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FORENSIC GEOLOGY APPLIED TO THE SEARCH FOR HOMICIDE GRAVES

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Abstract. The percentage of discoveries due to traditional and non-traditional searches for homicide graves is still meager in Italy. A critical exam of the scientific approaches followed by Italian law enforcements, in recent cases of unsuccessful ground searches for homicide graves, should be seriously done for evidencing the possible errors done. In order to assist law enforcements in the ground searches, the present research reports on: i) the appearance of a clandestine grave with the related main characteristics; ii) the factors influencing the choice of the burial site; iii) the modern approaches usable during ground search activities as proposed by UK experts; iv) the main results of remote sensing investigations and the Red-Amber-Green search prioritization system carried out for the search for three different clandestine graves.

1. Introduction

Concealments by burial may be used by criminals and criminal organizations for illicitly hiding weapons, moneys, stolen goods, and corpses in the subsoil (France *et al.* 1997; Ruffell and Wilson 1998; Ruffell 2002, 2004, 2005; Manhein, Listi, and Leitner 2006; Salsarola and Cattaneo 2009; Harrison 2011; Larson, Vass, and Wise 2011; Pringle *et al.* 2012; Donnelly and Harrison 2013; Ruffell *et al.* 2017; Sagripanti *et al.* 2017; López Batista, Rodríguez López, and Fieguth Batista 2018; Rocke, Ruffell, and Donnelly 2021; Rocke and Ruffell 2022; Somma 2022; Somma and Costa 2022). The selection of the gravesites may be influenced by the geography of the sites, a factor conditioning the criminal behavior of the concealer. The approach used by investigative psychologists with the Geographical Profiling (Canter 2003; Hirschfield and Bowers 2003; Douglas *et al.* 2006; Kamaluddin *et al.* 2021; Berezowski, MacGregor, Ellis, *et al.* 2023; Somma 2023b; Somma and Costa 2023) may overlap with some purposes of the search for concealed bodies in underground by forensic geologists (Murray and Tedrow 1975; Tindall 1994; Murray 2004a,b; Pye 2005, 2007; Pringle and Jervis 2010; Fitzpatrick and Donnelly 2021; Somma and Costa 2022; Somma 2023c; Somma and Costa 2023).

In cases of missing persons[1] for which the burial/concealment of a corpse underground is suspected, a team of experts may be involved in the search for the location of a homicide grave. In countries, such as UK, an expert or a team of experts may be involved in ground searches for clandestine burials, based on traditional and non-traditional methods. These searches usually lead to encouraging results.

In Italy, most of the clandestine burials have been found as a fortuity by passers-by, runners, hunters, mushroom searchers, or thanks to the indications of witnesses and informants, included self-confessed offenders or concealers. Unfortunately, the percentage of success, due to traditional and non-traditional searches conducted by police forces and experts, is still meager in this country. As demonstrated by the recent case of the young woman disappeared at Novellara (Reggio Emilia, Italy), notwithstanding the impressive deployment of forces (over 500 *carabinieri*, and other forces), resources, canine units, and instruments (drones, electro magnetometer, and Ground Penetrating Radar - GPR), searches were unsuccessful and the body was found buried in a grave only thanks to information provided by one of the self-confessed concealers who brought the *carabinieri* on the gravesite, indicating the precise site of the burial.[2]

These discouraging results could cause the Italian judicial system and law enforcement officials to determine the use of geophysical instruments is not useful during search activities.

A critical exam of the scientific approach carried out at Novellara or in any other site where ground searches were unsuccessful should be seriously considered for evidencing the possible errors done, in order to achieve better results in the next future. With this in mind, this paper was aimed to improve the knowledge on the topic of crimes involving corpse concealment to render this information available for judicial authority, law enforcements, and lawyers. The main contents on this topic were: i) the appearance of a clandestine grave with the related main characteristics; ii) the factors influencing the choice of the burial site; iii) the modern approaches usable during search activities for clandestine graves as proposed in UK (Donnelly *et al.* 2021); iv) the main results of remote sensing investigations carried out for the search for three different clandestine graves, two simulated caseworks and one real criminal case.

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[1] *Commissari.gov.it. Commissario Straordinario Del Governo Per le Persone Scomparse. Report Primo Semestre 2022.* *https://commissari.gov.it/persone-scomparse/* (Accessed online 15 January 2023).

[2] *"Chi l'ha visto?"* *http://www.chilhavisto.rai.it/dl/clv/index.html* (Accessed online 25 November 2022).

https://mediasetinfinity.mediaset.it/video/quartogrado/il-giallo-di-saman-le-immagini-del-casolare-dove-sepolta-saman_F312094901011C13 (Accessed online 25 November 2022).

https://mediasetinfinity.mediaset.it/video/quartogrado/il-giallo-di-saman-aggiornamenti-sulle-ricerche-del-corpo_F312094901011C09 (Accessed online 20 Dicember 2022).

