Chapter 8
Satellite-Based Monitoring of Archaeological Looting in Peru

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Abstract Illegal excavations represent one of the main risk factors which affect the archaeological heritage all over the world, in particular in those countries, from Southern America to Middle East, where the surveillance on site is little effective and time consuming and the aerial surveillance is non practicable due to military or political restrictions. In such contexts satellite remote sensing offers a suitable chance to monitor this phenomenon. The chapter deals with the results obtained on some areas of Cahuachi (Peru) by using a time series of very high resolution satellite images. The rate of success in detecting changes related to archaeological looting has been fruitfully improved by adopting a semiautomatic approach based on spatial autocorrelation.

Keywords Archaeological looting • Spatial autocorrelation • Cahuachi • Peru

8.1 Introduction

Archaeology contributes much more than other disciplines to the history and knowledge of ancient civilizations. It stimulates high interest in ancient artefacts and objects, and thus, unfortunately, strongly boosting illegal searching for treasure which causes irreversible damage to archaeological sites.

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R. Lasaponara and N. Masini (eds.), *Satellite Remote Sensing: A New Tool for Archaeology*, Remote Sensing and Digital Image Processing 16,
DOI 10.1007/978-90-481-8801-7_8,

In many countries of Southern and Central America, Asia and Middle East looting and clandestine excavations affect archaeological heritage more than other man-made and natural risks, denying this cultural heritage to new generation (Atwood 2006).

Clandestine excavation activity is mainly linked to illicit trade of antiquities in Europe and North America (Brodie and Renfrew 2005; Luke 2006). To contrast this phenomenon since 1956 the General Conference of the United Nations Educational, Scientific and Cultural Organization recommended all the Member States to take "all necessary measures to prevent clandestine excavations and damage to monuments and also to prevent the export of objects thus obtained" (UNESCO 1956).

The 1956 UNESCO Recommendation increased the international cooperation in adopting repressive measures and in returning objects derived from clandestine excavations or theft to their countries of origin. In particular, since the 1960s most of the UNESCO Member States took measures which obliged museums to ascertain that acquired archaeological objects were not procured by clandestine excavations, theft or any other methods regarded as illicit by the competent authorities of the country of origin.

To contrast site looting and illegal trade of archaeological objects we also cite the role of excavation services, museums and their representative associations which lend assistance in order to ensure or facilitate the recovery of objects derived from clandestine excavations or exported in infringement of the legislation of the country of origin. This was much more strictly after the adoption in 1970 by the UNESCO of the "Convention on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property" (UNESCO 1970).

The looting phenomenon is much more dramatic during wars or armed conflicts, as occurred in Iraq during the two Gulf Wars. At such regard, Elizabeth C. Stone comments that "total area looted was many times greater than all the archaeological investigations ever conducted in southern Iraq" (Stone 2008). Media reports described the massive looting in broad daylight and destruction of the Iraqi museums and other cultural institutions. Between 2003 and 2004, several buried ancient cities have been completely eaten away by crater-like holes (http://www.savingantiquities.org/feature_page.php?featureID=7), and many other archaeological sites would be pillaged without the valuable activity of the Italian Carabinieri, responsible for guarding archaeological sites in the region of Nassyriah (Fig. 8.1).

In spite of a new ethical environment against the acquisition of unprovenanced antiquities followed to the UNESCO conventions (Brodie and Renfrew 2005) much more efforts need to be addressed to contrast the looting and smuggling of antiquities which increasingly affect archaeological monuments and sites all over the world.

An effective approach used in Europe is based on the cooperation of public departments for the management and protection of cultural heritage, superintendences, heritage protection services and non-profit archaeological groups, which compose a synergic network for direct surveillance on site.

However such approach is time consuming, expensive and not suitable for remote archaeological sites, characterized by difficult accessibility.

Fig. 8.1 Aerial surveillance of archaeological sites in Iraq by Italian Carabinieri, responsible for guarding cultural heritage in the region of Nassyriah (Courtesy of Italian Carabinieri)

To cope with such difficult conditions, in many countries the protection activity is carried out by using remote sensing. In particular, aerial images allow the monitoring of the most valuable archaeological heritage to contrast the clandestine excavations, to limit the impact of illegal urbanization and anthropic activities.

Since the 1930s of the twentieth century aerial surveillance has been a common manner to monitor the phenomenon of archaeological looting and damage. Aerial images had been long appreciated by archaeologists and conservators as it permits not only the discovery of unknown sites but also the monitoring of know sites and the estimation of risk factors, such as environmental (landslides, flooding) and man-made (i.e. the impact of urban and industrial infrastructures) issues.

The effectiveness of aerial prospection as manner to contrast and monitor the archaeological damage depends on the possibility to carry out the surveillance on a regular time basis with a systematic scheduling. To optimize performance, costs and time the approach used is based on : (i) the integration of vertical and oblique photographs (the latter emphasize microrelief or shadow-marks caused by looters), (ii) and the gaining of aerial views with different vectors such as helicopter, airplane, hot air balloons, scaffolds or cameras attached to kites.

Aerial observation is used with effectiveness in the US and in most of European countries for monitoring archaeological sites and territories of cultural interest.

