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Perspective

The Importance of Soil on Human Taphonomy and Management of Portuguese Public Cemeteries

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Abstract: Cemeteries from the European Romantic period (18th–19th centuries) are often compared to small cities that hold memories, art, and history. Portuguese public cemeteries were first established in 1835 and became an interesting combination of fauna, flora, and monumental sculptures to mourn the dead at a location outside the limits of the city. Over the past 187 years, laws have been created and amended taking into consideration the needs of the population and the scientific knowledge available at each time point in history. Nevertheless, cemeteries have long been struggling with the lack of burial space which has been emphasised during the two years of the COVID pandemic. This work aims to review the development of Portuguese public cemeteries since their establishment, highlighting the imposed measures for the inhumation and exhumation of the deceased. It will also discuss the importance of soil as an abiotic agent, focusing on eight specific soil properties and their significance on the characterisation of graves. It is expected that a better understanding of the impact of soil on human taphonomy supports the role of city halls in managing public cemeteries, particularly the lack of burial space.

Keywords: forensic taphonomy; graveyards; human decomposition; soil characterisation; soil properties

1. Introduction

Burying and mourning the dead is a practice which dates back to our closest human relatives. Excavated bedrocks and the anatomical position of bones and skeleton imprints dated from the Palaeolithic (c. 2.5 Ma–10 Ka BCE) show how Neanderthals (*Homo neanderthalensis*) and anatomically modern humans (*Homo sapiens*) had intentionally buried their relatives [1–3]. In the course of history, mortuary practices have changed, showing how inherently connected they are to distinct cultures and religious beliefs. Nevertheless, cemeteries have long been used by societies. For example, the Mount of Olives Jewish Cemetery, in Jerusalem, was established during the First Temple Period (c. 960–586 BCE). Burials still take place today, with a total of seventy thousand graves [4]. In the Wadi

Al-Salam Cemetery in Najaf, Iraq, approximately five million bodies have been buried since its foundation in 791 CE, making it the largest cemetery in the world [5,6].

In a Catholic setting, between the eighth and the eighteenth centuries, burials would occur inside and around the walls of local churches so that the human soul could benefit from their sacred environment [7–11]. The concern about the unhygienic nature of traditional entombment began in 1706 with the Italian anatomist, epidemiologist, and physician Giovanni Maria Lancisi (1654–1720) advising Pope Clement XI to build four cemeteries outside the urban area of Rome [12]. The former line of argument led to the prohibition of burials in churches in distinct European countries such as France (1776), Sweden (1783), and Spain (1785–1787) [12]. Nevertheless, it was only with the opening of the Parisian Père-Lachaise Cemetery (1804) under Napoleonic influence that a substantial change took place [13]. The so-called "new cemeteries" would be a mixture of fauna, flora, and monumental sculptures, setting a place to worship the dead outside the limits of the city (Figure 1). Public cemeteries of such kind would arouse emotional reactions and incorporate the bucolic characteristics of the artistic Romantic movement, hosting individuals of all religions. The idea soon spread around Europe, including to Portugal.

Figure 1. Graves and chapel vaults at the Cemetery of Monte d'Arcos, Braga, Portugal (**A**). Example of an ornamented vault at the same cemetery (**B**). Photographs taken in September 2021.

The present manuscript aims to review the establishment and development of Portuguese public cemeteries over the past 187 years. Acknowledging the current lack of burial space in Portuguese cemeteries, this paper also aims to review the importance of studying soil properties from burial sites to understand the effects of soil on human taphonomy and, consequently, inform cemetery management.

2. The Establishment and Development of Portuguese Public Cemeteries

In 1760, Portuguese thinkers started questioning the immorality of the living sharing the same space as the dead: after all, churches crowded with corpses were unsanitary, and such a scenario was violating the dignity of the deceased [11]. Therefore, during the reign of Queen Maria I, the magistrate Diogo Inácio de Pina Manique (1733–1805) established the Decree of 9 August 1834 to buy lands for the establishment of new public cemeteries. At that time, two areas of land were bought in Lisbon: one in Campo de Ourique, and the other in Penha de França. However, the absolutism the country was going through made it impossible to execute such liberal measures. After a Civil War (1832–1833) and a cholera epidemic (1833), the Decree of 21 September 1835 was implemented. In representation of

Queen Maria II, the Minister of the Kingdom Rodrigo da Fonseca (1787–1858) established a set of fourteen articles ruling how burials would take place from that moment onwards.