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https://mediasetinfinity.mediaset.it/video/quartogrado/il-giallo-di-saman-le-immagini-del-casolare-dove-sepolta-saman_F312094901011C13 (Accessed online 20 Dicember 2022).

https://mediasetinfinity.mediaset.it/video/quartogrado/la-tomba-nel-casolare-chi-ha-ucciso-saman_F312336501008C52 (Accessed online 20 Dicember 2022).

2. Clandestine grave characteristics

Illegal burials may be done outdoor in the countryside or in buildings (cellar, garage floors, wall). The knowledge of the main characteristics of a clandestine grave in outdoor environments is paramount for the search personnel who should be aware of the aspect of a grave should have to recognize a site suspect.

When searching for a clandestine gravesite, investigators should use the principles and practices of forensic taphonomy to aid in their search. Forensic taphonomy deals with the symbiotic relationship between the process of decomposition and the surrounding environment. This is directly applicable to the concept of clandestine gravesite detection because the process of digging and recovering a grave as well as the body decomposing within the grave will alter the surrounding environment in a way that is detectible by investigators. These environmental changes to soil and vegetation can be detected using both visual observation and instrumentation.

The digging of a pit may produce the destruction of the underground stratigraphy. The original soil layers and bedding of the underlying bedrock may be destroyed. This activity and the consequent infilling of the dug soil determine the interruption of the natural stratigraphy against sub-vertical walls of the pit and the lateral transition to heterogenous and not layered materials. The homicide graves show different shapes in plan and section views depending on the instrument used for digging them. The two-dimensional (2D) shapes in plan-view are mostly elongated with a length and a width equal to the height and largeness of the victim, respectively. These elongated shapes may exhibit ovoidal, foot-like (Figure 1) (Somma and Costa 2022, 2023), or rectangular perimeters with rounded or angular edges. The three-dimensional (3D) shapes are likely to be parallelograms or with a bathtub-like forms. The grave depth depends on the force and ability of the digger, the digging instruments, and the available time for the excavation.

Shallow graves with rounded edges are generally dug with hand instruments (pickaxe, spade, shovel) and are characterized by a depth ranging from 0.30 to 1-1.5 m (mean value of 1 m). Excavations showing rectangular perimeters with angular edges and depths over 2-2.5 m are generally dug with mechanical excavator.

Many homicide graves may show some significative surface anomalies: i) a relief over the grave due to the exceeding soil/sediment (on its turn due to its increased porosity and introduction of volume represented by the corpse) present since the burial realization; ii) a depression over the grave due to the decomposition of the corpse, the subsidence of the ribcage, and skeletonization *phenomena*. The appearance of the depression occurs after the burial in function of the speed of human decay, depending on the soil/sediment composition, texture, structures, soil water contents, and climate. Moreover, a pool of rain water may appear in the depression.

Other anomalies that may be present on the grave may be represented by surface markers such as: i) different colour and texture with respect to the surrounding soil/sediment; ii) vegetal components (leaves, branches) partially covered by soil/sediment and arranged at high angle with respect to the surface (Figure 2a); iii) the occurrence of peculiar entomological *fauna* (Byrd and Castner 2009; Byrd and Sutton 2023); iv) absence of vegetation or differences with respect to the surrounding vegetation (different plants, such as *Asphodelus*

L., regrowth, and heights). The frequency of occurrence of these anomalies is generally associated with the time between burial and discovery.

There are two main timeline groupings associated with visual characteristics of a clandestine grave: recent and extended. While there is much variation in interpretation, recent graves are generally those that are days, weeks, or less than 6 months old. That is, for gravesites to be considered recent, the time between when a suspect initially dug the grave that contains the decomposing remains and the discovery of the gravesite by investigators should be no greater than 6 months. Recent gravesites are often characterised by raised areas over the grave due to soil displaced by the remains within the grave. The soil within and atop the grave may be variegated and intermixed with still-green grass, leaves, or other vegetation. The foil adjacent to the grave may have excess soil piled nearby that was left over from the process of digging the grave; this adjacent soil is called overburden.

Often, the offender may seek to conceal their attempts at burying remains through the use of concealment attempts. The anomalies associated with burial sites, after infill with the previously dug soil/sediment or the available material, may be camouflaged by the offender/concealer, to avoid that these could attract the attention of others leading to the discovery of the illicit action. As a matter of facts, the concealing of the burial site may be realized pounding the relief of the excess material (Figure 3) to level it or covering it with anthropogenic (garbage, wooden beams, bricks, mattresses) and natural materials (leaves, branches, trunks) available on the site. With the time, it is note-worthy that also a natural concealment of the illicit grave will occur due to the leave cover effect related to the weather conditions (rain and wind). In certain circumstances, the burial is concealed by the cementation of the grave with a layer of lime or cement.

