2023 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Rome, Italy, October 19-21, 2023

Satellite automatic extraction and characterization of looting features in the Peruvian desert.

Alessia Brucato[1,3], Rosa Lasaponara[2], Nicola Masini[3]

[1] *University of Bari Aldo Moro, Str. della Torretta 70122 Bari BA, Italy, alessia.brucato@uniba.it*
[2] *Institute of Methodologies for Environmental Analysis CNR, C. da S. Loya, 85050 Tito Scalo, Potenza, Italy, rosa.lasaponara@imaa.cnr.it*
[3] *Institute of Heritage Science CNR, C. da S. Loya, 85050 Tito Scalo Potenza, Italy, nicola.masini@cnr.it*

***Abstract* – Archaeological looting is a known threat and causes irreversible damage to historical heritage. In Peru, grave robbers' looting is a diffuse and ancient problem, starting since the first centuries of the Spanish colonization: the "search for gold" of the 'Conquistadores.' The desert areas of the Peruvian southern and central coast are the most affected by the relentless plundering of archaeological sites. In recent years, many studies have succeeded in monitoring archaeological contexts via satellite remote sensing and automatic digital workflows to counter this scourge. In this paper, we propose a further step in these studies, presenting an automated workflow to extract and classify the superimposed looting pits of heavily disturbed sites, establishing a relative chronology of the illegal activities.**

I. INTRODUCTION

Archaeological looting is the primary source of artefacts for the black market. Moreover, illegal excavations finance many criminal activities and, in some cases, even wars (i.e., Syria). The desert regions of our planet are particularly affected by this problem because the vast, harsh, and unhospitable environment makes it very difficult to survey, visit or study historical sites directly. Looting not only causes the loss of many important artefacts but also inflicts considerable damage to the stratigraphy of an archaeological context and causes the irretrievable loss of essential information for historical reconstruction.

Peru hosts over 100,000 archaeological sites, less than 10% of which have been uncovered. Looting is a historical issue in this country, starting with the Spanish colonization of this region. In the first centuries of this process, the 'Conquistadores' tried to obtain as many "treasures" (especially golden artifacts) as possible, recurring to any means at their disposal. Despite the limits of the Peruvian 1982 law [1] on archaeological object exportation and thanks to the actions of the '*huaqueros*' (grave robbers), after the 1960s, this phenomenon abnormally intensified to supply the national and international requests of illegal antiquities buyers.

Thousands of pit holes and soil accumulations shockingly scar the surface of the deserts on the southern and central Peruvian coast.

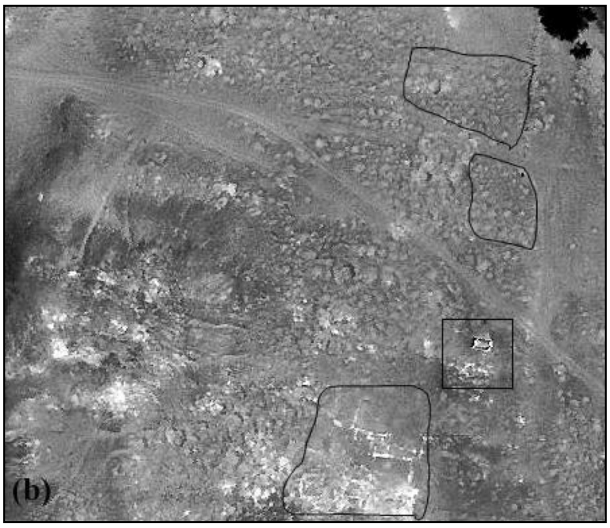

Fig. 1. Satellite view of heavily looted desert areas near the archaeological site of Cahuachi (Nasca Perú). Layout by Nicola Masini.

Many recent studies proved that combining Earth Observation data, image analyses, and digital approaches provides reliable information and results to detect looting activities quickly [2, 3]. These techniques are all based on spectral and morphological properties of the looting pits, and they are mainly processed via commercial software (ENVI, eCognition, ArcGIS, QGIS). Nowadays, these technologies can be tapped to: 1) understand the distribution of such occurrences in specific areas and time frames and 2) create protocols for illicit trades in antiquities tracing.

Detecting the most recent illegal excavations and spotting their patterns and trends is relevant to prevent further losses. For this purpose, we think it is fundamental to approach the detection and the analysis of the looting activities as archaeologists, meaning adopting a methodology that considers stratigraphy, reasons, and drives, as well as material testimonials of such occurrences.

