

Can paper documents endure burial concealment? An investigation into preservation of questioned documents using Electrostatic Detection Apparatus (ESDA) analysis

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Declaration

I, Megan Trent, confirm that the material presented in this document is the result of my own efforts, and where any material from other authors/investigators has been used, it has been acknowledged in the text of the document and listed in the references section. I also hereby declare that the following material has only been presented for review as part of the BSc H forensic science with criminology at the University of Greenwich, and has not been presented elsewhere for review as part of any other undergraduate degree course.

Signed,

A handwritten signature in black ink, appearing to be the initials 'MT' in a cursive style.

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Abstract

This investigation tested the effectiveness of different materials at preserving documents from burials using Electrostatic Detection Apparatus (ESDA) analysis. Both forensic document analysis and forensic archaeology are two important fields regarded in forensic science but there is little research into these fields in conjunction. ESDA analysis can be a valuable tool within ongoing forensic cases as it can reveal important leads that can help convict suspects. Thus, testing the limits and boundaries of ESDA is crucial in order to have a better insight of its precision and purpose in particular cases. The hypothesis for this study was that materials that are more impermeable will have better ability at preserving documents in burials and so will produce higher quality ESDA results. The study took place by placing documents into six different experimental materials and burying them for a time period of one month. After the one month period, the documents were analysed using the ESDA procedure. The results of the ESDA analysis showed that the unconcealed documents, as expected, showed the highest quantity of positive ESDA developed images. The only experimental condition to produce positive ESDA results were the documents buried in plastic wallets. All other experimental conditions produced negative results. It was concluded that the negative results were due to the materials being more permeable, therefore, allowing environmental factors such as moisture and changes in soil pH to interfere with the documents. The findings support the notion that there are many factors that can be detrimental to potential forensic evidence.

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Introduction

Analysis of several crimes including burglaries, abductions, homicides, and terrorism are frequently correlated with the retrieval of paper documents that were written by the culprit (McLaughlin *et al.*, 2021). The majority of the casework dealt with by a forensic document examiner is involved with financial misconduct, consisting of relatively smaller crimes such as misuse of cheques to bigger crimes such as company frauds (Hall, 1995). Forensic investigation of documents involves specialist assessments on any kind of document for the objective of verifying authenticity. It stands as one of the first fields of forensic science and remains one of the most significant, considering the value of documentation in the current society, regardless of the growing use of electronic forms that have simultaneity entwined during the last decades (e Brito *et al.*, 2017). The most frequent substrate for documentation is conventional paper (Allen, 2015). Moreover, it has been found that offenders tend to follow a pattern of leaving a trail of sheets of conventional paper in the tasks of the crime (Hall, 1995). These sheets of paper are known as questioned documents and they can offer a range of forensic evidence, for example, deoxyribonucleic acid (DNA), latent fingermarks, and indented handwriting (McLaughlin *et al.*, 2021). Document examiners can aid the investigator by gathering these types of evidence from the paper trail that can provide leads to the criminal (Hall, 1995). One of the types of evidence, indented impressions, can be investigated and highlighted by Electrostatic Detection Apparatus (ESDA) (Jasuja & Singla, 1991).

The imaging method was firstly documented by Foster and Morantz in 1968 (Morantz, Foster, & Ellen, 1978). Soon afterwards in the late 1970's, Foster and Freeman Ltd. launched the manufacturing of the ESDA machine commercially for function in laboratories (Tolliver, 1990). The method of ESDA entails five stages (Roloff, Offa, & Turner, 2017). The first stage is positioning the questioned document onto the grounded sintered brass platen (Foster and Freeman Ltd, 2007). The second stage consists of a vacuum being utilised to pull the document down and a layer of mylar film being pulled across it. The third stage is administering an electrostatic charge to the mylar film by moving a corona wire that remains at a negative voltage (-8000 V) over the mylar film (Yaraskavitch *et al.*, 2008). The fourth stage is administering toner with a negative charge onto the document, as the toner is especially drawn to the areas of indented markings, therefore, permitting imaging. The fifth and final stage is using a transparent adhesive lift to protect and maintain an image of the indented markings (Roloff, Offa, & Turner, 2017). Seward (1988) suggested that positive ions present around the atmosphere attach to locations of paper-to-paper friction generated in the course of the indentation, which gives a positive charge at the surface of those locations. A perturbation voltage is then sourced from this charge (Yaraskavitch *et al.*, 2008). Charge transport across the mylar paper is accelerated in areas of indentation because of the

perturbation voltage (Yaraskavitch *et al.*, 2008). This produces a fairly positive electric potential above indentations following a stage of charge decay. Seward's (1988) model was founded on charging the mylar to a consistent surface potential by means of applying a nonuniform surface charge.

During the ESDA procedure, the image can be developed one of two ways, the first way being a fine spray of toner powder applied using an injection nozzle over the mylar film (Baier, 1983). The second option is known as the cascade developer technique where the ESDA plate should be lifted to a 30° angle and small pellets (roughly 0.5 mm in diameter) of toner are poured over the mylar film (Daéid, Hayes, & Allen, 2008). Both methods accomplish the same aim of covering the mylar with toner. The distribution of the toner relates to indentations on the paper, with the more pronounced indentations having more toner adhere to its precise location, and thus rendering harsher dark markings (Baier, 1983). Once the toner has developed the image, it can be fixed with a transparent adhesive film. As the procedure is non-destructive, the research can be repeated numerous times (Jasuja & Singla, 1995). Owing to this, the decision was made to carry out three repeats of ESDA analysis for each document. According to Foster and Morantz (1979), the charging process seems to not be critical. A study by Baier (1983), found that it is essential to increase the charging process if the injection nozzle (aerosol technique) is utilised to allow for image development. Whereas the duration of charging process is not highly important if the cascade developer approach is employed (Baier, 1983).

The importance of ESDA is that it is useful for determining unidentified letter writers. Other important uses are in drug cases where contact names, phone numbers, and other information may have been written down and then demolished (Marsh, 2006). Therefore, analysis of the pages underneath using ESDA could be evidentially beneficial (Marsh, 2006). The ESDA technique has also been shown to be useful in investigating physical fits within the trace evidence field (Brooks *et al.*, 2020). Physical fits in forensic science occur in numerous ways, for instance, torn textile pieces, detached fragments of duct tape, and even separated fragments of paper (Brooks *et al.*, 2020). A physical match is the realignment of at least two items to demonstrate that they previously formed a single object, as defined by the American Society of Trace Evidence Examiners (ASTEE) (2018). These physical fits can yield connections in forensic investigations. One article that demonstrates the use of ESDA for physical fit analysis is Barton (1989) whereby a technique for effective visualisation of paper delamination, which is the uneven ripping of paper layers, was found during ESDA examination for handwriting indentations. As the damaged papers were positioned onto the ESDA with their damaged layered borders facing up, these areas emerged dark in comparison to the rest of the piece of paper in the subsequent ESDA image (Barton, 1989). Thus, the ESDA was valuable for fast visualisation of corresponding rips in the paper.

The application of ESDA became more commonly recognised after the trial concerning the shooting of the Israeli Ambassador in London during the 1980s (Marsh, 2006). Out of the three suspects from that event, two of three got away. There was a note found in the pocket of the suspect that did not get away, and the note was thought to be a hitlist. The police then recovered a notepad from the location of the other two suspects and indented impressions of the specific writing was found (Marsh, 2006). Following this trial discussed by Marsh (2006), there was a series of other police trails regarding accusations of written notes, and this caused ESDA to become more high profile as forensic evidence.

Everyone has their own personal style of writing which is developed through life as they establish their unique handwriting characteristics (Sharma *et al.*, 2020). During someone's teenage years, their handwriting is very variable with characteristics changing until they ultimately find a style that is comfortable to the individual (Marsh, 2006). Although changes still may occur to this style over the years, provided adequate contemporaneous handwriting it is achievable to distinguish more than two pieces as positively being written by the same person (Marsh, 2006). Starting with a generation perspective of handwriting, it is important to consider the numerous functions concerned. The first function begins with a communication intention where a message is assembled at the semantic, syntactic, and lexical levels and transformed into a group of allographs (letter shape models) along with graphs in particular occurrences which are constituted of strokes to create a pen-tip trajectory that can be documented online using an instrumented pen (Lorette *et al.*, 1994; Marsh, 2006). Trajectory is more commonly recorded on paper (Fatima, 2019). The significance of handwriting generation is due to its influence of handwriting analysis practices, especially in explaining the variability of handwriting (Fatima, 2019).

The aspects of handwriting that should be considered are motion, force from the hand, distinct characters, and the spatial interactions between them (Jia *et al.*, 2019). It is followed as standard forensic practice for the detection of the author and legitimacy of signature on written documents, which are often given the name questioned documents (Levinson, 2001). Questioned documents could entail criminal cases with forgery, fraudulent cheques, indentation, alteration, obliteration, and erasures (Fatima, 2019). The conclusions attained from forensic handwriting examination and questioned document expert testimony are admissible in the court of law (Fatima, 2019).

One case that used ESDA lifts for handwriting comparison took place in 2008, after a woman went missing in 2002 in New York (Wisbey, n.d). Police recovered paper from the missing woman's residence, and after ESDA analysis of this paper there were indentations visualised that implied a suicide note was written, however, the whereabouts of this letter was unknown. In 2006, known writings of the missing woman were subjected to handwriting comparison to ESDA lifts created earlier in 2002, however, even though some similarities were found, they were not adequate

enough to distinguish her as the writer. In 2008, trainee police divers discovered a sunken car in Onondaga Lake. Found within this car was both the missing woman and a suicide note. Following comparison of the recovered suicide letter to known writings of the woman, there was confirmation that she was the writer. A few characteristics for example letter shape, format, and connecting strokes were examined in the ESDA lifts and known samples. The suicide letter was retrieved six years after the woman went missing, from a plastic bag within the interior of the car (Wisbey, n.d). This case influenced both the interest concerning different materials and their ability to preserve documents for analysis, and also the results of ESDA analysis for forensic evidence. Especially as each crime scene is unique, so testing the effect of a range of materials could provide useful insight to potential materials found at crime scenes and their ability to protect forensic evidence (Mokwena, 2012).

