geosciences

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Unraveling Crimes with Geology: As Geological and Geographical Evidence Related to Clandestine Graves May Assist the Judicial System

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Abstract: The geological and geographical evidence related to crime scenes involving clandestine graves is valuable data to consider during judicial investigations because it can provide useful criminological and criminalistic information. Research results on the nature and main features of historical cases and thirty criminal burials are reported. Among the studied cases, a recent homicide clandestine grave was analyzed through remote sensing. This latter allowed the definition of GIS-based RAG maps and search priority scenarios and ascertain that the study grave fell in a high priority Red coded area, validating a method previously based only on simulated crime scenes.

Keywords: geology; geography; geoforensics; clandestine grave and burial site; GIS; red-amber-green color-coded system; criminological and criminalistic investigations; concealment act

Citation: Somma, R.; Costa, N. Unraveling Crimes with Geology: As Geological and Geographical Evidence Related to Clandestine Graves May Assist the Judicial System. *Geosciences* **2022**, *12*, 339. https://doi.org/10.3390/geosciences12090339

Academic Editors: Sabatino Ciarcia and Jesus Martinez-Frias

Received: 19 August 2022
Accepted: 8 September 2022
Published: 12 September 2022

1. Introduction

The number of missing people is enormous worldwide, and the trend of concealments of homicide victims seems to be an escalating phenomenon worldwide [1]. From Italy to Colombia, the criminal Police reports testify to a significant problem related to forced disappearances and the scientific activities for discovering the possible ground concealments. In Italy, there have been 72,442 active complaints for missing persons reported to law enforcement in the last 48 years [2]. Among the missing people, the percentage of possible victims of homicide that could have been buried in clandestine graves or burial sites could not be negligible as it can also be deduced by data reported by mass media regarding the findings of bodies/human remains in criminal graves, recovered from northern to southern Italy [3–44].

A clandestine grave is usually chosen in a determinate site by a concealer for minimizing risk of being caught burying a body/item, and it being later found by chance, avoiding detection and arrest [45]. The choice of the burial site is not casual, but it depends on the concealer's mental map [46,47]. The places are often familiar and well-known localities (near home, work, parents' home) and near easily recognizable reference points, such as trees, peculiar plants, walls, stone blocks, and cliffs. According to the principle of Winthropping, these latter represent markers in the landscape that may be used by the offender to relocate the burial site for further post-crime visits [45]. The choice of the site may be influenced by many psychological factors, and analyzed by the psychologists of the sites and criminologists, experts in behavioral and geographical profiling [1,45–47].

The main characteristics of a burial site searched by the concealers for finding the "best site" to realize an efficient clandestine grave may be synthesized as follows: (i) soft and thick soils; (ii) plain surfaces or gentle slopes; (iii) no surface expressions; (iv) invisible localities from eyewitnesses; (v) familiar and well-known locations; (vi) easily accessible on foot or by vehicle; (vii) reference points for monitoring the site; and (viii) stable areas [48,49].

Among these factors, the easiness of digging (diggability) assumes a predominating role in the concealment because digging a hole requires that the terrains are diggable. Most concealers search for burial sites with soft and thick soil, as soft terrains allow a quick and efficient burial, and a thick terrain allows the corpse to be effectively concealed, avoiding that it may be discovered as too shallow or exposed on the surface and subject to removal from the burial site for natural causes, such as alluvial floods or wild animal activities, or anthropogenic activities such as plowing of the fields by farmers or construction works. Notwithstanding, concealment acts are also known along the rivers [50,51], in areas affected by landslides [52], or, in rare cases, dug by wild animals [27,28,30]. The ease and efficiency with which the ground may be dug may be evaluated by the forensic geologist conducting a field survey of the diggability. Diggability may depend on several geological features (composition and grain-seize, relative density degree, and soil strength parameters of granular deposits), the thickness of the superficial deposits, groundwater occurrence, and possible barriers (roots, rock blocks, anthropogenic structures). The diggability may vary from very easy to very difficult, and forensic geologists may evaluate it using a T-metal bar [49]. Diggability is correlated to the used digging instruments, the perpetrator's ability and physical force, and the item typology to conceal [49].

During judicial investigation on corpse concealments, the clandestine graves' shape and dimensions (length, width, and depth) may be valuable features to consider. The entity of the pit's length and width is generally projected by the offender considering the victim's body dimensions. In contrast, the pit's depth depends on several factors, among which the most relevant are the diggability, the ability/skill and force of the offender, or the available time-lapse for the concealment.

The search for clandestine graves can be compared "to looking for a needle in a haystack" if the ground search lacks technical support [53–67]. For this reason, and of prime interest for the legal inquiry, specific procedures are fundamental to reduce the time and costs spent on searches, increase the probability of locating burial sites, reconstruct the judicial truth, and individuate the criminals [49]. In Italy, scientific criminal investigations related to the search for missing people suspected to be killed and concealed in clandestine graves rarely conclude with finding the remains and burial site [49]. Most cadavers and human remains buried in the ground are casually found by runners, hunters, farmers, and passersby; few are the cases of victims found by investigators using scientific methods and without the collaboration provided by the self-confessed offenders or eyewitnesses. In Italy, the percentage of findings due to scientific investigations [49] is only 5%, whereas better encouraging results were obtained in Great Britain, Australia, and Latin America [53–67].

To assist law enforcement officers during a ground search [53–67] for clandestine burials of missing people or crime-related items (such as weapons, firearms, drugs, explosives, stolen items/money, etc.) is one of the main goals of geoforensics (or forensic geology) [68–79], being this latter the "application of geosciences techniques to assist defense or criminal prosecutions (serious crimes, environmental crimes, etc.) and legal inquiry" [68]. In the case of a search for clandestine graves, the forensic geologist in a team with other experts can provide proper support to forensic investigators searching, identifying, and evaluating the peculiar geological, geographical, geopedological, geomorphological, and geophysical features of the ground burial sites. These data may be elaborated by forensic geologist in the Red-Amber-Green (RAG) color-coded search prioritization system (also known as the traffic light system by search practitioners) for assisting law enforcement and dog handlers during the ground search for clandestine graves [52,80,81]. The RAG maps derive from the military system [80] and were initially used during the first and second world wars to easily individuate the places to dig for the trenches. The RAG system applied to the search for clandestine graves is aimed to individuate the sites at high, medium, and low priority of search, respectively, to be used by searching staff and canine scent detection teams.

Geomatics and GIS application may be used in forensic investigations [82–91]. In particular, the GIS-based RAG system may be used to assist police and the judicial system in criminal investigations for the discovery of clandestine graves [49]. This system (Figure 1) allows to realize a geographical model designed on a conceptual model (Figure 1A) based on the available specific criminal and investigative information. The method uses cross-referenced RAG maps with cumulative suitability factors to host a clandestine grave, in order to edit different search scenarios for ground searches showing high-(Red), medium-(Amber), and low-(Green) priority areas.

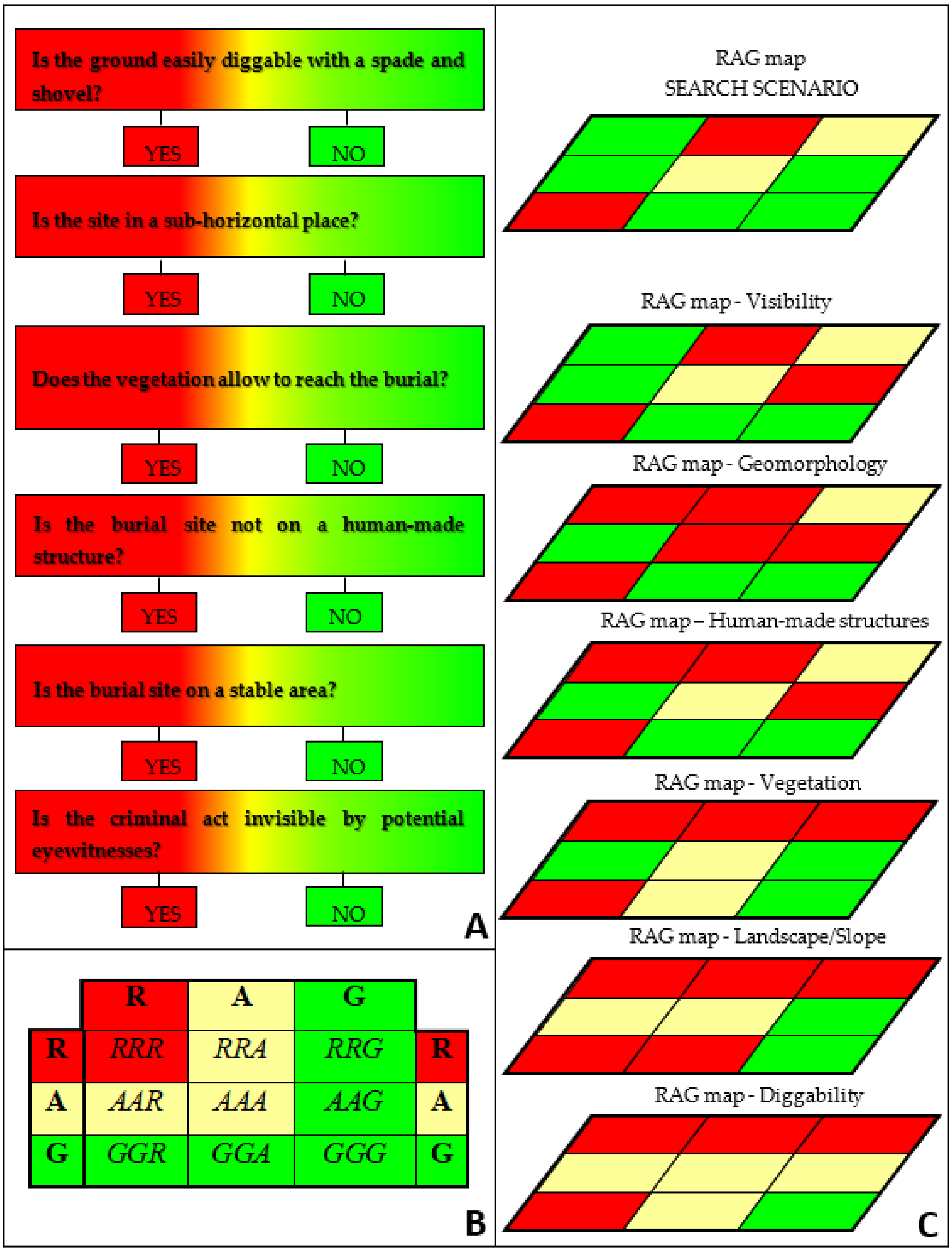

Figure 1. RAG color coded system applied to the search for clandestine graves and adopted in the present research. (**A**) RAG system conceptual model. For each question related to the considered factor: a positive answer means that the place is suitable for hosting a burial, and consequently, it indicates a site at high priority of search (assigned to Red-code); a negative answer means that it is not suitable for hosting a burial and consequently it indicates a site at low priority of search (assigned to Green-code). (**B**) An example of color-code matrix to explain the method for assigning RAG color-codes to each area of the RAG map. (**C**) Scheme based on the conceptual model (**A**) for constructing the RAG map search scenarios. The search scenario is obtained crossing geographical information from the RAG maps related to the six suitable factors.