In 1833, due to the high number of deaths during the epidemic, a temporary cemetery was built in the land that is today known as the Cemetery of Prazeres (Campo de Ourique, Lisbon) [14]. This is considered the largest and most important Romantic cemetery in Portugal, being a place of rest for renowned politicians and artists [15]. The first autopsy room placed outside the National Institute of Legal Medicine is located at the cemetery, in the Chapel of Prazeres. The second cemetery opened to the public was the Cemetery of Alto de São João (Penha de França, Lisbon), in 1839 [16]. Still in the process of being classified as a site of national heritage, the cemetery hosts victims of 5 October 1910 (Day of the Foundation of the Republic), soldiers from the First World War (1914–1918), and opponents of the dictatorship (1926–1974). New public cemeteries started to be built across the continental and insular Portuguese territory in cities such as Porto (Cemetery of Prado do Repouso, 1839; Cemetery of Agramonte, 1855), Évora (1840), Vila Real (1841), Funchal (1842), Horta (1846), Ponta Delgada (1846), Angra do Heroísmo (1848), Viseu (1856), Coimbra (1860), and Braga (1870) [12]. In 2010, cemeteries from the city of Porto became members of the Association of Significant Cemeteries in Europe, joining the European Cemeteries Route that enables visitors to discover and learn about the national heritage at rest in cemeteries. The Cemetery of Agramonte gained special interest from the media and science due to its relation with one of the most intriguing cases of poisoning that motivated the restructuring of the Portuguese medicolegal services [17–19].

Over the years, laws were created and amended regarding the construction, surveillance, and maintenance of public cemeteries, taking into account the needs of the population at each time period. As described below in more detail, Portuguese legal experts introduced and removed distinct procedures over a total of five decrees and two decrees-law due to health concerns and the increased lack of burial space. However, as illustrated in Table 1, the inhumation and exhumation processes were only slightly altered over three decrees and one decree-law.

The Portuguese Cemeterial Legislation

The Decree of 21 September 1835 required that all villages must have a piece of land identified for a public cemetery (Article 1), which would be located outside their urban area due to health concerns (Article 3). City halls are the responsible entities and, if there was no suitable land for that purpose, a new one could be acquired (Article 9). Pre-existing cemeteries must be moved to a more suitable location if their conservation becomes a public health concern (Article 7). Families whose houses host graves and/or vaults can acquire similar places at the new cemetery and transport the deceased to that cemetery although they are not obligated to do so (Article 8). Priests or any other clergymen are prohibited to conduct burials outside the cemeteries, being dismissed of any function if they fail to comply with the ruling (Article 13). A body must be inhumed for five years (Article 2) in an individual soil grave of at least 1.1 m depth and separated from other graves by at least 0.33 m (Article 5). All cemeteries must be surrounded by solid walls of at least 2.2 m high (Article 4), and it is the role of the Cemetery Police to make sure all regulations are followed (Article 14).

According to the Decree No. 6:137 of 29 September 1919, the distance between a cemetery and a school building should be of at least 200 m (Article 27).

According to the Decree No. 13:337 of 25 March 1927, the distance between a cemetery and a school building should now be of at least 500 m (Article 3).

Prior to the thirty articles that comprise the Decree No. 44220 of 3 March 1962, the latter starts by justifying the necessity of altering the law that was being executed until that moment. Based on the allegations of two Portuguese hygienists and epidemiologists, Ricardo de Almeida Jorge (1858–1939) and Carlos de Arruda Furtado (1886–1953), it was decided that there was no need for cemeteries to be so far away from other buildings. According to both scholars, inhumations only required basic conditions and were not a public health issue. Research conducted by Ricardo de Almeida Jorge in 1884, at the Cemetery of Prado do Repouso (Porto) and at the Cemetery of Prazeres (Lisbon), showed that the water in both places was drinkable. A study led by the Institute of France illustrated that the gases at the surface of French cemetery soils were the same as anywhere else. It was even established that the diseases of the dead did not spread to the living. For these reasons, ten meters of distance between a cemetery and another building was considered enough. The Decree states that choosing a piece of land on which to construct a new cemetery must consider the nature of the burial soil: it should be silicious-limestone, clayey-limestone, or silicious-clayey (Article 2). The area required for burials must serve the population for fifty years, having in consideration the death rate of the region (Article 8). The walls surrounding the cemetery must be between 1.50 m and 2 m high (Article 16), and the main gate at least 2.50 m width for the convenience of funerary vehicles (Article 17). Trees, shrubs, and grasses must be planted with the former away from the graves (Article 20). It is forbidden to use solid wood, zinc, and lead coffins on temporary soil graves (Article 22). Once the five years of inhumation are completed, the body must be inhumed for five more years if it is not fully decomposed on exhumation (Article 24). In cases where the body is skeletonized, bones can be removed or buried deeper in the same grave (Article 24).

Table 1. Regulations implemented for inhumation and exhumation of deceased individuals under the Decree of 1835, Decree of 1962, Decree of 1968, and Decree-Law of 1998.