This paper presents a satellite and machine learning-based workflow to detect and classify different kinds of looting pits in heavily plundered contexts. This study's principal aim is to reconstruct the pit holes' relative chronology and hypothesize trends in two archaeological areas of the Nasca desert (home of the renowned geoglyphs): Cahuachi and Paredones (Fig. 1).

II. MATERIALS

Depending on the region, the looting pits could vary greatly in technique, pit hole shape, density, and position. Combined with satellite imagery and classification workflows, these variables could provide an interesting analysis of the ancient and modern looting trends [3, 4].

Considering the satellite visualization (Fig. 1) of such pits, all the aforementioned parameters can be grouped in the analyses of the shadow marks cast by the Sun on the depressions of interest (Fig. 2).

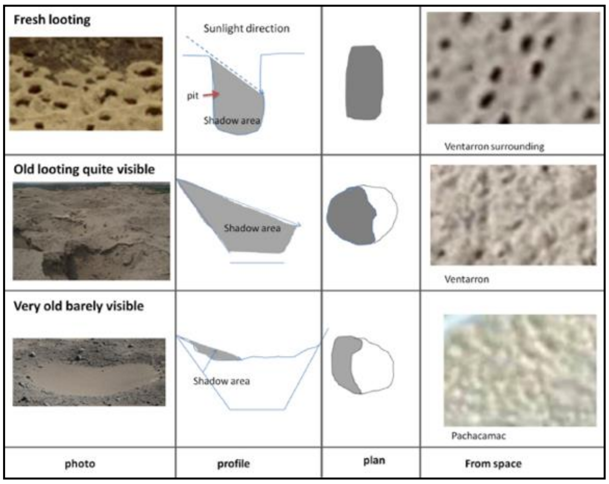

Fig. 2. Looting holes and shadow marks morphologies on the ground and in satellite RGB imagery. Layout by Nicola Masini.

For this study, we selected two open-access repositories of VHR satellite imagery:

- Google (Earthstar Geographics SIO, 2023 Maxar)
- Bing Maps (Landsat 8 NASA, IKONOS, QuickBird)

A. Cahuachi

The ceremonial and burial sites of Cahuachi are located in the hydrographic basin of the Rio Grande de Nazca (Southern Peru). Cahuachi is dated to the 4th century BCE (before the Nasca Civilization) - 5th century. CE (Huari invasion) presents many geoglyphs, a great pyramid, a stepped temple, some thirty adobe buildings, and many burials [5-7]. Because the density of surface artefacts is very low over the burial areas, some of the tombs have been preserved and studied. Still, the Huaqueros nowadays destroy most of the funerary contexts. The looting pits in Cahuachi (Fig. 3) are predominantly distinguished in phases by their size [4].