In the cases of clandestine graves, the significant factors influencing the spatial position of the investigated target may be identified and evaluated in RAG maps of the factors and RAG search scenario priority maps. The six RAG factors suitable for hosting a grave are: (i) Diggability, (ii) Landscape/Slope, (iii) Vegetation, (iv) Human-made structures, (v) Geomorphology, and (vi) DSM (Digital Surface Model)-based Visibility (Figure 1A,C) [49]. In particular, the Digital Elevation Models (DEMs) are useful tools in remote sensing activities for ground-search for clandestine graves, providing a georeferenced fly-through visualization of the topographic surface. The DSMs are a digital surface interpolating ground as well as vegetation and human-made structures (building, roads, etc.).

The identified control factors had to be evaluated in GIS layers, assigning to each point of the investigated area a Red-, Amber-, and Green-code, assigned for suitable, medium suitable, and unsuitable points, respectively, to host a clandestine grave. The search scenario of a determined investigation target is obtained crossing the RAG color codes of the six control factor layers of RAG maps, assigned on the base of a color-coded matrix (Figure 1B). Red-code is assigned to each point of the search scenario obtained crossing six Red-codes; Amber-code is assigned to each point obtained crossing six Amber-codes, or a total of six Red- and Amber-codes with at least one Amber-code; Green-code is assigned to each point obtained crossing six Green-codes, or a total of six RAG colors with at least one Green-code (Figure 1C) [49]. In other terms, the color-code assigned to each point of the search scenario depends on the occurrence of at least one color-code with lowest priority value with respect to the other codes (Figure 1B), and the Red-, Amber-, and Green-coded colors of the search scenario will correspond to high, medium, and low search priority (Figure 1). Different search scenarios may be elaborated for searches related to concealments occurring at night and in daylight. In the first case, the "search scenario without the visibility" will be the most effective; in the second case, the "search scenario with the DSM-based visibility" will be the most appropriate [49].

The present paper is devoted to the study of the nature of clandestine graves. Historical cases, thirty clandestine graves, and three pits dug in experimental fields were examined in order to understand whether clandestine graves and cadaver findings may show common and recurring features that may be used to understand the possible excavating modalities and skills of the offender, and the crime premeditation. Special attention was devoted to a remote sensing application on a case study related to a clandestine grave recently discovered in the Catania province (Italy) [43,92–103], for which the reconstruction of GIS-based RAG maps and search scenarios was carried out. Previous research on the GIS-based RAG system [49] was applied to simulated cases, not crime scenes. For the scientific and academic community, obtaining scientific information on the geological, naturalistic, and geographical framework of a crime scene represented an extraordinary and uncommon opportunity. The GIS-based RAG system applied to the case study allowed to validate the method previously based only on simulated crime scenes.

2. Materials and Methods

2.1. Clandestine Graves

Criminological and criminalistic information concerning clandestine graves was reported for some historical cases and thirty selected burial sites.

Primary information provided for the selected cases was related to the following data: (i) the name of the victim and offender; (ii) the date of disappearance, death, or finding of the missing person; (iii) who found the grave; (iv) dressed or stripped victim; (v) victim conservation state; (vi) the modality of recovering; (vii) the site geographic locality; (viii) the familiarity of the site for the offender; (ix) the site geomorphology; (x) the site vegetation; (xi) the site diggability; (xii) the site sediment types and depositional environments; and (xiii) the pit depth. Unfortunately, the complete thirteen information typologies were unavailable for all the examined graves, but available for most. Most data were acquired through OSINT (Open Source Intelligence) analysis, mainly related to data reported by police press releases, videos, and interviews, TV news, and mass media [3–44] after cross-verifying different information resources and published researches.

Three pits dug by the authors in experimental fields were also analyzed to provide primary information on the shape, dimensions, and typology of instruments used to dig.

2.2. GIS-Based RAG Coded Prioritization System Applied to the Case Study

A case study related to a recent homicide clandestine grave was analyzed applying the RAG prioritization system.

The six RAG factors suitable for hosting a grave above mentioned, together with the information layer "Limits and exit-entry points of the search area", were uploaded to the GIS-geodatabase for reconstructing the GIS-based RAG color-coded maps of the factors. After this first phase of data elaboration, the RAG maps' georeferenced information was crossed to evaluate "cumulative" suitability to host a burial. The cross-referenced RAG maps with the cumulative six suitability factors to host a pit allowed to edit two different search scenarios for ground searches with high-(Red), medium-(Amber), and low-(Green) priority areas: (1) "search scenario without the visibility" for concealments occurred at night; (2) "search scenario with the DSM-based visibility" for concealments occurred in daylight.

The software used for the GIS-based RAG method was QGIS, an open source GIS desktop application. Georeferentiation data were reported in orthophotographs (years 2012–2013) and topographic maps at 1:10,000 (years 2012–2013) and 1:2000 scales (year 2004) provided by the Territorial and Environment Department of the Sicilian regional authority. A multi-space and -time analysis of the studied territory was made on the available satellite and aerial photographs from 1985 to 2022 to ascertain the landscape and vegetation variations related to natural and anthropogenic events.

For further details on the GIS-based RAG map prioritization system method, the authors refer to Somma et al. 2018 [49].

3. Results

3.1. Clandestine Graves

Clandestine graves may be dug underground or in anthropogenic contexts, such as the concrete floor and under a cellar or garage. Instruments for digging are hand instruments such as spades, shovels, hoes, and metal bars. The spades and the hoes are the most valuable instruments to dig a hole because of the flat blade allowing to cut, break, penetrate, and till the soil, with the aid of the foot posed on edge to force it into the ground. The shovel is mainly used for digging up and moving sediment from (during the digging) and in (during the filling) the pit because of the concave blade. In some circumstances, concealers use mechanical instruments such as excavators, pickaxes, or jackhammers when the concrete floor is present. An unskilled digger may learn how to dig a hole and the necessary instruments by watching tutorials online or website explanations [104,105].

3.1.1. Case Histories

In Italy, one of the oldest clandestine graves went back to 1924 in the fascist epoch and regarded Giacomo Matteotti, a well-known deputy and secretary of the unitary Socialist Party, kidnapped, stabbed to death, and concealed in the underground by the fascist political police in Italy [3]. For the first time in Italy, Matteotti's case demonstrated that the search for clandestine graves carried out by police with the assistance of an elementary method could be effective. A Brigadier of Carabinieri, with the help of his dog, notwithstanding that it was not trained for this aim, found the grave hosting Matteotti's cadaver two months after his disappearance. The pit was dug with a car jack and rasp up to 50 cm of depth in a very easy diggable wood soil localized in an unfrequented site at a distance of 150 m from Flaminia Street, about twenty kilometers from Rome.

Fifty years later, in Alaska, during the 70s–80s, Robert Hansen, a psychopathic serial killer, concealed his victims underground after committing sexual and sadistic type homicides [50,51,106]. Hansen used to bury most victims in shallow clandestine graves dug along the banks of the Knik river (Figure 2). This glaciated valley flows in an inhabited area characterized by highly braided channels of easy to difficult diggable alluvial plain deposits chiefly formed of sands and gravels containing cobbles, silts, and clays. Hansen was allured by this river where he could easily access the arduous territory with his airplane or 4 × 4 jeep [50,51]. Two police officers casually found the remains of one victim during hunting activities along the Knik River six months later the disappearance. Investigators found the other graves and human remains after one of the kidnapped women was able to escape and contact the police. To mark the burial sites or the crime scenes on a map may be a typical behavior of most serial killers. Hansen used to evidence the burial sites with crosses in a topographic map [50,51]. Additionally, in the case of the serial crimes committed by the Florence Monster, different physical evidence was found, such as a street map with two countries' names of the crime scenes evidenced by pen [107] or a painting modified by coloring and adding six little crosses [108].

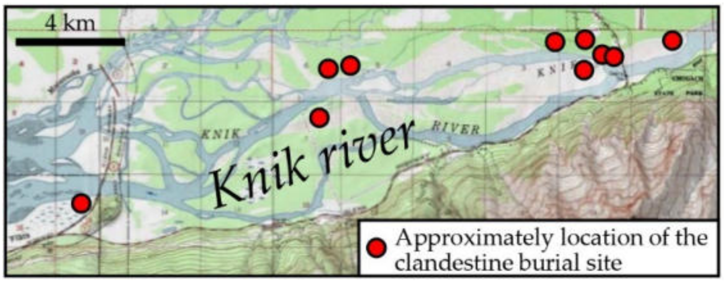

Figure 2. Map of the Knik River (Alaska) showing the localization of the clandestine graves dug by the serial killer Robert Hansen in the river alluvial deposits.

At the end of the 80s, a man was killed and buried in a pit dug in the easily diggable sands of the Buzios beach in Brazil before the homicide [36]. The Mafia-type criminal associations used to bury their victims in clandestine graves usually dug before. In 2016, a young man was shot by mafia criminals and buried in a 50 cm deep pit dug previously in farmland [24,25].

Fifty years later, in Italy, in 2021, another criminal pit, known to a broader public for the mediatic relevance of the case, was discovered in the province of Brescia (Italy). The hole was dug in the alluvial plain deposits and was 50 cm deep [37]. The data related to OSINT studies allowed the observation of the features of the hole [37–40]. The excavation walls appeared sub-vertical and cutting a stratigraphic succession involving sandy gravels with cobbles in a sandy-silty matrix [37]. Near one side of the pit, stretched along the long dimension, there was a pile of alluvial cobbles [37]. Along the pit walls, several broken roots up to some centimeters in diameters could be observed [37]. The pit was presumably dug before the homicide and abandoned [37–40], representing only a test pit. It is probable that, considering the conditions of diggability and the texture of these deposits (deposits very difficult and not suitable for concealment), it was not possible to prepare a pit adequate to host the body. A second pit was realized in the surrounding area and used for concealment, but the hole, also in this case, being too small presumably for its shallowness, released the body three months later during a river flood, allowing its finding [37–40].

3.1.2. Selected Clandestine Graves

Thirty clandestine graves [3–44,49], whose data were obtained by OSINT analyses, were analyzed to characterize general criminological and investigative features of corpse concealments and ground burials, shapes, and depths of criminal holes.

From the examination of the acquired criminal information on the thirty burials, it came to light that most concealed victims were men, found dressed and in an advanced state of putrefaction or skeletonized usually within one year from the date of disappearance; most of the graves were found by passersby; the recovering modality of the remains was usually by using a mechanical excavator and spade and shovel; burial sites were localized in areas on alluvial planes or wooded lands, with no dense vegetation, and easily diggable.

The shape in the plan view of the analyzed pits resulted to be elongated with an ellipsoidal, rectangular, or irregular shape.

The pit depth resulted to be ranging from 20–30 to 250 cm, with an average value of 91 cm. Depths lower and higher than 150 cm usually indicate graves dug by hand with a spade, shovel, and excavator, respectively.

Men dug 86% of the studied graves. Few were the graves (14%) dug by women. Available data on the graves dug by women indicated that the pit depth reached a medium value not exceeding 30 cm and that holes were realized by hand with a spade/hoe and shovel (Figure 3).