	Decree of 21 September 1835	**Decree No. 44220 of 3 March 1962**	**Decree No. 48770 of 18 December 1968**	**Decree-Law No. 411 of 30 December 1998**
Decree/decree-law number	Non-existent	44220	48770	411
Time of inhumation (years)	Five	Five	Five	Three
Depth of soil graves	Minimum of 1.1 m	Minimum of 1.15 m (adults) and 1 m (non-adults)	Minimum of 1.15 m (adults) and 1 m (non-adults)	Not mentioned
Width of soil graves	Not mentioned	Minimum of 0.65 m (adults) and 0.55 m (non-adults)	Minimum of 0.65 m (adults) and 0.55 m (non-adults)	Not mentioned
Length of soil graves	Not mentioned	Minimum of 2 m (adults) and 1 m (non-adults)	Minimum of 2 m (adults) and 1 m (non-adults)	Not mentioned
Distance between soil graves	0.33 m	Minimum of 0.40 m	Minimum of 0.40 m	Not mentioned
Measures of ossuaries	Not mentioned	0.80 m (length), 0.50 m (width) and 0.40 m (depth)	0.80 m (length), 0.50 m (width) and 0.40 m (depth)	Not mentioned
Measures of vaults	Not mentioned	2 m (length), 0.75 m (width) and 0.55 m (depth)	2 m (length), 0.75 m (width) and 0.55 m (depth)	Not mentioned
Measures of chapel vaults	Not mentioned	Not mentioned	Minimum of 1.50 m (width) and 2.30 m (height)	Not mentioned
Type of coffin (bodies)	Not mentioned	Easily destroyable wood (temporary soil graves) and lead with a minimum thickness of 1.5 mm (vaults and chapel vaults)	Easily destroyable wood (temporary soil graves), wood, zinc, or lead (perpetual graves) and lead with a minimum thickness of 2 mm (vaults and chapel vaults)	Easily destroyable wood (soil graves and aerobic consumption), wood easily destroyable by heat (cremation) and zinc with a minimum thickness of 0.4 mm (vaults and chapel vaults)
Type of coffins (bones)	Not mentioned	Not mentioned	Not mentioned	Wood (cremation) and zinc (ossuaries, vaults and chapel vaults)

According to the Decree No. 48770 of 18 December 1968, the inhumed, exhumed, and relocated bodies must be registered (Article 3 and Article 5), which is the responsibility of the senior employee of the cemetery who also ensures all regulations are followed (Article 4). Inhumations can take place at soil graves or vaults (Article 6). In order to fasten body decomposition, twenty litres of hydrated lime must be placed in bodies buried in wooden coffins, and eighty litres of hydrated lime should be placed in lead and zinc coffins (Article 7). Lead and zinc coffins must be hermetically sealed and should be welded at the cemetery (Article 8). Graves can be temporary or perpetual and should be located in different plots of the cemetery (Article 17). Graves and vaults are considered abandoned if the relatives of the deceased do not exercise their right of mourning the dead for a period of ten years and cannot be contacted by the cemetery personnel (Article 42).

The Decree-Law No. 274/82 of 3 July 1982 comprises a total of forty-one articles establishing how to properly relocate, cremate, and incinerate human remains.

According to the Decree-Law No. 411/98 of 30 December 1998, the police authority is now the *Guarda Nacional Republicana* (National Republican Guard) and the *Polícia de Segurança Pública* (Public Security Police) (Article 2). In vaults, bodies can only be buried in zinc coffins (Article 12). Burials in common graves are forbidden except in emergency situations, and to bury abandoned foetuses or anatomical pieces (Article 14). Ashes from the cremation can be placed inside an urn and be kept at a cemeterial ossuary, grave, or vault, or be under the guardianship of a family member (Article 19). After three years of inhumation, the body must be buried for two successive years if not fully skeletonized on exhumation (Article 21).

3. Soil Properties and Their Influence on Human Taphonomy

As established by the Decree-Law No. 411/98 of 30 December 1998, it is prohibited to open any type of burial place without a warrant within three years after the inhumation. This timeframe of three years has been considered adequate for skeletonization to take place so cemeteries can re-use graves for future burials. If a body is completely decomposed, human bones can be relocated to an ossuary, family plot, or even cremated according to the relatives wishes. If a body is not entirely decomposed when exhumed, the inhumation must continue for successive periods of two years until complete skeletonization is achieved.

Though the inhumation period was originally reduced from five to three years, this timeframe has proven insufficient for skeletonization to take place in several Portuguese cemeteries [20,21]. Despite the endogenous features of the cadaver which may influence decomposition (e.g., cause of death, age-at-death, and fat content), a major concern is the burial soil and its impact on human taphonomy. Soil comprises solid components (organic and inorganic), an aqueous phase with dissolved elements, a gas phase, and biological components [22]. As an abiotic environmental taphonomic agent, soil plays an important role in human decomposition and preservation. To better understand the bilateral relation between soil and buried human bodies, studies have been conducted over the years using human remains which have been donated to science [23–25], exhumations carried out in cemeteries [26,27], and experiments performed with non-human animals used as proxies [25,28–30]. Although forensic experts can analyse a long list of physical, chemical, and biological soil properties, the authors have summarized and discussed eight specific proprieties as presented in Table 2.