By contrast to recent graves, extended graves are generally those that are a year or older. Of course, it is not unusual for a gravesite to be discovered in the period of 6 months to 1 year after it was initially buried. Gravesites within this timeline are considered to be intermediate and may possess some characteristics of both recent and extended gravesites as it represents the transitional phase in the process of taphonomic and environmental change to a gravesite. Intermediate gravesites often have areas that are barren and lacking foliage associated with the decomposition process being harmful to the growth of plants. As the timeline for intermediate gravesites trends toward extended – that is, approaches 1 year or longer since burial – the vegetation will begin to regrow in the area above and around the grave. The vegetation associated with an extended grave is frequently larger, healthier, and greener than the same species of plants in the same general vicinity. This is due to the benefits of the aerated soil accomplished in the process of digging the grave. With extended gravesites, there may also be a depression in the area of the gravesite due to volume loss of the remains from the decomposition process as well as the compaction of the soil over time.

Clandestine graves, camouflaged or not, exhibit another significant anomaly regarding the porosity and aggregation state of the material used for infilling the excavations. This material shows a reduced density with respect to that of the surrounding terrains, because of an increased porosity due to the mobilization of the granular structure. This porosity with the time tends to decrease in function of the composition and texture of the terrains, rains, climate, and environmental conditions. Experimental fields with simulated graves showed that the initial porosity may be reacquired in several years.

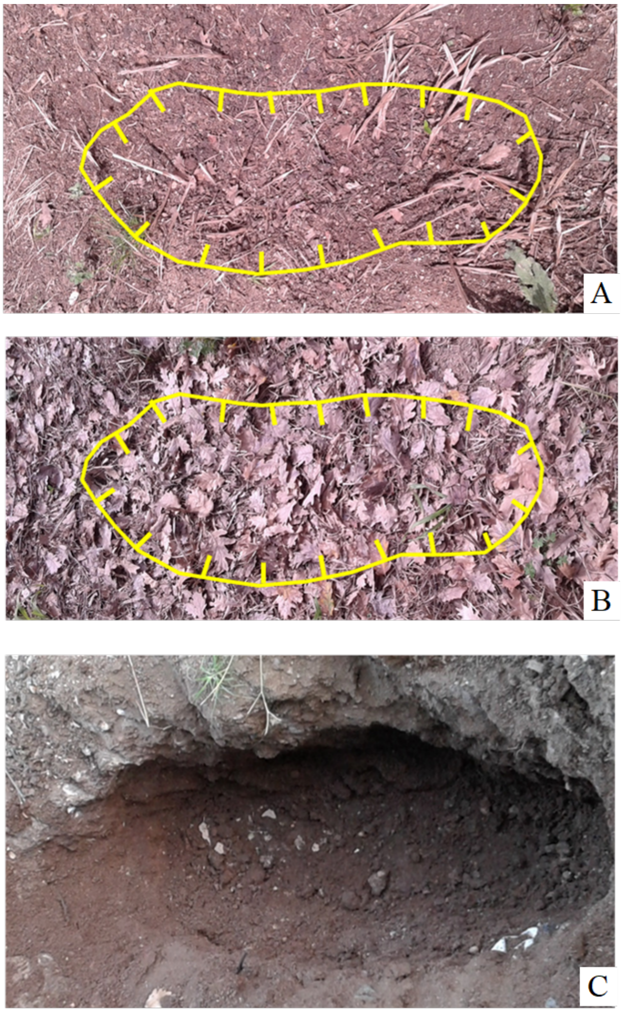

FIGURE 1. Simulated homicide grave. A) The grave was concealed by dry oak leaves. B) The depression associated with the grave was visible after the removal of the leaves. C) Open grave after the stratigraphic excavation. The corpse was simulated by a bust of a plastic mannequin inside a garbage bag. The line in yellow indicates the perimeter of the excavation. Source: Authors.

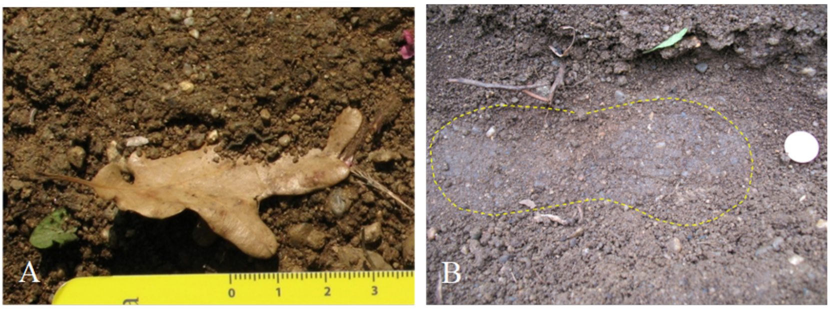

FIGURE 2. Simulated homicide grave. A) A leave of oak appears partially covered by sediments and arranged transversally to the ground surface formed above due to the exceeding material. The leave was mixed to the sediments during the infilling of the grave. B) Bottom of the grave showing a footwear imprint. This evidence, collected after the recovery of the overlying plastic bag containing the body simulated by a plastic mannequin and the infilling sediments, was conserved being protected by the plastic bag. Source: Authors.