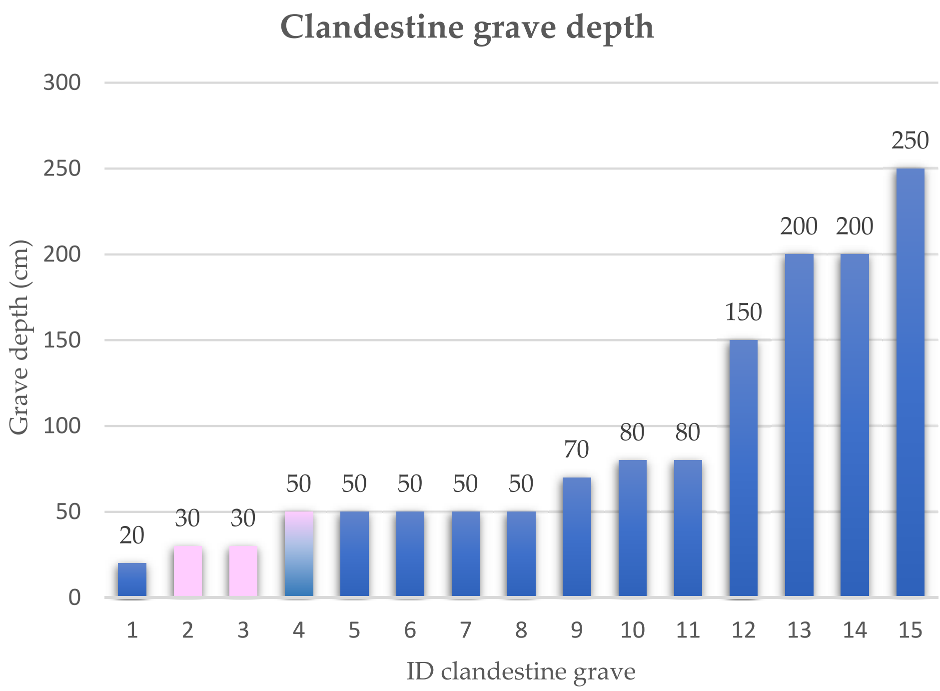

Figure 3. Histograms showing the clandestine grave depth of 15 graves dug from 1924 to 2022 [3–44,49]. Legend—Blue color: grave dug by men; pink color: grave dug by women; pink to blue color: grave dug by women and men together.

3.1.3. Experimental Pits

Two very shallow pits were dug by spade and shovel by one of the authors (R.S.) and another geologist of the Messina University in 2015 in the experimental field at the campus of the Messina University (Figure 4) and another one by means of mechanical excavator in the municipality of Alì in 2015 [49].

The pits dug by spade and shovel resulted in an ellipsoidal shape similar to the shape of a "foot" (Figure 4A). The 3D form of the ellipsoidal graves is peculiar and may resemble the shape of a "bathtub" showing three subvertical walls and one dipping towards the bottom (Figure 4C–F). The subvertical walls are generally due to an excavation modality with a spade or hoe, whereas the gently dipping wall is generally obtained for the use of a shovel.

Rectangular graves with sharp angles are typical in the holes dug by mechanical excavators as in the case of the pit dug at Alì where the excavation was 2 m long, 1 m wide, and 0.7 m depth with a 3D shape of rectangular parallelogram.

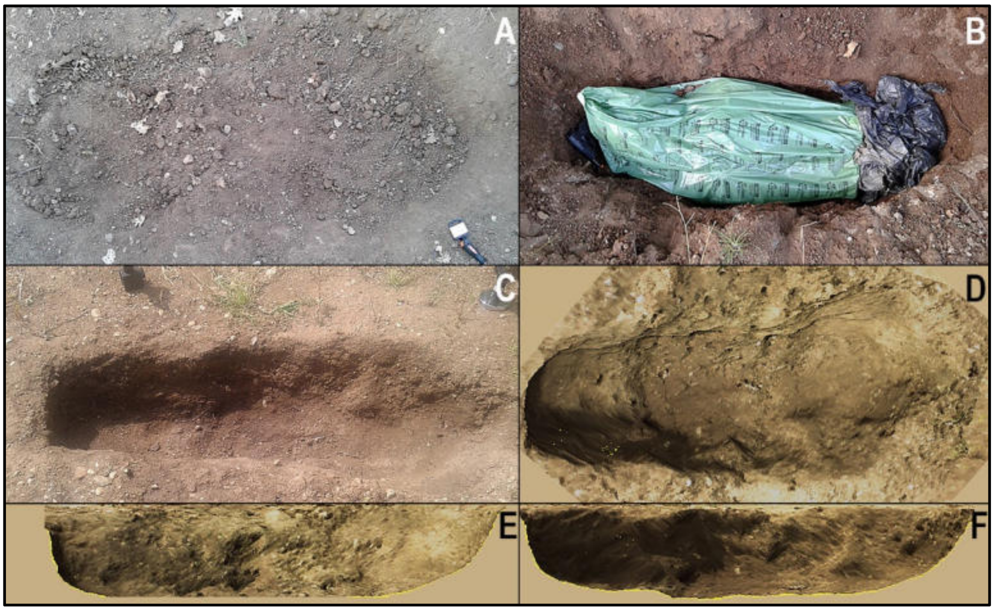

Figure 4. The appearance of simulated clandestine graves dug with a spade and shovel in the experimental field at the scientific campus of Messina University. (**A**) Plan view of a simulated shallow grave with an ellipsoidal shape and "foot-like" appearance closed after posing a bust of a plastic mannequin closed in two plastic garbage bags at the bottom. The pit was 50 cm deep and 1 m long. (**B**) Pit hosting the bust closed in two plastic garbage bags before the filling with sediments. (**C**) Plan view of a shallow grave with an elongated shape and "bathtub" appearance (for hosting the lower limb of a plastic mannequin) before the filling with sediments. The pit was 20 cm deep and 1 m long. (**D**) Plan view of the 3D reconstruction by laser scanning of the pit. (**E**) East lateral view of the 3D reconstruction by laser scanning of the pit. (**F**) West lateral view of the 3D reconstruction by laser scanning of the pit.

3.2. Clandestine Grave: The Case Study

On the southern slope of the volcano of Mount Etna, a homicide clandestine grave was found in an abandoned field of the Catania province (Italy) in June 2022 [43,92–103]. The victim was found semi-buried and hidden inside five plastic garbage bags [97]. A garden hoe and spade [98] were also found in the surroundings of the burial.

3.2.1. Geographical Background

In Figure 5 the localization of the burial [95,96,99] on Mount Etna DEM (Figure 5A) and satellite imagery (Figure 5B) through photograms captured from videos [95,99] is shown. Remote sensing realized through GIS technology was applied to the case study using satellite imageries, orthophotographs, and thematic maps. Remote sensing allowed to recognize the burial site in a plateau of about 200 square meters, at 611 m a.s.l.

3.2.2. Geological Background

The burial site was localized in the volcanic rocks of the Torre del Filosofo Formation of the Mongibello Unit [109,110]. The age of this formation ranges from 15,000 years to the present. Five time-intervals were distinguished: 1971–present; 1669–1971; 122 B.C.–1669; 3900–122 B.C; 15000–3900 [109,110]. The burial site was localized on the San Giovanni La Punta lava flow dating back to 122 B.C.–1669 time-interval (i3 in Figure 6) [109,110]. Archeo-magnetic dating attributes the frontal part of the flow to the Roman ages [111]. The formation in the studied area consisted of a historical scoriaceous lava flow with Hawaiitic-Mugearitic composition associated with fall pyroclastic products [109,110]. The thickness of the basaltic lava and pyroclastic products was about 5 m and 1 m, respectively.

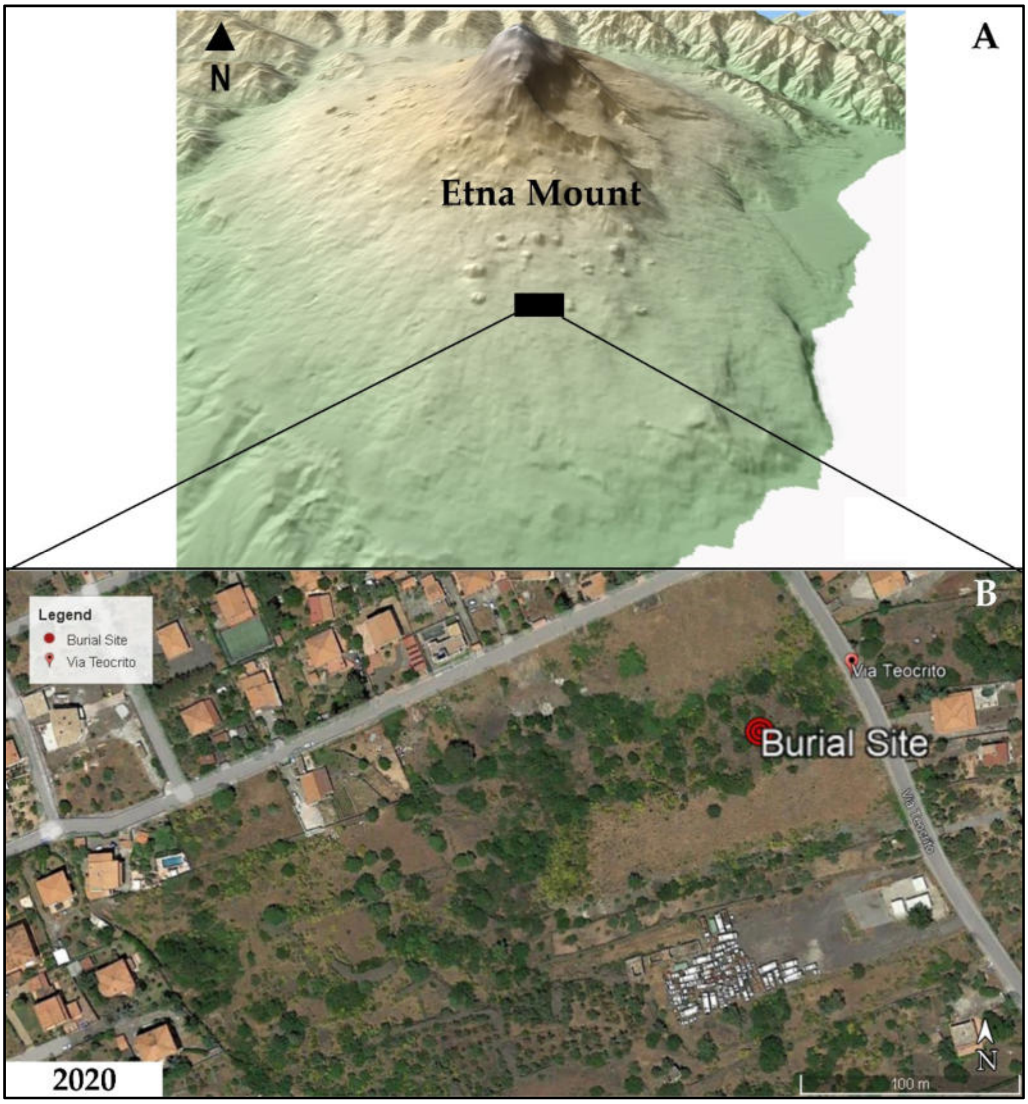

Figure 5. Localization of the burial site on the DEM of the Etna Mount (**A**) and on the satellite imagery (**B**).