3.1. Organic Matter Content

The soil organic matter (SOM) is composed of all soil living organisms, dead organisms partially decomposed, and humus—the latter affecting the bulk density of soil and contributing to the retention of moisture and nutrients. When analysing the SOM content, it is important to consider the soil pH, soil type, and local climatic conditions, given that these factors influence microbial activity [44]. Soil microbes (e.g., bacteria) and animals from the phylum Nematoda (i.e., non-segmented worms) are the primary decomposer organisms associated with cadaveric decomposition [45]. The introduction of cadaveric material into the soil is also regulated by the activity of insects and scavengers [46]. Cadaver decomposition islands (CDI) are soil areas around and below a decomposing corpse, and are associated with high levels of soil microbial biomass and activity [47].

Table 2. Soil studies previously conducted for taphonomy purposes: summary of the main conclusions.

Species	Summary	Reference
Beef (*Bos taurus*)	Cadaveric decomposition appears to increase soil electrical conductivity in sandy soil with a subsequent decline of it.	[25]
Human (*Homo sapiens*)	Cadaveric decomposition appears to increase soil electrical conductivity in sandy soil with a subsequent stabilization.	[25]
	The rate of decomposition appears to be the same in clay, silty clay, and fine sand soils. Mummification occurs in alkaline soils (pH 8.20–8.24).	[26]
	The rate of decomposition appears to be faster in silty soils (rather than sandy soils).	[27]
	Organic matter content appears to be higher at the surface of the graves (rather than on their interior). Soil acidity appears to be directly related with burial graves depth.	[31]
	Organic matter content and colour are in accordance with each other (soils with higher organic matter content are darker in colour). pH was slightly acidic (pH 5.28–6.28) in five different sections of the grave. Moisture content and electrical conductivity results are not in line but no relation with taphonomy appears to exist. Bulk density slightly varied (0.95–1.2 g/cm) but no relation with taphonomy appears to exist.	[32]
	Bone is better preserved in slightly alkaline and neutral soils.	[33]
	Cadaveric decomposition appears to increase soil electrical conductivity.	[34]
	Soil surrounding coffins was grey in colour.	[35]
	Detected bacteriological contamination at a cemetery groundwater.	[36]
	Detected pharmaceutical contamination at a cemetery groundwater.	[37]
	Detected high levels of chemical elements associated with coffin construction at burial graves.	[38]
Lamb (*Ovis aries*)	Cadaveric decomposition appears to increase soil electrical conductivity in sandy soil with a subsequent decline of it.	[25]
Pig (*Sus scrofa*)	Soils with pH between 5 and 9 appear to be favourable for adipocere formation (rather than pH 2.4 and pH 12.6).	[39]
	Hydrated lime and quicklime appear to increase alkalinity in soils. All species were skeletonized when exhumed although lime showed to delay cadaveric decomposition.	[40]
	Cadaveric decomposition appears to increase soil electrical conductivity in sandy soil with a subsequent decline of it.	[25]
Pig (Sus scrofa domesticus)	The rate of decomposition appears to be the same in silty clay loam, fine sand, and fine sandy loam soils. All species were in putrefaction after fourteen months buried.	[29]
	Sand and silty sand soils appear to accelerate adipocere formation when moist.	[41]
Rat (*Rattus norvegicus domestica*)	The rate of decomposition appears to be the same in loam and sandy loam soils. All species were skeletonized after two months buried. The remains in loam soil were moister than the ones in sandy loam.	[42]
Rat (*Rattus rattus*)	Mass loss appears to be higher in sandy soils when moist or wet (rather than dry). Mass loss appears to be higher in loamy sand soils and medium clay soils when moist (rather than dry or wet). Dry conditions appear to delay the increase of soil pH in sandy soils. Wet conditions appear to delay the increase of soil pH in loamy sand and medium clay soils. Cadaveric decomposition appears to increase soil pH in all soil types with a subsequent decline of it.	[43]

During the characterisation of soil in an exhumed cemetery in Singapore from the 1900s [31], it was noted that SOM content was higher at the surface of the graves than in their interior, which might be explained by the leaf-litter fall from the vegetation at the soil surface. Nevertheless, in a preliminary study conducted in five graves at the Cemetery of Prado do Repouso (Porto, Portugal) [32], SOM content ranged from 3.23% to 5.52% in a total of nineteen samples collected at the surface of the grave, on top of the upper coffin board, and under the lower coffin board in three distinct body regions (head, pelvis, and feet). Interestingly, the highest SOM value obtained was from the head section of a skeletonized individual and not from the surface of the graves. Given that two of the five bodies exhumed were not skeletonized, it was not possible to collect samples under the lower coffin board; even so, the authors expected to find a low SOM content in burial graves with preserved remains.