Fig. 8.2 Some archaeological sites looted in Iraq during the second Gulf War: Abbas al Kurdi (*upper left*), Sifr (*upper right*), Jokha (*lower left*), and Tell Medinah (*lower right*) (Courtesy of Italian Carabinieri)

Unfortunately, it is non practicable in several countries due to military or political restrictions, unless aerial surveillance is carried out within of peace-keeping missions as in the case of Nassyriah in Iraq, where the Italian Carabinieri Protection Nucleus, between May 2003 and January 2004, surveyed several sites from late Uruk to early Islamic targeted just before and after the 2003 invasion. Aerial survey put in evidence the significant damages of numerous archaeological sites, such as Tell-Medinah, Abbas al-Kurdi, Jokha, Sifr, Tell Schmid, Umm al-Aqarib, Zabalam (Fig. 8.2). The Italian Carabinieri's activities opened a way to reduce or even prevent further damages to the archaeological heritage in the following years.

Today the problem is to assure a continued surveillance on site and by means of aerial observation. Both of them are actually little practicable for security reasons and because they are very expensive and time consuming. In particular, the georeferencing is time consuming not only for large archaeological areas but also small archaeological sites, when frequent revisitation times are required. Finally, aerial surveillance is little effective for huge areas and for difficult environmental settings (desert, rain forest).

In such contexts very high resolution (VHR) satellite imagery such as Ikonos, QuickBird2 (QB2), WorlView1 (WV1), GeoEye and WorldView (WV2) offer a suitable chance thanks to their global coverage and a frequent re-visitation time.

Recently, QB2 satellite data have been used in Middle East to survey and quantify the looting damage on the archaeological heritage of Southern Iraq during the last armed conflicts (Stone 2008). The available VHR satellite time series, from 2002 January to 2005 November, allowed to address many issues such as (i) analysis of the chronology of looting of several sites, (ii) estimation of the percentage of damaged area for each site, (iii) evaluation of size and the number of holes and (iv) distribution of damage in relation with size and historical periods of archaeological sites (Stone 2008).

Declassified satellite imagery acquired in the 1960s and early 1970s by Corona represent a further data source not only for detecting archaeological features (Fowler 1997), but also for monitoring cultural resources from the 1960s of the twentieth century to the present. To such regard, in the regions where declassified satellite scene are available, multitemporal observations in the last 40 years put in evidence the dramatic loss of archaeological sites caused by illegal urban expansion, infrastructures, mechanized agriculture and looting.

For example, in some areas in Egypt investigated by Sarah Parcak (2007), maps available from the nineteenth century and high resolution satellite data time series, put in evidence that at least around the 88% of the overall sites were lost over the past 200 years, with the majority of destructions occurring within the last 40 years (Parcak 2007). By using SPOT4, with four bands at 20-m ground sample distance (GSD), Landsat 7 (with seven bands at 30-m GSD) and QB2 together with declassified Corona KH-4B scenes acquired in 1972 (1.8-m GSD), Parcak (2007) proposes a model for documenting the impact of plunder and demographic changes on ancient tells in the East Delta of Northern Egypt and in Middle Egypt. To obtain this model the author compared visual analysis with band combinations, principal component analyses, supervised and unsupervised classification classifications.

A significant improvement regards the use of very high resolution satellite for studying clandestine excavations has been provided by Lasaponara and Masini (2010). The authors devised a semiautomatic data processing approach mainly based on the use of geospatial analysis. The integration of remote and GIS technologies was applied to the archaeological heritage in the desert coastal areas of Southern Peru. The high satisfactory results put in evidence the great potentialities of satellite earth observation for monitoring of archaeological looting. The spatial resolution generally well fits with the dimensions of illegal excavations and the geospatial analysis enables us to easily identify traces and patterns linked to archaeological looting. This encouraged the authors of this chapter to further improve the semi automatic object extraction procedures. An application on the Ceremonial Centre of Cahuachi is herein shown.

8.2 Archaeological Looting in Cahuachi

Since 2007, two institutes of the Italian CNR have been using VHR satellite data to support archaeological investigations in some sites of southern and northern desert coastal areas of Peru (for additional information on the scientific investigations of CNR in Peru, the reader is referred to Chap. 14; Masini et al. 2009a, b; Lasaponara et al. 2011), where the clandestine excavations are a plague, very difficult to face by only on-site and aerial surveillance. The measures set up by Peruvian Government, in terms of aids awareness and contrast of illicit art trade, reduced this problem in some regions. However much efforts should be still addressed to guarantee an effective monitoring of cultural sites and areas, which can be effectively approached by using the novel technologies of Earth Observation, as it has been done in Cahuachi since 2008.

Cahuachi is the largest adobe Ceremonial Centre in the World, built in the southern desert of Peru by the Nasca Civilizations. The archaeological area is characterized by around 40 semi-artificial mounds, spread out on the south bank of the Nasca river and facing the Pampa de San Jose, where the majority of the famous Nasca Lines were etched (see Fig. 14.1 in Chap. 14). The archaeological investigations in the last 25 years (Orefici 1992, 1993; Orefici and Drusini 2003; Silverman 1988, 1993) allowed the understanding of the functional and cultural evolution of the site between 400 B.C. and 400 A.D. It was at the beginning a shrine (*Huaca*), then a ceremonial centre and later the Theocratic Capital of the Nasca State. The difficult environmental setting of the Nasca territory favoured an intense ceremonial activity with rituals, precious offerings and sacrifices to propitiate the gods, to have rich harvests and prevent natural disasters such as earthquakes and flash floods (Orefici 2009). The enormous quantity of precious offerings and rich tombs has been very tempting target for looters since the nineteenth century. Thus, a vast amount of polychrome Nasca ceramic was unearthed and sold to antique collectors in Lima. However, the looting in Cahuachi increased dramatically in the early twentieth century, after the first excavation campaign carried out by Max Uhle. The looting increased dramatically in the next 25 years during which the looters (named in Peru *huajeros*) dug about 30,000 tombs (Silverman 1993).

