

GPS RTK Mapping, Kite Aerial Photogrammetry, Geophysical Survey and GIS Based Analysis of Surface Artifact Distribution at the pre-Hispanic site of the Castillo de Huarmey, North Coast of Peru

Miron BOGACKI^{a1}, Miłosz GIERSZ^{a, b}, Patrycja PRZĄDKA-GIERSZ^b, Wiesław MAŁKOWSKI^a,
and Krzysztof MISIEWICZ^{a, c}

^a *Institute of Archaeology, University of Warsaw, Poland*

^b *Center for Pre-Columbian Studies, University of Warsaw, Poland*

^c *Institute of Archeology and Ethnology of the Polish Academy of Sciences, Warsaw, Poland*

Abstract. A comprehensive archaeological survey of the Castillo de Huarmey site, one of the most important pre-Hispanic Middle Horizon period (AD 600-900) ceremonial and religious centers on the Peruvian North Coast, was carried out by Polish scholars. The survey compared different non-destructive methods: GPS RTK mapping, kite aerial photogrammetry, cesium magnetometry and spatial analysis of surface artifact distribution. The survey data was combined with spatial information using a geographic information system database to record the monumental mud-brick architecture and the vast necropolis of the high-ranking members of pre-Hispanic elites, and to reflect the subsurface site. The undertaking of methodical and comprehensive nondestructive archaeological survey on the North Coast of Peru was one of the first such projects in this region, and is promising for achieving significant advances in the current understanding of local pre-Hispanic societies.

Keywords. Archaeological site monitoring and detection, GPSRTK, GIS, kite aerial photogrammetry, magnetometry survey

Introduction

Non-invasive and non-destructive archaeological survey techniques are still largely ignored by Andean archaeologist. Thanks to funding provided by the Polish Ministry of Science and Higher Education (MNiSW, Warsaw, Poland) in the framework of its “Non Co-Financed International Projects” research program, a comprehensive archaeological survey of the Castillo de Huarmey site, one of the most important pre-Hispanic ceremonial and religious centres on the Peruvian North Coast, was carried out by Polish scholars. The survey compared different non-destructive methods: GPS RTK mapping, kite aerial photogrammetry, cesium magnetometry and spatial analysis of surface artifact distribution. The survey data was combined with spatial information using a geographic information system database to record the monumental mud-brick architecture and the vast necropolis of the high-ranking members of pre-Hispanic elites, and to reflect the subsurface site. The project is directed by dr. Miłosz Giersz and realized on a cooperative basis by Center for Pre-Columbian Studies of the University of Warsaw and the Pontifical Catholic University of Peru in Lima under a bilateral agreement between the two universities.

¹ Corresponding Author: Miron Bogacki, Institute of Archaeology, University of Warsaw, Krakowskie Przedmieście 26/28, 00-927 Warsaw, POLAND. E-mail: miron.bogacki@gmail.com

1. Castillo de Huarmey archaeological site

The Castillo de Huarmey site is located 1km east of the city of Huarmey, in the Huarmey province, Ancash department, Republic of Peru. Castillo de Huarmey is the largest Middle Horizon Period (AD 600–900) site in the southern part of the North Coast of Peru. The site is located about 1km east of the modern town of Huarmey, at the top of elongated rocky spur that protrudes into the valley. This center is situated on the northern border of the river valley, at the entrance of a small adjacent dry canyon, some 4km directly eastward from the Pacific Ocean.

The site extends over 45 hectares. It consists of ca 17 hectares of scattered monumental architectural remnants and burial grounds. Architectural compounds are clearly multifunctional, incorporating space for public, domestic, and ritual activities. Constructions are still visible on the surface. The main ceremonial sector, called El Castillo, contains a pyramid erected with adobe bricks (ca 200m long, 65m wide, 14m high). Two minor structures surround the main platform from north and south at the level of the agricultural fields. Unfortunately, due to its close to town location and its fame, the site has suffered more from looting than most other pre-Hispanic sites in the region.