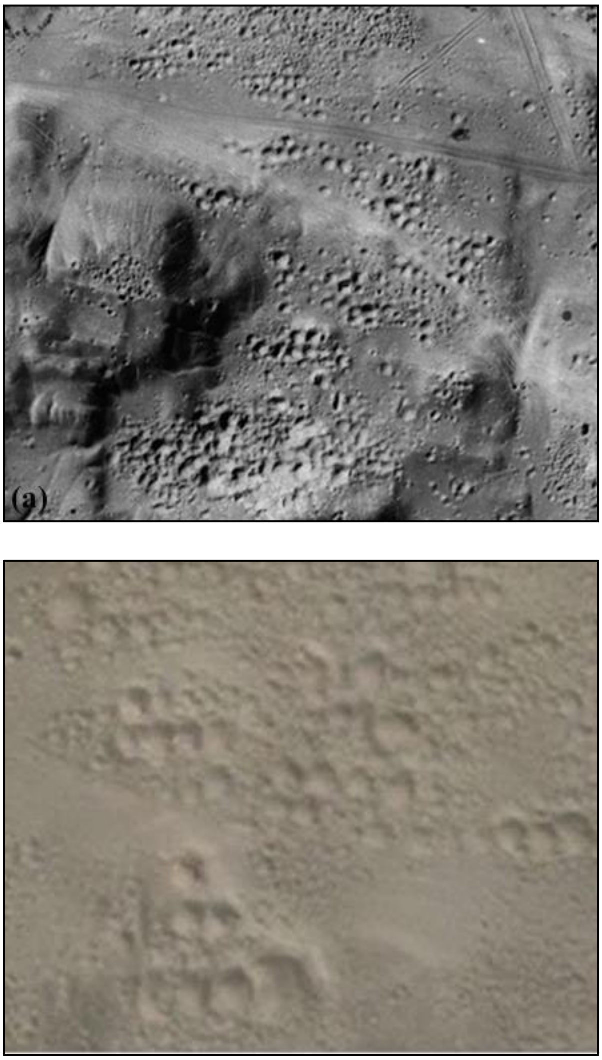

Fig. 3. Looting pits in Cahuachi. Images from Google Satellite and Bing Map.

B. Paredones

South-East of Cahuachi, another important archaeological area is Paredones [7]. This site is characterized by a monumental Settlement (West of Zone 5) and vast areas of burials near other geoglyphs (East of Zone 5). Paredones is dated to the Middle Horizon, during the government of Tupac Inca Yupanqui (1471-1493) in the period of the greatest Inca expansion.

Grave robbers have plundered Paredones in search of rich tombs and ritual offerings. Still, the illegally excavated areas show a dramatic superimposition of looting pits, making it difficult to interpret the subtraction phases (Fig. 4).

Fig. 4. Looting pits in Paredones. RGB images from Bing Map.

III. METHODS

The images have been collected via Bing Map Explorer, SASPlanet, and Google Earth Engine. At the same time, the identification and classification of the looting pits have been performed via ENVI and QGIS, thanks to the many routines and plugins offered by the two software. The research workflow was based on applying the ALFEA [3] method and further image classification.
The ALFEA method consists of four macro-phases (Fig. 5-6):

1. Image pre-processing, parameter selection, and consequent application of filters and masks. This way, any natural, anthropic, weather, or sensor disturbance is removed, and the pit proxy indicators are enhanced. In the two case studies, we found filtering the images with a PCA was particularly efficient.
2. Lisa Geary's C Spatial Autocorrelation: a spatial analysis that compares the differences between neighbouring pixels to the standard deviation to measure dissimilarity within a dataset. In our case study, we selected, as a rule, the Queen's Case (all eight neighbouring pixels) [8].
3. Iterative Self-Organizing Data Analysis Technique (ISODATA). The first of the two Machine Learning techniques applied in the ALFEA is an unsupervised classification based on a Clustering method, like K-Mean. This algorithm merges and splits clusters of pixels if their separation distance in a multispectral feature space is less or more than a user-specified value.
4. Segmentation is an unsupervised process of image partitioning in segments (also regions or objects). It works on a thresholding method, and the result simplifies the source image. Segmentation requires setting a minimum population and several neighbour pixels for the resulting segments. In our case studies, we tested three combinations of these two parameters (Table 1).
5.

Table 1. Segmentations parameters.

Segmentation stage	pm	nn
S1	10	4
S2	50	4
S3	100	8

pm: population minimum; nn: numbers of neighbours

After this process, the resulting raster files have been automatically vectorized and are now undergoing a looting classification process. This step is based on dimensions thresholds, morphology, and shape completeness. This way, it will be possible to automatically separate the most recent and better-preserved looting pits, superimposed to the disturbed previous ones, and map the sequence of the events.

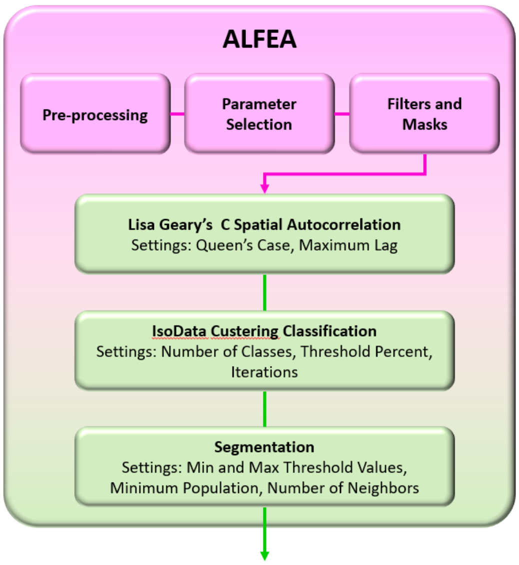

Fig. 5. Part 1 - ALFEA method and Classification workflow. Layout by Alessia Brucato.