The designers of ESDA have expressed that the process is non-destructive and since then many document examiners have reiterated the methods being non-destructive (Jasuja & Singla, 1995). However, following several years of running ESDA methods in both investigational experiments and real cases, it has been noted that the procedure may in fact be modifying the face of a few documents to some extent, particularly when original pencil markings are present (Tolliver, 1990). As an incomplete transfer of the pencil markings from the paper to the back of the mylar film has been detected, this deposit is then transferred to the white backing paper (Tolliver, 1990). To assess whether the observation that ESDA may be slightly destructive especially when pencil markings are present, Tolliver (1990) carried out a study that aimed to quantitate how much pencil residue was thought to be removed from the paper following ESDA analysis. She carried out this experiment using eight distinct pencil types written on four distinct kinds of paper. To quantify the residue lost, the density was taken by X-Rite 810 Color Photographic Densitometer using the visual reflected mode on the bottom right and left corners, along with the bottom midsection amongst the corners. Once an average density was documented, a baseline density was established, and this was repeated for each type of pencil on each four types of paper. They were then all processed by ESDA, and density readings recorded again. A control sample was also used that had not been subjected to ESDA analysis. The results of this study found an overall loss of density after ESDA examination across each different paper type. There was variation in density loss across the different types of pencils. Supporting the argument that ESDA can be slightly destructive, particularly when pencils have been used and so, consequently contradicting the statement by Foster and Morantz (1979) that the ESDA technique is non-destructive. This study also indicates that the severity of destructiveness of the ESDA can be depended on the particular writing implement used. Thus, in the experiment discussed in this paper, pencils were not used, and all the writing was completed using the same pen (A liquid ink rollerball pen with a 0.7mm roller with black ink, from the pilot

corporation of Europe) to ensure ESDA is being used in the least destructive way and at a consistent level.

One advantage of using ESDA is that it eliminates some of the meticulous troubles required using conventional methods, for example, analysis by oblique lighting; as it takes a long time and also offers troubles in attaining a full image of the specimen in such a way that it can be photographed and documented (Baier, 1983). As mentioned previously, ESDA is also argued to be non-destructive compared to chemical techniques, for example, iodine fuming as it can cause damage to the document (Kumar *et al.*, 2016). A comprehensive inspection of the unit's possibilities gives rise to the assertion that ESDA under particular conditions can replace any conventional method in this line of work (Baier, 1983).

Radley (1993) expresses some drawbacks of ESDA; including the necessity for the document to be sized sufficiently to fit the machine's dimensions, the document also must not be treated with chemicals or be challenged with elevated humidity and liquids. The document should also not have fingermarks on (Scheidat, Kalbitz, & Vielhauer, 2017). Due to these findings, the experimental design of the study discussed throughout this paper considered these drawbacks and made adjustments, for example, gloves were worn during the handling of all the documents and whilst carrying out the ESDA process. Another adjustment was ensuring that when handling the documents, there was no contact with liquids or chemicals. Another disadvantage of ESDA is that regardless of the seeming simplicity of the technique, the truth behind its procedure is not entirely understood or appreciated and this could be due to the multiple fundamental processes that run conditional to the paper being examined (Wanxiang & Xiaoling, 1988). It is also not viable to obtain thorough quantitative knowledge regarding the impression produced by a writing implement such as deepness, variations or profiles (Kalbitz, Scheidat, & Vielhauer, 2016). In addition to this, very little investigation has been conducted into employing computers to enhance and automate the analysis attained by forensic document analysts (Srihari & Leedham, 2003).

ESDA's capacity to expose latent pressure designs has been demonstrated to be reliant on the paper type, the writing tool utilised with the accompanying pressure, the quantity of sheets of paper between the writing and recipient sheet, and also environmental circumstances, for example, relative humidity (Pearse & Brennan, 1996). Baier (1983) executed an investigation based on a cross-over process between every step of variable A to variable F, as seen in figure 1 and 2. Crucial factors such as deviation of the duration or mode of use of the corona charging unit were kept controlled and consistent, at two or three passes of the wire over the mylar film from a distance of around 2 cm. Overall aspects such as humidity, storage, exposure to light sources of any kind were controlled and kept constant (Baier, 1983). The ESDA results obtained from this study were interpreted based on the scale that can be seen in figure 3. In regard to changing variable C (the

developing method), either injection nozzle or cascade development techniques can be used, although, the differences between them were found to be rather small. It appeared that usually injection nozzle (aerosol technique) is more appropriate to develop images for documents in a good condition. Whereas the cascade developing technique was found to be favoured for documents in bad conditions. Due to these findings, the decision was made to carry out the development using the cascade technique due to the potential bad conditions the documents may be subjected to from being buried. However, Noblett and James (1983) found great variation in developed image qualities among a range of 10 different kinds of paper, and deduced that aerosol development, only holding the corona wire with a little gap from the mylar film, and an interval of 15 minutes preparation at 40–60% relative humidity gave the greatest quality results. Regarding variable H (surface texture of the document) in Baier's (1983) study, the document having no special treatment of the surface, or the document being crunched and crumpled which has then been smoothed. It was found that the texture of the document transpired to be one of the most hindering aspects in attaining high quality results with ESDA. The crumpled documents presented the worst quality results regardless of if it had been flattened and smoothed down prior to ESDA examination (Baier, 1983). This could indicate how some of the documents in the experimental study may produce poor quality ESDA results if they get damaged, crumpled, or wet during the burial period. Potentially suggesting how the material preserves the document will have a direct impact on the quality of ESDA results and, therefore, the resulting forensic evidence, based on either the texture and/or water content.

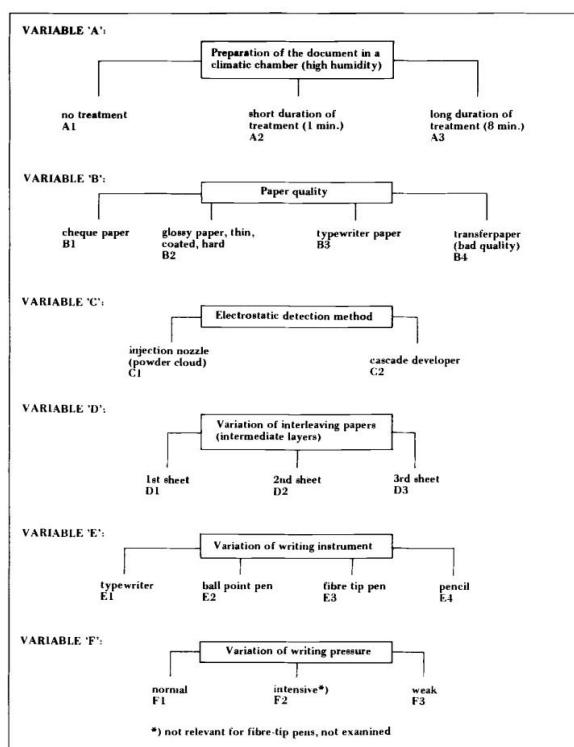


Figure 1 – Diagram to show the crossed independent variables distinguished in stages for Baier's experimental method design (Baier, 1983).

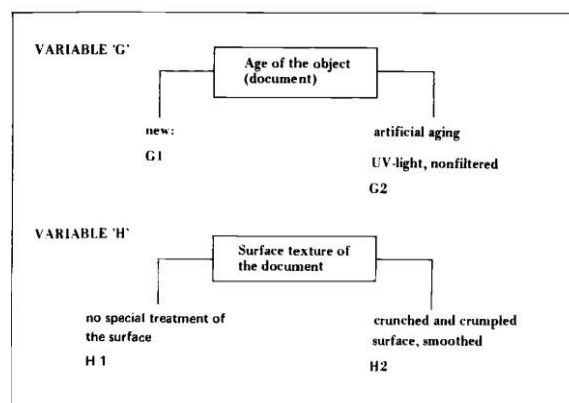


Figure 2 -Continued diagram to show the crossed independent variables distinguished in stages for Baier's experimental method design. (Baier, 1983)



Scaling: 4 = excellent legibility



Scaling: 3 = good legibility



Scaling: 2 = visible



Scaling: 1 = faintly visible



Scaling: 0 = not visible anymore

Figure 2 - Scale for establishing the quality of the ESDA developed images (Baier, 1983).

A disadvantage of many of the studies investigating the factors affecting ESDA is that some of the humidification, charging, and development conditions are not controlled. One way Baier's (1983) study was not completely controlled is due to the use of the aerosol development technique which allows very limited regulation on how much toner gets released from the nozzle, which could directly impact the quality of the image produced (Yaraskavitch *et al.*, 2008). Toner concentration and volume in regard to cascade development can be much more readily regulated which presents another advantage of this method (Yaraskavitch *et al.*, 2008). However, pouring the toner onto the plate to obtain a uniform development is usually subjective. Therefore, the absence of full control in the procedures used may have negatively impacted the validity of some of the inferences from the study (Yaraskavitch *et al.*, 2008).

Returning to the topic of relative humidity as a factor that should be considered when using ESDA analysis, Foster and Morantz (1979) stated that there was no evidence that humidity had a part to play in affecting the quality of ESDA results. Though, the manufacturers of ESDA in the recent ESDA operating instructions advise that if the relative humidity is less than 40%, then the

documents should be humidified for a couple minutes using a saturated humid environment (Foster and Freeman Ltd, 2007). Numerous studies have since revealed that for laboratory conditions, highest quality ESDA results were attained at 48%-76% relative humidity (Roberts, 2007). Some minor variations have been found dependent on the type of the paper, although there is still a common agreement that higher humidity improves the quality of results (Daéid, Whitehead, & Allen, 2008). For example, one study by Daéid, Whitehead and Allen (2008) found that when the experimental conditions had a relative humidity above 60% the impressions were visibly developed to a high standard with a consistent background. These studies influenced the decision to carry out the investigation discussed in this paper in a laboratory with a higher relative humidity in order to bypass the extra step of humidifying the documents before analysis.