3.2. Texture

Soil texture reflects the proportion of clay (<2 µm), silt (≥2–20 µm), and sand (≥0.02–2 mm) present in the soil [48]. Considering human taphonomy, texture is mostly studied to test for a relationship with the rate of decomposition. Subsequently, the conclusions obtained from previous studies can be transposed to a more efficient management of modern cemeteries.

Research carried out at an Italian cemetery in Parma showed a higher number of skeletonized remains in silty soils in contrast with two burial sections that contained a higher percentage of sand [27]. Nevertheless, a study conducted on pig carcasses (*Sus scrofa domesticus*) [29] on silty clay loam, fine sand, and fine sandy loam soils showed no visual differences in decomposition on the different soil textures: all carcasses were still in a state of putrefaction after fourteen months. Similarly, research carried out on loam and sandy loam soils with laboratory rats (*Rattus norvegicus domestica*) [42] showed the same stage of decay. After two months, the rats were skeletonized with dry skin and hair; however, the remains in the loam soil were moister than the ones in the sandy loam soil. In two Portuguese cemeteries located at Figueira da Foz, exhumations were carried out and soil was sampled near the bodies [26]. In one cemetery, two individuals were exhumed from clay soil graves and were completely skeletonized. In the other cemetery, soils were either silty clay or fine sand according to the graves section; nineteen out of thirty-one bodies exhumed were skeletonized.

3.3. pH

pH is defined as the negative logarithm of the hydrogen ion concentration [H^+] and it is easily measured in pH units with a pH meter [49]. The amount of hydrogen ions in the soil and its pH are inversely proportional, affecting the solubility of minerals and nutrients. A buried body causes a large influx of organic acids that increases the acidity in its immediate surrounding [50]. This stage is then followed by a decrease in the acidity due to the influx of base ions but, as decomposition continues, the soil gradually becomes more acidic again since nutrient cycling and dissolution reduce the quantity of base ions.

A study on juvenile rats (*Rattus rattus*) [43] buried in three different soil types—whose pH ranged between 5.3 and 7.1—showed that the cadavers increased the soil pH to approximately pH 8 in all grave soils. Overall, soil pH began to decrease by the twenty-eighth day. Furthermore, a study conducted on the walls of burial graves at a Singaporean cemetery [31] showed that the deeper the sample was collected, the more acidic the soil. Nevertheless, in a preliminary study conducted at the Cemetery of Prado do Repouso (Porto, Portugal) [32], pH was slightly acidic (pH 5.28–6.28) at the surface of the grave, on top of the upper coffin board, and under the lower coffin board in three distinct body regions (head, pelvis, and feet).

While bone is better preserved in slightly alkaline and neutral soils [30,33], according to scientific literature, human mummification can occur in both acidic and alkaline environments [51,52]. Proof of that is the analysis conducted at the Oriental Cemetery (Figueira da Foz, Portugal) where mean values of soil pH varied between 8.20 and 8.24, and two bodies were completely mummified [26]. Moreover, a study using adipose tissue from the abdominal region of pigs (*Sus scrofa*) aimed to correlate adipocere formation with pH [39]. In controlled environments, samples were buried in damp loamy sand soils with different pH values (pH 2.4, pH 5.2, pH 8.5, and pH 12.6), and collected after a period of twelve months. The most suitable environments for adipocere formation were the ones with a pH between 5 and 9, with the highest alkaline setting significantly inhibiting decomposition and the formation of adipocere. Adipocere is the natural postmortem conversion of adipose tissue into a solid material made predominately of saturated fatty acids [53,54]. A common effect of adipocere formation is the production of a surface shell which shields enclosed soft tissues from further decay [55]. The presence of lime has also shown to alter soil pH. During an experiment [40], pigs (*Sus scrofa*) were buried with hydrated lime, quicklime, and without any type of lime as a control treatment. While the graves without lime remained the same, alkalinity increased in soils with carcasses covered with lime. Additionally, lime slowed cadaveric decomposition, although the carcasses were all skeletonized when exhumed. It is worth noting that lime has long been used in burials with the belief that it will accelerate decomposition [56,57], and it is still used in burials in some Portuguese cemeteries due to its antiseptic properties. Both hydrated lime and quicklime are calcium compounds, with the former being quicklime to which water has been added.

3.4. Moisture Content

Soil moisture is related to the soil type and permeability, and can have an impact on decomposition given that it can affect the metabolism of decomposer microorganisms [45].

A study performed in loamy sand, sand, and medium clay soils with juvenile rats (*Rattus rattus*) [43] correlated moisture with other environmental factors. No differences on mass loss between all dry soils were detected. In sand, the greatest mass loss occurred in moist and wet soils. On the other hand, the greatest mass loss in loamy sand and medium clay soils were in the moist soils. It was also shown that wet conditions reduced the increase of pH in loamy sand and medium clay soils, while dry conditions reduced the increase of soil pH in sandy soils. In adipose tissue of domestic pigs (*Sus scrofa domesticus*) buried for twelve months [41], sand and silty sand soils accelerated adipocere formation when moist. In a preliminary study at the Cemetery of Prado do Repouso (Porto, Portugal) [32], it was hypothesised that soils with a low percentage of moisture content would be directly related with a low percentage of organic matter content and, consequently, inversely proportional to human preservation. Three out of five exhumed bodies were completely skeletonized, one was partially mummified and skeletonized, and the remaining one was partially putrid, mummified, and skeletonized. The values obtained oscillated between 5.6% and 24.74% but, according to the authors, the results cannot accurately be transposed into reality given that it was raining throughout three exhumations.

