Review Article

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Using geospatial information sciences for the search of clandestine graves

Abstract

This review article seeks to gather recent experiences using Geospatial Information Sciences (GISc) in searching for clandestine graves. Around the world, missing persons are registered daily, and this is a current problem in Mexico that is why we seek to gather recent experiences to find some applications that may be useful. One of the main findings is that the authors agree on the importance of bringing together multidisciplinary teams and using different techniques. This review is divided into three parts: the theoretical and methodological tools of environmental criminology, the use of GISc in confinement contexts, and the use of environmental criminology in the field. Most of the items located are found in this third category, highlighting the use of remote sensing techniques and, more recently, unmanned aerial vehicles or drones.

Keywords: clandestine graves, spatial analysis, remote sensing, geographic profiling, forensic sciences, geospatial information systems

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Abbreviations: GIS, geospatial information systems; GISc, geospatial information sciences; RS, remote sensing; MESP, spatial and statistical predictive modeling; RAG, coded with green, yellow, and red colors; UAV, unmanned aerial vehicles

Introduction

Mexico's recent history is marked by an internal armed conflict that began on December 11, 2006, when just days after taking office, then President Felipe Calderón Hinojosa, in his capacity as supreme commander of the armed forces, declared a war against drug trafficking that began in his home state of Michoacán; It is worth mentioning that the antecedents of this conflict go back years, but the difference lies in the unprecedented increase in violence, since then the number of homicides and missing persons in Mexico has increased considerably and continues to this day. Coupled with this crisis of violence and after, especially the disappearance of 43 students from the Isidro Burgos Normal School in Ayotzinapa, Guerrero, in September 2014, countless graves and clandestine burials have been discovered in the country since then, efforts have increased to try to dimension the problem of violence in Mexico and the search for missing persons. In October 2017, the General Law on the Forced Disappearance of Persons was issued. However, these efforts are still insufficient and disjointed; this phenomenon makes it practically impossible to access information accurately; the collection of information and the elaboration of records are extremely complex tasks, whether from official or open sources.

To find missing persons, it is necessary to use all possible tools to search for clandestine graves in Mexico. According to the National Search Commission, there is a registry of more than 73 thousand missing or unlocated persons, from December 2006 to June 2021. The realization of studies in the current Mexican context is considered indispensable since, in practice, the authorities and groups dedicated to the search for clandestine graves require a lot of time in the field and tools that in most cases can alter the crime scene and even damage the bodies or remains; therefore, the help that can be provided from the cabinet with sufficient information about the territory, environment, and context through social and criminal characteristics, as well as remote sensing and image processing can contribute to the realization of more efficient searches. This is why we ask ourselves: How can GISc contribute to detecting clandestine graves? We look for experiences around the world and, as far as possible, everything that has been written on this subject, and thus, we decide what can help us in the Mexican case. In other words, let this great problem in Mexico serve as a precursor for a review of the use of science and geography in the search for missing persons.

This paper has two objectives: first, to review the contribution of Geospatial Information Sciences (GISc) to search efforts in other countries, whether in conflict or peace contexts, and second, to document the advances made in Mexico and some suggestions for further studies derived from this review. However, before continuing, it is important to clarify two definitions for developing this text.

First, GISc is the field of basic research that seeks to redefine geographic concepts and their use in Geographic Information Systems. This discipline also examines the effect of GISc on individuals and society and the influences of society on GIS. It re-examines some fundamental themes in disciplines that have traditionally had a spatial orientation, such as geography, cartography, and geodesy while incorporating more recent developments in cognitive and computational sciences. It overlaps with and takes elements from more specialized research fields such as computer science, statistics, mathematics, and psychology, contributing to progress in these fields. It supports political science and anthropology research while drawing elements from these fields on geographic information and society studies.[1] This definition is taken because it is considered broad and incorporates Geographic Information Systems (GIS), the use of remote sensing, and image processing.

Secondly, clandestine graves are understood to be all those places where burials, sepulchers, or holes in the ground have been made to bury one or more corpses secretly for fear of being accused of a crime before the law or to evade grave means burial, sepulcher, hole in the ground to bury one or more corpses. Meanwhile, clandestine means secret, hidden, and especially done or said secretly for fear of being accused of a crime before the law or to evade it.