The Castillo de Huarmey has never been subjected to systematic excavation-based studies, although some unsuccessful attempts in the past to begin such studies are known indeed [1,2,3]. The earlier lone investigations of the site were limited to some field research and studies of certain archeological artifacts originating from Castillo de Huarmey and deposited in museum collections [4,5]. From the scientific point of view, the site is the key to the understanding of one of most puzzling issues in modern Andean archeology: the genesis, form and role of social, political and cultural transformations that occurred throughout this area in the *Middle Horizon Period* (AD 600-900). The Castillo de Huarmey site, the place of origin of the largest known collection of pre-Columbian Moche-Wari-style textiles (unfortunately acquired through plunder excavations [5] is a natural candidate for a primary center of authority during the second half of the first millennium AD. There are also credible premises, that within the perimeter of this site exists a necropolis of the high-ranking elites of the Wari culture [2], who arrived in the region probably in the first half of the 8th century AD, spreading out from the area of today's Ayacucho basin (Central Peruvian Andes), and then culturally interacted with local population of the Moche culture.

2. GPS RTK survey

The location & altitude survey was carried out with the help of two dual-frequency (L1, L2) Topcon HiPer PRO integrated GPS receivers. Locally, the connection of sensors was achieved with a UHF-band radio modem. While conducting the survey, a set of coordinates was defined as *UTM South – Zone 17 84W – 78W* according to the WGS 84 reference ellipsoid. The stabilization of the base station receiver with a known network point permitted to maintain a centimetre-level accuracy during differential measurements (Real Time Kinematics – RTK). This in turn permitted to define the survey scope, including the demarcation of the geophysical prospection and surveying network for planned excavation studies. Additionally, was also inventoried the architecture visible on the surface: the El Castillo principal hill and tomb relics within the burial grounds' areas. A contour plan was generated for the entire site occupying a terrain calculated to extend over ca 45 hectares. GPS was also used to record the artifacts collected on the surface, and the photopoints used to adjust the kite-captured aerial images. Measurements were carried out as individual records of coordinates X(N), Y(E) and H, but also in the automatic mode according to the entered horizontal distance, while maintaining RTK measurement accuracy: horizontal H: $\pm 10 \text{ mm} + 1 \text{ ppm}$; vertical V: $\pm 15 \text{ mm} + 1 \text{ ppm}$.

In the effect of the processing of the survey's results a digital map was produced – the model for the Castillo de Huarmey site enhanced by a system of georeferences for raster imaging (aerial orthophotographs, geophysical images-maps). A vector version of the Castillo de Huarmey map shall be

consequently used as a basis for the site’s specific analysis and for an active work with the databases within a unique integrated data model.

2.1. Software

GPS field surveys benefited from the Top Surv 7 application, used to mark out, to register points, to perform geodetic computations, etc. ASCII files were processed with the Winkalk geodetic calculation software. A preliminary interpolation of grade lines was achieved with the Mikromap program, and the final drawing of the digital map as performed with AutoCAD MAP 3D. Geophysical maps were produced with the Surfer 9.0 application and subsequently attached to the AutoCad platform and transformed into georeferential images with the RASTER DESIGN raster graphics software.

2.2. Results

The survey that was carried out for this site has revealed a great concentration of archeological artifacts in the proximity of the principal pyramid, as well as three burial grounds in the nearby valley, occupying a total of ca 4 hectares (Figure 1). The graves are located at the foot of the surrounding hills, and while they indeed show traces of frequent plunder and damage, they remain legible within the terrain’s topography, and their extent is additionally confirmed and itemized by geophysical prospection. At the top and on the escarpment of the principal pyramid are visible numerous architectural relics. The roughly 1m-thick walls were erected with *adobe* mud bricks mixed with stone, and the additional architectural elements in evidence in that monumental structure are the wooden beams. The walls constitute the boundaries of structures that are strictly contiguous and adapted to the specific axes corresponding to the shape of the hill. Within the limits of this complex extending over ca 5 hectares, it is possible to discern the deflection point of the main axis, more or less in the midpoint of the hill rising about 14 metres above the level of the surrounding terrain.

