclusions on the logic of settlement patterns and land use in the past (theory → hypothesis → observation → confirmation) (Stančič and Kvamme 1999). While the inductive approach is more open-ended and exploratory, especially at the beginning, the deductive is more narrow in nature and is concerned with testing or confirming hypotheses. The model we are developing will draw on both approaches, but more heavily on the inductive one since it requires less basic knowledge. This approach can be called abductive and that works on interaction of data exploration and human (operator) perception (Anselin 2005). At the same time the model will be based on good observations (data sources) that, with experience, will (hopefully) lead to generalisations and theories.

Problems have arisen in recent years with archaeological predictive modelling, especially questions of relevance. Potential problems of predictive modelling include (Kamermans 2004): the quality and quantity of archaeological input data; the relevance of the environmental input data; the need to incorporate social and cultural input data; a lack of temporal and/or spatial resolution; the use of spatial statistics; and testing of predictive models. The primary problem in most of the predictive models was the uncertain quality of spatial data and poor tests of indicators and models. Biased indicators produce biased models. An acceptable solution is suggested for relevant data control: half of the data sources or sites might be used for modelling the prediction, and the other half might be used for testing. With data of low quality and small quantity, it is therefore almost impossible to derive a precise predictive model. The problem that can occur with predictive modelling of the Maya society is that their social and political structure was quite complex, so the indicators for prediction are not as easily definable as they are, for example, with ancient societies in North America. We hope that on a small scale, for low precision, the model will not be too complex (Estrada-Belli and Tourtellot 2000).

Tools and data sources for the study

In this study we have used basic and advanced processing methods using GIS-tools to determine some locational properties of Maya sites in the central Yucatan Peninsula. This was the first step towards a model that could predict possible locations of unknown sites and thus simplify field surveys. The area is covered with dense vegetation and has been only partially prospected. The research performed so far suggests that up-to-date technology, especially GIS analyses, supported with extensive knowledge of the natural environment and Maya culture, can contribute to a better understanding of their activities and give quantitative answers to settlement hypotheses.

To apply the GIS methods in archaeology – or any other discipline – a good spatial dataset is required. In our project an archaeological database of southeastern Campeche area that includes 63 sites with appropriate attributes has been used. To eliminate “noise” in the processing, only larger sites were considered for most of the analyses, i.e. major and medium centres (33 in total). Many additional spatial data obtained from different sources has been utilised, most importantly, a digital elevation model and remote sensing images. A DEM has been produced from hypsometrical data sources in scale 1:50,000 with the final cell size of 20 m and vertical accuracy of several meters.

Environmental characteristics of sites

Detection of archaeological sites is possible by observing contrasts between areas with archaeological features and natural backgrounds. Two related hypotheses were tested. The first, a very general one, was that the site centre positions depend on the terrain's roughness. The second one was that the rough terrain was not within the site but rather in its close neighbourhood. The second hypothesis is more accurate – the sites are near exposed terrain. Therefore they should not be in valleys or on poorly visible areas. Considering the first hypothesis, it was assumed that relative height changes and steeper surfaces might be significant around the sites' centres. For that a simple visual check was performed with basic spatial analysis. Characteristic points (peaks, sinks and saddles) on the DEM were calculated. Later the DEM was generalised step by step; characteristic points were recalculated at each step. As one can see in Figure 2, the results were not promising for resolutions of either 180 or 540 m. At a resolution of 180 m, higher/lower concentrations of peaks are represented as darker/lighter surfaces. The figure shows the well known fact that peaks (and also sites) are not in bajos, but correlation between peaks and sites is poor. At the resolution of 540 m, we can see that more peaks, shown as circles, may be near the sites, but not significantly close. One of the reasons for this is that the peaks, calculated with this simple algorithm, are normally quite sharp, and such peaks are not attractive as population centres. For better results, better algorithms have to be produced or used.