FIGURE 3. Simulated homicide grave showing the relief formed above due to the exceeding material, after the reinstatement of the sediments. Source: Authors.

The appearance of a grave changes in the time and space, because the burial site undergoes a series of *phenomena* due to exogene and human decay processes. Figure 4 synthesized the evolution of a clandestine grave dug outdoors in the countryside. During the initial stages, the surface of the grave may be characterized by the presence of a relief (Figures 3 and 4 - 1). Remnants of the excavation material may be present, stretched on the lateral sides of the grave or concentrated in a pile. Evidence of the margins of the excavation, due to the cut of the digging instrumentation, may still appear on the ground surface. The surface of the grave is usually devoid of vegetation cover or may exhibit some dry or broken plants (Figure 4 - 1). Rain water may infiltrate in the grave and Volatile Organic Compounds (VOCs) are realised in the atmosphere and the geological material overlying the body, due to the human decay *phenomena* (Figure 4 - 2). New plants, analogus to those present in the surrounding area, may grow up on the relief, but different *genera*, such as *Asphodelus L.*, 1753, may appear over the grave (Figure 4 -2). During stage 3, the wheatering and erosion level out the original relief. A depressed area may develop in the zone of the grave surface corresponding to the chest, due to its collapse. Human leachate is realised by the body and a leachate plume develops in the ground underlying the body, infiltrating and expanding in the sediments. The shape and dimensions of the leachate plume depends on the hydrological features of the sediments (porosity, permeability, ground water), the slope, and the tectono-stratigraphic setting of the underground. Vegetation cover continues to grow up over the tomb (Figure 4 -3). Finally, during stage 4, the previously described depression extends its surface amplitude in corresponance of the entire body, skeletonized at this stage. The rise of the plants is similar over and surrounding the grave.

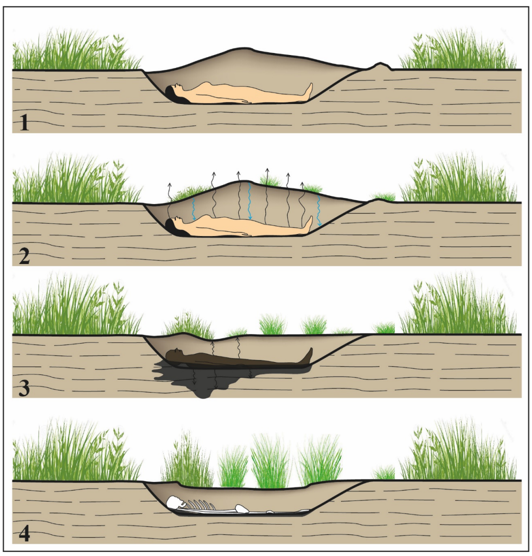

FIGURE 4. Evolution of the main *phenomena* occurring in a clandestine grave dug outdoors in the countryside and the corresponding stages. Source: Authors.

3. The search for clandestine graves

The searches for missing persons or illicit objects, suspected to be buried and concealed in the ground, may be offensive or defensive, depending if the search is carried out, respectively, after or before a crime is committed (Donnelly *et al.* 2021). These searches require complex investigations, mostly inspired to military techniques (Doyle and Bennett 1997), aimed to inspect, identify, and evaluate sites exhibiting anomalies or peculiar physical or chemical characteristics on the surface, subsurface, and underground. The ground search activities imply the involvement of police officers, cadaver dogs, and experts in forensic geology. A multidisciplinary team working with the common effort to find and recover the victim (or other concealed targets, such as money, stolen goods, Spoto 2023) may involve disciplines, such as stratigraphy, sedimentology, palaeontology (Marra, Di Silvestro, and Somma 2023; Somma *et al.* 2023a; Somma and Maniscalco 2023), geomorphology, geomatics (Davenport 2001; Valenti and Nardini 2004; Herrmann and Devlin 2008; Wolff and Asche 2009; Elmes, Roedl, and Conley 2014), applied geophysics, hydrogeology, geochemistry (Spoto, Somma, and Crea 2021; Spoto, Barone, and Somma 2023), taphonomy (Marra 2023; Somma 2023c) and many other forensic fields, such as legal medicine (Baldino *et al.* 2023; Somma *et al.* 2023a,b,c,d), forensic anthropology, archaeology (Tagliabue *et al.* 2023a,b), geographical profiling (Somma 2023b), botany (Brown 2006; Morabito, Mondello, and Somma 2023; Morabito and Somma 2023; Somma 2023a), and entomology (Byrd and Castner 2009; Byrd and Sutton 2023).

3.1. Search strategy. In Italy, until recent times, the involvement of forensic geologists in the search activities during ground searches was low. The most used search strategies usually consisted of visual and line searches involving police, firemen, and military officers, or untrained volunteers, and cadaver dogs with handlers. In some circumstances, suspected sites or localities suggested by informers were investigated by means of the use of non-destructive geophysical methods such as GPR or magnetometer, or directly through excavations by means of hand instruments or mechanical excavators.