If in the early of the twentieth century the *huajeros* worked mainly individually, in the subsequent decade they started to work in teams for their own gain or for second parties. The looting was considered by people as a work to take pride in so much so distinguished between “looters of finesse” and the “brutal profaners” (Silverman 1993).

Illegal excavations do not only damage the cultural heritage, they also cause a loss of context which makes interpretation of remains unearthed by archaeologists very difficult.

Looters’ holes are usually recognizable by circular pits (Fig. 8.3), somewhat filled with sand, and by scattered remains such as human and animal bones, sherds of the pottery sells broken by *huajeros* or left by Nasca as part of their mortuary rituals. A tomb can be recognized by *huajeros* by a surfacing big *huarango* post stood upright linked to an underneath wood roof which covered a square or rectangular adobe-walled chamber.

After the WW2 mounds and flat areas follow to be eaten away by crater-like holes, as proved by comparing aerial photographs of 1947, 1952 and 1970. From the 1990s the looting starts to decrease. However it is still a big problem to face by direct surveillance. Moreover, the difficulty to recognize points of reference makes also the aerial surveillance little effective and time consuming, especially for extensive areas, as in the case of Cahuachi.

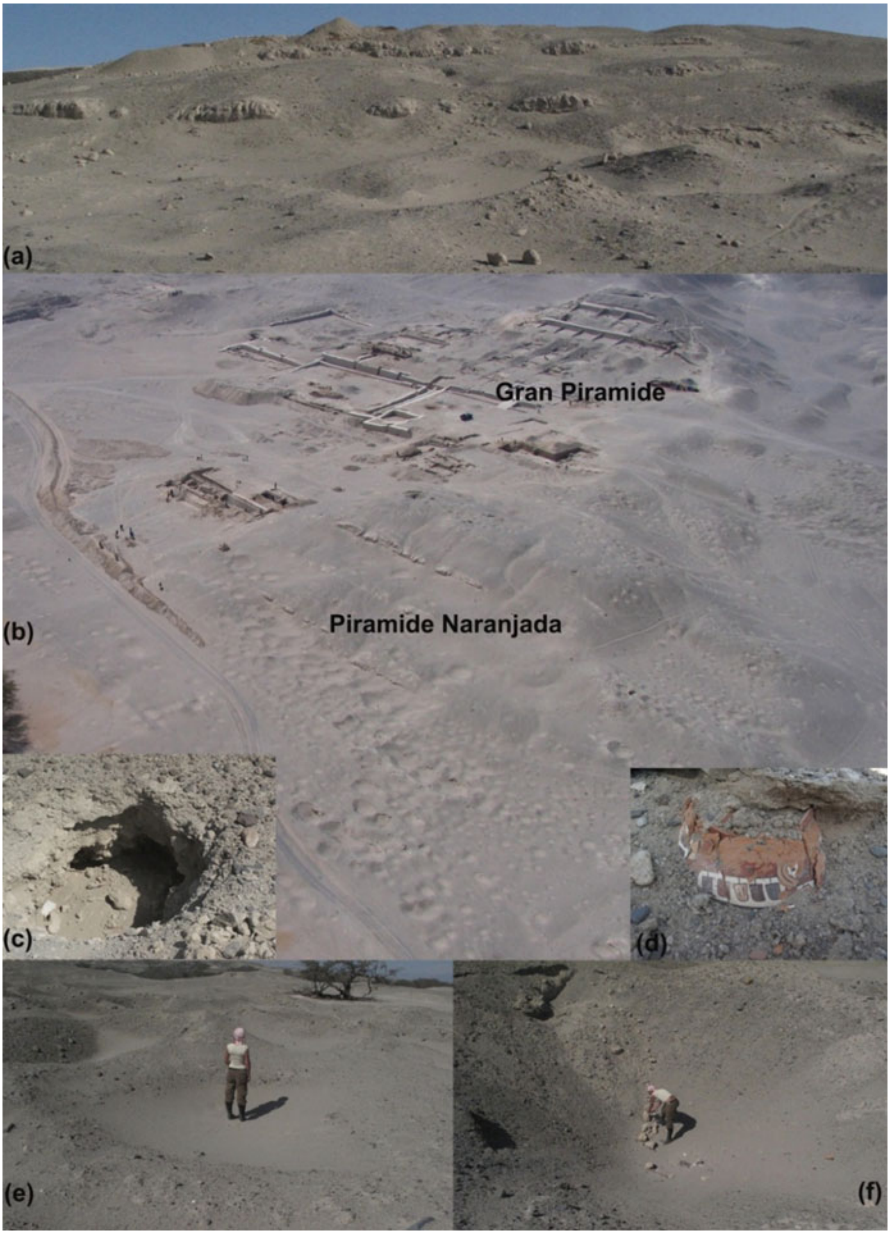

Fig. 8.3 Archaeological looting in Cahuachi. The looted areas are characterized by circular holes (**a**), with diameters ranging from 1 m (**c**) to 6–10 m (**e**–**f**) which affect large areas (**a**) of Cahuachi, included the pyramids (**b**). Clandestine excavations are mainly linked to illicit trade of Nasca ceramics (**d**) in Europe and North America