One factor that is usually investigated with humidity in relation to ESDA is temperature. D'Andrea *et al.* (1996) observed that temperature has minimal influence on the quality of ESDA developed images, with the exception of one type of paper. Hence, temperature may be disregarded as an influence in most instances. However, Pearse and Brennan (1996) carried out a study investigating the significance of absolute humidity in relation to ESDA analysis and found that at the standard operating temperature of 20°C the most optimal relative humidity for high quality developed images was around 75%. This study's findings therefore contradict the study by D'Andrea *et al.* (1996) as they revealed at elevated levels of relative humidity with low temperatures there is a substantial decrease in the quality of results. Even at low relative humidity and elevated temperatures, they found sufficient results can still be achieved. Highlighting the effect temperature may have on the development of ESDA images. This led to the decision to take temperature readings of each burial site, in addition to the temperature in the laboratory.

As previously mentioned, forensic investigation of documents focuses on verifying authenticity. There have been increasing difficulties in authenticating documents over the years, owing to the newer and more advanced technologies in addition to progressively more sophisticated methods of committing forgery (e Brito *et al.*, 2017). One of these difficulties being experienced by forensic document examiners is the determination of the succession of traversing ink lines, for example, which order did two ink contributions intersect in on a questioned document (e Brito *et al.*, 2017). This is particularly valuable in instances involving signatures, for example, when a document is believed to have been modified secretly where one of the parties is unaware. Hence, establishing which ink line was created last may aid in resolving the debate (Cheng *et al.*, 1998). This difficulty was already a concern in the 1930's, as stated by Mathyer and Pfister (1984), although the most significant forensic developments followed the 1960's. One of these advances being ESDA. Various other methods have also been developed over the years to resolve this issue, some of these being morphologic analysis of the lines (e Brito *et al.*, 2017). Some of the techniques are sufficient

to solve the majority of cases; but occasionally these techniques deliver inconclusive or ineffective outcomes (e Brito et al., 2017). While many researchers assign these inadequate results to weaknesses of the procedures, the scientific understanding behind the physicochemical aspects of two inks applied over each other in a paper document remains superficial (Menzyk, Zadora, & Sajewicz, 2015). In reality, the intricacy of the matter concerns the quantity of crossing combinations that can be put together in addition to the numerous manipulating variables, for example, the particular kind of writing tool, the kind and pigment of the ink, the paper type, and pressure variation (Ellen, 2006).

The 90's proposed ESDA for document analysis and a different method to establish the order of crossing ink lines. Radley (1993) investigated the order of writing indented impressions and ballpoint pen ink lines on various papers, and various writing forces employing the ESDA methodology. He used nine distinct ballpoint pens in black, blue, and red inks to create samples on three distinct paper types (e Brito et al., 2017). Radley (1993) also ensured there were two separate writers with efforts made to deliver differing levels of pen pressure. A preliminary study was launched using a grid structure of horizontal and vertical lines on top of comparably constructed grid lines appearing as impressions on the paper, and vice versa (e Brito et al., 2017). The results from this preliminary study were favourable, however, the test was artificial. Next, a follow up study of two blind trials consisting of 150 writings over impressions and impressions over writings were produced. This could create 20-50 intersections per specific sample (Radley, 1993). In addition to the blind trials, a substantial number of intersections were investigated in notebooks where the order of writing and impressions were already established. ESDA analysis was then carried out around one week later and the intersection points were analysed using a x4 magnification hand lens. The findings for the impressions on top of ink strokes revealed that in several instances, a continuous impression ran across the ink line (e Brito et al., 2017). The incidence of a continuous ESDA impression line was not detected at all intersections within individual samples, but roughly 10%-40% of the intersections in any one sample of impressions on top of writing revealed this feature (Radley, 1993). There were no false positives of handwriting on top of an impression displaying a continuous impression line documented. However, 11% of the impressions over ink strokes seemed to indicate no substantial continuity of the impression through the ink stroke, and were consequently deemed as false negatives (e Brito et al., 2017). The overall findings of this study demonstrate how ESDA has the capability to provide useful forensic evidence as it can distinguish impressions. The findings also reveal how ballpoint pens can cause striation patterns that the black toner clings to, thus allowing the incorrect conclusion that the line was continuous. There was found to be several inaccurate inferences regarding white pen inks, perhaps as ballpoint pens leave striation lines that the toner sticks to, causing erroneous inferences of a continuous line (e

Brito et al., 2017). These findings influenced the decision to not use a ballpoint pen, and to only use a black ink pen in order to remove any possible inaccuracies.

There has been further research into ESDA examinations in various experimental circumstances, for example, research by Giles (1993) where more accurate determinations were discovered. She also used various angles during analysis of crossings along with two individuals visually analysing the samples in a blind trial with magnification together with powerful fluorescent lighting. So, it could be argued that Giles's (1993) results are more reliable than Radley (1993). However, it must be acknowledged that such investigations were very dependent on the forensic document examiners' experience and interpretation, and additional samples ought to be studied in later investigations, given that only one kind of pen and one kind of paper were employed (e Brito et al., 2017).

One study into recovery of DNA from questioned documents and the impact on ESDA was carried out by Parsons, Sharfe and Vintiner (2015). DNA recovery from documents may be beneficial as forensic evidence as it is highly probable that the writer had skin contact with the document, therefore, touch DNA could have been transferred (Parsons, Sharfe, & Vintiner, 2015). In the study, they discuss findings from DNA recovery in usually handled areas of documents using swabs and water, similar to the method described by Sweet *et al.* (1997). The findings from the study found that the wet/dry swabbing procedure for DNA on documents created white smeared markings on the film of every document after ESDA analysis which hid any overlapping indentations. This is thought to be due to the introduction of moisture to the documents when wet swabbing to potentially trigger the fibres of the document to be altered, causing a decline in indentation detail (Parsons, Sharfe, & Vintiner, 2015). Dry/dry swabbing techniques have been found to cause an analogous yet less intense effect than the wet/dry technique. As following the dry/dry technique, the white smeared marks were less pronounced and, thus, enabling the indentations to be more easily distinguished (Parsons, Sharfe, & Vintiner, 2015). These studies were an important influence of the investigation as it questions moisture's effect on the quality of ESDA results. This potentially highlights how different materials may be better at preserving documents for ESDA analysis than others. If moisture is detrimental to the quality of ESDA results, like these results show, waterproof materials should be expected to preserve the documents for better quality ESDA results.

Forensic archaeology is intimately connected to investigations that are assisted by archaeological procedures (Borkowski & Trzciński, 2018). The distinction between forensic archaeology and traditional archaeology is that forensic archaeologists contribute to acts completed relative to a continuing case (Morse, Crusoe, & Smith, 1976). Borkowski & Trzciński (2018) also argue that the practices of treating the ground employed in forensic archaeology are essentially the same as in traditional archaeology. Forensic archaeology is established at the crossover of several evidential

schemes that convey distinct and frequently incompatible expectations for archaeological procedure (Crossland, 2013). For instance, Haglund (2002) summarises five components to the exhumation of mass graves as part of human rights investigations. These include the search for legal evidence, the identification of the deceased, the formation of precise historical documentation, and the necessity to understand the dignity of human life (Haglund, 2002). Grandmaison and Durigon (2001) state that evidence gained from exhumation is regularly recognised as self-evident, and capable of contesting the mistruths that arise from the individuals accountable for the crime. Exhumed artifacts are treated as evidence to indicate past events and thus are implemented as evidence for various objectives, regardless of if its legal, historical, or personal (Peirce, 1955). Therefore, forensic archaeologists are a valuable part of a forensic team (Melbye & Jimenez, 1997). If a region is not correctly excavated, the opportunities for missing evidence and/or skeletal remains are heightened greatly (Melbye & Jimenez, 1997).

Conventional destructive practices consist of techniques including T-bar probes, using shovels to dig, and excavating using trowels (Schultz & Dupras, 2008). The drawback of these invasive techniques is the damage to the crime scene and the possibility of damaging forensic evidence which could in turn may cause a loss of context that may reduce the prospect of reconstructing events of the crime (Schultz & Dupras, 2008).

Forensic soil analysis is a discipline that covers numerous areas of research since soils are highly idiosyncratic and may be differentiated using several methods, involving texture, soil shade, pH value and consistency (Ruffell, 2010). Carter, Yellowlees and Tibbet (2010) carried out a study to explore the influence of soil moisture on the underground forensic taphonomy and the magnitude and activity of the microbial population that likely leads to adjustments in soil pH. The study utilised juvenile rat cadavers. Cadaver mass loss was calculated, and the soil CO₂-C evolution was established. The soil pH was also quantified utilising traditional procedures. Information involving soil pH from this study were analysed applying univariate analysis of variance (ANOVA) (Carter, Yellowlees, & Tibbett, 2010). The results from the study observed that cadaver burial caused a rise in the pH value of the soil. It was also noted that wet environments slowed the rise in pH whilst dry environments slowed the rise of pH in soil taken from a differing location. Moreover, the soil pH started to decrease by the 28th day was reached in each soil type studied. Revealing how there are many factors that can influence the pH value of soil. Many studies, for instance, Vass *et al.* (2008) only centred around establishing advanced forensic applications of taphonomy. However, very little studies have explored the underlying processes that cause these forensic applications, highlighting the importance of the study carried out by Carter, Yellowlees and Tibbet (2010) as is helped to fill a gap in this area of research.