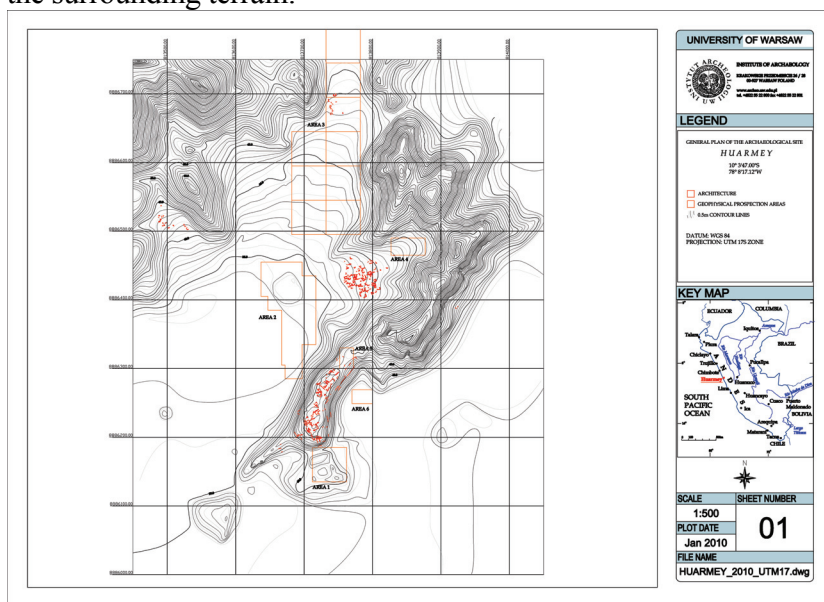


Figure 1. Topographical map of the Castillo de Huarmey archaeological site.

3. Kite aerial photogrammetry

The Huarmey site in Peru is located near the coast of the Pacific Ocean. In January 2010, the conditions there were very favourable to take photographs from a camera suspended under a kite. Almost daily a strong wind blew from the ocean. The El Castillo region landscape is quite advantageous

and permits to move around with the kite all over the area. Typically 2 or 3 persons took part in the shooting of photographs from the kite. The remote-controlled photo camera was operated by Miron Bogacki and the kite was controlled by Wiesław Małkowski (Figure 2). In more complex situations, they were helped by Miłosz Giersz and by Roberto Pimentel Nita. Launching a kite single-handedly and operating a camera at the same time is not possible due to the kite's strong lifting force. The kite's operator doesn't grasp a kite's line in a direct way. Rather the line is threaded through a series of pulleys and attached to the elements of a climbing harness, owing to which it is possible to freely progress along with the kite, and without much effort.

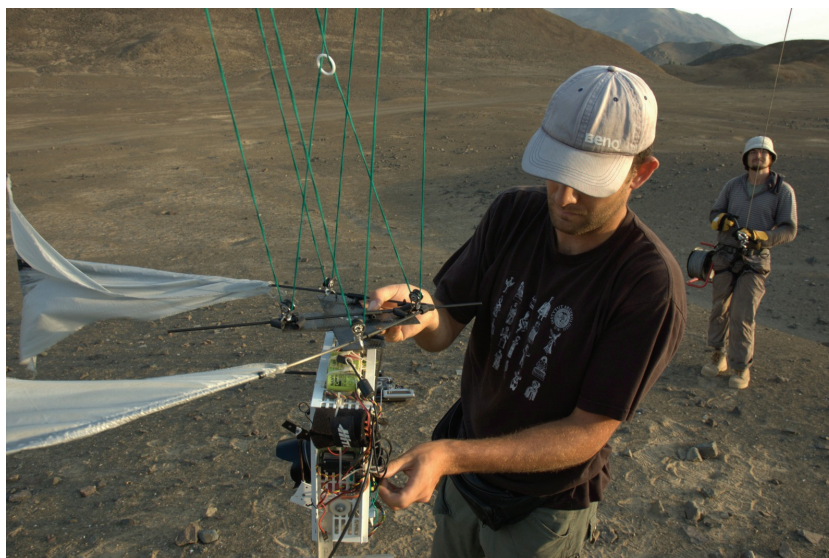


Figure 2. The remote-controlled photo camera used at Castillo de Huarmey site.

Three FlowForm kites of different sizes were used (Figure 3). In strong winds only the smallest kite, 2 m by 3 m, was employed. In moderate or low winds were used either the mid-sized kite or the largest one, with a surface of 12m². The kites are ribless, so they don't break in stronger winds. Owing to their right shape, they achieve a great flight stability and allow thus to obtain unblurred, high resolution images. Kites do not rise vertically. To capture an image of an area that interests us, we had to move within the foreground of the sites from the same direction from which the wind blew. The images were taken from various altitudes, usually ranging between 100 and 200 metres.