The burial site was localized in an ENE-WSW trending belt, 50 m wide, formed of light grey lava flows exposed on the surface but mostly covered by a thin layer of dark soil or volcaniclastic products deriving from chemical-physical weathering and pedogenetic phenomena involving both volcaniclastic material and scoriaceous elements of the lava flows. The clandestine grave was dug in the volcaniclastic material. From photograms captured from videos [43] it was possible to observe that the pit appeared very shallow and under-dimensioned, with an elliptical shape in plan view and a 3D shape similar to an overturned and asymmetrical truncated cone.

3.2.3. Botanical Background

The burial site was localized on an ENE-WSW trending belt covered by shrubs of the Mediterranean Macchia (Figures 5B and 6), on the back of two abandoned and uncultivated fields (Figures 5B and 7).

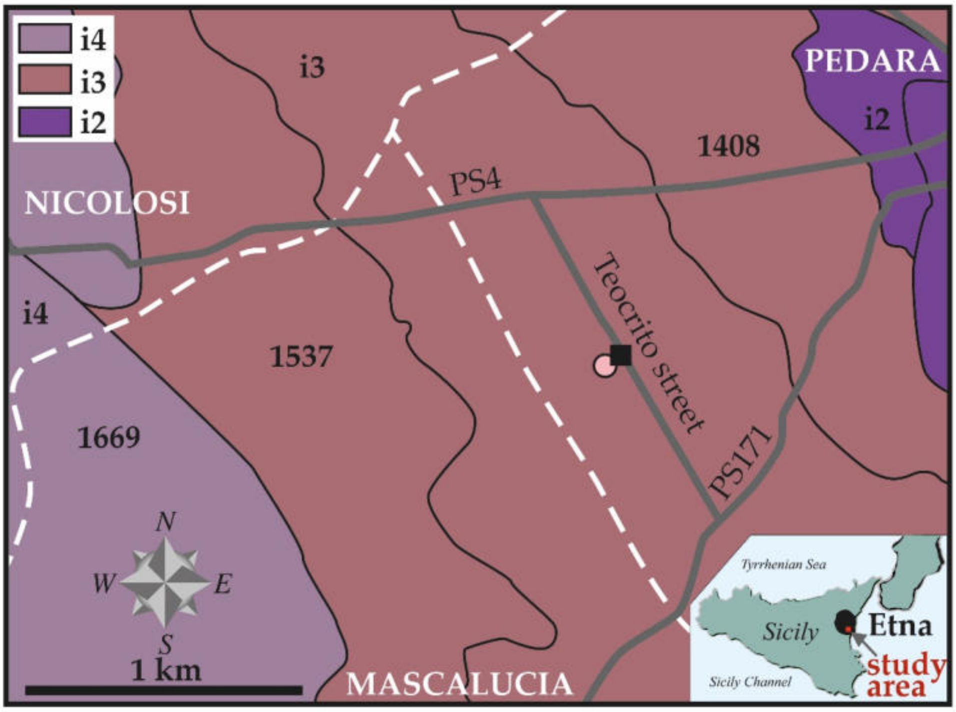

Figure 6. Geological map with the localization of the burial site (pink circle) [95,96,99,109,110] and sample 1 (black square). Legend—Formation Torre del Filosofo of the Mongibello Unit: (i4) historical lava flows of the 1669–1971 time interval; (i3) historical lava flows of the 122 B.C. and 1669 time interval, (i2) lava flows of the 3900–122 B.C. time interval. The grey and white lines represent the main streets and the municipality limits, respectively.

Figure 7. View of the burial site (seen by Teocrito Street, Figure 5B). The burial site is on the back of the southern uncultivated and abandoned field (in the foreground), in the middle of the Mediterranean Macchia (in the background).

The Mediterranean Macchia is a particular plant formation formed by an impenetrable interior of shrubs and small trees no higher than 4–5 m. This formation is usually composed of evergreen and sclerophylls plants and is diffused on Mount Etna. The main plants recognized on the study area were myrtle (*Myrtus communis* L.), mastic (*Pistacia lentiscus* L.), tree heather (*Erica arborea* L.), black locust (*Robinia pseudoacacia* L.), wild blackberry (*Rubus ulmifolius Schott*), wild olive (*Olea europaea* L. var. *sylvestris*), and wild grape vine (*Vitis vinifera* L.). A vegetation and land use map of the study area was synthesized in Figure 8.

Figure 8. Vegetation and land-use map showing the distribution of the dense vegetation.

Photograms captured by videos of the burial sites [43,99] allowed to observe in particular three main grape vine plants surrounding the burial site. The site appeared attached and in front of an isolated small grape vine plant, NW of another isolated grape vine plant, and to the north of a man-made volcanic block circle, containing a flourishing grape vine plant.

3.2.4. The Volcaniclastic Products

A specimen of pedogenized volcaniclastic products (sample 1) was sampled in surface along the border of Teocrito Street at the same latitude of the burial (Figure 6) to define compositional and textural characters useful for defining the diggability factor. It was composed of volcaniclastic material of dark color (very dark grayish brown—10YR/3/2 Munsell Soil color chart ascertained on the <63 µm fraction). The sample resulted composed of granular sandy deposits containing organic components (dry remains of plant roots). The grain size distribution obtained by dry mechanical sieving (Figure 9A) and laser diffraction (Figure 9B) indicated that the sample consisted of gravelly sands with grains from very thick to very fine (sands 81.07%; gravel 14.43%; silt/clay 0.53%; Figure 9A) and that the fine fraction consisted of silts (Figure 9B).

The volcanic particles of the sample were characterized by porphyric texture. These were visually inspected using a stereomicroscope and interpreted as angularity and roughness end-members (Figure 10). The sample showed good sorting, moderate sphericity, high porosity, permeability, shear strength, and low compressibility.

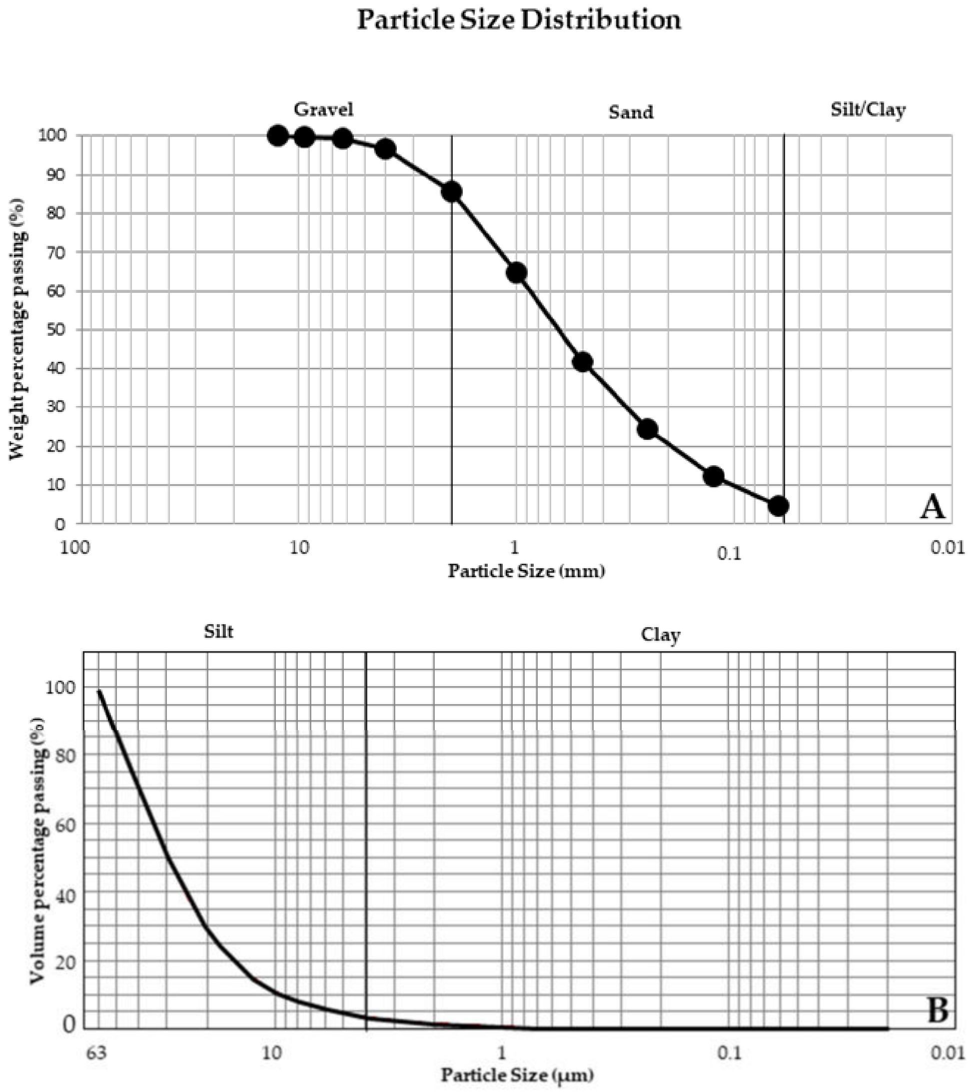

Figure 9. Cumulative grain-size frequency curves of the volcaniclastic deposits. (**A**) Distribution obtained by dry mechanical sieving of the particle size > 63 µm. The curve indicated that they consisted of gravelly sands with grains from very thick to very fine. (**B**) Distribution obtained by laser diffraction granulometric analysis of the grain size < 63 µm. The curve indicated that they consisted of silts (d0.9: 53.145 µm; mode: 45.870 µm).

3.2.5. RAG Prioritization System

The method of the GIS-based RAG color-coded system [49] was applied to the case study related to the Catania grave in order to ascertain through remote sensing activities in which RAG-color coded areas of the factor maps and search scenarios the clandestine grave fell for the consequent evaluations on the validity of the method. In the first phase, the method edited the RAG maps of the factors suitable for the burial site. The georeferenced information layers of the factors used in the GIS-geodatabase for constructing the RAG maps were related to Limits and exit-entry points of the search area, Diggability, Landscape/Slope, Vegetation, Human-made structures, Geomorphology, DSM-based Visibility (Figure 1). The percentages of the RAG coded areas obtained for each factor were reported in Figure 11.