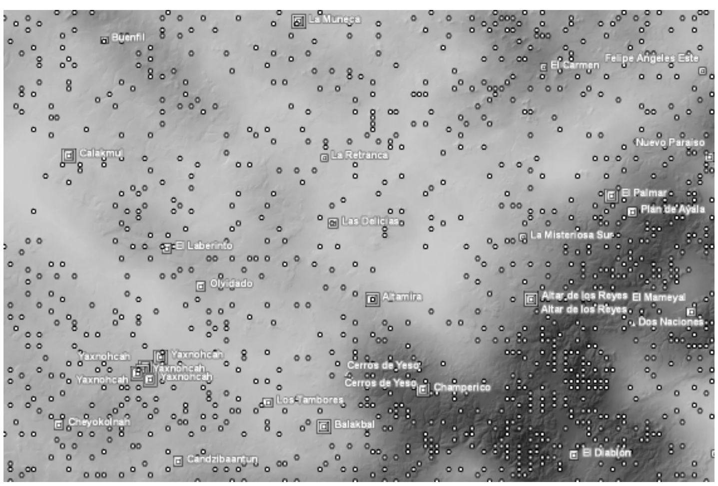
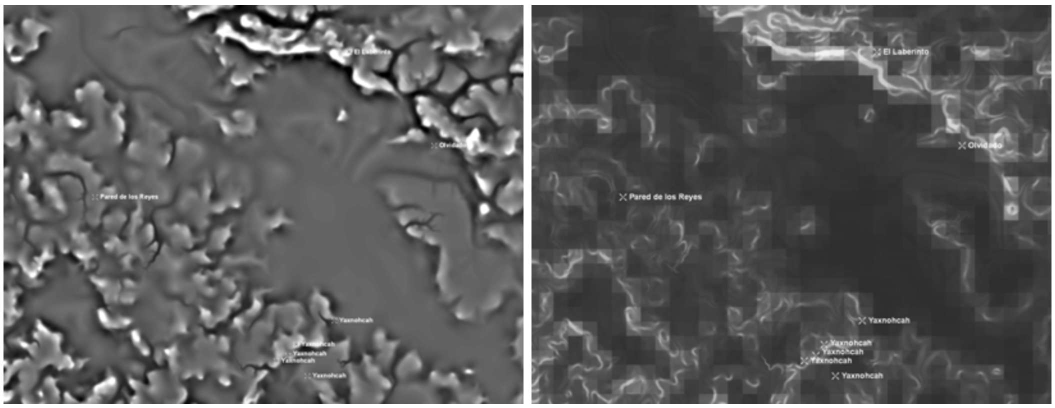


Figure 2. Correlation between sites and modelled peaks at a resolution of 180 m (darker colours correspond to higher concentration of peaks) and at a resolution of 540 m (peaks represented as circles).

Terrain convexity was calculated from terrain curvature produced from DEM and as a difference between original and smoothed DEMs. Because the two methods show the same attributes of terrain, but their results are slightly different, we integrated both derived data layers together with averaging. Figure 3a shows that the sites are typically situated on the exposed (convex) areas rendered in lighter colours; a fact also confirmed statistically. Therefore the sites are not likely to be found in valleys and in areas with reduced "sky view". To produce even more complex terrain roughness, a combination of slope and absolute values of curvature was calculated. With a significant reliability the connection between all locations of sites and terrain roughness was confirmed. In Figure 3b, bright colour patterns with high-resolution of 20 m correspond to higher degrees of terrain roughness. An even closer relationship with the sites is evident when roughness layer is averaged to the resolution of 540 m. With this approach – resampling to coarser resolution is the same as generalisation of the data to a smaller scale – the neighbourhood of the sites is therefore better considered. Figure 3b shows the addition of the coarser roughness of 540 m over the fine roughness with grid cell of 20 m described before. The lighter areas are rougher than darker ones. This coarser resolution can substitute for approaches which calculate buffer zones corresponding to impact areas around the sites, but the combination with finer resolution data envisions kind of multi-resolution analysis.



a b

Figure 3. Sites related to convex (lighter) and concave (darker) areas (a). Sites and terrain roughness in a combination of fine and coarser resolutions; lighter areas are more rough (b).

The examples shown above demonstrate some practical principles of the inductive approach in developing indicators for the predictive modelling as one of the final plans. With the described studies we can also better extract the bajo areas that were most probably not settled. With possible further analyses, by using the combined data for soil, vegetation, and different terrain characteristics, the bajo borders could be more clearly determined and eliminated from the prediction potential of the sites.

Visibility studies

Visibility analyses are among the most important tools in archaeological spatial analyses (Gaffney and Stančič 1991). Before performing them, one should reconstruct paleoenvironmental and cognitive aspects of past cultures. We assumed that vegetation cover in the case study area was different from the present one: during the zenith of Maya culture, the areas around their settlements were cleared. It is therefore important to examine their spatial relationships and intervisibility. The visibility studies can contribute to the understanding of several questions: Is visibility from archaeological sites connected with the Maya landscape perception? Are natural aspects of site locations significantly different from other (average or randomly selected) areas? How did the visibility and inter-visibility influence the location choices? Are there any significant spatial patterns? Was it possible to communicate between the neighbouring centres or to control others from the tops of the pyramids? How much of the area was controlled from the sites (Gaffney et al. 1997)? Are the answers to those questions clear and significant? Our primary assumption is that visibility played an important role in settlement patterning in the Maya Lowlands. It is likely that the first settlers in the “relatively hostile” central

Yucatan area largely followed the characteristics of the natural landscape and environment to accommodate their activities (Estrada-Belli and Tourtellot 2000).