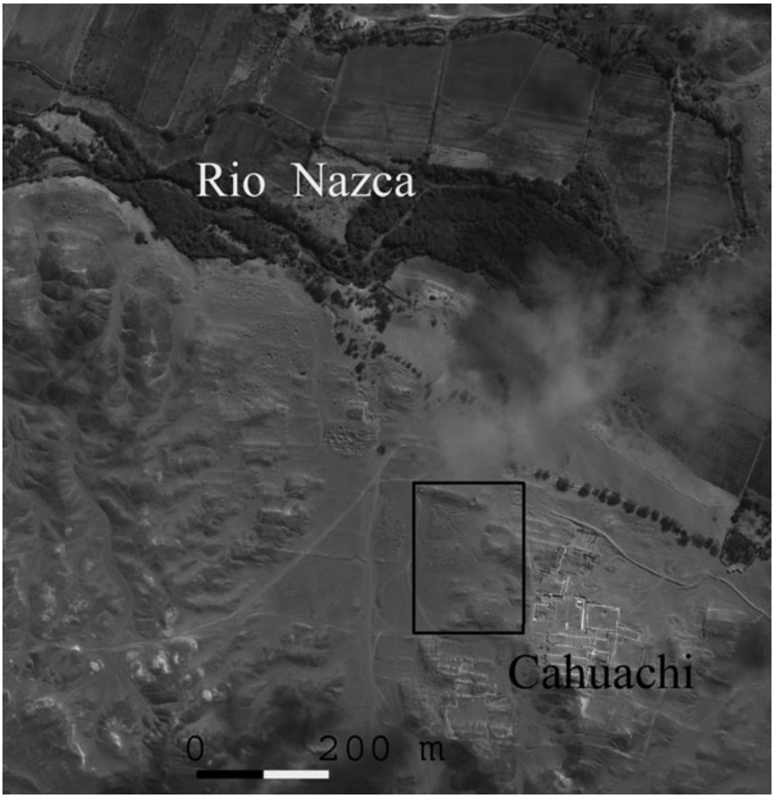

Fig. 8.4 Cahuachi. The black rectangular box indicates the investigated test site characterized by illegal diggings, located between the core of the ceremonial Centre and the *Rio Nasca*

Such considerations suggested to develop a monitoring method based on the use of very high satellite imagery, which is tested near the archaeological area (see Fig. 8.4).

8.3 Methodological Approach

The reliability of the satellite imagery in detecting changes linked to looting has been previously experienced and assessed by using a time series of panchromatic and multispectral QB2 and panchromatic WV1 images. The QB2 data used for this study were acquired on the 16th September 2002 with Ground sample distance (GSD) of 61.90 cm and the 25th March 2005 with GSD = 63.40 cm. WW1 data were acquired on the 31st July 2008 with GSD = 58.10 cm.

The multitemporal observation put in evidence a differential and selective occurrence of looting. Some areas are intensively plundered, whereas other came through *huajeros*. The rate of success in detecting looted areas has been assessed by field surveys carried out on some test sites. The evaluation has shown a rate of success was very high in some areas and unsatisfactory for other areas. This suggested follow an approach based on the integration of image processing and geostatistics, which achieved remarkable results for a wide spectrum of applications (Curran and Atkinson 1998; Hyppänen 1996; Atkinson and Lewis 2000; López-Granados et al. 2005 are just some examples). This chapter shows the results obtained by means of an approach based on the spatial autocorrelation, already experienced for archaeological site discovery (Ciminale et al. 2009).

Spatial autocorrelation measures the degree of dependency among events, considering at the same time their similarity and their distance relationships. For event we mean the number of spatial occurrences in the considered variable s_i (more information on spatial autocorrelation approach adopted in this case study are included in Chap. 2). In the context of image processing, the spatial event is the pixel, so spatial autocorrelation statistics are calculated considering geographical coordinates of its centroid.

In case of a non-autocorrelated distribution of a given variable s_i the probability $P(s_i)$ to have a s_i event in the point with (x, y) coordinates is computed. For an autocorrelated distribution, fixed a neighbourhood for each event, spatial autocorrelation expresses how $P(s_i)$ is modified from the presence of other elements belonging to same variable n inside that neighbourhood. In particular, two effects cause the presence of autocorrelation in a spatial distribution: (1) first order effects which measure how the expected value (mean of events number) varies in the space, (2) second order effects which they concern local interactions between events and are measured by covariance variations (the reader is referred to formulas 2.38 and 2.39 in Chap. 2, respectively; see also Gatrell et al. 1996).

Even if the definition of these two effects is clear, to separate their study in the practice is not possible. Under their effect, a distribution can be: (i) clustered, (ii) uniform and (iii) random, for which the autocorrelation will result positive, negative and null, respectively. In other words, we can have respectively: (i) attraction between events (when they are near and similar); (ii) repulsion between events (when, even if they are near, they are not similar); (iii) and no spatial effects, neither about the position of events, neither their properties (for additional information, see Fig. 2.14 in Chap. 2).