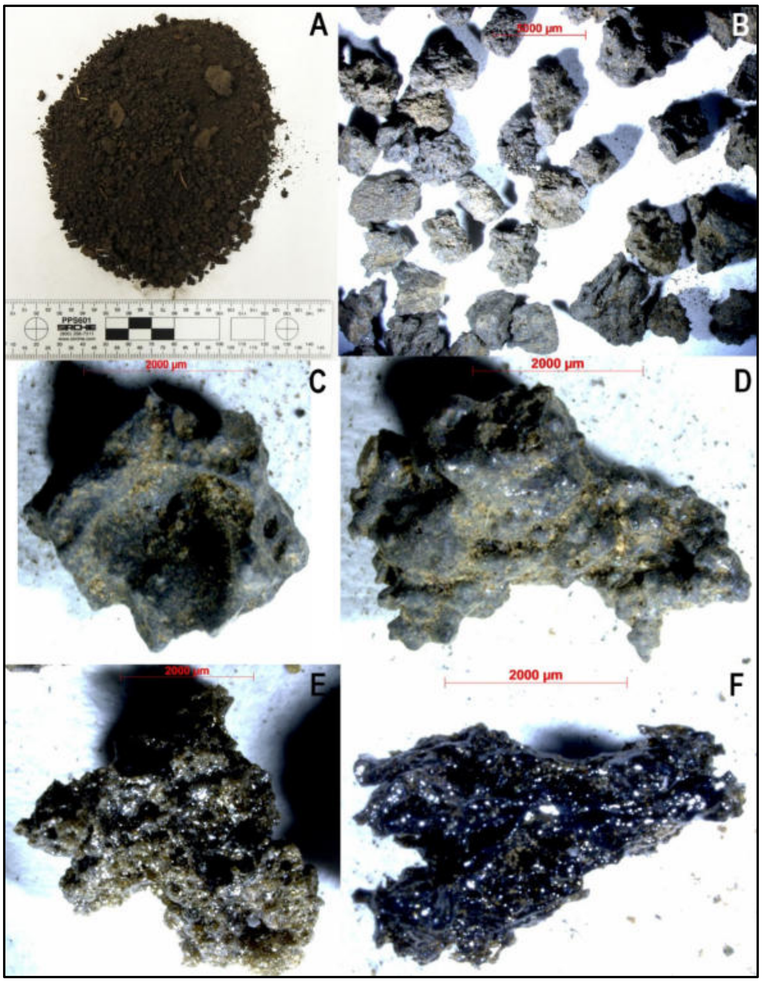

Figure 10. Specimen of volcaniclastic products from the case study area surroundings (sample 1). (**A**) Original sample before treatments. (**B**) Volcanic particles of the fraction retained by the sieve 4 mm, showing high angularity and roughness. (**C**) Sub-spherical particle. (**D**–**F**) Elongated particles. Elongated particles were glassy and with a vesicular texture and showed high angularity and roughness.

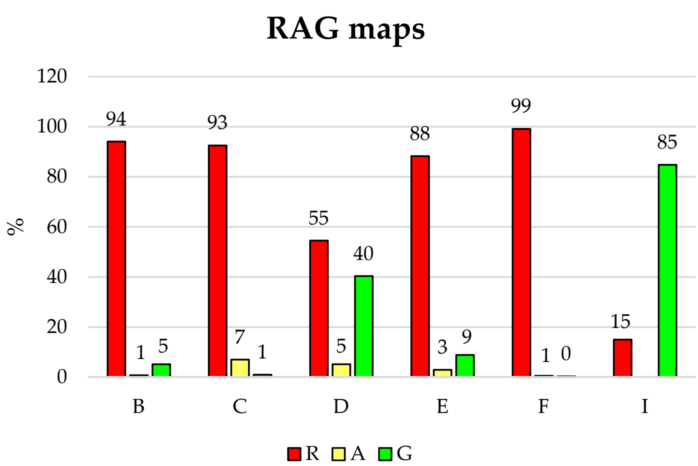

Figure 11. Histograms showing the percentages for each factor suitable for burial site in the RAG maps. Legend: R: Red code, A: Amber code, G: Green code. Factors for each RAG map: B—Diggability, C—Landscape/Slope, D—Vegetation, E—Human-Made Structures, F—Geomorphology, I—DSM-Visibility.

Limits and Exit-Entry Points of the Search Area

The "Limits and exit-entry points of the search area" layer (Figure 12) of the GIS platform was elaborated with the information provided by the aerial and satellite imageries from 1985 to now, the cadastral data, and investigative data provided by OSINT data. The search area covered an area of almost five hectares. Public streets mostly delimited the search area to NW (Turati Street, Figure 12) and NE (Teocrito Street, Figure 12). Along these two main streets, limits were mainly made of a wire mesh, 1 m high on Teocrito Street and 1.5 m on Turati Street, as observable from the street view function in Google Earth Pro. Limits were also given by piles of volcanic blocks or dense shrubby vegetation. The south-eastern limit fell inside a closed area with a car-storage. The exit-entry points were identified in four broken or uprooted wire sectors: two were localized in Turati Street, one in Teocrito Street, and another at the crossroad between these two streets. Along Turati Street, two parking areas were present. The westernmost area coincided with a possible exit-entry point, but the presence of volcanic blocks and detritus could hinder the crossing. The easternmost parking area was delimited by intact wire mesh 1.5 m high hindering the crossing toward the field from this site. The two exit-entry points nearest to the burial sites were the point at the crossroad and the point on Teocrito Street. The first one was nearest to the previously described parking area, at about 40 m distance. The exit-entry point in Teocrito Street was at a 100 m of distance from the first available parking site to the South.

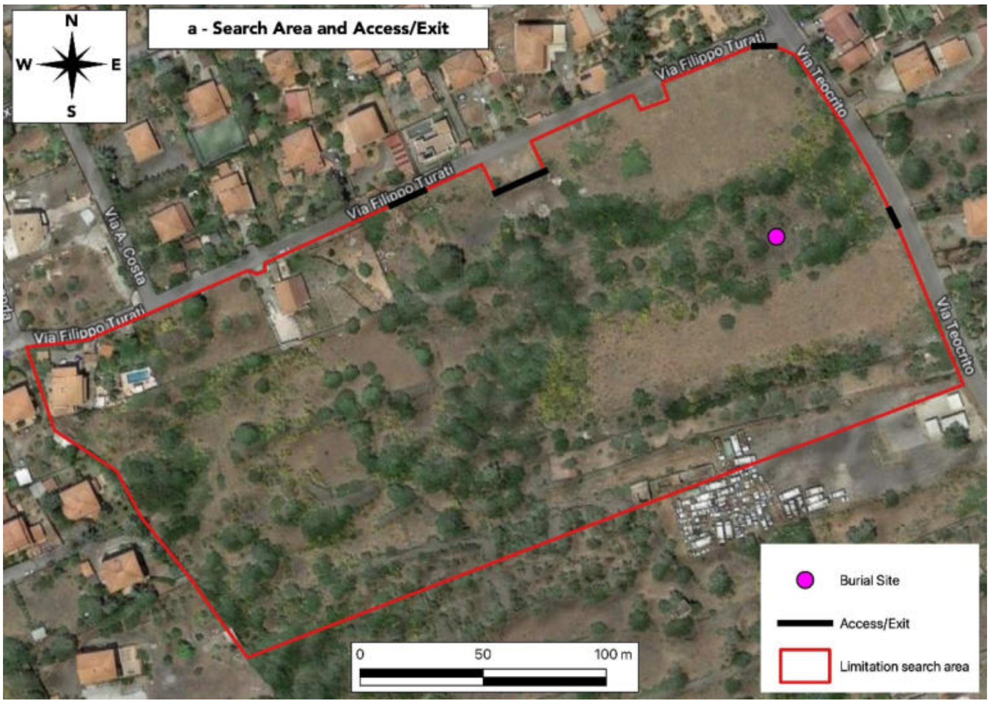

Figure 12. Map of the GIS-based georeferenced layer "Limits and exit-entry points of the search area".

Diggability RAG Map

The "Diggability" layer (Figure 13) of the GIS platform was elaborated considering the aerial and satellite images, the geological/pedological maps, and the field survey of the area for identifying the outcropping bedrock and soil. The diggability qualitative evaluation was realized considering the soil features (composition, texture, structure, and engineering properties) analyzed in test pits and along some natural sections during a pre-search reconnaissance visit in the surrounding areas. The diggability was evaluated for a hole dug by hand instruments, such as a spade or hoe and shovel. The volcaniclastic products represent the most extensive outcrops of the area. The outcrops of basalts were identified along the steepest slopes to the North and the South of the burial site. Some little outcrops of basalts were not reported. The diggability resulted as very easy in the volcaniclastic gravelly sands occurring in most of the study area. The no diggable rocks were represented by basalts (Figure 13). The Diggability RAG map was characterized mainly by soil outcrops with thicknesses ranging from a few decimeters to over one meter, and second by outcroppings of basalts up to 5 m thick. The drift geology of the area was characterized by a natural granular soil showing a texture of gravelly sands (Figure 9), overlying bedrock of basalts of the San Giovanni La Punta volcanic flow. The areas with outcropping granular soils were included in the Red class (high suitability) and constituted 94% of the total. The areas with outcropping basalts were included in the Green class (low suitability) and represented 5%. The Amber class (medium suitability) included a belt 1 m wide in the transition zones and covered 1% (Figures 11 and 13). The burial site fell on the Red coded area (Figure 13).

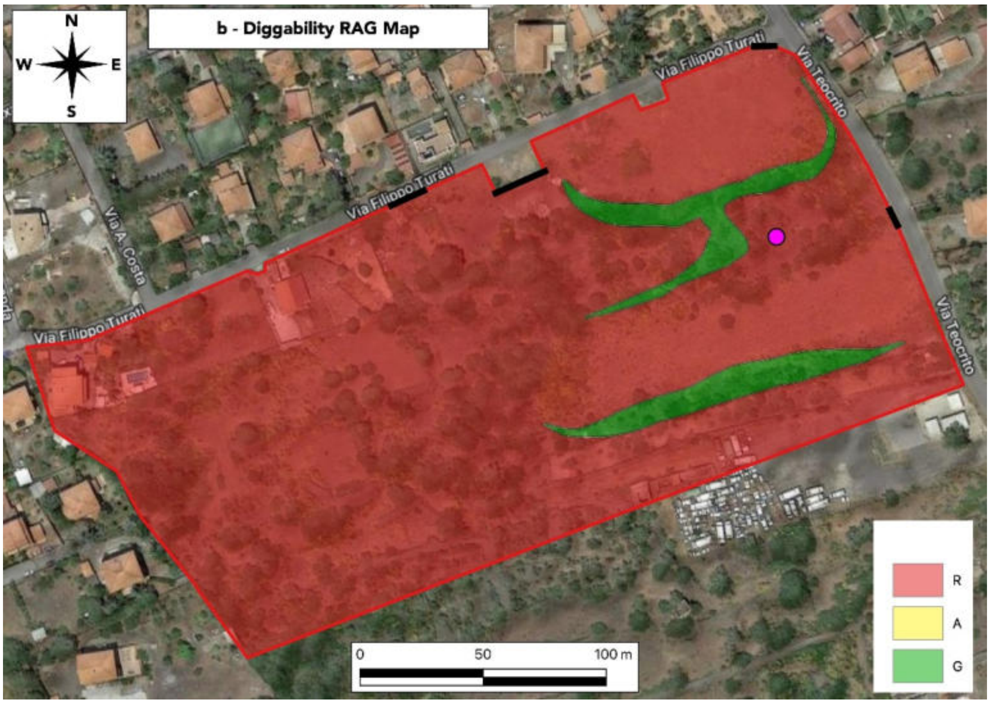

Figure 13. RAG map of the “Diggability” layer of the GIS platform. The burial site (pink circle) fell on the Red coded area. For the percentages of RAG color-coded areas see Figure 11 (the Amber-coded area is not visible covering the 1% along the Red and Green area boundary).