It is important for investigators to recognize that the use of instrumentation such as GPR is not always as simple as it may seem and does not always yield a clear and immediate answer. These techniques help investigators to identify what are called "anomalies", which may be items of investigative and forensic value such as soil profiles, grave margins, human remains, weapons, or other items of evidence. However, these techniques also detect other anomalies that may not be of forensic significance such as tree roots, block of concrete, or other buried debris. It is critical for the investigator or other qualified equipment operator to ensure that they are properly trained in the operation and interpretation of data for application to medicolegal casework.

In United Kingdom, until 90', great attention was paid to the improvement of a specific and articulated search strategy. A Geoforensic Search Strategy (GSS) is defined as *"the design, management and implementation of a ground search based primarily on geological principles, methods and techniques and combined with low enforcement intelligence, tactics and operational support. The GSS shall be based on the concept of a Conceptual Geological Model (CGM), an evaluation of diggability and an assessment of the likely detectable items, to provide a High-Assurance Search for the presence or absence of a specific target being sought"* (Donnelly *et al.* 2021). Table 1 synthesizes the idealized search strategy organized in pre-search, search, and post-search phases and thirty different stages (Donnelly *et al.* 2021).

TABLE 1. Main phases of a search strategy and related stages (from Donnelly *et al.* 2021).

Pre-search phase	**Search phase**	**Post-search phase**
"Define search type"	"Methodology"	"Invasive investigations"
"Briefing"	"Marking and recording search activities, GIS, geomatics"	"Forensic recovery"
"Geolocation"	"Controls"	"Forensic recording"
"Desk study"	"Detector dog survey 1"	"Levels of assurance and search report"
"Reconnaissance"	"Geophysics"	"Exit strategy"
"Search boundary"	"Probing"	
"Environmental, geographical, and behavioural profiling"	"Detector dog survey 2"	
"Feature focused survey"		
"Detectability"		
"Diggability"		
"Red-Amber-Green (RAG) map of diggability"		
"Conceptual Geological Model"		
"Select search assets"		
"Management and logistics"		
"Written search strategy and SOP"		

3.2. Near- and far-field search activities. Near- and far-field activities and geophysical prospecting techniques may be accomplished during the search phase.

Among the most common near-field activities there is the visual inspection of the sites, also known as visual line or comb-like search, police officers and volunteers are aligned and side by side, and walk simultaneously to inspect the area. The search for recent clandestine burials is primarily devoted to the search for potential disturbances and anomalies in the soil or sediment outcrops and vegetation. During the initial evolutive stages of a clandestine grave (Figure 4), the visual search is easier then when the body becomes skeletonized, if no surface expression, such as a depession, is not particularly evident. Moreover, the original properties of the infilling sediments, such as the consistency and porosity, tend to be reacquired with the time depending on climatic conditions and sediment composition, texture, and composition. This was observed in experimental fields disposed at the scientific *campus* of the Messina University by applying the T-bar test. After five years, the penetration of the T-bar was identical on and around the grave, indicating a consolidation of the infilling sediments.

The main near-field instruments used for detecting underground anomalies (on the base of the related detectability of the targets) may be (Ruffell and McKinley 2005, 2008; Ruffell 2010; Ruffell and McAllister 2015; Ruffell and Barry 2021):

i metal probe (T-bar) for detecting variation in the soil density and soil probe for detecting the underground stratigraphy;
ii GPR for detecting a target on the base of the diffraction *hyperbola* displayed in the penetrating radar slices, in the images of the electromagnetic reflections or diffraction waveforms;
iii electro-magnetometer for detecting a target on the base of variations in the electrical properties;
iv magnetometer for detecting a target on the base of variations in the magnetic susceptibility;
v geo-resistivimeter for 2D and 3D Electrical Resistivity Tomography (ERT) for detecting a target on the base of resistivity/conducibility anomalies,
vi gravimeter for detecting a target on the base of small variations in the Earth's gravitational field;
vii Gas Chromatography Mass Spectrometer (GC-MS) for detecting the release of VOCs from the underground.

The initial work with far-field activities, such as remote sensing surveys may be carried out during the investigation's first steps.

Non-invasive examination of the search area may be carried out by using high resolution aerial images acquired via drone, helicopter, plane flights by means of camera, thermal camera, Light Detection And Ranging (LiDAR), photographs in the visible, infrared, or other frequencies provided of a resolution adequate to the burial sizes search. The acquisition of recent aerial photographs by drone flights is strongly recommended. From these imageries, the DTMs (Digital Terrain Models) and DSMs (Digital Surface Models) may be extracted providing powerful search tools for searches. The DEM (Digital Elevation Model) provides a georeferenced fly-through view of the terrestrial surface, which is essential for ground searches, georeferenced topographic expressions relating to suspect burials, and detailed images of vegetation anomalies from the DTMs and DSMs analyses carried out in Geographic Information System (GIS) platforms (Ruffell and McKinley 2008; Bunch, Kim, and Brunelli 2017; Somma *et al.* 2023a).