Figure 3. The flow-form kite during the survey.

Images were taken with a Canon 5D camera equipped with Canon 35mm f2.0 and Canon 28 mm f1.8 lenses. This camera has a full-frame sensor of nearly 13 megapixels and produces high-quality images even at high-sensitivity settings. Fixed-focus lenses were chosen, because the greater mechanical stability of their internals makes them more compatible with photogrammetric software.

The camera was mounted on a special, remote-controlled frame designed by Miron Bogacki. This rig is capable of rotating horizontally and vertically and allows to shoot images in all the directions. The frame is self-levelling owing to a Picavet-type suspension [6]. This equipment has been used earlier, in similar conditions, during excavations in Libya, in Ptolemais [7,8]. The photographer employs radio control to achieve a full command of the camera's movements, the shutter release and the autofocus. The use of 2.4 GHz wireless image transmission from the camera allows to preview the captured images on a monitor in the command console and to properly crop the frame.

Image-taking usually took place after 5 p.m., when the wind was suitably strong and the sun shone from a lower altitude, highlighting the terrain's texture. Five photographic sessions took place during which it was possible to capture the entire area. Each session involved 500 photographs, which subsequently underwent a selection to extract the best ones. In most cases vertical images were taken. However oblique photographs were also taken to show the site from a more natural perspective (Figure 4).



Figure 4. The oblique photography of the Castillo de Huarney archaeological site.

3.1. Transforming aerial photographs into cartometric images

For archeological documentation's purposes, the most useful are the vertical images. However, they do not constitute a cartometric reflection of reality. The lengths and dimensions measured on raw, recalibrated only photographs differ from the objects real dimensions. Firstly, this is related to the fact, that a photograph is a perspective projection - not an orthogonal one - of the image captured by the CCD sensor. Secondly, the distortions on the photograph are introduced by the camera itself, and particularly its lens. We never deal with ideal lenses – each and every one has some kind of flaw, like distortion for example. A lens's class only tells us if the lens's flaws are important, or of little significance in respect to a given photograph [9]. To eliminate the impact of these flaws, it is necessary to define the distortion's parameters. This happens during the camera calibration process [10,11]. Thus, to obtain the most accurate three-dimensional documentation of the investigated area, photogrammetric software had to be used [12].

On the basis of properly captured and processed photographs, the Image Master Pro application creates a three-dimensional DSM (Digital Surface Model) and an orthoimages [12]. If the software is

to work properly, several criteria must be met. In a first stage, the camera must be calibrated - together with the lenses used to shoot the pictures - with the Image Master Calib module [10,11]. The camera profile prepared in this way, distinct for each lens, is used to remove optical and perspective aberrations present in the images.

After calibration, the project's processing could start with the Topcon Image Master photogrammetric software. In a first stage, it is necessary to mark ground control points on the photographs taken. The greater is their number, the better and more accurate is the Digital Surface Model. Ground control points are subsequently captured on the photographs as photopoints - points of reference. This process is called image georeferencing [12,13]. For this reason, the investigated Castillo de Huarmey area was marked with ca 0.5m crosses painted with highly visible paint. The photopoints – the crosses – were disposed within an irregular pattern. The distances separating them ranged from 15 to 80 meters. Exact reference points measurements were carried out with the GPS RTK method by Wiesław Małkowski.

A text file with the designations and coordinates (X – north; Y – east, Z – altitude) of these points was entered in the program at the processing stage. Next were registered into the program the images that covered this area. Eight pairs of photographs were used to produce both the DSM and the orthophotomap of the site. Individual photographs covered areas with a longer boundary measuring between 55 and 210 meters. The basic rule was, that a pair of images had to overlap by some 60 to 80%. For the project's purposes, each image was reoriented and a stereoscopic model of the captured area was thus created. Project showed both the reference points permitting to convert them according to a predefined set of coordinates, and additional points reciprocally linking individual photographs. In this way, they could be merged more accurately [10].