Landscape/Slope RAG Map

The “Landscape/Slope” layer (Figure 14) of the GIS platform was elaborated considering the aerial and satellite images, the topographic maps, and the DEMs.

The burial site was at an altitude of 611 m a.s.l. The ENE-WSE trending belt containing the burial site was limited by a sub-horizontal plane located at a medium altitude of 615 m a.s.l. to the North and 609 m to the South. The general landscape of the search area was characterized by a plane from sub-horizontal to gently dipping to SSE with values lower than 20°. The steepest areas with slope angles higher than 20° and 27° were represented by two main ENE-WSW trending belts localized North and South of the burial site. These steep slopes were related to the morpho-structure of the basaltic lava flow. The high slope values along the street were due to anthropogenic deposits of blocks and waste (Figure 14). The three different RAG color-coded classes attributed to the slope were defined as follows: (i) the Red class for the horizontal to sub-horizontal lower than 20° slopes (high suitability); (ii) the Amber class for the 20° to 27° slopes (medium suitability); and (iii) the Green class for the higher than 27° slopes (low suitability) (Figure 14). The Red, Amber, and Green classes constituted 93%, 7%, and 1% of the total, respectively (Figures 11 and 14). The burial site fell on the Red coded area (Figure 14).

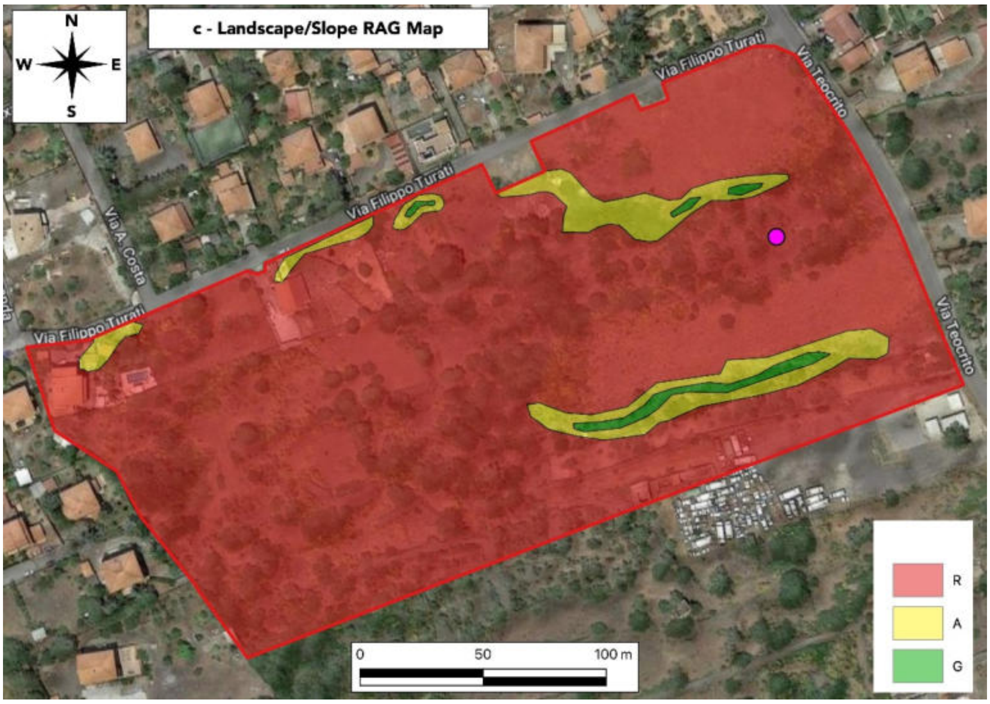

Figure 14. RAG map of the "Landscape/Slope" layer of the GIS platform. The burial site (pink circle) fell on the Red coded area. For the percentages of RAG color-coded areas see Figure 11.

Vegetation RAG Map

The "Vegetation" layer (Figure 15) of the GIS platform was elaborated considering the aerial and satellite images, the topographic maps, and the vegetation and land-use map reported in Figure 8.

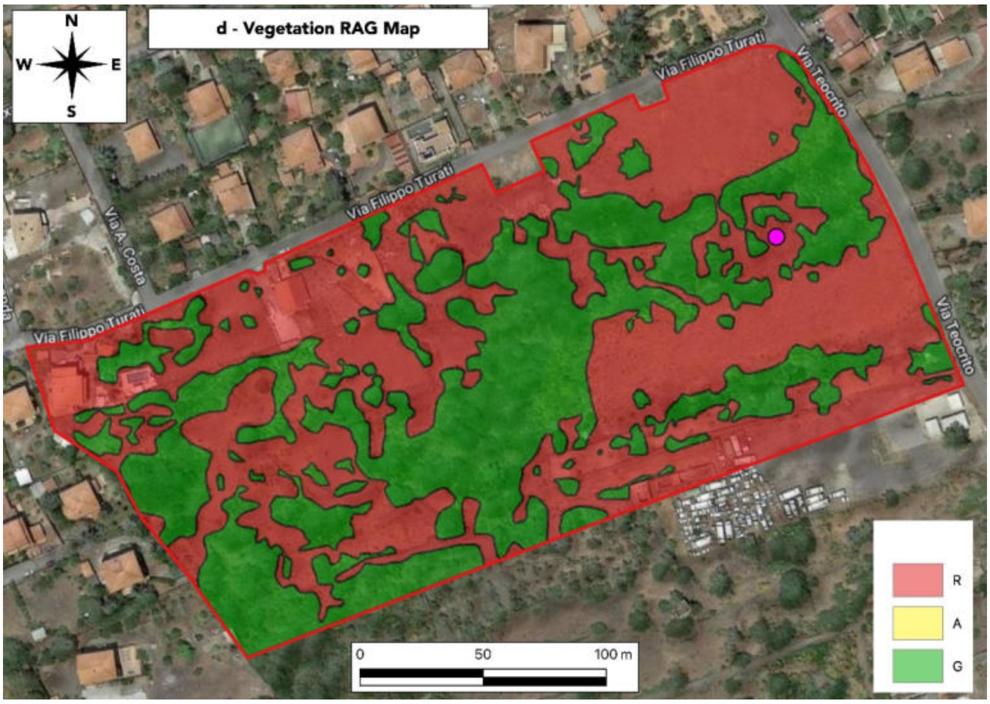

Figure 15. RAG map of the "Vegetation" layer of the GIS platform. The burial site (pink circle) fell on the Red coded area. For the percentages of RAG color-coded areas see Figure 11 (the Amber-coded area is not visible covering the 5% along the Red and Green area boundary).

The burial site appeared, both to the North and South, hidden by shrubs of the Mediterranean Macchia mainly developed onto an ENE-WSW trending belt (Figures 5B, 6 and 8).

During control inspections made along the public roads delimiting the search area, it was possible to verify that the burial site was not visible by potential observers, being covered by vegetation (Figure 7).

The qualitative evaluation of the vegetation considered the following typologies: (i) absent or thin (with grass, isolated shrubs and trees, uncultivated and degraded areas); (ii) moderately dense; (iii) dense with brambles, shrubs, and trees of the Mediterranean Macchia. The search area was mainly formed by uncultivated fields and belts of the Mediterranean Macchia (Figure 8). This latter was mainly stretched along the exposed or very shallow basaltic lavas. The uncultivated fields and degraded areas were ascribed to the Red color code (high suitability), being reachable sites for concealment. The dense vegetation of the Mediterranean Macchia was ascribed to the Green color code (low suitability), being this latter difficulty reachable and impenetrable for concealment. A 1 m wide belt with intermediate characteristics, stretched between the Red and Green-coded areas, was attributed to the Amber code (Figure 15). The Red, Amber, and Green classes constituted 55%, 5%, and 40% of the total, respectively (Figures 11 and 15). The burial site fell on the Red coded area (Figure 15).

Human-Made Structures

The "Human-made structures" layer (Figure 16) of the GIS platform was elaborated considering the aerial and satellite images, the topographic and land-use maps, and cadastral information to individuate anthropogenic structures, such as roads, dirt paths, buildings, and walls. The search area mainly covered an inhabited and abandoned place, where farmers cultivated mostly vine grapes and olives before the abandonment of the countryside occurred in Italy in the immediate afterwar in the 1950s. Evidence of human-made structures (Figure 16) was given by numerous old dry walls partially ruined, made of blocks of local basalts, up to 4 m wide and 3–4 m high. Most recent walls and structures were observed in the NW and SE border zones, where cottages with paved gardens and some ruins with disused car storage activities were recognized, respectively. Evidence of waste dumps was also evident along Turati Street. The areas not involved by human-made structures were ascribed to the Red color code, suitable for concealment. The areas involved by anthropogenic structures were ascribed to the Green color code, being these latter not diggable through hand-instruments. A 1 m wide belt with intermediate characteristics, stretched between the Red and Green-coded areas, was attributed to the Amber-code (Figure 16). The Red, Amber, and Green classes constituted 88%, 3%, and 9% of the total, respectively (Figures 11 and 16). The burial site fell on the Red coded area (Figure 16).

Geomorphology RAG Map

The "Geomorphology" layer (Figure 17) of the GIS platform was elaborated considering the aerial and satellite images, the topographic, and hydrogeological risk maps. The search area mainly covered a stable area. No critical and unstable phenomena were observed except along the two belts at the foot of the two slopes, corresponding to the outcrops of basaltic flow. These belts corresponded to areas subjected to gravitational fall of basaltic blocks. The stable areas were ascribed to the Red color code, suitable for concealment. The unstable areas were ascribed to the Green color code, which is unsuitable for concealment. A 1 m wide belt with intermediate characteristics, stretched between the Red and Green-coded areas, was attributed to the Amber-code (Figure 17). The Red, Amber, and Green classes constituted 99%, 1%, and 0% (0.31) of the total, respectively (Figures 11 and 17). The burial site fell on the Red coded area (Figure 17).

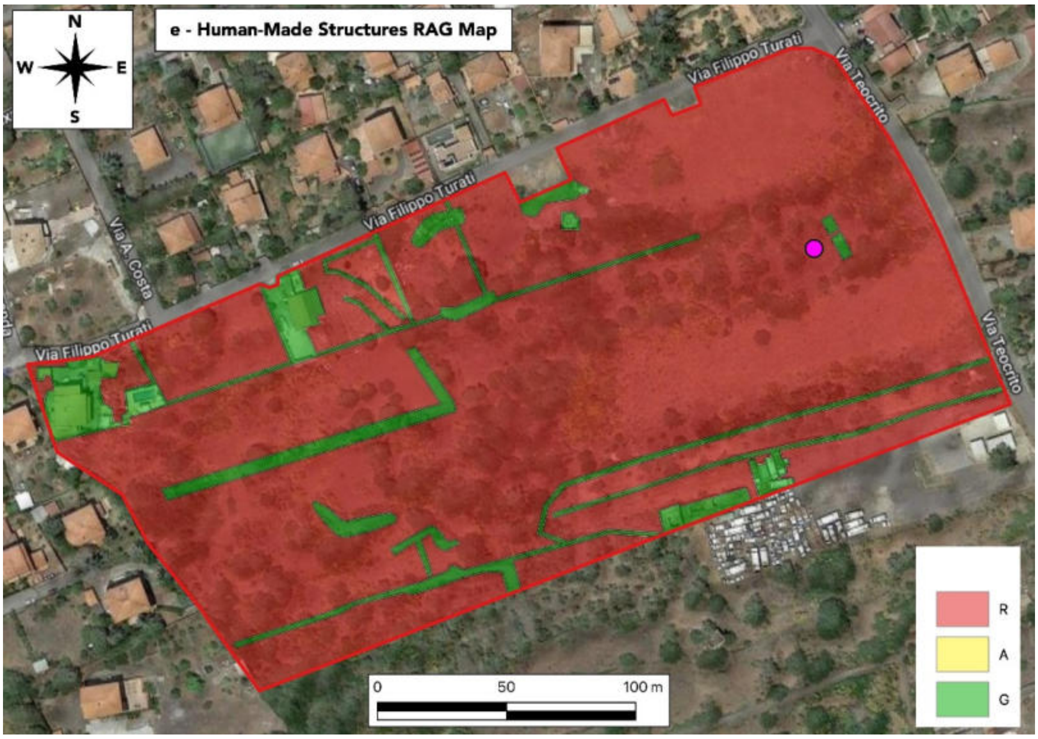

Figure 16. RAG map of the "Human-made structures" layer of the GIS platform. The burial site (pink circle) fell on the Red coded area. For the percentages of RAG color-coded areas see Figure 11 (the Amber-coded area is not visible covering the 3% along the Red and Green area boundary).