According to what said since now, the study of spatial autocorrelation requests to know: (i) the quantitative and (ii) the geometric nature of dataset.

In the context of image processing, the quantitative aspect is given by the intensity equal to the value of each spectral band. So, it is necessary to measure the degree of dependency among spectral features. Whereas, the conceptualization of geometric relationships is the lag distance that is the distance between events which can be equal to or a multiple of pixel size.

For what concern the method, Euclidean distance (see formula 2.40 in Chap. 2) is the most used. For what concern direction, three are the methods used. They consider contiguous events and include them in the calculation only if they are in the admitted direction, take their name from the game of chess. They are called tower, bishop and queen contiguity, thus taking their name from the game of chess.

As a whole, the output is a new image which contains a measure of autocorrelation for each pixel. Such measure could be done by computing global and local indicators.

Global indicators of autocorrelation measure, with one summarizing value, if and how much the dataset is autocorrelated.

One global indicator of autocorrelation is the Moran's I (Moran 1948). If $I \in (-1; 0)$ there's negative autocorrelation; if $I \in (0; 1)$ there's positive autocorrelation; if I converges to 0 there's null autocorrelation (see formula 2.47 in Chap. 2).

Another global indicator is the Geary's C (Geary 1954).

$C \in (0; 2)$; if $C \in (0; 1)$ there's positive autocorrelation; if $C \in (0; 2)$ there's negative autocorrelation; if C converges to 1 there's null autocorrelation (see formula 2.49 in Chap. 2).

Local indicators of autocorrelation allow us to understand where clustered pixels are, by measuring how much are homogeneous features inside the fixed neighbourhood.

In this study we used three indicators: the Local *Moran's I* (Anselin 1995), the Local *Geary's C* (Cliff and Ord 1981), and the Local *Getis-Ord Gi* (Getis and Ord 1992; Illian et al. 2008), defined according to formulas 2.50, 2.51, and 2.52 in Chap. 2, respectively.

These indicators show a different concept of spatial association:

1. In the local *Moran's I* high value of the index means positive correlation both for high values both for low values of intensity;
2. With the Local *Geary's C* it is possible to detect areas of dissimilarity between events;
3. In the *Getis and Ord's Gi* high value of the index means positive correlation for high values of intensity, while low value of the index means positive correlation for low values of intensity.

Geostatistical analysis tools are available in several commercial softwares, such as GIS and image processing ones. We used ENVI packages for the current study.

8.4 Data Processing and Results

The time series of panchromatic and multispectral satellite images described in Sect. 8.3 has been used to map looting in Cahuachi from 2002 to 2008. The investigated area (see Fig. 8.5), strongly damaged by illegal diggings, is located between sector B and the zone where the excavation are in progress (Gran Piramide and Piramide Naranjada). Looting pits are characterized by circular shape (0.7–10 m diameter), somewhat filled with sand, and by scattered remains