A study was conducted to investigate the influence of certain environmental factors such as pH on pollen deterioration (Phumphumirat, Mildenhall, & Purintavaragul, 2009). The results found that group one species were pollen that's deterioration varied with time. Group two species consisted of pollen that's deterioration seemed to be affected by soil pH. Group three species were pollen that's deterioration seemed to be regulated by influences excluding time and pH. The pollen deterioration progressed more gradually in alkaline soil. This highlights how pH can have an effect on the quality and use of potential forensic evidence (Phumphumirat, Mildenhall, & Purintavaragul, 2009).

There was an additional study carried out by Young *et al.* (2014) that looked at the effect of pH on forensic evidence in the form of DNA extraction from forensic soil samples. It was found that the pH of the soil is possibly the factor that can influence the DNA absorption to clay minerals the most. This is due to the pH affecting the electrostatic properties of the DNA phosphate (Young, *et al.*, 2014). As the DNA phosphate group can be in, and remain in several oxidation states (Conklin, 2013). These oxidation states are capable of affecting the intensity of the interaction to the mineral surface (Young, *et al.*, 2014). Frostegård *et al.* (1999) carried out one study that utilised 20 soil samples to demonstrate a rise in DNA yield with increased extraction buffer pH, with an optimum of pH 9. Furthermore, several studies have displayed a rise in DNA adsorption on soils with low pH (Cai *et al.*, 2006). This provides further indication into how pH can have an influence on forensic evidence; highlighting the importance of recording soil pH values during experimental procedures to investigate whether pH has a similar effect on questioned documents as it does to other types of forensic evidence.

The aim of this research is to investigate which material is most effective at preserving paper documents during burial concealment, for follow up analysis by ESDA. This will involve the ESDA apparatus, taking pH readings of the soil, and careful excavation of burials sites for the recovery of exhibits. This study could contribute to exploratory methods concerning questioned documents and burials, the effect of different materials at preserving potential forensic evidence for analysis, and the influence of environmental factors on questioned document analysis. The hypothesis for this study is the materials that are more impermeable will have better ability at preserving documents in burials, and thus will produce higher quality ESDA results.

Method and materials

Table 1 - Table of full list of equipment and quantity used in the study.

Equipment	Quantity
Paper (Wilko A4 white 'everyday paper', 75 grams per square meter)	X6
Pen (pilot corporation of Europe branded liquid ink rollerball pen with a 0.7mm roller with black ink.)	X1
Scissors (Titanium Bonded Scissors)	X1
Shovel (Spear & Jackson 2000AC)	X1
Wire flag markers (Any colour)	X12
pH meter (JENWAY 550 pH meter, serial number D20085172)	X1
Phone (iPhone 12)	X1
ESDA machine (ESDA 2, batch 25929/6)	X1
Personal protective equipment (Lab coat, goggles, gloves)	X1, X2 for gloves
Roll of polyester film (Mylar film)	X1
Black toner powder (Foster + Freeman ESDA 2 Cascade developer 1kg, batch A307/02)	X1
Glass board	X1
Plastic document wallets (PLDZ, size A5, batch 20200620)	X3
Children's raincoat (Next, 9yrs, 65% polyester, 35% cotton)	X1
A pair of jeans (TU, 14R, 82% cotton, 17% polyester, 1% elastane)	X1
Paper envelopes (Nu:Mail envelopes)	X3
Bubble envelopes (Nu:Mail envelopes)	X3
Adhesive vinyl sheets (Evergreen Goods 10 Sheets A4 Quality Glossy White Sticker Vinyl, waterproof)	X6
RS Components High accuracy Thermo-Hygrometer (Stock No. 204-072)	X1

Burial

In preparation for the burials, 21 pieces of paper were cut to the same exact size (A6, 105 mm x 148 mm). Using the same pen, the same message “3 rose cottages, Gillingham, Kent, ME4 1MG” was written on each piece of paper by the same individual. Three repeats were then placed into a specific type of material, for example, plastic document wallet, and repeated for each material. Next, six burial sites were dug at Pembroke Lawn that measured 40 cm x 60 cm and 30 cm deep (+/- 2 cm). Following this, three repeats were placed into each burial site and a pH meter was used to take the pH of the soil. A thermometer was used to record the temperature of the soil. Then each burial site was backfilled, and two coloured flag markers were placed at either side of each burial site for later identification.

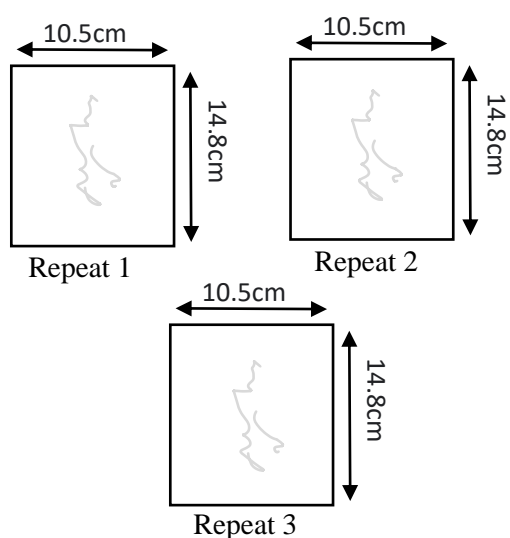


Figure 3 - Diagram showing the dimensions of the questioned document repeats made for each condition with lines representing where the indentation marks are. (Not to scale) (Made by author)

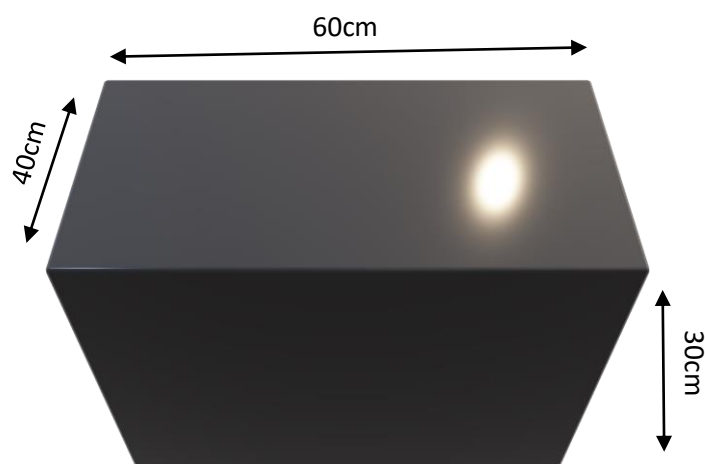


Figure 4 - Diagram to show the dimensions of each burial made (not to scale) (made by author)

Retrieval

After a month, the burial sites were excavated, and the documents were retrieved. The pH and temperature of the soil was then taken upon each retrieval.

ESDA

In preparation for carrying out ESDA analysis, the retrieved documents were pressed between a flat surface and a glass board until all documents were flat. The temperature and humidity in the laboratory were also measured using a high accuracy thermo-hygrometer. The first repeat from burial site one was placed onto the metal plate and the machine was turned on by pressing the red button. Then the mylar film was pulled carefully and tightly over the document until it was pulled

down flat to the plate. Next, the blue corona button was pressed so a solid blue light appeared. Once the blue light began to flash on and off, the corona wand was hovered back and forth over the document until the blue light turned off. The wand was then placed down, and the metal plate lifted up to an approximate 30° angle. The black toner was then poured over the document. After this, a sheet of transparent adhesive vinyl was placed on the mylar film. The ESDA machine was then switched off and the mylar film with the adhesive vinyl on was removed and excess mylar film was cut off. This process was then repeated for each repeat per burial site. This process was also repeated for three unconcealed control repeats that were documents that were the same size, encompassing the same written message on the same paper using the same pen as the experiment repeats.

ESDA operating details

The corona wire was passed over the polymer film to charge the film ten singular times for each document (at a rate of one pass per two seconds) with the wire being held at around 5 cm above from the metal plate, making complete moves parallel to the long side of the plate. The black toner powder that was used to develop the results was used without any time delay following the completion of the film charging. Four passes of black toner were poured across the polymer film over each document for development. The black toner powder was stored in a plastic airtight container throughout the duration of the study in the laboratory.

Method development

Preliminary experiment

The original experiment carried out was the recovery of questioned documents from burial sites after different time intervals for ESDA analysis. There were six burial sites which each had 3 repeat questioned documents placed into. Each burial was then backfilled and both pH and temperature were recorded (these results can be seen in tables 2-5). The documents were then recovered in intervals of one week, with the first retrieval being completed on 18/11/21, the second being completed on 25/11/21 and the third on 2/12/21. The reason this experiment was preliminary is due to the fact that recovery of the documents after the second retrieval became unfeasible due to environmental factors causing the paper to break up into many small pieces, making ESDA analysis non-viable. Due to this, changes were made to carry out the actual experiment discussed in this thesis.



Figure 5 - Two out of the three questioned documents retrieved from burial site 1 on 18/11/21 (preliminary experiment)

As seen in figure 6, the documents were able to be retrieved fully on the 18/11/21 after being in the ground for a week. The documents were still damp and covered in mud as a result of the environmental conditions, nevertheless, there were no tears or loss of documents.



Figure 6 - Piece of questioned document retrieved from burial site 2 on 25/11/21 (preliminary experiment)



Figure 7 - Pieces of one of the questioned documents retrieved from burial site 2 on 25/11/21 (preliminary experiment)

Both figures 7 and 8 show the incomplete retrieval of the repeat questioned documents after the second interval where the documents had endured burial concealment for two weeks. The difficulty of document retrieval that early on, indicated further difficulty of retrieval as the time intervals increase. As only fragments of the documents were able to be recovered, it would mean any ESDA analysis would be incomplete, therefore, potentially hindering the forensic evidential value.



Figure 8 - Image showing burial site three on day of retrieval (2/12/21) showing retrieval couldn't be complete due to the paper being broken into many small fragments.