3.5. Electrical Conductivity

Soil electrical conductivity (EC) is defined as the ability of soil to conduct an electrical current, and it is closely related with soil moisture, salinity, and texture: saline soils are the most conductive (±50–900 mS/m) followed by clay soils (±20–200 mS/m), silty soils (±5–50 mS/m), and sandy soils (±0.2–11 mS/m) [58].

A study [25] with buried skeletal muscle tissue of beef (*Bos taurus*), human (*Homo sapiens*), lamb (*Ovis aries*), and pork (*Sus scrofa*) demonstrated that soil EC increased up to thirty days. The experiment was performed in sandy soil with pH 6.1 and low levels of salinity (26 µS/cm). Soil EC for human tissue reached approximately 300 µS/cm, stabilising after that point. The values obtained for the remaining animal tissues reached approximately 350–550 µS/cm, and then decreased. Similarly, a study conducted with two human donors [34] showed that EC of control soils was lower (mean = 15 µS/cm) than the ones from the CDI (mean of first donor = 118 µS/cm; mean of second donor = 77 µS/cm). In a preliminary study at the Cemetery of Prado do Repouso (Porto, Portugal) [32], the results obtained ranged between 89 µS/cm and 1997 µS/cm in the CDI while the variation at the surface of the grave and at the upper coffin board was between 55 µS/cm and 504 µS/cm. The authors stated that EC results were not in line with the moisture content results, but texture and elemental analysis might be able to explain such findings.

3.6. Bulk Density

Soil bulk density (ρ_b) is an important soil property in agriculture, soil mechanics, and geotechnical engineering mainly due to its correlation with soil strength and compaction [59]. As mentioned by Chaudhari et al. [60], ρ_b is influenced by the SOM content and texture. The dry bulk density of a soil sample is inversely proportional to its porosity [61] which is strongly correlated with particle size. In an agricultural context, ρ_b values are considered normal when between 1.0 mg/m and 1.6 mg/m for clay soils, and 1.2 mg/m and 1.8 mg/m for sandy soils [60].

In taphonomic contexts, soil ρ_b is occasionally mentioned but analysis is seldom carried out [62]. However, in a study performed at a cemetery in Singapore [31] with a sandy clay loam soil texture, the average values obtained for ρ_b were 1.6 g/cm being in line with those of an agricultural setting. Yet, the cemetery was already exhumed when the study was conducted, and there is no mention as to the rate of decomposition and its relationship with ρ_b. In a study conducted at the Cemetery of Prado do Repouso (Porto, Portugal) [32], ρ_b slightly varied between 0.95 g/cm and 1.2 g/cm even though the exhumed individuals were showing different states of decomposition and preservation.

3.7. Elemental Analysis

Chemical elements (e.g., alkali metals and heavy metals) are present in all ecosystems, being commonly analysed in forensic studies given that their signature is highly specific to each geographic area [63].

In a grave, groundwater can gain access to the buried body and expose it to exogenous agents with chemical effects. Given that tissue enzymes are inherently sensitive to heavy metal ions often present in groundwater, inactivity of the enzymatic decay processes by heavy metal ions can result in postmortem tissue preservation [55]. There are, however, concerns arising that anthropogenic factors (e.g., chemotherapy and embalming fluids) may be responsible for contaminating groundwaters due to leakage from burials [64,65]. In Portugal, embalming is not a common practice though it might occur if an individual is to be buried outside the country, being crucial to delay tissue decomposition. Studies have nevertheless been conducted on Portuguese cemetery wells showing bacteriological (e.g., faecal streptococcus and faecal coliform) [36] and pharmaceutical (e.g., salicylic acid and carbamazepine) contamination [37]. An investigation conducted on soil samples from a cemetery in Ohio (USA) from the mid-1800s showed high levels of arsenic—commonly used as a coffin wood preservative—and high levels of copper, iron, lead, and zinc used in the construction of coffins [38]. Due to lixiviation, these elements can also contaminate groundwater. In order to understand the bilateral relation between human taphonomy and the possible contamination of soil, it is important to also analyse hair and nails from exhumed bodies [66].

3.8. Colour

Colour is an important property to measure when characterising soil given that it changes with other proprieties (e.g., organic matter and moisture contents). In addition, soil colour can be an indication of the presence of chemical elements, such as copper that gives soil a greener colour [67] and iron oxides that give soil a brownish, reddish, or yellowish colour [68].