Technically, visibility analyses describe visually exposed areas and are performed by the so called viewshed analyses (Franklin and Vogt 2006). To perform them, a digital elevation model is a prerequisite; however, additional data, such as physical obstacles, can be obtained by considering land use data. Observation or source points, which in our case are archaeological sites (population centres), are needed next. Observed or target points may be positioned on the relief or above it with a chosen offset (height). Offsets of about 1.5 to 2 m can simulate (standing) human observation. The same height can be assigned for the target points to simulate persons watching from any position around the observation point. By changing the observation heights one can also simulate both artificial "lookouts" (e.g. pyramids) and possible errors of the DEM or archaeological site position. Since a radius of interest (maximum distance) of 50 km from the sites was used, visibility function was corrected for the Earth's surface curvature and refraction effect. The results of the visibility operations are viewsheds, i.e. binary grids that show visible and invisible areas. A value of 1 denotes visible areas and 0 invisible ones.

For our visibility analyses, only 40 centres (major, medium and minor) were included. At these centres, 53 prominent structures (mostly pyramids) with known heights were selected. Visibility was in all cases calculated from one particular (individual) observation point and analyzed on all other target points. This procedure was therefore repeated n-times (n is the number of points) for each type of site and individual binary viewshed grids were produced. First, the environmental characteristics of all sites were analyzed, without considering the heights of pyramids. Visibility from the known heights of pyramids for 53 cases was computed next. More precise analyses were applied for larger sites that are better defined and are more important for understanding regional settlement distribution than were for smaller ones.

To get better insight into natural aspects of site locations, visibility from all 53 structures with the 2 m offset from the surface for both the observation and target points was produced. The observation points were then raised to 10 and 25 m, and finally an extreme example with offset of 30 m was employed. These extreme simulation groups are useful for better understanding of the natural terrain characteristics regarding chosen observer points and data quality. They can also help us understand why the founders of particular sites chose their positions and what they might have possibly seen from the trees before they built the settlements: we would like to understand visual communications between the sites, e.g. their intervisibility. Finally, we considered the real heights of pyramids in order to produce viewsheds that are as real as possible. Additional offsets from the tops of pyramids were 2 m either for observation or observed target points. Figure 4 presents visibility simulations of different parameters for Structure B-3 of Yaxnohcah. Picture a shows visibility from the ground with both offsets of 2 m (2/2 m); it reveals that the site's visibility potential was rather poor before the pyramid was built. Picture b with offsets 10/2 m presents visibility from small pyramids or trees about 10 m high; we can see that large areas to the NW have become visible. Picture c shows an extreme case with offsets of 30/30 m, when the observer stays on the top of tree and observes the tops of other trees. The last picture, d, shows a real situation after the pyramid with height of 20 m was built and assuming that vegetation was cut down; it is view from top of Structure B-3 to the area around and to other pyramids with real heights above the terrain, too.