Figure 9 shows burial site three and how after three weeks of burial concealment, any retrieval of documents was not feasible due to how integrated the small fragments of documents became with the soil. This also meant that no ESDA analysis could have been carried out.

Figures 6 to 9 therefore indicate the necessity to alter the methodology to the experiment to ensure documents were able to be recovered in good enough quality for ESDA analysis. Which led to the decision to bury documents in different materials to examine which materials preserve the paper documents the most successfully during burial concealment for analysis by ESDA. Therefore, which material has the potential to preserve exhibits the most effectively, for the highest quality of forensic evidential value.

In addition to carrying out the preliminary study, preliminary practice of the use of the ESDA machine was undertaken to ensure appropriate use of the machine for successful application. It also assisted in establishing the standards in the methodology used, such as an appropriate number of passes of the wand to charge the mylar film.

Preliminary results tables

Table 2 - Table to show the pH of the soil at each burial site.

Burial site	pH of soil at burial site
1	6.64
2	7.15
3	7.14
4	6.94
5	7.37
6	7.27

Table 2 shows the pH of the soil at each burial site. The total range in pH across all the burial sites is 0.73 demonstrating there is minimal breadth.

Table 3 - Table to show the pH of the first three burial sites at time of retrieval

Burial site at time of retrieval	pH of soil at burial site at time of retrieval
Week 1(burial site 1) (18/11/21)	7.79
Week 2 (burial site 2) (25/11/21)	7.40
Week 3 (burial site 3) (2/12/21)	7.28
Week 4 (burial site 4) (9/12/21)	N/A
Week 5 (burial site 5) (16/12/21)	N/A
Week 6 (burial site 6) (13/12/22)	N/A

Table 3 shows the pH of the first three burial sites. Only the first three burial sites had data because documents were only able to be recovered in the first three. Therefore, the total range of pH at time of retrieval was 0.51 which is the same range of the original pH values for the first three burial sites.

Table 4 - Table to display the initial temperature of the soil at each burial site.

Burial site	Temperature (°C) of soil at burial site
1	13.5
2	14.4
3	13.4
4	13.8
5	15.5
6	14.3

Table 4 displays the initial temperature of the soil at each burial site. The lowest temperature recorded was at burial site three with 13.4°C and the highest temperature was at burial site five at 15.5°C. The total range in temperature was 2.1°C.

Table 5 - Table to display the temperature of the first three burial sites at time of retrieval.

Burial site at time of retrieval	Temperature (°C) of soil at burial site at time of retrieval
Week 1 (burial site 1) (18/11/21)	12.9
Week 2 (burial site 2) (25/11/21)	11.4
Week 3 (burial site 3) (2/12/21)	9.8
Week 4 (burial site 4) (9/12/21)	N/A
Week 5 (burial site 5) (16/12/21)	N/A
Week 6 (burial site 6) (13/12/22)	N/A

Table 5 displays the temperature of the first three burial sites at time of retrieval as these were the only sites that documents were able to be recovered from. The range in temperature was 3.1°C which is larger than the range in initial temperature for the first three burial sites.

Table 6 - Table to display the depths each burial site.

Burial site	Depth of burial site in cm
1	27
2	28
3	27
4	27
5	27
6	27

Table 6 displays the depths of each burial site. Five of the six burial sites were 27 cm deep and only burial site two was 1 cm deeper at 28 cm.

Results

Experiment Tables

These burials were conducted on the 16/12/21

Table 7 - Table to display the initial pH of each burial site.

Burial site	pH of soil at burial site
1 (plastic document wallets)	7.04
2 (children's raincoat)	7.09
3 (jeans)	6.61
4 (paper envelopes)	7.02
5 (bubble envelopes)	6.32
6 (documents – no materials)	7.04

Table 7 displays the initial pH of each burial site. The overall range of pH values across these burial sites was 0.77

Table 8 - Table to show the pH of each burial site at time of retrieval.

Burial site at time of retrieval (24/01/22)	pH of soil at burial site at time of retrieval
1 (plastic document wallets)	7.75
2 (children's raincoat)	7.82
3 (jeans)	7.68
4 (paper envelopes)	7.58
5 (bubble envelopes)	7.46
6 (documents – no materials)	7.35

Table 8 shows the pH of each burial site at the time of retrieval. The overall range was 0.47, lower than the range of initial pH values.

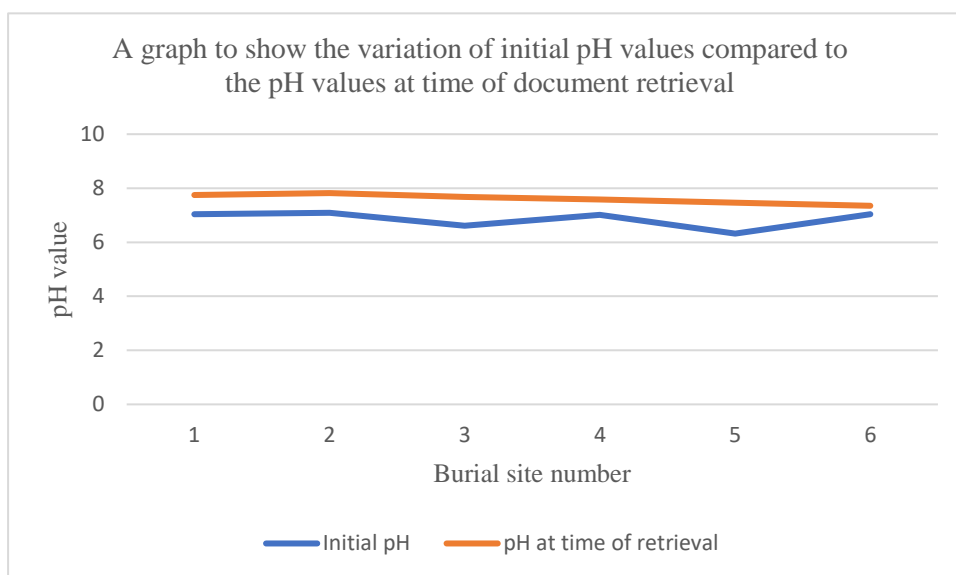


Figure 9 - Graph showing the variation of initial soil pH values in comparison to retrieval soil pH values.

Table 9 - Table to show the initial temperatures across each burial site.

Burial site	Temperature (°C) of soil at burial site
1 (plastic document wallets)	11.6
2 (children's raincoat)	11.8
3 (jeans)	11.8
4 (paper envelopes)	11.9
5 (bubble envelopes)	11.5
6 (documents – no materials)	11.8

Table 9 shows the initial temperatures across each burial site. The total range of temperature was 0.4°C

Table 10 - Table to display the temperatures of each burial site at time of retrieval.

Burial site at time of retrieval (24/01/22)	Temperature (°C) of soil at burial site at time of retrieval
1 (plastic document wallets)	7.2
2 (children's raincoat)	7.1
3 (jeans)	7.8
4 (paper envelopes)	7.0
5 (bubble envelopes)	7.1
6 (documents – no materials)	8.1

Table 10 displays the temperatures of each burial site at the time of retrieval. The overall range of temperatures was 1.1°C, which is a much higher range in comparison to the initial temperatures.

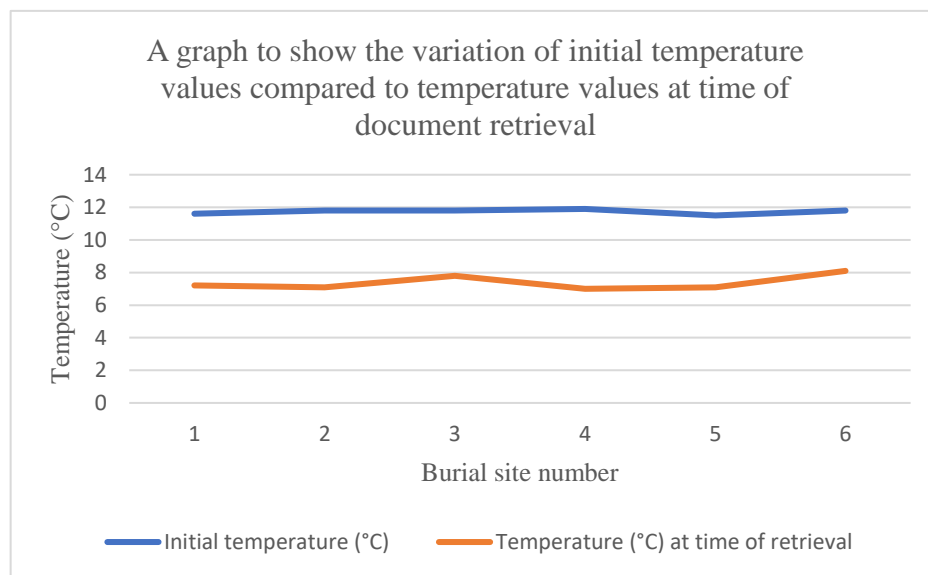


Figure 10 - Graph showing the variation of initial soil temperature values in comparison to retrieval soil temperature.

Table 11 - Table to demonstrate which burial sites allowed successful retrieval of documents.

Burial site at time of retrieval (24/01/22)	Recovery of documents
1 (plastic document wallets)	Yes
2 (children's raincoat)	Yes
3 (jeans)	Yes
4 (paper envelopes)	No
5 (bubble envelopes)	Yes
6 (documents – no materials)	No

Table 11 demonstrates which burial sites allowed retrieval of documents. Four out of the six allowed for retrieval. No documents were able to be recovered from paper envelopes and no material burial sites.

The temperature in the laboratory where the ESDA analysis was conducted = 15.7°C

The relative humidity in the laboratory where the ESDA analysis was conducted = 64%

Table 12 - Table to display the number of positive ESDA results from the documents retrieved from burial site one.