This article is organized into four parts; the first section describes the materials and methods for article selection and subsequent searches and how the results were organized. In the second section, a review of works in which GISc has been used to search for missing persons in other parts of the world is presented; in the third part, a review of the main criminological theories and their relationship with GISc is presented, as well as the use of these concepts in the search for body concealment sites and, finally, some conclusions are discussed, as well as the challenges and areas of opportunity regarding the use of GISc in the search for clandestine graves and human remains.

Materials and methodology

Google Scholar was used to search for documents, and the following keywords were used in the searches, always in English: "*clandestine graves, spatial analysis", "clandestine graves, remote sensing*" and "*clandestine graves, geographic profiling*", the articles were searched in order of relevance, regardless of the date of publication. With these filters, we selected 58 academic papers. However, it was necessary to subsequently search for some key authors that appeared more frequently to detect publications related to the topic that were not detectable with the search words. Finally, 60 documents were collected for this review, including articles, book chapters, conference proceedings, and theses. Since this review is focused on the use of GISc, papers whose core areas of research were geophysics, anthropology, and forensics were discarded. Table 1 shows the grouping by major topics.

Table 1 Documents by major topics

Temas	Number of documents
Theoretical perspective: Environmental criminology and the search for clandestine graves	1 Book chapter 3 Master thesis 7Papers
In conflict context	2 Book chapters 1 Master´s thesis 1 Doctoral thesis 5 Papers 1 Conference paper
In peace contexts, experimentation sites and remote sensing techniques	2 Book chapters 1 Bachelor´s thesis 4 Master´s thesis 1 Doctoral thesis 17 Papers 1 Conference paper
Geophysics	1 Book chapters 10 Papers
Anthropology	1 Bachelor´s thesis
Forensic	1 Paper

Theoretical perspective: environmental criminology and the search for clandestine graves

The theories of environmental criminology and its fundamental concepts are important to understand how the place is crucial when a crime is committed. Therefore, GIS can help in the search for crime-related sites. According to environmental criminology, there are four dimensions to understanding crime phenomena: the legal dimension (creation and enforcement of laws), the offender dimension (dominant field of contemporary criminology concerned with offender motivations), the victim dimension (study of why certain targets are victims of crime) and the place dimension (spatial component).[2] In the present section, environmental criminology is taken up primarily as a term used to encompass a variety of theoretical approaches. All are focused on studying the environment within which a crime occurs: the rational choice perspective, routine activity, and crime pattern theories, briefly described below.

The rational choice perspective provides the basic justification for defining place as important. It suggests that offenders select goals and define the means to achieve them in a way that can be explained.[3] The idea is basically economic: an individual chooses by maximizing utility and minimizing costs. The routine activity theory seeks to explain the occurrence of criminal events as the confluence of several circumstances. First, there must be a motivated offender. Second, there must be a desirable target. Third, the target and the offender must simultaneously be in the same place. Finally, three other types of controllers (intimate controllers, guardians, and place managers) must be absent or ineffective.[3] Crime pattern theory is particularly important in understanding crime and place because it combines rational choice theory and routine activity to help explain the distribution of crime across places. The distribution of offenders, targets, manipulators, tutors, and administrators over time and place describes crime patterns. Pattern theory explores offenders' interactions with their physical and social environments that influence offenders' choice of targets.[3]

All the above concludes that location matters, which has also been considered in the search for body deposit sites. Recently, several academic papers have been published that take up these unified theories in the construction of geographic profiles, and the main question is whether these theoretical constructs that, in principle, should help to locate criminals can also be used for the location of clandestine graves or human remains.[4] In these works, the concept of *Winthropping*, initially developed for terrorist purposes, is taken up again. The basic concept is to find where a person has hidden something; we should imagine we are that person and attempt to hide the same thing.[5] In recent years, different works have put on the table the use of these theories and have proposed methodologies to contribute to the search for missing persons, agreeing that fieldwork is arduous and that it is necessary to use different approaches to try to model the behavior of the perpetrators with criminological tools that can be of help in forensic tasks.[4,6–11]