3.2. Results

After the program generated the stereopairs, a three-dimensional Digital Surface Model could be created. TIN surface (triangulated irregular network) was created for the area designated by the user [12]. To facilitate data manipulation, the grid resolution was set at 0.5 m. This resolution may be increased by reducing the size of a single triangle to even a few centimetres. The grid was produced on the basis of all the photographs and finally consolidated within one, three-dimensional model with a surface equal to 169469 m² (Figure 5, left). The model fits within a rectangle of 700 m by 500 m. It is possible to freely modify this model, to create cross sections, create contour maps, to extract and outline archeologically significant elements, to measure distances and surfaces, etc. Each area may be analyzed and processed separately.

An orthoimage of the entire area was also produced with a resolution of 3cm/pixel - 12321x23751 pixels (Figure 5, right). The map was saved in the GeoTiff format, so it may easily be imported into other programs while preserving the georeferences. A three-dimensional terrain model was also exported to the VRML format, allowing its quick processing with 3D programs (i.e. Autodesk 3D Studio Max) as well as web publication. Data obtained are mutually complementary and integrate in the GIS Autodesk Autocad Map environment with the data from:

- the geodesic GPS RTK survey by Wiesław Małkowski
- the geophysical survey by Krzysztof Misiewicz
- the archaeological surface survey by Patrycja Prządka-Giersz and Roberto Pimentel Nita the geophysical survey by Krzysztof Misiewicz
- the archaeological excavation by Miłosz Giersz

The general accuracy of the Digital Surface Model that was generated may be considered as fully adequate for archeological purposes. Discrepancies between the coordinates of the control points defined on the basis of the 3D terrain model and the coordinates of the same points surveyed

with the GPS RTK method did not exceed 3 cm. Altitude accuracy was inferior however, and attained even a dozen or so centimetres.

During the 2-week long mission at the Castillo de Huarmey site, kite photography revealed only a few minor flaws. The greatest problem consisted in obtaining a photogrammetric coverage of the entire archeological site's terrain. This area proved to be larger than it resulted from an earlier reconnaissance. Another difficulty concerned the integration of data from several stereopairs within one common project. This required a great amount of time and work to be spent on processing individual photographs with the photogrammetric software.

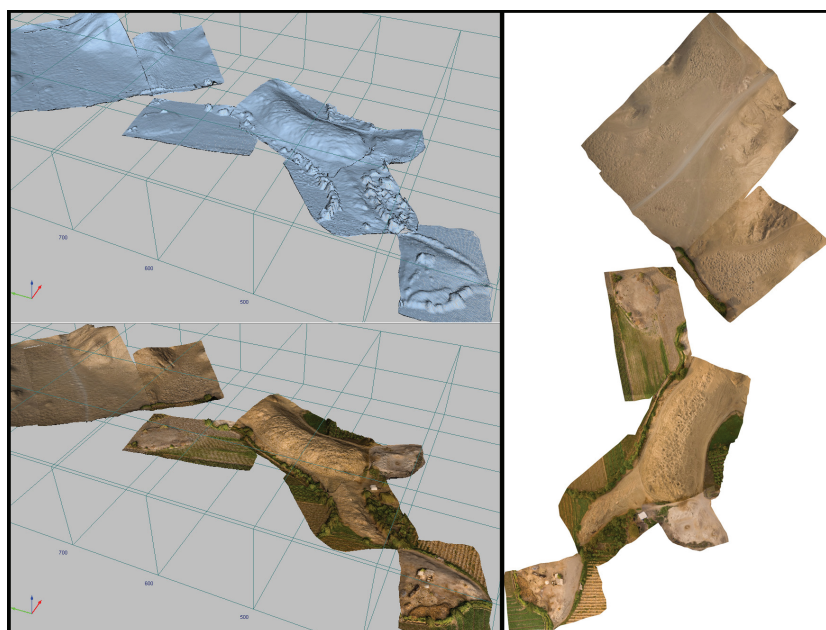


Figure 5. The consolidated three-dimensional model with a surface equal to 169469 m² (left) and orthoimage of the entire area with a resolution of 3cm/pixel.

In the result of kite photogrammetry were obtained: photographs - vertical and oblique, orthoimages and TINs of individual site locations and of the entire terrain. The submitted materials document the site's state of preservation prior to the beginning of excavations. They also constitute an important and exhaustive argument for the continuation of this work and further archeological studies.