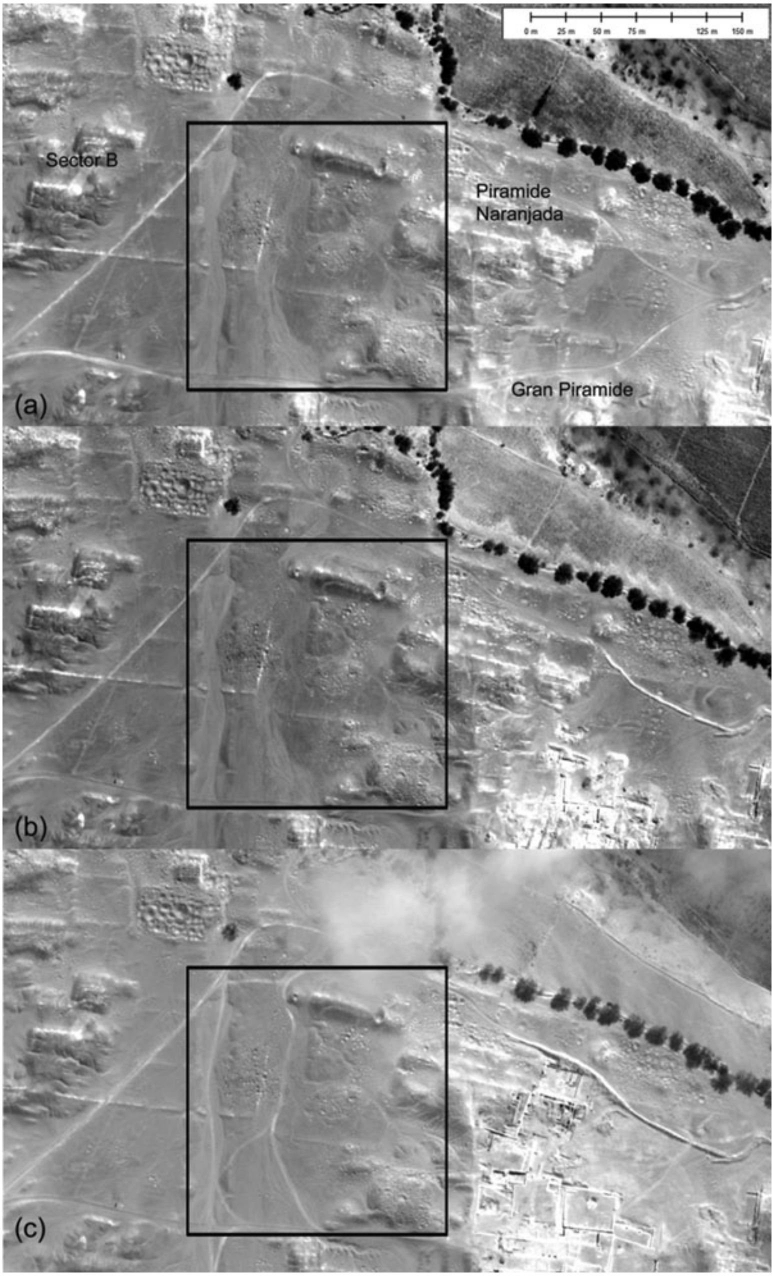

Fig. 8.5 Cahuachi. Panchromatic data time series: (**a**) 2002 QB2; (**b**) 2005 QB2; (**c**) 2008 WV1. The black box denotes the area where the method based on spatial autocorrelation has been tested. It is located between sector B and the area where the excavation are in progress (*Gran Piramide* and *Piramide Naranjada*)

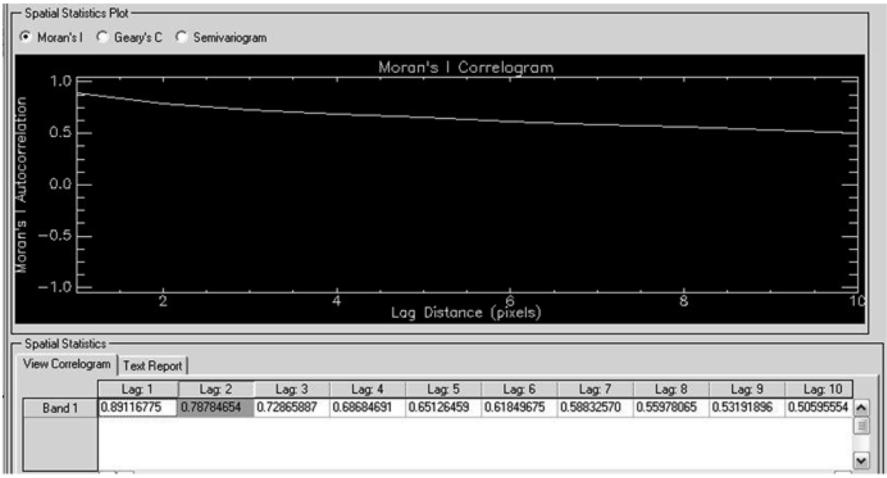

Fig. 8.6 Results obtained with global Moran's I and lag distance between 1 and 10 computed on 2002 panchromatic image

(human and animal bone, pottery fragments) (see Fig. 8.3). Some parts of them are illuminated, others are in shade.

Consequently all these characteristics, pixels with holes show very different values of reflectance, so we supposed to find a break in autocorrelated zones (soil without holes). The comparative visual inspection of the available satellite dataset put in evidence that the panchromatic images are more suitable than pansharpened spectral bands to emphasize the pitting holes. This is due to the fact that for the study area there are no significant spectral variations in the four bands of QB imagery.

On the basis of these results, we focused only on satellite panchromatic scenes. The reliability of the detection was evaluated by field survey carried out in November 2008 on some test sites selected on mounds and flat areas. The evaluation has shown that the rate of success was very high for flat areas (higher than 90%) but unsatisfactory for mounds (40–70%), due to the effect of wind erosion and geomorphological features.

To overcome this drawback, an approach, based on local spatial autocorrelation statistics applied to panchromatic imagery, such as *Moran's I*, *Geary's C*, and *Getis-Ord Gi* index, has been employed.

The first step to use the local indicators is to choose parameters to introduce in the calculation: the lag distance and the rule of contiguity.

About the rule of contiguity the queen's contiguity was chosen, because the analysis should be done in all the directions also for the curve configuration of holes.

To find the optimal lag distance global *Moran's I* and *Geary's C* were used. These indexes were calculated for different values of lag distances.

The best value is the lag that maximizes *Moran's I* (Fig. 8.6) and minimizes *Geary's C* (Fig. 8.7), allowing to capture in the best way the autocorrelation of the image. The lag chosen for all the 3 years is 2.

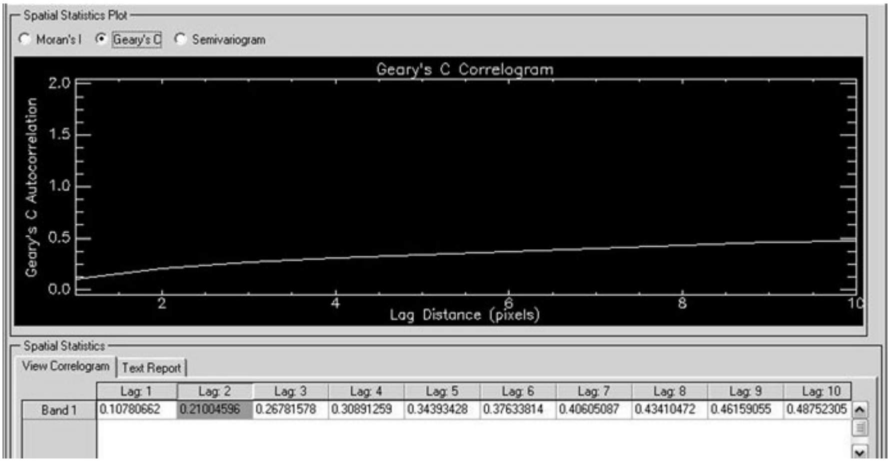

Fig. 8.7 Results obtained with global Geary's C and lag distance between 1 and 10 computed on 2002 panchromatic image

At this point the local indicators of spatial association were calculated, using the queen's contiguity.