In Italy, as in other parts of the world, searches for clandestine graves are mainly guided by witness statements. Roberta Somma and her co-authors developed a GIS coded with green, yellow, and red colors (RAG) for the discovery of clandestine graves or burials, based on cross-referencing with cumulative suitability factors to host a burial, thereby showing priorities with traffic light colors and different scenarios. According to the authors, most offenders look for burial sites that have the following characteristics: 1) Soft and thick soil, the first characteristic allowing for quick and efficient burial, the second allowing for effective concealment of the body/object, 2) A flat surface or as gentle a slope as possible, 3) Little or no surface change in soil characteristics, 4) Location hidden from potential eyewitnesses, 5) Familiar location (to monitor the site), 6) Easy access on foot or by vehicle (to satisfy the principle of minimum effort), 7) Reference points to be able to monitor the cemetery (known as the *Winthropping* principle and 8) Stable areas unaffected by erosion; however, depending on the behavioral and geographic profile, offenders may prefer burials located on riverbanks or landslides. The RAG they elaborated prioritizes search zones with different layers: search area and accesses, areas of easy excavation, terrain slope (in degrees), vegetation, structures made by humans, geomorphology, visibility, land use, geology, cadastral maps, inspection visits, high resolution aerial and satellite orthophotos, elevation, terrain, and digital surface models. Its recommendations highlight cabinet support in fieldwork and the formation of multidisciplinary teams for searches (Somma, Cascio, Silvestro, & Torre, 2018). This work stands out for the number of variables and crosses that are made in a GIS to prioritize the search areas.

In conflict situations

Conflict contexts are considered internal and external wars, for example, the Spanish Civil War, the armed confrontation in Bosnia-Herzegovina, the war against drug trafficking in Colombia, and the current war between Russia and Ukraine. In all these cases, GIS have been used to search for clandestine graves and missing persons.

Derek Congram conducted his doctoral thesis on developing a spatial analysis and predictive modeling of clandestine graves during the Spanish Civil War (1936-1939). Among the materials he used were witness statements, detention sites, search sites (positive and negative), population density, roads by type, communities (autonomous and provinces), and topography of the time and preferences of perpetrators. This thesis demonstrated that the locations of clandestine graves in Spain are the result of the perpetrators' behavior, which is logical and quantifiable, and patterns in the selection of death sites were identified. According to the author, the results may help to locate more missing persons.[12]

The same author, Derek Congram, together with other researchers, used spatial statistics in the context of conflict in Bosnia and Herzegovina to analyze point patterns and thereby decrease the number of search sites. The motivation for this work is that, in most cases, testimonies are the main source of information; however, in armed conflict contexts, these may not be entirely reliable (which does not mean that they are dismissed or useless) due to the complexity of the events they may be traumatic and if some years have passed the memory may fail or even worse, the testimonies may be deliberately false. The results show that the use of spatial analysis can be useful; in an exercise with 154 finding points and with Ripley's K and L statistical tests, the null hypothesis was rejected; that is, there is no randomness in the spatial distribution. In this sense, there is a pattern of accumulation of burials, on average 10 kilometers.[13]

In 2017, Congram and his co-authors describe that the introduction of spatial data can improve the understanding of errors in data collection and processing, which can escape conventional, i.e., non-spatial, databases, In this paper they also study the case of the conflict in the former Yugoslavia, in particular in Bosnia and Herzegovina (1996-2001) and Kosovo (1999-2000), this article suggests that the spatial perspective helps to build a temporal and geographical narrative for research. This paper classifies the type of soil in which clandestine burials took place and tries to link the information of the place where the victims were last seen and the place of finding, concluding that it is not easy to make this linkage. However, they found as a relevant fact in this case that schools were used as places of shelter before the executions. In addition, it is important to consider three recommendations. First, context is key, "there will never be a model that can adequately encapsulate the complexities of clandestine disposal of bodies; a deep understanding of the conflict and culture is necessary to draw more meaningful conclusions from a model." Second, data quality is very relevant; accurate geographic coordinates are important, but meaningful interview questions that can assist in the search for the missing are just as important as extremely accurate geospatial locations. Third, the products of site prediction maps are not maps that represent the absolute location of where the graves were, but rather, the site prediction maps are not maps that represent the absolute location of where the graves were, rather, the site prediction maps show where the pits are likely to have points in common with already known pit locations and say that these maps should not be taken as absolute truth, but rather as guides to help focus search and recovery efforts.[14]