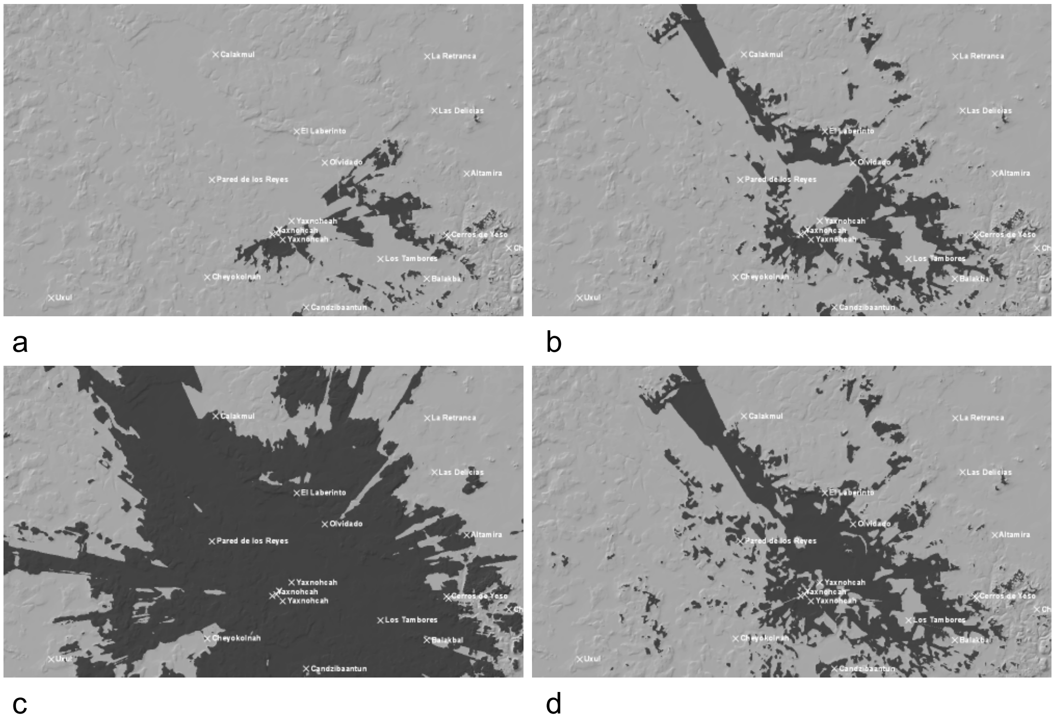


Figure 4. Viewsheds from Yaxnohcah Structure B-3 with different offsets, showing the visibility potential of the site. Offsets are 2/2 m (a), 10/2 m (b), 30/30 m (c) and heights of all selected pyramids (20 m for Yaxnohcah Structure B-3) with offset 2/2 m (d).

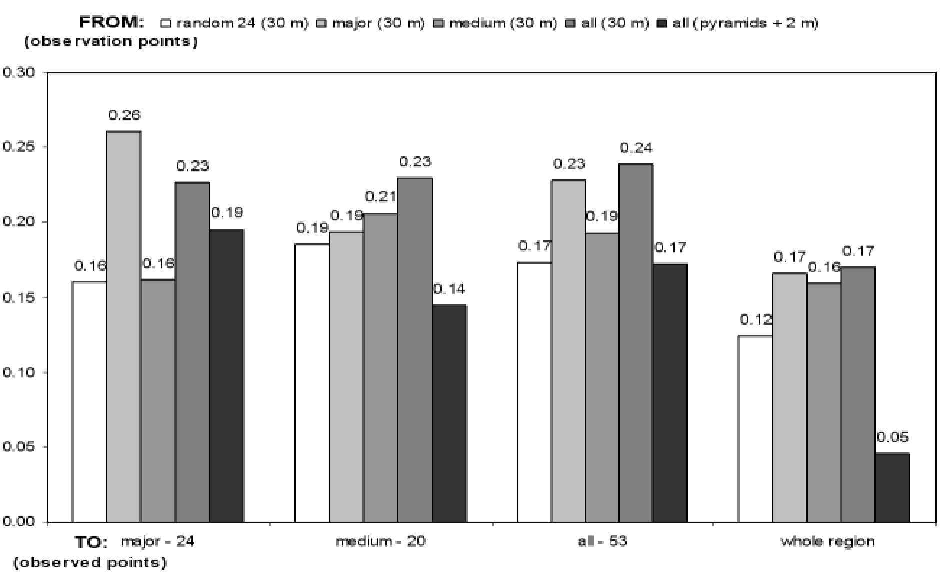


Figure 5. Normalised cumulative viewsheds (NCV) (based on the mean visibility occurrence) from five classes of observation points to four groups of observed (target) points. The five classes of observation points are: random points, major centres, medium centres, the three types of centres together (major, medium, minor) with 30 m offset from terrain, and actual pyramid tops (real heights). The observed

points are: major centres, medium centres, the three types of centres together, and the whole study area.

Figure 6 shows normalised cumulative viewsheds (NCV) on the tested case study area (shown as a rectangle with dimensions of 87 by 57 km) for the 72 random points, 15 major centres, all 40 centres, all with 30 m offset, and for 40 site centres with actual heights of pyramids. All of the examples show many similarities in spatial patterns. The most dispersed pattern can be seen on picture a, where NCV is produced from random points. The smallest extent of visible area is exhibited in picture d, the most realistic example, and also in picture a, which indicates general low visibility from random points. Comparing visually, the pattern of random points (picture a) is the most distinct from the pattern of major sites (picture b), a fact that was confirmed statistically (Figure 5).