	ESDA burial site 1 –plastic wallets questioned documents results		
	ESDA Analysis re- peat 1	ESDA Analysis re- peat 2	ESDA Analysis re- peat 3
Questioned document in plastic wallet repeat 1	Negative	Negative	Negative
Questioned document in plastic wallet repeat 2	Positive	Negative	Positive
Questioned document in plastic wallet repeat 3	Positive	Negative	Negative

Table 12 displays the number of positive ESDA results from the documents retrieved from burial site one – plastic wallets. Three out of the nine results were positive results.

Table 13 - Table to display the ESDA results from the documents retrieved from burial site two.

ESDA burial site 2 –Raincoat questioned documents results			
	ESDA Analysis re-peat 1	ESDA Analysis re-peat 2	ESDA Analysis re-peat 3
Questioned document in raincoat repeat 1	Negative	Negative	Negative
Questioned document in raincoat repeat 2	Negative	Negative	Negative

Table 13 displays the ESDA results from the documents retrieved from burial site two-raincoat. There are only two document repeats because the third one was unable to be retrieved. All ESDA results were negative.

Table 14 - Table to illustrate the ESDA results for all three repeat documents that were recovered from burial site three.

ESDA burial site 3 – Jeans questioned documents results			
	ESDA Analysis re-peat 1	ESDA Analysis re-peat 2	ESDA Analysis re-peat 3
Questioned document in jeans repeat 1	Negative	Negative	Negative
Questioned document in jeans repeat 2	Negative	Negative	Negative
Questioned document in jeans repeat 3	Negative	Negative	Negative

Table 14 illustrates the ESDA results for all three repeat documents that were recovered from burial site three – jeans. All nine ESDA results were negative.

Table 15 - Table to illustrate the ESDA results from all three repeat documents retrieved from burial site five.

ESDA burial site 5 – bubble envelopes questioned documents results			
	ESDA Analysis repeat 1	ESDA Analysis repeat 2	ESDA Analysis repeat 3
Questioned document in bubble envelope repeat 1	Negative	Negative	Negative
Questioned document in bubble envelope repeat 2	Negative	Negative	Negative
Questioned document in bubble envelope repeat 3	Negative	Negative	Negative

Table 15 illustrates the ESDA results from all three repeat documents retrieved from burial site five – bubble envelopes. All nine ESDA results were negative.

Table 16 - Table to display the ESDA results for all three control document repeats.

Control questioned documents results			
	ESDA Analysis repeat 1	ESDA Analysis repeat 2	ESDA Analysis repeat 3
Questioned document repeat 1	Positive	Positive	Positive
Questioned document repeat 2	Positive	Negative	Negative
Questioned document repeat 3	Positive	Negative	Negative

Table 16 displays the ESDA results for all three control document repeats. Five out of the nine ESDA results were positive.

Tables 12 to 16 demonstrate that the control experiment gave the highest number of positive results with each document repeat giving at least one positive ESDA result, with the first document repeat giving all three ESDA repeats a positive result. Only four out of the nine ESDA repeats gave

negative results. It can also be seen that, out of the experiment questioned documents, only one set gave positive results. The questioned documents in plastic wallets (burial site one) gave three out of nine positive results, only with the first repeat questioned document giving no positives for three ESDA repeats. The other two questioned document repeats from the plastic wallets gave at least one positive result in their ESDA repeats. The questioned documents in the raincoat, jeans, and bubble envelopes all gave negative results across each repeat questioned document and all ESDA repeats.



Scaling: 4 = excellent legibility



Scaling: 3 = good legibility



Scaling: 2 = visible



Scaling: 1 = faintly visible



Scaling: 0 = not visible anymore

Figure 11 - Scale for establishing the quality of the ESDA developed images (Baier, 1983).

Figure 12 displays the scale that was used to interpret the quality of each ESDA result in this study. It provides a suitable range of each ranking along with an example for each. The developed ESDA results were compared to the examples exhibited in the scale and ranked accordingly. Based on this scale, tables 17 and 18 were created.

Table 17 - Positive ESDA results for controls with scale ratings.

Positive ESDA results	
Controls	Scale rating
control document 1 repeat 1	1
control document 1 repeat 2	3
control document 1 repeat 3	2
control document 2 repeat 1	1
control document 3 repeat 1	3

Table 17 displays the scale ratings of the positive ESDA results for the control documents. The most frequent scale rating was equally one and three, with only one of the positive results scoring two.

Table 18 - Positive ESDA results for plastic wallet documents with scale ratings.

Positive ESDA results	
Plastic wallet documents	Scale rating
plastic wallet ESDA document 2 repeat 2	4
plastic wallet document 2 repeat 3	2
plastic wallet ESDA document 3 repeat 1	1

Table 18 displays the scale ratings of the positive ESDA results for the questioned documents concealed in plastic wallets. There was not a most frequent scale rating. The range of scale ratings was also larger than the scale ratings that were present for the positive ESDA results of the control documents. The highest ranking of the scale was also reached.

Q A

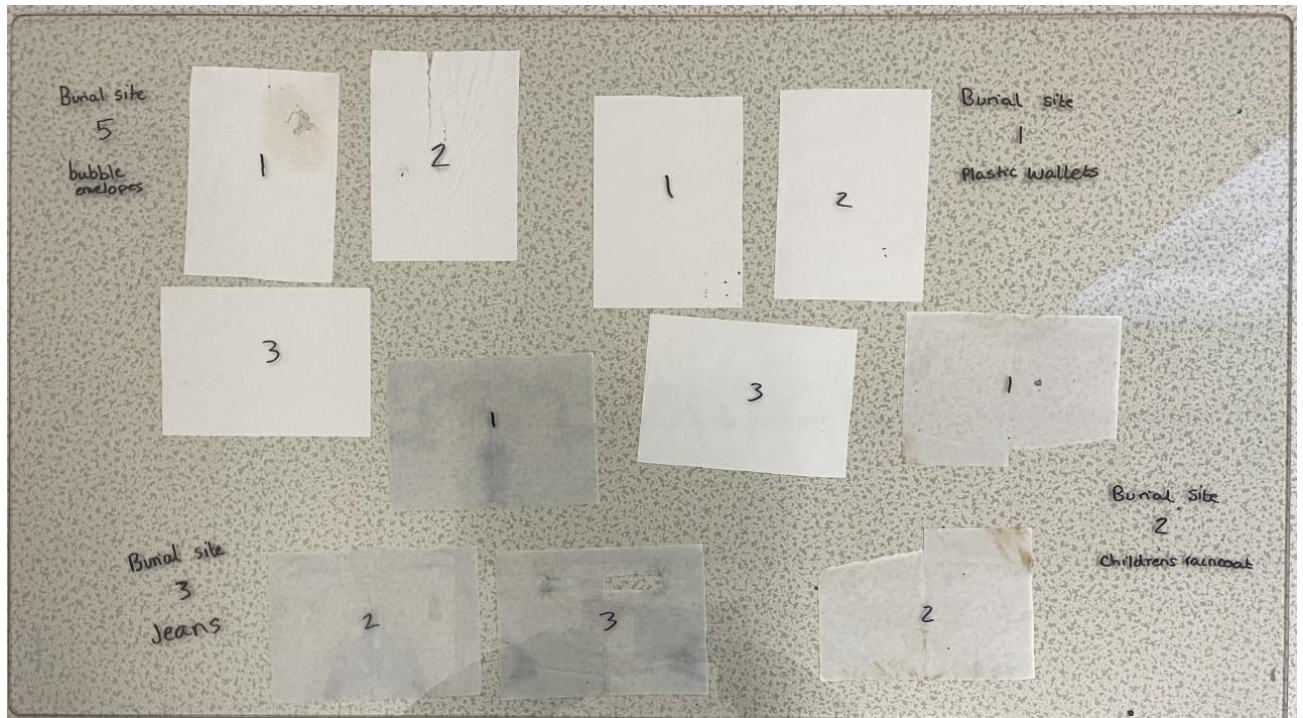


Figure 12 - Documents after retrieval from burials under a glass board to flatten them

Figure 13 illustrates the documents that were recovered from burial sites one, two, three, and five following the retrieval process and immediately after they were placed in the lab.