In Colombia, Carlos Molina and other researchers used a database to centralize, compile and triangulate relevant information on missing persons, activities, known criminal and paramilitary locations, military bases, police reports, and previous search and exhumation information (e.g., burial style, soil type, surrounding vegetation, location, etc.). In addition, the parallel activity of matching information from the respective victim's family was reviewed, mainly the place of the disappearance of the missing persons when known, witness testimonies when available, and the social activities of the missing persons with the available spatial location. These two steps were then used to process, classify, analyze, and visualize two planned locations for further terrain investigation. They also conducted exploratory capacity tests; surveys were conducted by probing or digging to measure the ease with which the ground could be excavated and backfilled. As a result, they developed a traffic light system (RAG, red-amber-green) to determine the most likely location for a clandestine burial. For example, in the case of soil types, those that allow easy and fast excavation (coded in green) would be preferred to soil that requires a lot of effort and time to excavate (coded in red). They conclude that GIS can be used to link geospatial (location) and other data (topography, land cover, land use, and transportation networks) with other descriptive information, such as water pollution, animal conservation, and crime recording. GIS technology is already helping intelligence-led policing predict future crime, and GIS has also successfully determined the location of clandestine burials.[15]

Another Colombian case stands out, in which the scientific organization "Equitas" together with the organization of victims of forced disappearance "Familiares Colombia" built a GIS-based tool called "Un radar para encontrarlos" (A radar to find them) in which they use spatial modeling and predictive statistics in the framework of a Regional Search Plan for the missing persons of Recetor and Chámeza in Casanare, Colombia; This work highlights the participation and accompaniment of family members in the development of maps and antemortem information. In this tool, two basic sources of information were used: the base cartography containing coverage of administrative division, urban centers, roads, vegetation cover, hydrography, contour lines, soils, climate, housing, educational centers, and geographic reference points such as hills, road crossings, etc. and the forensic information that contains data on field diligences (surveys and exhumations) whose attributes are given by the characteristics of the diligence and the findings, and testimonial information of context among which is the location of paramilitary camps, military bases, access roads, among others. The result was the construction of the Spatial and Statistical Predictive Modeling (MESP) tool, which allows open spaces of participation for the relatives of the victims in the search process and centralizes the information related to the search for missing persons from different State organizations; to have search alternatives that privilege techniques developed by archeology, geography and statistics, over the traditional forms of search based primarily on the testimony of informants and; to evidence the potential of the implementation of the National Search Plan (PNB) for Missing Persons when it is carried out in a rigorous manner and taking into account the particularities of the cases. Recommendations include the role of the victims as protagonists in the construction of the MESP and keeping the information updated with dates close to the occurrence of the disappearances under investigation. Furthermore, the success of a tool of this type depends on having sufficient geolocalized contextual information, as well as the greatest amount of data from the field (exhumations and negative surveys, without finding human remains);

lastly, it is suggested that when the field diligences are developed, the greatest amount of antemortem and genetic reference information should be available for the identification comparisons of the bodies that are recovered.[16]

Aiming to narrow down search areas in the state of Guerrero, Mexico, in the wake of the more than 300 clandestine graves found in searches following the events of the disappearance of 43 students from the Isidro Burgos Rural Normal School in Ayotzinapa, José Luis Silván conducted a study in which satellite imagery and relevant geographic layers were used to model the potential distribution of grave locations in the vicinity of Iguala, Guerrero.[17] One of the fundamental concepts developed in this work is Clandestine Space. According to this work, the illegal nature of clandestine graves forces creators to choose hidden locations. Still, also the physical geographical context imposes accessibility restrictions, especially because the movement of people against their will or of human remains requires fast and discreet transportation, so the transportation network, which added to the slope of the terrain and the type of vegetation, should play an important role, as they influence the visibility from various points of a site. These two dimensions can be quantifiable, which makes it possible to divide the geographical space into four classes: 1) Public space, areas of high accessibility and low privacy; 2) Private space, areas of low accessibility and high privacy; 3) Scenic space: has both low accessibility and low privacy and 4) Clandestine space: has both high accessibility and high privacy. In this work, it is presumed that clandestine graves are more likely to be found in the clandestine space; this is also supported by the theories of environmental criminology since, according to rational choice, the perpetrator of a crime will always look for a space that seems comfortable to achieve his goal and will also seek that there are no controls that inhibit him.[3] In this sense, delineating these spaces can provide a prioritization scheme for search tasks. Overall, this article shows how the conceptualization of geographic space in terms of the fundamental requirements for creating a clandestine grave can lead to better prioritization of search areas through geospatial models.[18]