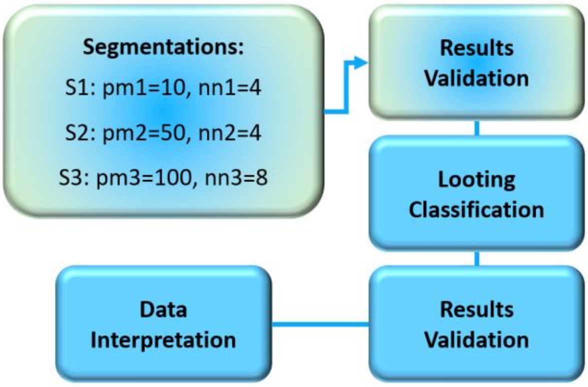

Fig. 6. Part 2 - ALFEA method and Classification workflow. Layout by Alessia Brucato.

IV. RESULTS

The preliminary results of the ALFEA method in Paredones led to the classification of 3 different types of shadow marks that vary in shape, dimension, and concentration (Fig. 7-8).

The deeper the clandestine excavation pits, the more visible the shadow marks. The depth and visibility of such looting pits (all other site boundary conditions being equal) are inversely proportional to the digging time.

Consequently, the extracted three classes could reasonably refer to three distinct (from a temporal point of view) phases of disturbance by grave robbers.

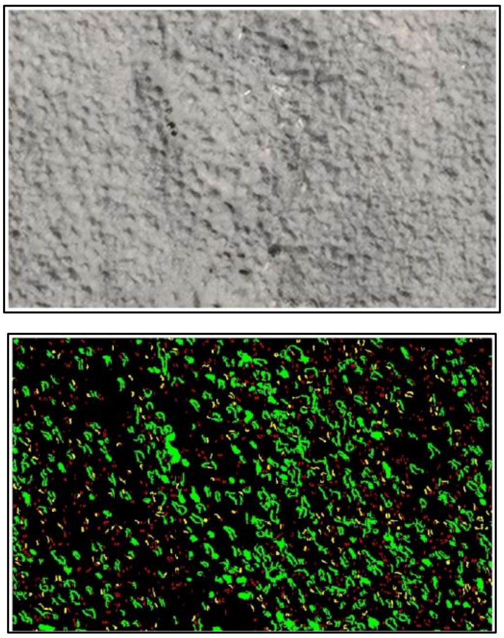

Fig. 7. Applied ALFEA method in Paredones. Layouts by Alessia Brucato.

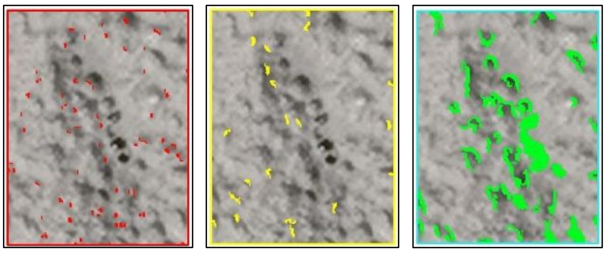

Fig. 8. Applied ALFEA method in Paredones. Layouts by Alessia Brucato.

V. DISCUSSION

The largest and neat group of looting features belongs to the most recent excavation phase, with very regular shapes and identifying characteristic shadow cones (Figs. 9-10). On the other hand, the other two groups of results could belong to the same looting phase disturbed by the upper one or to multiple past excavations. To discriminate their nature, we need to finish the final classification process.