While evaluating kite photography's usefulness in conjunction with photogrammetric software, it is essential to notice the numerous advantages it provides. If compared to images taken from satellites, airplanes or helicopters, kite-captured images proved to be less expensive. In addition, the photographs could be taken at any time of the day and covered all of the selected terrain. If compared to remote-controlled planes and helicopters used for the same purpose, the gear proved to be easier to transport (also by air), less expensive, as well as less complicated to build and to operate [14]. Owing to kite photography in association with photogrammetry, it was possible to obtain a documentation that is objective, up-to-date, high resolution and accurate, outperforming the more expensive methods.

4. Geophysical survey

Six areas were marked out for investigation, with a total surface of more than 3.5 hectares. In the first three areas, a wide-area reconnaissance was carried out to locate preserved archeological artifacts. The remaining ones were used for validation purposes - in respect to the identified structures. Geophysical prospection was carried out with the help of a *Bartington grad601-2 dual* fluxgate gradiom-

eter and a *Geometrics G858 MagMapper* cesium magnetometer in its gradient version. Measurements were made within 30x30m or 50 m x 50m squares, by marking up lines every 1m and recording the changes of the measured values at points distant by 0.25 m along each profile. The results were presented in the form of maps and three-dimensional layout models of measured magnetic field intensity values, with the help of the Surfer 9.0 graphic suite by Golden Software Inc.

4.1. Results

The most interesting results were obtained in areas 1-3, where are located the remnants, invisible from the surface, of *adobe* mud brick architecture (Figure 6). In the investigated area linear structures may be observed, which maintain right angles and parallel lines, and which have dimensions that are typical of residential and sepulchral complexes (*area 2*). In the first area some anomalies were recorded, caused by the presence of preserved fragments of a burial structure. Significant damages to the terrain and the presence on the surface of contemporary metal structures causing dipole anomalies do not permit to unambiguously determinate the precise locations where the artifacts that are looked for remain. They only allow an accurate definition of the boundaries of the preserved structure. A reconnaissance of the northernmost - in respect to the principal Huarmey pyramid - burial area (*area 3*) permitted to recreate the manner in which the burials were organized, to isolate this concentration of structures and to define their state of preservation under the surface of the ground (graves either plundered, or untouched).

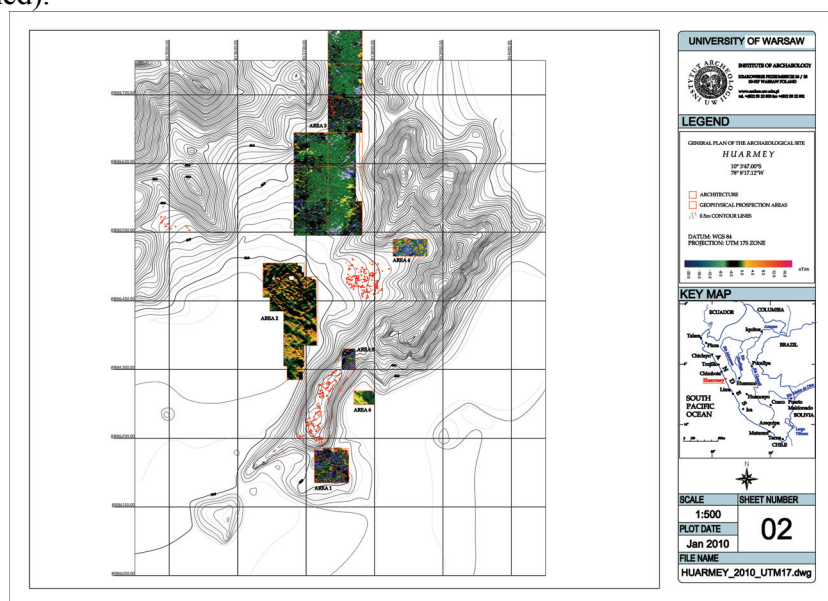


Figure 6. Location of the geophysical survey areas at the Castillo de Huarmey site.

5. GIS-based analysis of surface artifact distribution

In modern archaeology, a site surface survey is used for finding site boundaries, assessing its function, studying the distribution of artifacts and planning further on-site excavation. Within the scope of our project, we conducted a full-coverage systematic site surface survey. The survey entailed a systematic visual inspection of cultural features and the collection and documentation of all the artifacts on the site's surface.