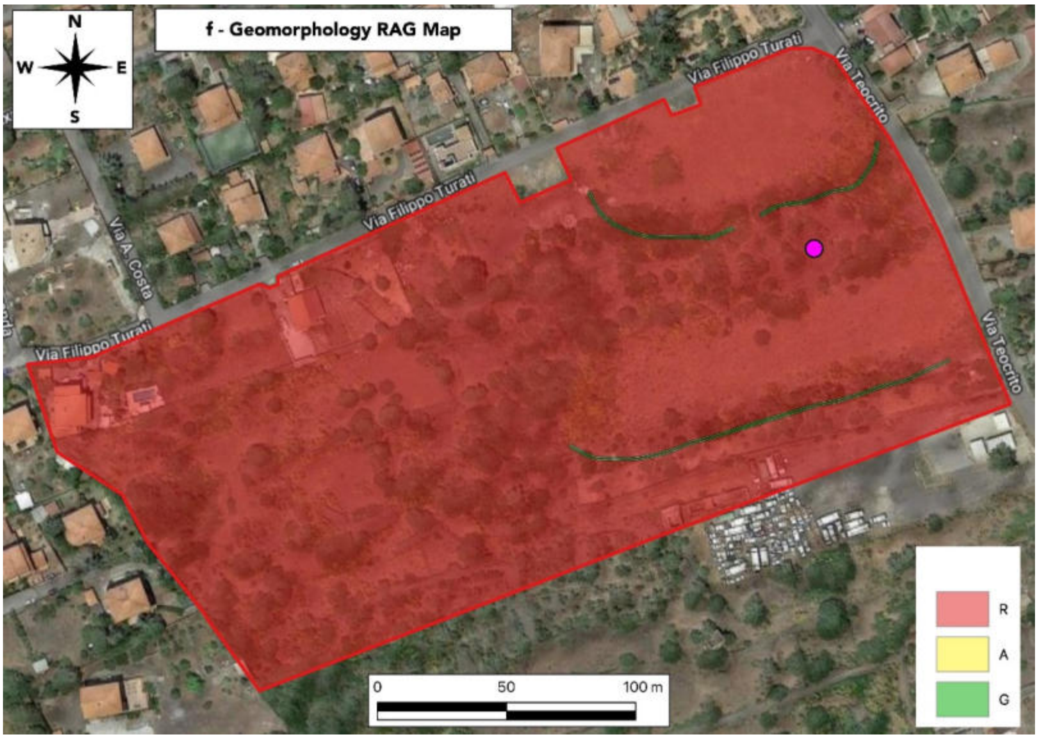

Figure 17. RAG map of the "Geomorphology" layer of the GIS platform. The burial site (pink circle) fell on the Red coded area. For the percentages of RAG color-coded areas see Figure 11 (the Amber-coded area is not visible covering the 1% (0.56) along the Red and Green area boundary).

Visibility

The visibility map may be obtained using the view-shed analysis and is helpful when the hole is dug in daylight [49]. The "Visibility" layer of the GIS platform was elaborated considering the DSM of the area. The analysis was accomplished after considering the country's urbanistic structure characterized by single houses generally consisting of a number of floors from one to two. In rare cases, some houses on three floors were observed. The view-shed analysis was carried out following the method reported in Somma et al. (2018) [49]. The possible eyewitnesses for the view-shed analysis were localized in the most strategic observation positions around the search area, distributed along the main streets surrounding the site and the main houses. Forty viewpoints were localized, as shown in Figure 18. The position of the eyewitnesses was at an average distance of 25 m along the main streets, with an observation point at 1.65 cm from the ground (considering the mean height of population in Catania) and a length of observation of 500 m. Viewpoints were also distributed on the balconies of the most elevated building in the area. The efficiency of the viewpoint distribution was verified through the elaboration of the view shed analysis. In the DSM-based visibility layer (Figure 19), the hidden areas depend on the cover effect of the landscape, vegetation, and buildings. The Red areas included invisible zones from any viewpoint (high suitability). The invisible areas were suitable for the concealment act, as nobody might see the criminal action. The Green areas included the visible areas and were not suitable for a concealment, being visible by potential eyewitness. The Red and Green classes for the DSM-based visibility layer constituted 15% and 85% of the total, respectively (Figures 11 and 19). The burial site fell on the Red coded area (Figure 19).

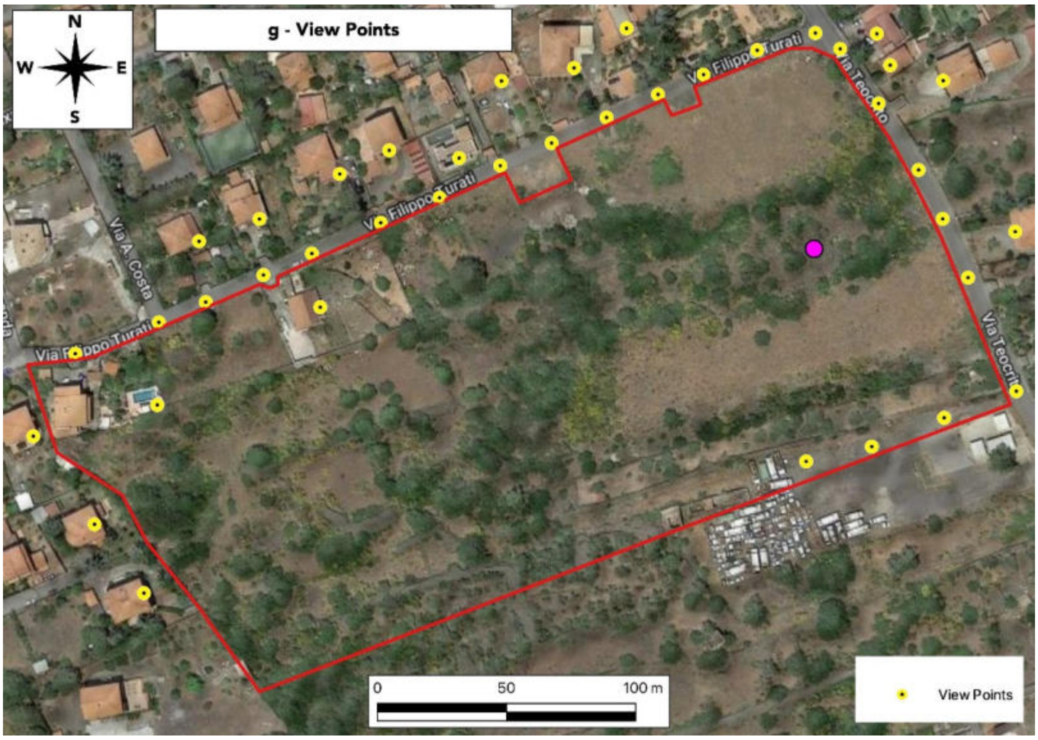

Figure 18. Localization of the viewpoints used for the view shed analysis.

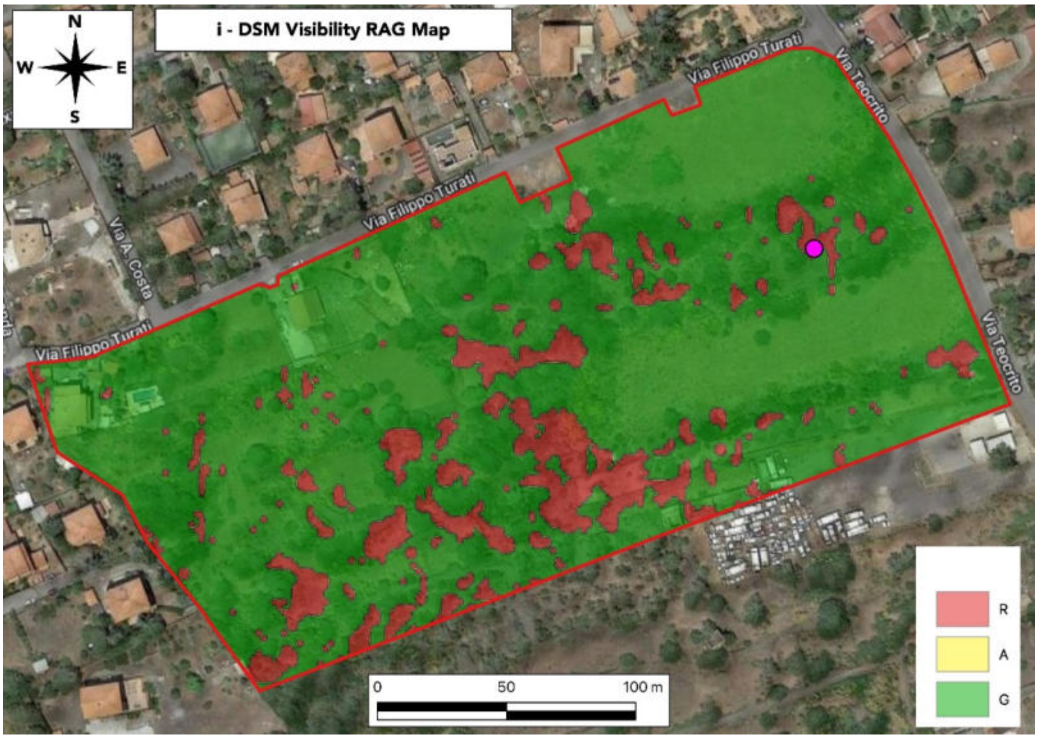

Figure 19. RAG map of the "DSM-based visibility" layer of the GIS platform. The burial site (pink circle) fell on the Red coded area. For the percentages of RAG color-coded areas see Figure 11.

Search Scenarios

After having elaborated the RAG maps for each suitable factor, the used GIS-based method was devoted to create two search-scenario maps (Figures 20–22), one for a concealment in daylight and the other one for a concealment during the night.