Figure 13 - ESDA results from documents in plastic wallets

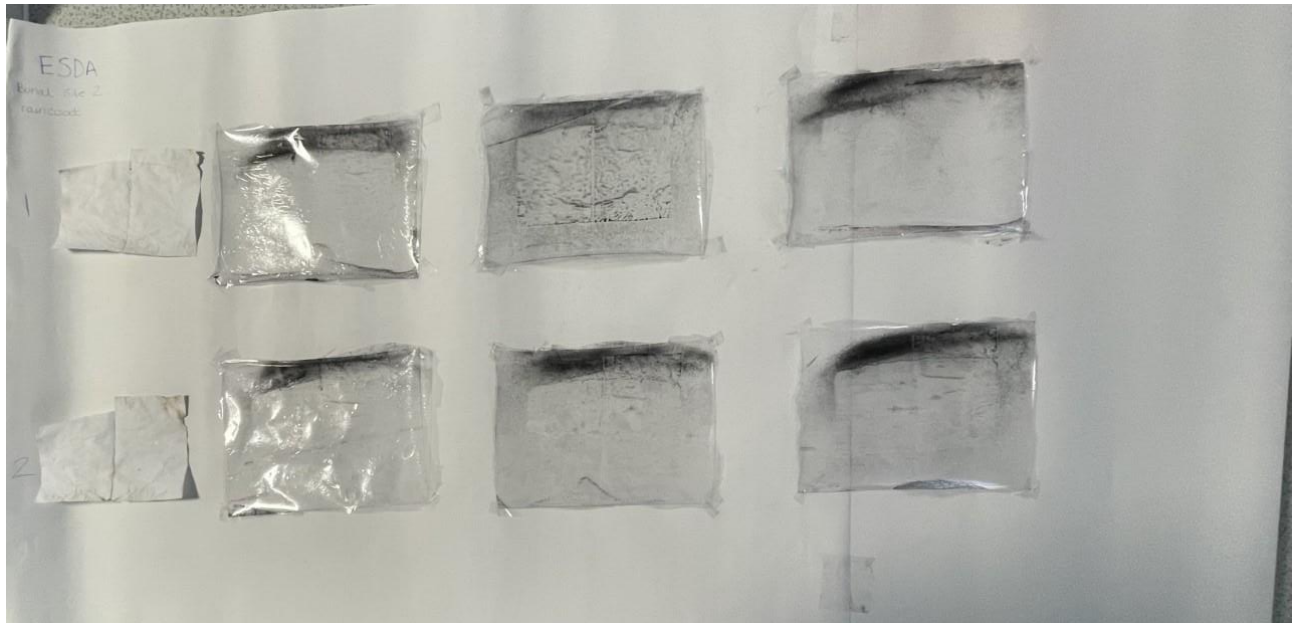


Figure 14 - ESDA results from documents in the raincoat



Figure 15 - ESDA results from documents in jeans



Figure 16 - ESDA results from documents in bubble envelopes

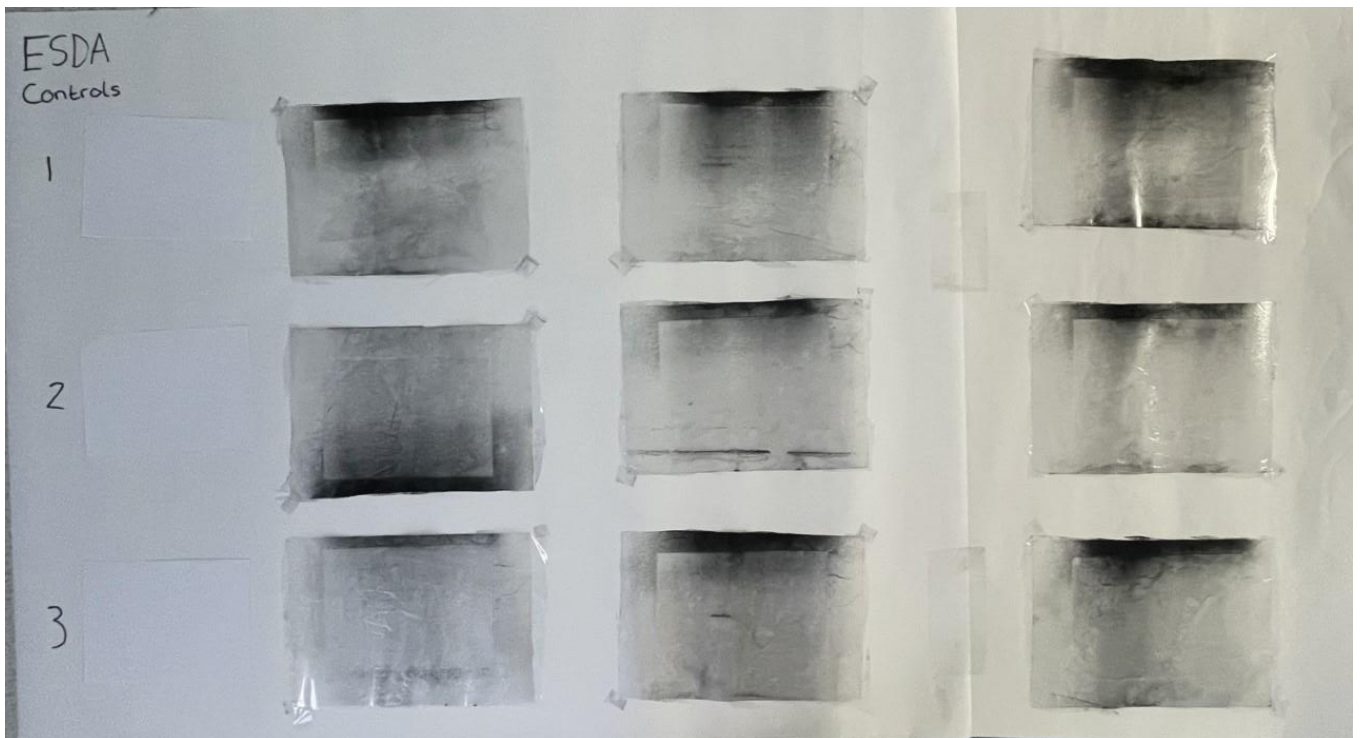


Figure 17 - ESDA results from control documents

Figures 14 to 18 demonstrate all the ESDA developed images from all of the documents retrieved from the different burial sites in addition to the ESDA developed images from the control documents.

Close-up Positive Results

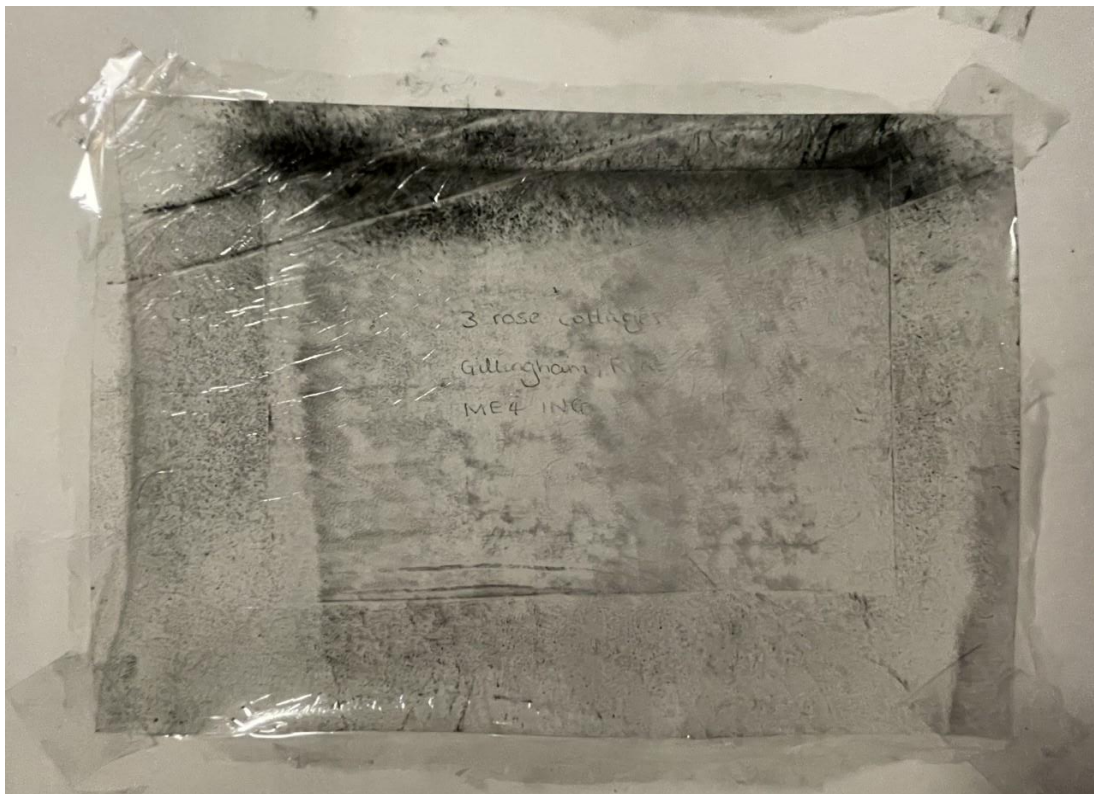


Figure 18 - Positive ESDA result (plastic wallet ESDA document 2 repeat 1)

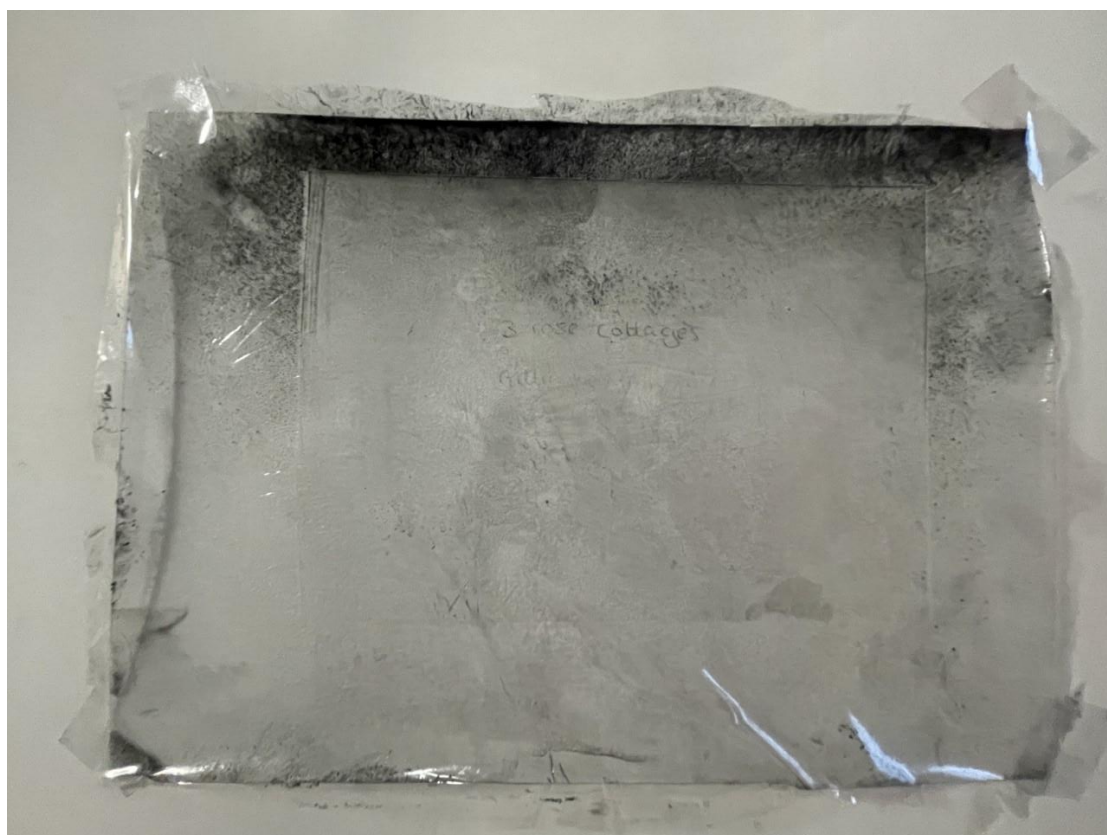


Figure 19 - Positive ESDA result (plastic wallet document 2 repeat 3)