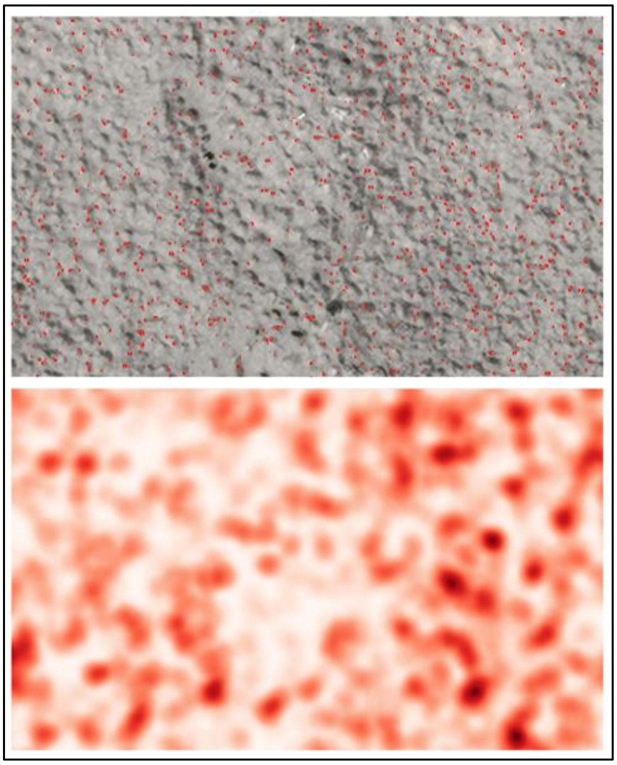

Fig. 9. Interpretation of the Results: older looting marks. Layouts by Alessia Brucato.

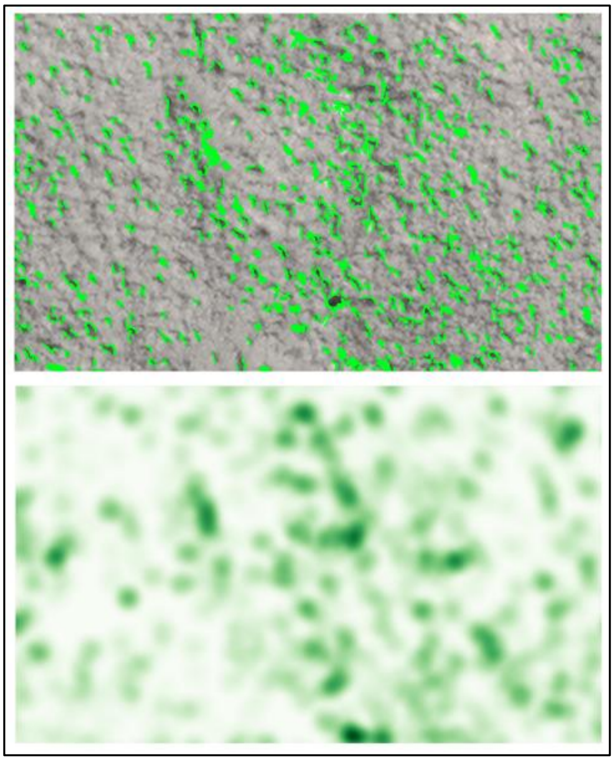

Fig. 10. Interpretation of the Results: recent looting marks. Layouts by Alessia Brucato.

REFERENCES

[1] Higueras A. (2008). Cultural Heritage Management in Peru: Current and Future Challenges. The Handbook of South American Archaeology, 2008, doi: 0.1007/978-0-387-74907-5_54

[2] Tapete, D.; Cigna, F. (2019). Detection of Archaeological Looting from Space: Methods, Achievements and Challenges. *Remote Sens*. 2019, *11*, 2389, https://doi.org/10.3390/rs11202389

[3] Lasaponara R., Masini N. (2018). Space-Based Identification of Archaeological Illegal Excavations and a New Automatic Method for Looting Feature Extraction in Desert Areas. Surv Geophys (2018). https://doi.org/10.1007/s10712-018-9480-4

[4] Lasaponara R., Masini N. (2016). Combating Illegal Excavations in Cahuachi: Ancient Problems and Modern Technologies. In: Lasaponara R., Masini N., Orefici G. (Eds). The Ancient Nasca World New Insights from Science and Archaeology. Springer International Publishing, 2016, pp. 605-633, doi: 10.1007/978-3-319-47052-8_25

[5] Masini, N., Lasaponara, R., Orefici, G. (2009). Addressing the challenge of detecting archaeological adobe structures in Southern Peru using QuickBird imagery, Journal of Cultural Heritage, 10S (2009), pp. e3–e9 [doi: 10.1016/j.culher.2009.10.005]

[6] Silverman, H. (1993). Cahuachi in the Ancient Nasca World. Iowa City: University of Iowa Press

[7] Orefici, G. (1992). Nasca. Archeologia per una ricostruzione storica. Jaca Book.

[8] Anselin, L. (1995). Local Indicators of Spatial Association LISA. Geogr Anal 27: 93–115

[9] Conference CAA2023 50 Years of Sinergy, Presentations: 315, 318, 371