A study conducted on two German cemeteries [35] showed that the soil surrounding coffins was grey in colour which was associated with reduction conditions as demonstrated by a Fe^{2+} test. On the other hand, soils from a Singaporean cemetery [31] were either strong brown or yellowish brown as expected from old alluvium soils that characterise the region. Furthermore, soils from the Cemetery of Prado do Repouso (Porto, Portugal) [32] varied from greyish brown (10YR 5/3) to light yellowish brown (10YR 6/4) in dry samples, and from dark brown (10YR 3/3) to yellowish brown (10YR 5/4) in moist samples. According to the authors, the obtained results were in line with those from the SOM content analysis (i.e., having darker colours in the samples with higher organic matter content values).

4. Soil Sampling and Its Influence on Sample Analysis

In addition to soil properties being inherently related to each other, they are also dependent on soil components (e.g., mineral composition and water retention properties) [69] which are influenced by environmental and anthropogenic actions. For this reason, it is important to understand the impact of soil properties on various soil processes and how sample collection can influence soil analysis and related results.

As an example, soil texture varies with burial depth which, in turn, influences other properties such as EC, SOM, and moisture retention properties. One aspect that is common to the studies mentioned is the irregular depth at which samples have been collected. In experimental studies, samples were collected at 1 cm depth [25]; and at depths ranging between 0–15 cm and 15–30 cm [47]. In cemeteries, samples were collected at depths ranging between 0–30 cm, 30–50 cm, and 50–100 cm [31]; at a depth of 2.2 m [38]; and at a depth of 3.5 m [65]. In the last two studies mentioned [38,65], sampling was due to the legal depth of burials established by each country. The authors would like to draw attention to this situation given that the obtained conclusions on the studies may not be accurately transposed to contexts where sampling depths are different. Additionally, the attained findings for groundwater contamination [36,37] are dependent on the distance between cemetery burials and wells; the closer they are from each other, the higher the probability of cross-contamination between the two parties. For this reason—and as mentioned by Rodrigues and Pacheco [36]—the World Health Organization (WHO) recommends a minimum distance of 250 m between a well and a burial to avoid any contamination of potable water.

Another variable to consider is the location where soil is sampled: at the surface of the grave [31]; on the walls of the grave [31]; or within the CDI [47]. Soil data will automatically be influenced by the direct contact of soil with any vegetation or with body fluids of a decomposing corpse. It is also important to consider cases where experimental studies fail to consider the presence of a coffin in human taphonomy; a body will decompose differently if in direct contact with soil, and the bilateral relation between both will also be different [30].

During the exhumation of a body, sampling of soil from distinct areas within the grave should be considered (Figure 2). The samples obtained under the grave slab—or directly from the surface when there is no slab—will be suitable as control samples given that the soil is not in direct contact with, near, or underneath the body. During the inhumation period, the upper coffin board usually cracks with the weight of soil, environmental factors, and scavengers. Consequently, the soil sampled from this area would be in direct contact with the wood of the coffin, the released gases from putrefaction and, sometimes, even be in contact with the body itself. Assuming that the upper coffin board is destroyed, there will still be insufficient soil to collect under the body while inside the coffin. During decomposition, fluids can follow a horizontal and (mostly) vertical path, passing through the coffin to the soil around. Sampling should take place under the lower coffin board in three body regions, namely the skull, pelvic girdle, and feet. By dividing the body in three sampling regions, this can potentially shed light on human taphonomy, and on how soil properties are affected by the decomposition process in uncovered and covered regions. The skull is usually the first to skeletonise, followed by the feet—even though the latter are often covered by socks/tights and shoes (which are some of the most resistant garments to degrade). The pelvic region is frequently covered with a diaper/nappy, apart from the underwear and external clothes (i.e., trousers, dress, shorts, or skirt). Despite being the region where decomposition starts due to the presence of gastro-intestinal bacteria, garments might create microenvironments that significantly influence human decomposition [32,70]. With these suggestions, a complete burial characterisation might be achieved.