Results obtained (Fig. 8.8) enable us to recognize and quantitatively characterize patterns of spatial dependence at multiple scales, thus making them useful in detecting archaeological features.

In particular the local *Geary's C* index (Fig. 8.8d) allowed us to better represent the rough surface, while *Getis and Ord Gi* (Fig. 8.8e) needed a classification, before to be interpreted and used.

The classification of *Getis and Ord GI* (see Fig. 8.9a, b) shows that the clusters with the best results are those characterized by low values of reflectance and, at the same time, of *Gi* and those characterized by great values of Gi. These clusters were then converted to polygons with the aim to obtain the map of the looting phenomenon (Fig. 8.9c).

As a whole, the detection of looting pits on mounds has been significantly improved (75–90%) by applying local spatial autocorrelation statistics. Such improvement is still more evident if we compare the panchromatic satellite time series with the correspondent time series processed by local spatial autocorrelation statistics (see Figs. 8.9 and 8.10, respectively).

In detail:

Figures 8.10a–c show the panchromatic scenes (2002, 2005 and 2008) related to four mounds characterized by the typical circular pits dug by grave looters. Such traces of looting are visible thanks to the micro-relief, but the spatial resolution is not enough to appreciate significant variation between 2002 and 2008.

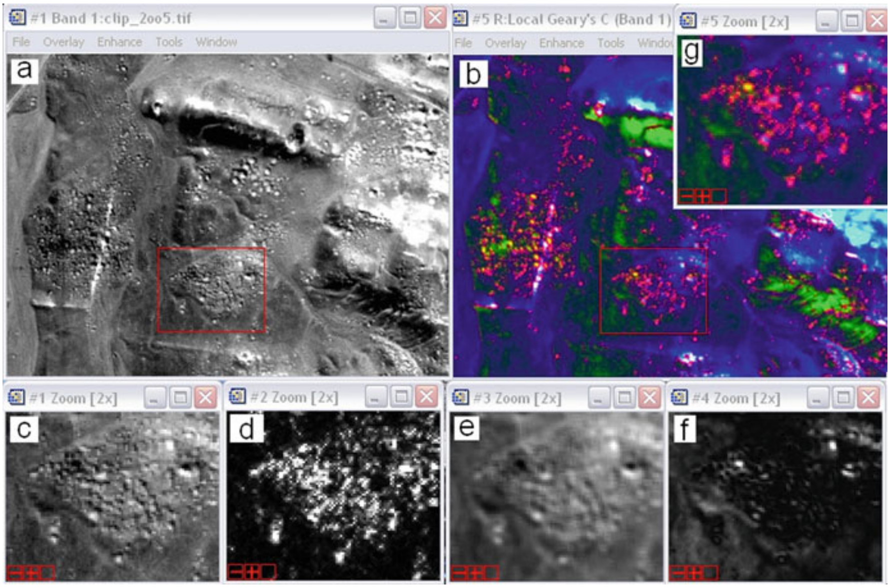

Fig. 8.8 Results obtained for 2005. (**a**) Panchromatic image, (**b**) RGB composition of the Geary's C, the Getis and Ord's Gi, and the Moran's I results. The figure shows also a zoom of the panchromatic image with holes (**c**), the Geary's C (**d**), the Getis and Ord's Gi (**e**), the Moran's I (**f**), and finally the RGB (see **a**)

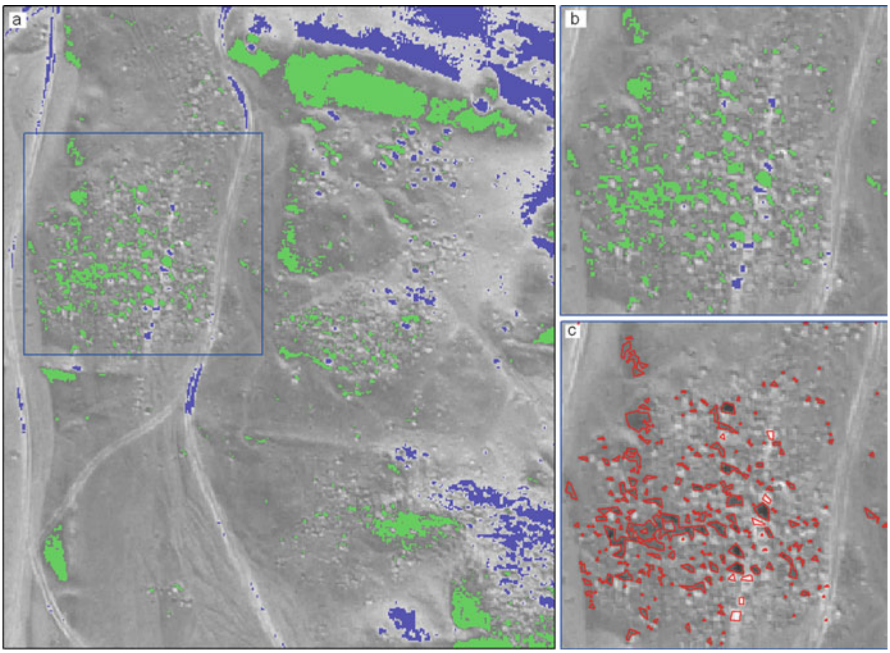

Fig. 8.9 Overlay between panchromatic image and clusters obtained with Getis and Ord's (**a**). In the zoom area (**b**) it is possible to see how clusters of low values and clusters of high values fit the holes distribution. (**c**) Conversion to vector of clusters found