For the case of the Guatemalan Civil War, Perla Santillán conducted her master's thesis entitled "Mass Grave Localization Prediction with Geographical Information Systems in Guatemala and Future Impacts." The objective was to determine if it is possible to predict the location of mass graves and, if so, if it was possible to determine how many individuals are in the predicted graves, as well as to create a more generalized model for predicting mass grave locations in Guatemala and other countries. One of the major challenges of this research is the lack of information related to mass graves, the location and circumstances of disappearances, as well as data on vegetation and soil conditions, and the identification of associated perpetrators such as army units and state and non-state actors. It did not reach the target on prediction. However, it has relevant findings, such as that most of the mass graves are within a specific range of distances to roads. Approximately 75% of the mass graves are less than 1 km from the nearest road, and the least cost path variable shows similar results.[19,20]

In the context of a current conflict, such as the war between Russia and Ukraine, Tressa Hobbs' master thesis explores the use of two tools for the location of clandestine graves in Ukraine. At least 15 graves have been located since February 24, 2022. On the one hand, she uses social media to locate and hyperspectral imaging to narrow down the search areas through the concentration of nitrogen in the vegetation.[21]

According to what has been observed, I found that all these works have in common the availability of data considered relevant with geolocation to carry out spatial and contextual analyses that form the basis for any study generated from the perspective of the GISc, especially they can be classified into 3 large groups:

I. Socio-criminal variables: homicides linked to organized crime, missing and unlocated persons, modus operandi, other related crimes and migration.

II. Built environment: highways and roads, ports, airports, border crossings, railways, security facilities, administrative divisions.

III. Physical: temperature, slope, altitude, precipitation, vegetation, type of hydrography.

In peace contexts, experimentation sites and remote sensing techniques

There are studies on the spatial distribution of graves or clandestine burials as an alternative to conventional forensic analysis in contexts without social conflicts or wars; this type of work has been carried out to solve serial crime cases and some experimental exercises. This section also presents controlled experiments to search for graves or clandestine burials using remote sensing and image processing; these studies can help to identify patterns and changes in the territory with the objectives of reducing the search areas and identifying characteristics that make field work more efficient. In some of these works, animal bodies have been buried, for example, pigs,[22–26] or hares in the case of the work of [27] and even human bodies.[28,29]

Remote sensing is an exploration tool that can be used to search larger geographic areas without putting research personnel at risk. Hyperspectral images acquired from aircraft or satellites provide over a hundred layers (bands) of data that can be selectively examined and analyzed to detect subtle changes in surface reflectance spectra.[22] In this work, the authors highlight that the spatial pattern of graves and the number of victims per grave can vary greatly between countries, and even between regions within a country, and may be a reflection of the confidence of the perpetrators and even, in some cases it is not always the perpetrators who make the graves, it may be the survivors who recover the bodies of the victims and bury them.

The work of Margaret Kalacska and Lynne Bell is particularly important because in the discussion they mention the conditions and care that should be taken when using this type of tools, as they have the risk of being misused inadvertently or without an understanding of their limitations, which can lead to overly optimistic results or disappointment in deliverables. In this regard, they list the key aspects to be taken into account by any analyst contemplating the use of such data: understanding the reflective and absorptive properties of the surface, taking into account the environment in which the analysis will be performed since techniques developed for one type of environment (e.g., sandy or attenuated desert) cannot be directly transferred to another (e.g., broadleaf rainforest).[22] Kalacska also participated in another of the first studies on pit detection with hyperspectral information; in this work, they examined the in situ spectral reflectance of an experimental animal mass grave in Costa Rica in a tropical rainforest environment and compared it to an identically constructed sham pit that was filled with soil but did not contain cattle carcasses over a period of 16 months. Unlike the interpretation of aerial photographs, where the information is only spatial or contextual, the multiple layers (bands) in a hyperspectral image contain other information about the surface (e.g., chemical composition) that can be interpreted from spectral responses. Thus, spatial information is not only present in the image but also enhanced by the spectral information in the multiple bands. Both natural (i.e., water, vegetation, soil, rock, etc.) and man-made (i.e., concrete, ceramic, etc.) materials have different spectral signatures that can be used to identify the type of material or target or even obtain more detailed information about the material, such as its mineral composition, type of vegetation and health, type of paint, type of construction material, among others. This analysis was extended to examine the spectral signature of the same experimental mass grave from an airborne hyperspectral image collected 1 month after burial. The results indicate that at both scales (in situ and airborne), the experimental grave had a distinct spectral signature that, therefore, was detectable in contrast to the sham grave. In addition, it was observed that vegetation regeneration was inhibited over the mass grave containing cattle carcasses for up to 16 months. This experimental study demonstrates the utility of airborne hyperspectral imaging for detecting a relatively small (5m2) pit within a specific climatic zone.[23]