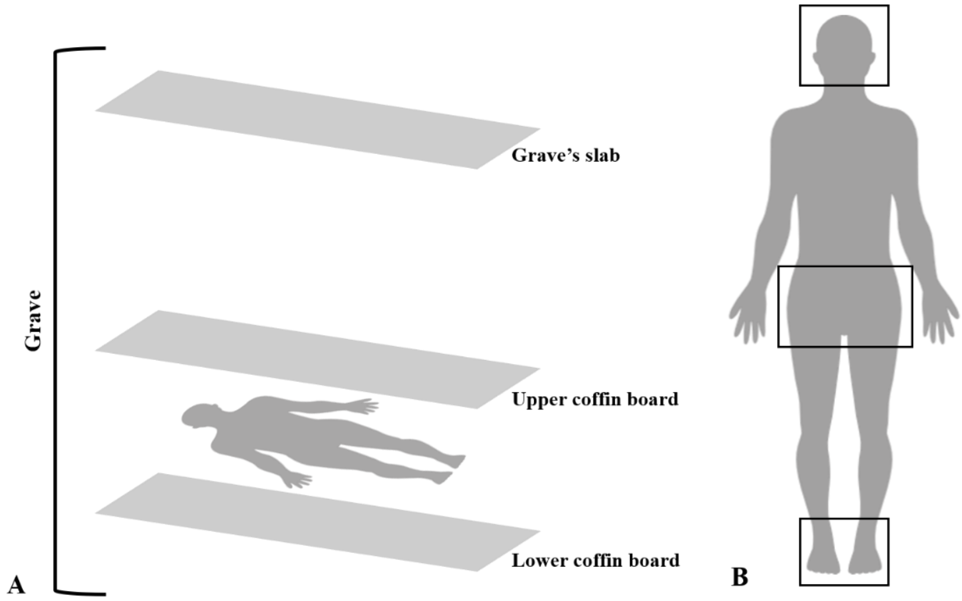

Figure 2. Grave areas (**A**) and body regions (**B**) where soil should be sampled during an exhumation for burial characterisation.

5. Soil Research in Human Taphonomic Facilities

From 1981 to 2020, a total of twelve human taphonomic facilities (HTF) opened across the United States of America, Australia, Canada, and the Netherlands [71]. A major benefit of having HTF in different countries is the possibility of studying human decomposition and its bilateral relation with diverse climates and soil types. Nevertheless, caution must be taken when extrapolating research conducted at HTF.

A study conducted at the Forensic Anthropology Research Facility (FARF) in Texas, USA, aimed to investigate post-burial changes in three individual graves and in a mass grave with six human cadavers [72]. In all graves, burial depth was 0.8 m and soil sensors were installed to measure temperature, EC, and moisture over a period of six months. It goes without saying that sensors installation is not possible inside cemetery graves; to investigate how soil properties change throughout time, the closest approach is analysing graves with different burial ages. A period of six months also does not seem to be sufficient to understand the relation between human decomposition and soil properties given that the minimum inhumation period in Portugal is three years. Even after that period, bodies may not be completely decomposed, and so the body will not be exhumed and soil will not be sampled under the lower coffin board for analysis.

At the Anthropology Research Facility (ARF) in Tennessee, USA, researchers evaluated the possibility of soils being saturated after thirty years of human decomposition studies [73]. Overall, the results obtained showed no significant discrepancies within the sampled areas of the HTF. Still, results showed significant differences between samples from inside and outside the facility—used as control samples—primarily in pH soil values which were higher in decomposing sectors due to ammonification. Soil saturation due to continuous body decay is an important aspect to consider in Portuguese cemeteries. In addition to the prolonged time period in which soils have been used, graves are often re-used on the same day an exhumation takes place. In a situation like this one, the process of decomposition of a body might be influenced by how soil responded to the decomposition of the previous body. This factor appears to not have been considered yet in HTF research, and it is plausible to think it can contribute to the slow decomposition rate in Portuguese cemeteries.

6. Conclusions and Future Perspectives

When public Portuguese cemeteries were first established in the nineteenth century, legal experts and government personnel had taken into consideration the scientific knowledge and necessities of the country at that time. Nowadays, cemeteries are either too small or insufficient in number to serve the needs of the population. Furthermore, there is no new land available to construct new cemeteries in urban areas, and the rate of cadaveric decomposition is not rapid enough. Despite aerobic consumption modules and cremation having become increasingly popular over the years particularly among younger citizens, regular burials are still the preferred way of mourning the dead in a country whose Catholic religious rituals persevere [74–76]. The overcrowding situation in cemeteries is now urgently requiring a solution and is of great public interest.

Although knowledge about human decomposition has been increasing thanks to scientific research carried out in different contexts, there is still a long way to go. Firstly, most studies conducted have only contained a small number of replicates; and for this reason, general observations must be interpreted with caution and cannot be strictly transposed into reality. Secondly, some experiments are performed in controlled environments and such scenarios cannot mirror the daily range of fluctuations in the many variables found at a public cemetery. Ultimately, conclusions of research carried out in real settings (e.g., Italian cemeteries) might indeed be specific to that location, given that climatic conditions may differ between and within countries. In fact, despite the lack of research conducted at Portuguese cemeteries [26,32], it is already possible to observe the disparity in soil properties from different regions of the country.

In order to understand and overcome the lack of burial space in Portuguese public cemeteries, the authors believe it is of paramount importance for forensic investigators to assist exhumations and conduct research in cemeteries around the different geographical regions of the country, collecting and analysing grave soil samples from the range of real exposed environments. Given that Portugal has not established a taphonomic or similar experimental facility, it is worth noting that such research and knowledge gained could also aid police forces in criminal investigations involving the burial of human corpses and held assist in the management of limited cemetery space.

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