The far-field activities may also be supported by another search method, useful in certain circumstances in terms of economic and human resources, and known as the Red-Amber-Green-coded (RAG) prioritization system (Table 1). Significant contributions to this system were previously provided by Ruffell and McKinley (2008), Donnelly and Harrison (2013), and Ruffell and McAllister (2015).

3.3. The method of the GIS-based RAG-coded priority search maps and search *scenario*. Recent research devoted to a more complex elaboration of the RAG system was provided by Somma *et al.* (2018) and Somma and Costa (2022, 2023). This new approach in the elaboration of the RAG system was developed in GIS-platform and implemented after having examined tens of burial sites, outdoors, for individuating the main features exhibited by the burial sites and understanding if some of them were common. Among the analysed characteristics, being several features recurrent and associated with the burial site, these were used in the geological conceptual model at the base of the GIS-based RAG system. Most of the burial sites resulted associated with the following characteristics:

(i) soft and thick soils or sediments, therefore easily diggable, allowing a quick and efficient concealment (diggability factor);
(ii) surfaces of the ground level from sub-horizontal to slightly dipping (landscape/slope factor);
(iii) stable areas not affected by erosion or landslides (geomorphology factor);
(iv) cover effect by potential eyewitnesses (visibility factor) due to infrastructures (urbanistic factor) or vegetation (vegetation factor), if the concealment occurred during daylight.

On the base of the above, a conceptual model and the related GeoDataBase were structured considering the areas "suitable" to host the burial. Seven factors/entities were reported in GIS layers: 1) Search Area and Access/Exit, 2) Diggability, 3) Landscape/Slope, 4) Vegetation, 5) Human-made Structures, 6) Geomorphology, and 7) Visibility. Such factors, excluded the first one, were classified into three Red, Amber, and Green color-coded classes corresponding, respectively, to high, medium, and low "suitability" to host a burial site. The procedure was distinguished in two phases: 1) the elaboration of the GIS-based RAG maps of the geographic factors; (ii) the elaboration of the GIS-based search *scenarios* based on the cross-referencing of all the data from the different GIS layers of phase 1, assigning a cumulative color-coded high, medium, and low suitability to host a burial for each entity. In the search *scenario* map, the Red code was provided to each point where crossed codes were Red in six RAG maps; the Amber code was provided to each point where crossed codes were Amber in six RAG maps, or in the case of a total of six Red- and Amber codes with at least one Amber code; the Green code was provided to each point where crossed codes were Green in six RAG maps, or in the case of a total of six RAG colors with at least one Green code.

The obtained GIS-based RAG *scenario* search priority map provided the high (Red), medium (Amber), and low (Green) priority areas to be used during ground searches for clandestine graves. Further elements that must be taken in consideration are related to the distances. The illicit gravesites are generally easily accessible by the concealer on foot or by car, and in particular the maximum distances walkable on foot by the offender, transporting a corpse, is usually lesser than 150 m from the site where the transport starts (Somma et al. 2018). Finally, the burial sites are commonly familiar and well-known to the concealer and may exhibit reference points for monitoring later the burial site (known as the Winthropping principle).

3.4. Case studies. A case of ground search for clandestine grave was assigned to one of the authors (R.S.) in recent times. The search was planned considering a pre-search, search, and post-search phase. During the pre-search phase, remote sensing analyses of recent aerial and satellite imagery was done and RAG prioritization search *scenarios* were elaborated. The near-field activities of search for anomalies in the surface, sub-surface, and underground were carried out in the field applying first of all the visual inspection, mostly in comb-like line, and with the assistance of dog handlers and cadaver dogs. A few sites suspect to have host a burial was identified and verified. Sites covered by stacks of branches, of rocky blocks, and mounds of sheep hair, after their removal, were investigated by using the T-bar followed by detector dog surveys in order to search subsurface anomalies.

After a week of searches, the human remains of the missing person were found on surface by a volunteer (expert of the sites), concealed under the Mediterranean maquis shrubs.

Other ground searches for clandestine graves were carried out in other three case studies localized in the following areas of the Peloritani Mountains and Etna volcano (Sicily, southern Italy): 1) Alì, 2) Messina, and 3) Catania (Figures 5 and 6). The Alì and Messina concealments were realized in fields simulated by one of the authors (R.S.), whereas the Catania case regarded a real crime scene. All the concealments occurred during the daylight.

The Alì clandestine grave was realized in a private countryside cultivated with olive trees. The body was simulated by a plastic mannequin contained in a plastic bag. The shallow grave was dug in 2015 with a mechanical excavator in the pedogenized sandy soil developed on Paleozoic phyllites of the Mandanici Unit (Somma, Martin-Rojas, and Perrone 2013).