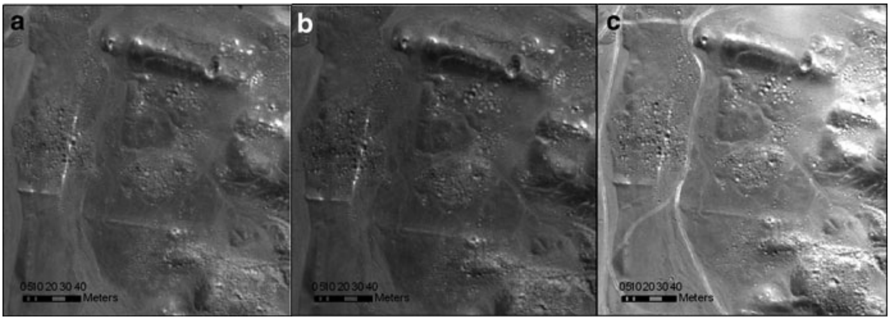

Fig. 8.10 VHR satellite panchromatic image provided in (**a**) 2002 (QB2); (**b**) 2005 (QB2); (**c**) WW1

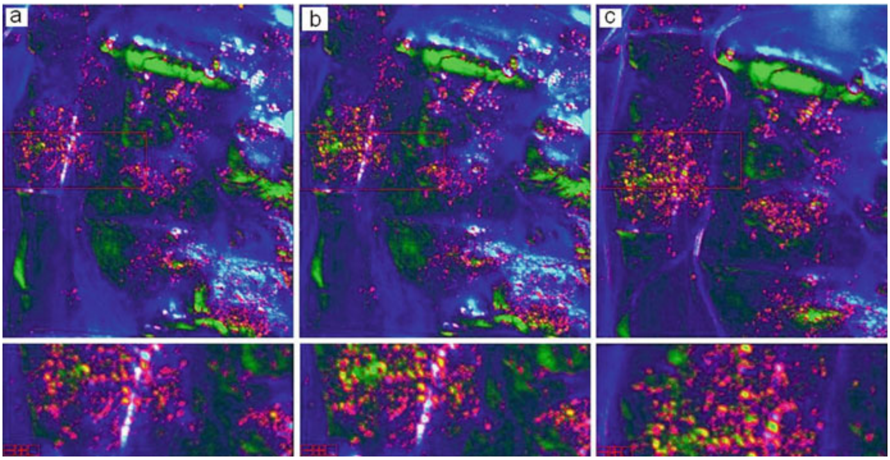

Fig. 8.11 RGB composition of Moran, Getis and Geary indices (R: Geary; G: Moran; B: Getis) applied to panchromatic images of 2002 QB (**a**), 2005 QB (**b**) and 2008 WW1 (**c**). RGB composition of Moran, Getis, and Geary indices enhances the edges of pits (*circled with magenta*). The multitemporal comparison of the three RGB images clearly shows an increasing number of pits from 2002 to 2008 and, therefore, the intensification of the looting phenomenon over the years

Figures 8.11a–c show the RGB composition of Moran; Getis; and Geary indices which does emphasize these pits enhancing their edges (yellow coloured). The multitemporal comparison of the three RGB images clearly shows an increasing number of pits from 2002 to 2008 and, therefore, the intensification of looting phenomenon over the years.

8.5 Final Remarks

"It is ironic that the fascination with the past, which motivates all possible public behaviour toward archaeological resources, also causes so much damage and destruction" (McAllister 1991). Archaeological looting is recognized as one of the most a serious threats to cultural resources throughout the world in both recorded and unrecorded sites. Many problems are associated with illegal excavations among them: (i) damaging of archaeological sites, (ii) loss of artefacts, (iii) destruction of the context of artefacts and therefore irreplaceable loss of valuable information, (iv) and denying this cultural heritage to new generation (Atwood 2006).

To contrast and limit this phenomenon a systematic monitoring is required. Up to now, the protection of archaeological heritage from illegal diggings is generally based on a direct or aerial surveillance, which are time consuming, expensive and not suitable for extensive areas. VHR satellite images offer a suitable chance thanks to their global coverage and frequent re-visitation times.

Unfortunately the spatial resolution is still a limit in detecting all the changes related to clandestine excavations. To overcome such limit a semiautomatic data processing approach based on spatial autocorrelation has been devised.

The chapter showed the results of a test performed in the Nasca Ceremonial Centre of Cahuachi in Peru. By using this approach, the detection of looting pits by VHR satellite images has been significantly improved.

The high satisfactory results encourage to continue in jointly using of VHR satellite data and geostatistics to identify traces and patterns linked to archaeological looting.

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