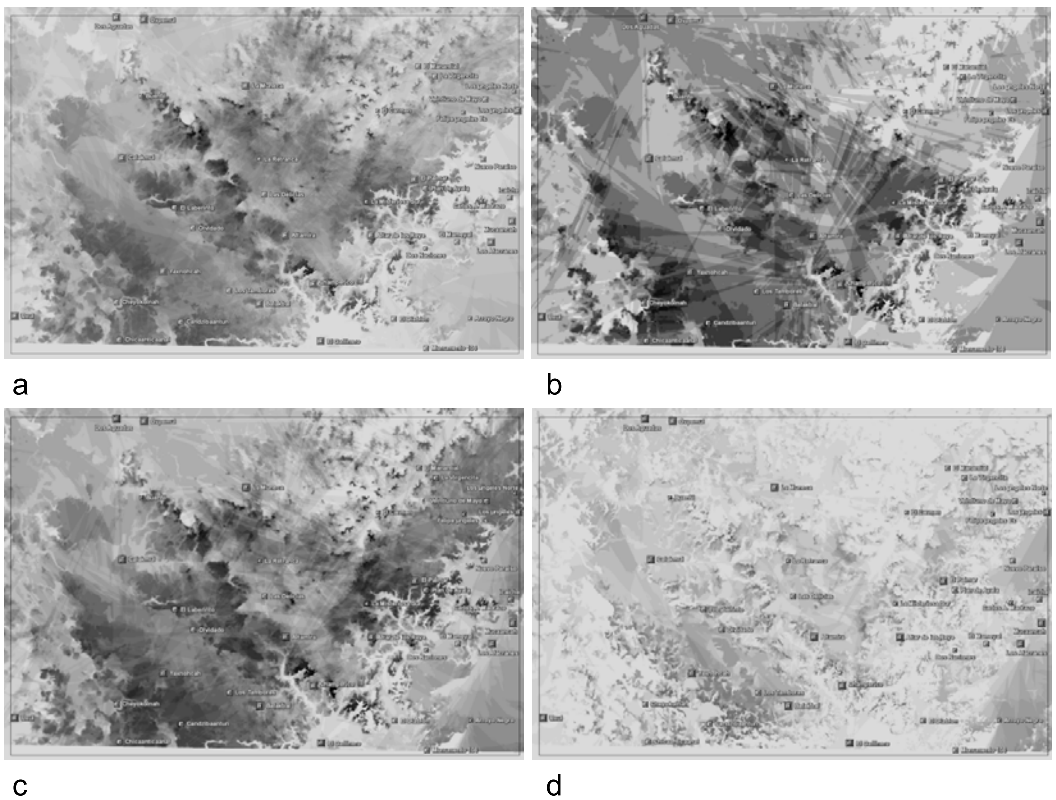


Figure 6. Normalised cumulative viewsheds (NCV) on the tested area for the 72 random points (a), 15 major centres (b), all 40 centres – all with 30 m offsets for observation and observed points (c), and all 40 centres, considering actual heights of pyramids + 2 m (d). Darker areas are more visible than lighter ones.

Conclusions

Geographical information systems (GIS) have become one of the standard tools in archaeological research. Detection of archaeological sites is possible by observing contrasts between areas with archaeological features and natural background. We have observed that environmental characteristics of major and medium centres differ from those of random points, especially regarding the relief and its derivatives. The sites frequently occur in prominent areas, being characterized with light slopes, higher curvature and roughness of the terrain (high local differences in heights, meaning more agitated relief) and higher relative heights. It has been shown that sharp peaks are not connected to site locations.

Visibility analyses present the viewshed potentials of the environment around population centres in comparison with whole study area. Viewsheds from all of the sites, with different offsets of heights for observation and observed (target) points, helped us to understand the terrain characteristics, possible visual communications between different centres, reasons for the chosen centres locations, etc. Additionally, with randomly selected points we simulated general visibility potentials of the study area. Further analyses considered real heights of pyramids within the population centres, describing actual (inter)visibilities between centres. We have proven that positions of the centres chosen by the Maya lie significantly in the areas that are more visible than the average (random) study area. Furthermore, most centres are positioned in the areas that allow a relatively high degree of visual communication with each other.

The results of the study are preliminary since the research is still ongoing. While some answers have been found through our work, many questions remain, and therefore the research will continue in several directions. We will use additional and better data sources, mostly acquired from processed aerial photographs and satellite images, i.e. high-resolution multispectral (or even hyperspectral) satellite images, multitemporal Landsat data to cover seasonal changes, multipolarization or multifrequency radar images, and lidar for better elevation data in smaller areas. Also the analyses and processing may eventually be improved with additional archaeological knowledge derived from future research, both in the area and elsewhere, including the methods of predictive modelling. The outcomes obtained so far have clearly shown that only advanced, sophisticated processing methodology is able to provide reliable indicators of archaeological sites under a dense vegetation canopy. The results, even though preliminary, enabled us to better understand some aspects of the logic underlying site location and settlement pattern in the central Maya Lowlands.

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