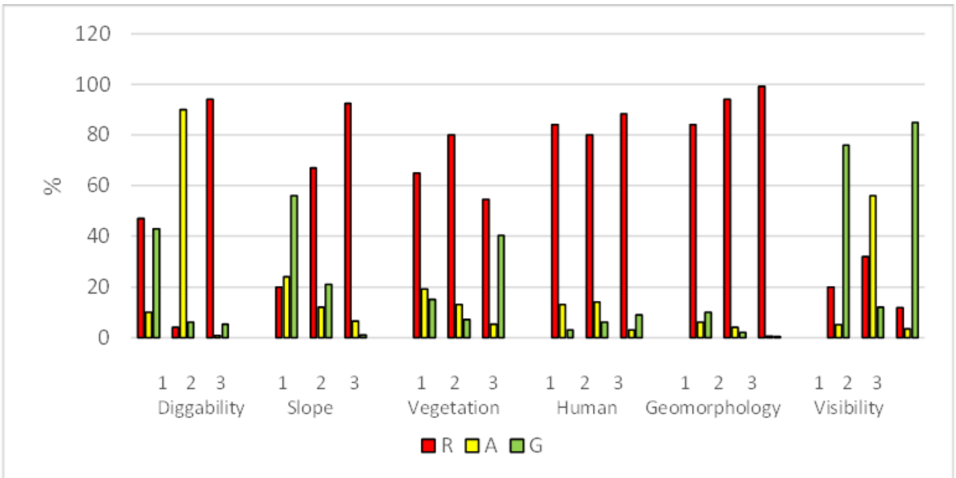

FIGURE 5. The six GIS-based RAG maps for the selected factors elaborated in the three case studies localized in: 1) Alì, 2) Messina, and 3) Catania. It is possible to observe as the visibility factor is one of the most significative parameters to influence the suitability to host a clandestine grave, due to the Red low values ranging from 11 to 30%. Source: Authors.

The Messina clandestine grave was realized in the countryside of the university *campus*, in an abandoned field with oak trees (Figure 1). The dismembered body was simulated with a *torso* of a plastic mannequin contained in a plastic bag. The shallow grave was dug in 2017 with hand instruments (pick and shovel) in the pedogenized sandy gravels of the middle-upper siliciclastic deposits of the Messina Formation.

The Catania clandestine was dug by the killer in an abandoned field of the Mediterranean maquis. The body was contained in plastic bags. The very shallow grave was dug the day before with hand instruments (spade and shovel) in the pedogenized volcanic sands of the Holocene San Giovanni La Punta Formation (Somma and Costa 2022).

For each case work, after considering the geological conceptual model, six GIS-based RAG maps, related to Diggability, Landscape/Slope, Vegetation, Human-made structures, Geomorphology, and Visibility, were elaborated (Figures 5 and 6). In particular, the visibility RAG map was based on the DSM, including this latter the vegetation responsible for a covert effect. The GIS-based RAG *scenario* search priority maps were finally elaborated cross-referencing the six RAG maps, in order to obtain the cumulative color-coded high (Red), medium (Amber), and low (Green) suitability to host a clandestine grave (Figure 6). The RAG priority search *scenario* maps (Figure 7), elaborated by cross-referencing the above reported six factors, showed the following percentages (Figure 7):

(i) Alì - Red code 6%, Amber code 6%, and Green code 88%.
(ii) Messina - Red code 2%, Amber code 33%, and Green code 65%.
(iii) Catania: Red code 5%, Amber code 2%, and Green code 93%.

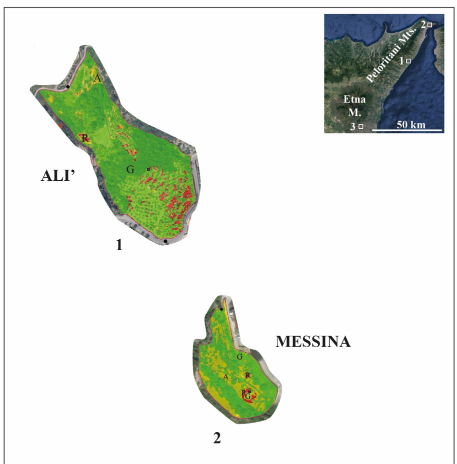

FIGURE 6. The RAG prioritization search *scenarios* for ground searches for clandestine graves elaborated in the three case studies: 1) Alì, 2) Messina, and 3) Catania. Symbols – square: grave, red line: limit of the search area; black circle and line: entry/exit area and point. R: Red-, A: Amber-, G: Green-coded colors. Source: Authors.