In Ottawa, Canada, George Leblanc and other authors conducted a project with blind tests; the purpose was to locate buried remains of pig carcasses, which are used as human analogs. One area contained no buried remains, and the other contained the remains of at least one buried pig. The Royal Canadian Mounted Police (RCMP) provided two defined areas within the Technical and Protective Operations Facility (TPOF) site. The objective was to collect airborne hyperspectral imagery data to predict coordinates for the estimated location of the remains and compare those results to known coordinates. The true locations of the remains were only known to the RCMP, and at no time during this project were these locations or the ages of the burials disclosed to project staff. The site consists of mixed forests and clearcuts. The tree vegetation in the clearcuts is predominantly composed of broadleaf and coniferous boreal forest with a mixed herbaceous understory. The soil in the two areas of interest is composed primarily of fine sand with clay horizons at various depths. The authors point out that in areas of basic research where the spectral bands of interest are not well known (as is the case in this work), a hyperspectral imaging camera is much more useful than a multispectral imaging camera because the former collects much more information with which to evaluate. The results of this work are promising about using hyperspectral imaging to aid in the detection of buried remains.[24] However, there is still a field to be explored in the use of these images, their accuracy and changes in different environments, and the size of graves or burials.

As an alternative to intrusive and costly methods at the grave or burial sites, José Luis Silván and co-authors propose using hyperspectral images for their localization. In this sense, they simulated seven graves with different numbers of domestic pig carcasses in Yautepec, Morelos, Mexico; subsequently, monitoring was performed for six months, and 12 hyperspectral images were obtained and using standard pattern recognition methods it was obtained that hyperspectral data may have a potential to detect buried remains, but detection can only be successful after at least three months after burial. In addition, useful wavelength ranges are mainly distributed over the 700-1800 nm spectral range and with several narrow ranges that could not have been discovered using multispectral sensors; therefore, hyperspectral imaging is necessary. However, given the costs involved in acquiring hyperspectral images, further examination of simulated multispectral data is needed to determine how much less expensive multispectral images can be used to detect fossae.[30] As part of this project in Yautepec, Dozal et al. applied a Brain Genetic Programming (BP) technique to automate the design of Hyperspectral Models of Visual Attention; this proposal proposes a new method to detect buried remains. The results showed that this method is useful in classification. Furthermore, they suggest that using spectral bands that respond to vegetation and plant water content provides evidence that the number of buried bodies plays a crucial role in successful detections.[26] Silván and other researchers obtained results on the detection of simulated animal graves with different optical remote sensing techniques, showing that spectral indices can be used to detect nitrogen enrichment in vegetation. Still, it is important to consider the size and the time that has passed since the burials. On the other hand, thermal imaging is useful for detecting subway voids through differential thermography, but the size of the pits plays a determining role; in this case, this technique is only effective with large pits and on bare ground. In addition to the above, 3D terrain reconstruction models with point clouds have also been used, and this is useful for detecting growth in vegetation, but it is not enough to detect land subsidence; it is important to continue in this sense some research, since one of the first anomalies detected by people with experience in field search work is the change in land subsidence, even by centimeters.[25]

Another controlled experiment using hyperspectral imaging to detect pits or burials was the master thesis work of Anni Helena Ruotsala. This thesis aimed to determine the potential of hyperspectral imaging as a tool to distinguish unmarked pits from other similar-looking soil disturbances also in a dry, temperate environment. In previous studies, differences in vegetation growth over a pit and other ground disturbances were the key factor in spectrally distinguishing a pit from the respective ground disturbances. However, the performance of hyperspectral imaging to distinguish pits from other ground disturbances has not been studied so far in a dry, unproductive environment.[27] In this experiment, an empty control pit and one with a hare carcass were used, and monitored with a hyperspectral camera at the burial; one week later and three weeks later, for analysis, an unsupervised classification method (ISODATA) was used that assigned the image pixels in each image to six spectrally distinctive classes: grave, control pit, vegetation, stones, and white and grey reference target.[27]