5.1. Survey and research methods

In January 2010, a full-coverage, systematic site surface survey was performed by Patrycja Prządka and Roberto Pimentel Nita before excavation commenced. All artifacts were mapped with the GPS RTK prior to their collection, providing spatial data with a centimetre-level accuracy. Surveyors collected every surface artifact found in each sector. Collected artifacts were identified, sorted, bagged, and recorded by artifact type. Later, these artifacts were cleaned, further analyzed, and documented. The survey yielded a wide range of bioarchaeological materials and a huge sample of archaeological materials representing a number of different artifact classes, primarily pottery, textiles, small metal, lithic and wood objects, all of which were diagnosed as pre-Hispanic forms.

The examination of artifact distribution included several different steps. The focus was on the patterns and clusters in the artifact data, based on the amount of the collected scatters and the possible reasons for those patterns and clusters. A data table listing all collected artifacts has been integrated within the AutoCAD Map 3D environment. The final map (Figure 7) illustrates the distribution of the individual artifact categories by amount.

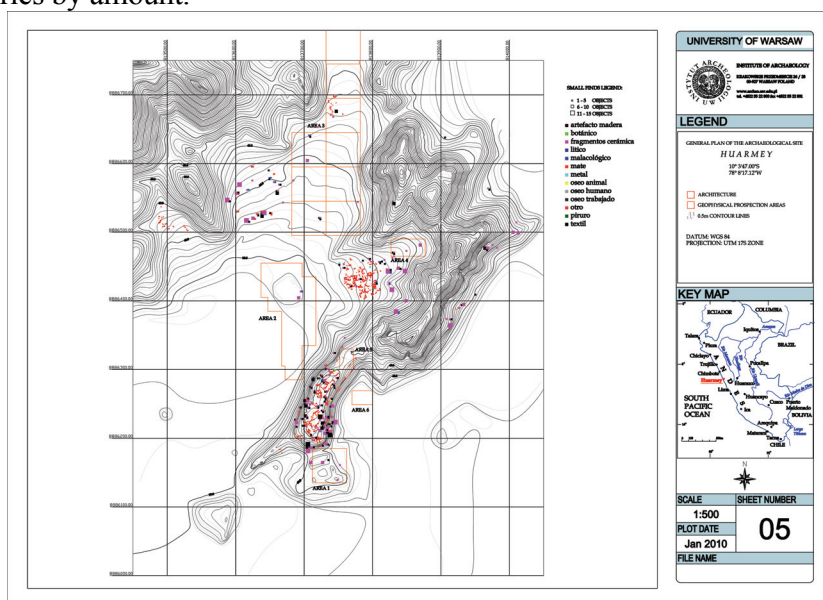


Figure 6. Distribution of the individual artifact categories by amount.

5.2. Results

In general, distributional patterns are directly related to looting. However, concentrations of scatters seem to reflect some important differences regarding the chronology, function and status of the related units. The pottery distribution's spatial pattern showed a general spread of ceramic materials across the majority of the surveyed area, both in the burial ground and in the settlement areas, without an obvious pattern. Other scatters, which consisted of artifacts like fine textiles and metal, lithic and wood objects, were mainly concentrated in the proximity of the principal pyramid, considered to be a necropolis of high-ranking, pre-Hispanic elites. The lack of these materials in the perimeter of two minor adobe structures suggests that these compounds played a different role than this of burial platforms. The absence of human skeletal remains clearly confirms this suggestion.

6. Conclusions

In this paper, we demonstrate methodological approaches that can be used to record, analyze, and interpret complex archaeological sites. Using modern, remote sensing techniques, the Castillo de Huarmey, a highly complex archaeological site, was recorded in just two weeks of fieldwork.

The combined methodology based on GPS RTK mapping, kite aerial photogrammetry, geophysical survey and GIS-based analysis of surface artifact distribution, vastly surpasses traditional surveying methods as far as accuracy, point density, and acquisition time are concerned. Data processing allowed to elaborate and visualize the detailed 2D and 3D models that will now be the starting points for further archaeological research. We feel reasonably confident in concluding that this methodology should be a mainstream one and become a standard, especially in the Andean setting, where specific environmental conditions are very conducive for the application of these methods.

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