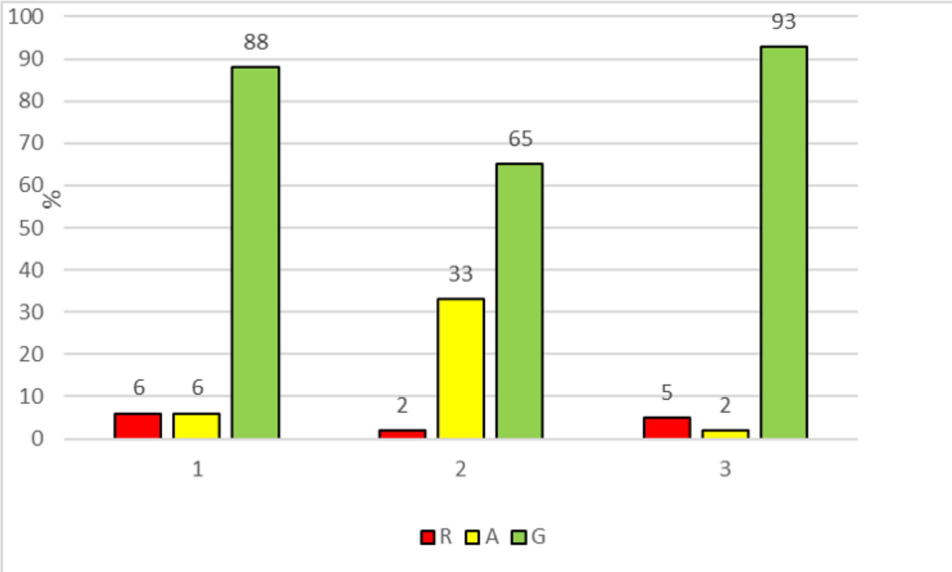

FIGURE 7. RAG prioritization search *scenarios*: Percentages of RAG color-coded area in the examined case studies: 1) Alì, 2) Messina, and 3) Catania. The Red low values, obtained cross-referencing of control factors, are very promising ranging from 2 (Messina) to 6% (Alì) with the real case in Catania at 5%. Source: Authors.

4. Discussion and Conclusions

Based on the above in future searches it is desirable that two main aspects of the clandestine gravesites should be seriously taken into account for an efficient search by investigators and the volunteers engaged during the search activities. These are: i) a more detailed knowledge of the main characteristics of clandestine gravesites (aspect, surface disturbances, geophysical and vegetational anomalies, depths, shapes); ii) modern search strategies. These should represent useful and indispensable information for the criminological and criminalistic upgrade of such personnel.

As concerns the far field remote sensing activities that may provide useful support to investigation, the GIS-based RAG *scenarios* may represent very promising tools to improve. Considering that the factors introduced in the geological conceptual model and GeoDataBase for a ground search for clandestine graves may strongly influencing the mental map of the offender in choosing the burial site, any ground search should take in consideration this information, in order to plan a search with searchers able to look for these characteristics. Recent research on this topic demonstrated as the high (Red) priority search area in the RAG maps showed very variable values. Only the Visibility factor, exhibited a Red coded area extending from 11% to 30%. In the related search *scenarios*, the areal extension of the high (Red) priority search areas in both simulated and real cases were comparable and attesting on low values among 2-6% of the search area (Figures 5 and 6). These very encouraging results reduced greatly the areal extents of the search areas. Under a criminological point of view, the evaluation of the extent of the high (Red) priority search areas might also provide useful indications to investigators for hypothesizing if a burial was presumably premeditated or not. If a clandestine grave is located in a site falling in a Red coded area provided of a very limited extension, it could be possible that the concealer carefully searched in the countryside, before the crime, for a site provided of certain characteristics, such as the invisibility by possible eyewitnesses, an easy diggable sediment, and an easy access.

In conclusion, the search for clandestine graves, being a very problematic issue, if not performed using scientific *criteria* and methods, can become what metaphorically may be defined as "the search for a needle in a haystack." In Italy, the search methods and techniques generally used include dog handlers with cadaver dogs and geophysical tools, but this approach revealed often ineffective. The evident absence of detailed search strategies with systematic planning of near- and far-field activities involving inter- and multidisciplinary team of experts involving also geologists/taphonomists/archaeologists/anthropologists could be in part responsible for this failure. On the other hand, the geoforensic search strategy provided by Donnelly *et al.* (2021), notwithstanding based on great experience and elaborated with great detail, including up to 30 stages, limited the use of RAG prioritization system only to the elaboration of the RAG map of the diggability. A most modern evolution of this approach, as proposed by Somma *et al.* (2018) and Somma and Costa (2022, 2023) could be even more helpful, if integrated in a more extensive geoforensic search strategy including GIS-based RAG search priority *scenario* maps, considering cumulative suitabilities of the factors to host a burial, among which the Visibility revealed to have a great influence.

Author Contributions

Conceptualization, R.S., L.S., J.H.B.; methodology, R.S., L.S., J.H.B.; software, R.S., L.S., J.H.B.; validation, R.S., L.S., J.H.B.; formal analysis, R.S., L.S., J.H.B.; investigation, R.S., L.S., J.H.B.; resources, R.S., L.S., J.H.B.; data curation, R.S., L.S., J.H.B.; writing original draft preparation, R.S., L.S., J.H.B.; writing review and editing, R.S., L.S., J.H.B.; visualization, R.S., L.S., J.H.B.; supervision, R.S., L.S., J.H.B.

Note

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