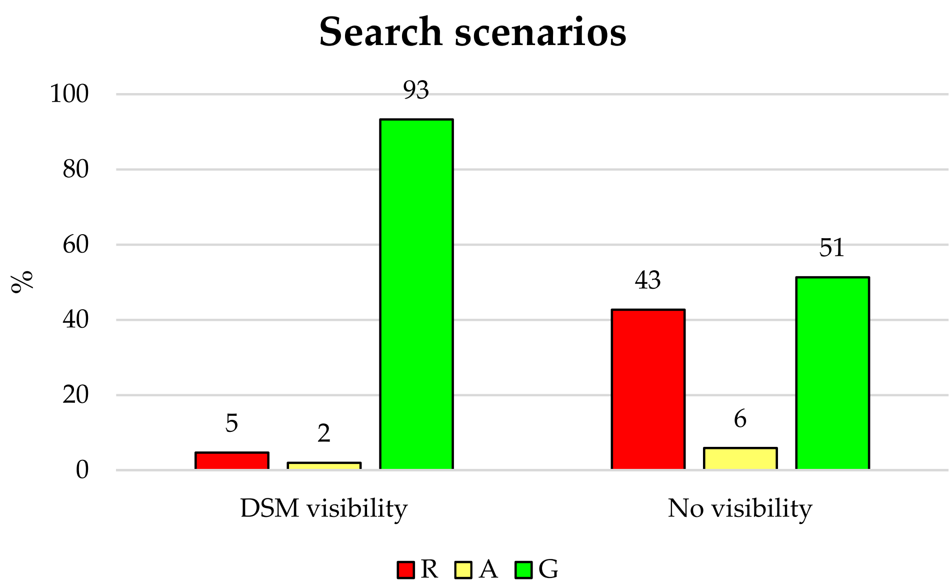

Figure 20. Histograms showing the percentages for each search scenario. Legend: R: Red code, A: Amber code, G: Green code. DSM visibility: DSM Search scenario, No visibility: Search scenario without visibility.

Figure 21. RAG map of the "DSM-based visibility search scenario" (for daylight concealments) of the GIS platform. The burial site fell on the Red coded area that covers the 5% of the search area. For the percentages of RAG color-coded areas see Figure 20 (the Amber-coded area is not visible covering the 2% along the Red and Green area boundary).

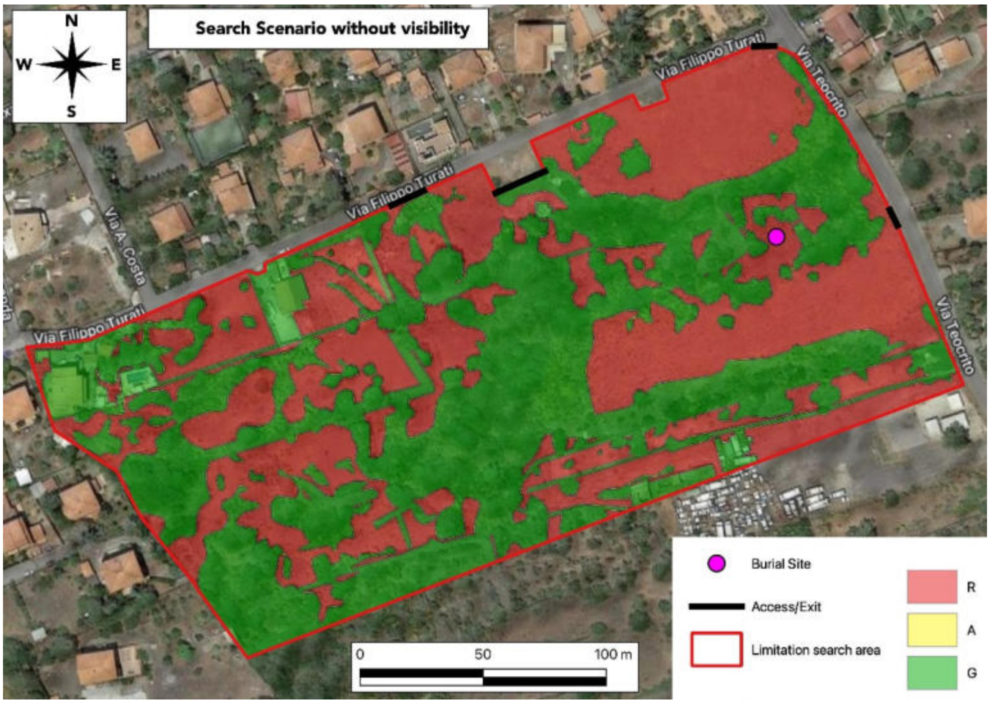

Figure 22. RAG map of the "Search scenario without visibility" (for night concealments) of the GIS platform. The burial site fell on the Red coded area. For the percentages of RAG color-coded areas see Figure 20 (the Amber-coded area is not visible covering the 6% along the Red and Green area boundary).

Search scenarios considered the cumulative suitability to host a burial by crossing information related to the RAG maps of the factors (Figure 1C). The two search scenarios individuated areas at high, medium, and low suitability for the burial corresponding to high-, medium-, and low-priority areas, whose percentages were calculated (Figure 20).

Investigative information provided by OSINT data [43,92–103] indicated that the digging activities were presumably carried out in daylight. If a concealment is made in daylight, then the search scenario including the DSM-based visibility layer will be the most appropriate and the amplitude of the Red coded areas will decrease respect to a concealment made during the night being not influenced by the visibility factor [49]. The search scenario including the DSM-based visibility will be influenced not only by the cover effect of morphology, but also by vegetation cover in function of the plant height and the elevated hand-made infrastructures, such as buildings (Figure 21). If a burial is realized during the night, it is necessary to reconstruct a search scenario without the visibility layer (Figure 22) and in this case the high priority area will increase the extents. The Red, Amber, and Green classes for the DSM-based search scenario (for daylight concealments) constituted 5%, 2%, and 93% of the total, respectively (Figure 20). The burial site fell on the Red coded area (Figure 21). The Red, Amber, and Green classes for the search scenario without visibility (for night concealments) factor constituted 43%, 6%, and 51% of the total, respectively (Figure 20). The burial site fell on the Red coded area (Figure 22).

4. Discussion

The main results of the study on thirty clandestine graves compared with those from three experimental pits dug by the authors with hand instruments and mechanical excavator, allowed to characterize the nature of ground burials, as here reported:

1. The shape in plan view of the pits is usually elongated with an ellipsoidal, rectangular, or irregular shape.
2. The ellipsoidal graves resemble on plan view a "foot" and are typical shapes of the pits dug in the underground with a spade/hoe and shovel as demonstrated by excavations realized in experimental excavations. The 3D shape of these ellipsoidal graves is peculiar and may resemble the shape of a "bathtub" showing three subvertical walls and one dipping towards the bottom. Experimental excavation demonstrated that in shallow burials, the sub-vertical walls are usually determined by the cut of the terrains made by a spade, pick, or hoe, whereas the gently dipping walls are usually determined by using a shovel in the act to move on the soil.
3. The rectangular graves with sharp angles are typical shapes of the holes dug by mechanical excavators. The rectangular graves studied in most of the thirty graves show considerable depths and are compatible with 3D shapes similar to rectangular parallelograms obtained in the experimental excavations.
4. The grave depth studied on fifteen graves (of the sample of thirty graves) results to range from 20–30 to 250 cm with an average value of 91 cm.
5. Depths in the sample of thirty graves lower and higher than 150 cm generally indicate graves dug by hand with spade and shovel and by excavator, respectively.
6. The 86% of the studied thirty graves was dug by men and only 14% was dug by women.
7. The little available data on the graves dug by women indicate that the pits are very shallow, the depth reaches a medium value not exceeding 30 cm, and that used instruments are hand tools, such as spade, hoe, pick, and shovel.

The remote sensing study through GIS-based RAG system applied to the case study allowed to establish that the pit appeared very shallow and presumably under-dimensioned. To dig a hole of adequate dimensions is a difficult activity without keeping in mind a dimensional target or having the possibility for testing dimension posing the body/item in the hole. Observations on the concealer behavior realized by one of the authors (R.S.) in experimental fields demonstrated that the concealer repeatedly tests the pit volume for seeing if the item to conceal fits into the hole during digging activities.

The method of the GIS-based RAG system allowed to reconstruct the RAG maps of the factors suitable for ground concealments (Figures 13–17 and 19) and search scenarios (Figures 21 and 22) from which it was possible to observe as the burial was localized in the Red-color coded area in each map. From the analysis of the considered factors suitable for ground concealment, it was possible to observe as the cover effect exerted by the dense vegetation of the Mediterranean macchia (Red coded area equal to 15% Figures 11 and 15) was the most restricting and determining parameter to render the burial site suitable for concealment. The DSM-based visibility search scenario elaborated in the present search for a daylight concealment provided a high priority area equal to the 5% of the search area within which the grave fell down (Figures 20 and 21). This value, if compared with the Red-coded percentages of the DSM-based search scenarios obtained in the simulated cases, is analogous, being the Red-coded areas at Messina and Alì burial sites ranging between 2% and 6%, respectively [49]. These encouraging results could have been useful for search teams and dog handlers and a better management of the involved resources, if this method had been applied for the search for a corpse concealment. Such results would have been less useful in the case of a concealment during the night, being the high priority area equal to the 43% of the search area. The results of the applied RAG prioritization System allow to validate a method previously based only on simulated crime scenes [49].

5. Conclusions

In conclusion, the present study on the nature of clandestine graves may provide useful features to be considered during judicial investigations for evaluating several hypotheses on the possible digging modality and the involvement of accomplices.

Moreover, GIS-based prioritization systems that are chiefly aimed for a better management of resources during the search for clandestine graves could also be used for evaluating hypotheses on premeditated or not premeditated corpse concealments, in criminal cases of homicide graves falling down in Red- or Green-coded areas, respectively. It is necessary to underline that such evaluating hypotheses may lead to investigation hints and need to be cautiously considered together with other investigative, criminalistic, and criminological data.

The authors were motivated to publish the present research because they firmly believe that a major knowledge on this particular topic of the forensic geology and criminological/criminalistic sciences to which geoforensics belongs could be useful and of benefit for the relevant authorities and defense investigations into the crime prevention and efforts to reconstruct the judicial truth. For this reason, the creation of a special unit in the Italian crime scene investigation system, devoted to the collection of the criminal information concerning the nature of clandestine graves, should be strongly recommended.

Author Contributions: Conceptualization, R.S.; methodology, R.S.; software, N.C.; validation, R.S. and N.C.; formal analysis, R.S. and N.C.; investigation, R.S.; resources, R.S.; data curation, R.S. and N.C.; writing—original draft preparation, R.S.; writing—review and editing, R.S.; visualization, R.S.; supervision, R.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received funding of the Messina University.

Institutional Review Board Statement: Not applicable.

Acknowledgments: The authors acknowledge Filippo Cucinotta, Alessio Altadonna, Giuseppe Martello, and Eugenio Guglielmino of the Engineer Department of the Messina University for the 3D images by laser scanner realized in the pit at the experimental field. R.S. is grateful to the criminologist Federica Obizzi for her critical suggestions. The authors acknowledge the anonymous reviewers for their corrections and useful suggestions that strongly improved the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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