In the experimental work carried out by Blau and his co-authors in Australia, six pits were created, three with human bodies and three control, to evaluate the differences between individual graves or with more than two bodies; in one pit, only one body was placed, another with three bodies and a final one with six, each grave was excavated to various depths to see if the depth as a variable potentially influences the detection when there are no bodies (control graves) comparing the depth of these graves with the bodies. Constant 24-hour monitoring was maintained over a three-year period; the site is located within a dry Cumberland sclerophyll forest (eucalyptus forest). The natural tree canopy creates a relatively dense but uniform canopy. They recorded data on temperature and humidity, time-lapse video, and an image every 10 minutes to record changes in the grave fill; images were also taken with drones equipped with multispectral sensors, combined with terrain elevation models, the latter served as a basis for future studies of light detection and ranging in the air (LiDAR) or 3D laser scanning. In addition, botanical surveys and collection of soil samples for chemical changes were completed. This is one of the studies that record different variables to evaluate changes over time; the results confirm that it is important to consider where the burials or pits are carried out; all this can change and depend on climate, vegetation, humidity, and elapsed time.[28] The burials were conducted in the winter of 2016, and some of the results were published in 2021.[31]

All these studies require a long time to monitor the results, but significant progress has already been made. However, it is necessary to consider that regions change, and it will be difficult to apply the results in different areas with different characteristics, especially on the type of vegetation and climate. In fact, thanks to the low-cost commercial access of some drones or unmanned aerial vehicles (UAVs), recent studies have made significant advances in the use of photogrammetry for the search of clandestine graves and human remains.[32–36]

Conclusion

The armed conflict in Mexico has now lasted 18 years, a considerably long time. It will surely continue to be studied for a long time to come and from the multiple angles that such an event deserves. GISc will be vital as a tool for understanding complexity and processes across time and space. Some conflicts have been years in the making before they are studied from GISc perspectives, for example, The Holocaust. In that case, it will surely take a few more years to study the concealment of human remains in Mexico due to the "war against organized crime" and the registration of more than 100,000 disappeared persons. The statements and testimonies are a primary source of information for the findings of clandestine graves, not only in Mexico but in all the cases that have been reviewed and are very relevant, but that does not make the searches in the field any less laborious and hard. In this sense, the GISc can provide tools to make this work more efficient as a complementary way to the testimonies and help identify places where these statements have not yet been searched or have and that present similar characteristics to those that have been observed in other sites with already confirmed findings. Some variables that could be included in the models that are already being carried out in Mexico[37,38] the form of points, in accordance with what has been reviewed in other cases, in addition to primarily having the sites of positive and negative findings with dates and locations as precise as possible: military headquarters and places of detention, prisons, shelters and migratory routes and border crossings.[39–64]

The findings of clandestine graves represent a difficult, complicated, and time-consuming detection problem. In most cases, information from the perpetrator or witness statements is necessary. Other detection methods that have been used are geophysical resistivity, magnetometry, and ground-penetrating radar. However, these methods require that the location of the grave or burial site be known accurately and that personnel be able to walk the grave site to conduct data collection physically. One of the coincidences in all these authors is the need to form multidisciplinary teams to complement forensic sciences, such as remote sensing, psychology, anthropology, sociology, and spatial analysis, among others, to try to predict or delimit search areas. Due to its context and diversity of climates, the case of Mexico may represent an opportunity for research development. This is why we seek to compile the most relevant works on the search for clandestine graves and organize the advances made from a theoretical perspective to study how the environment influences decisions to make certain sites more favorable for the concealment of bodies or human remains, according to the modus operandi of the perpetrators. Furthermore, we consider that the use of GISc and environmental criminology are useful tools for the search; bringing together these two aspects is considered relevant. Beyond their use in the current emergency in Mexico, they contribute to establishing methodologies and enriching the contributions of different disciplines to the forensic sciences.

This review is useful for future work since it combines various research that is the basis for determining theoretical elements of environmental criminology and combining them with GISc tools to analyze various variables in time and space, with various objectives. For example, a better understanding of the phenomenon of disappearance in different regions and compare, analyze specific sites reported by witnesses, and focus forensic work. Finally, it is important to note that one limitation of this work is the possibility of having left out some works due to bias in the search words; a pending task would be to continue updating this collection.

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Conflicts of interest

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