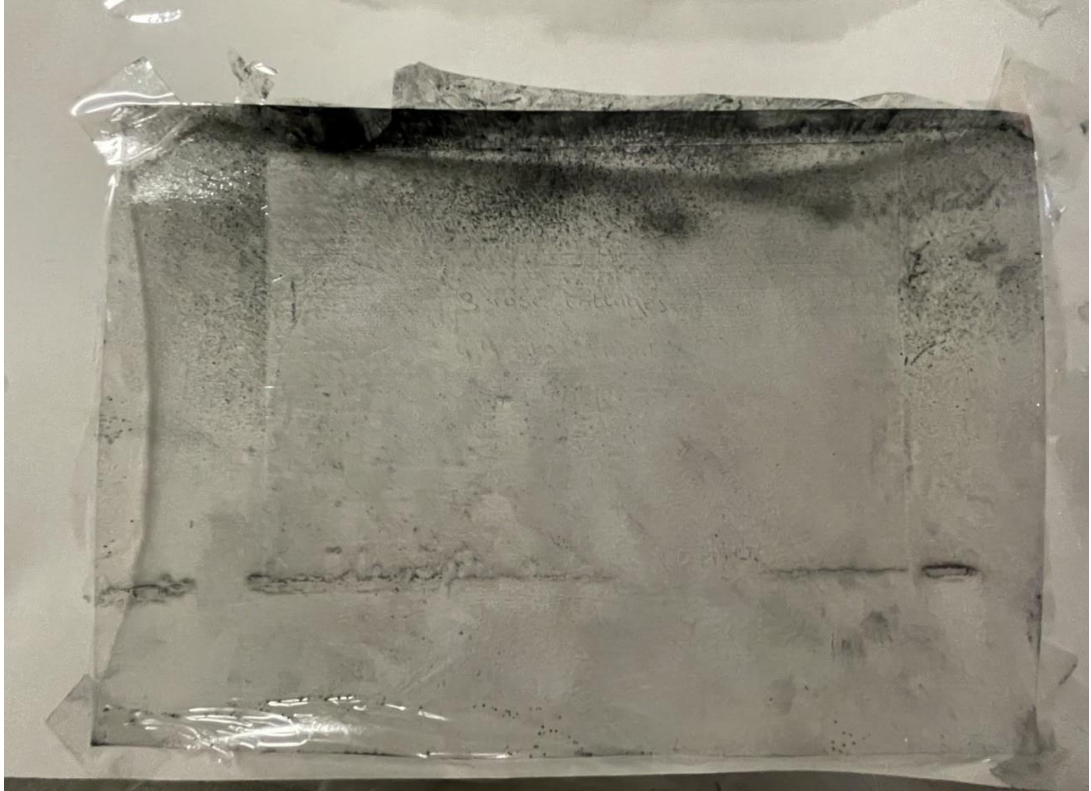


Figure 20 - Positive ESDA result (plastic wallet ESDA document 3 repeat 1)

Figures 19 to 21 show the close-ups of each positive ESDA result that was developed from the retrieved documents from burial site one, displaying the very varied quality of the positive results.

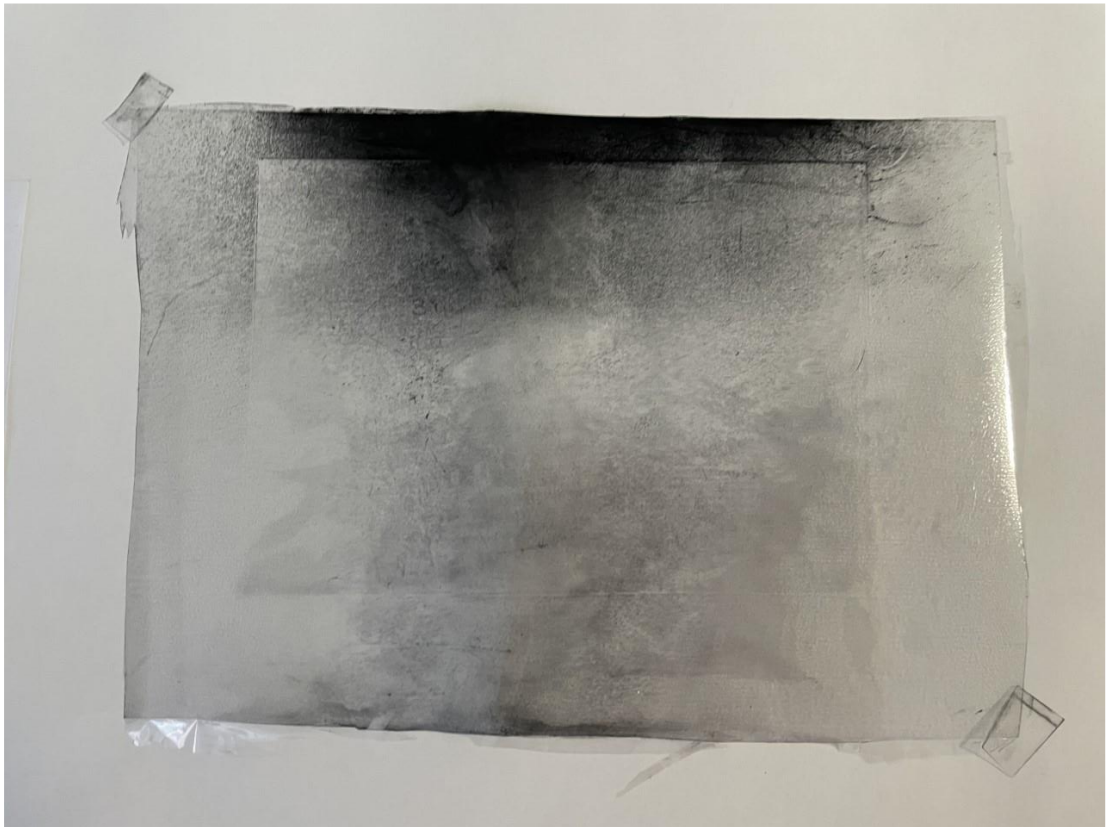


Figure 21 - Positive ESDA result (control document 1 repeat 1)

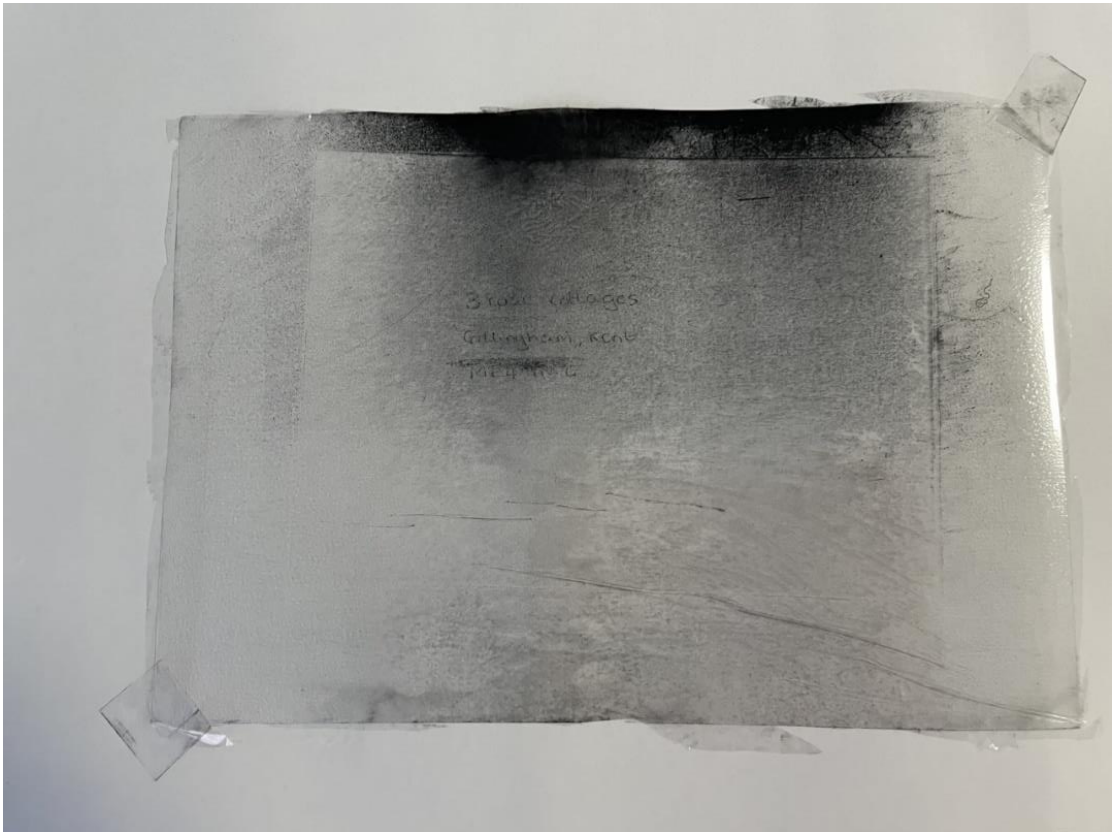


Figure 22 - Positive ESDA result (control document 1 repeat 2)

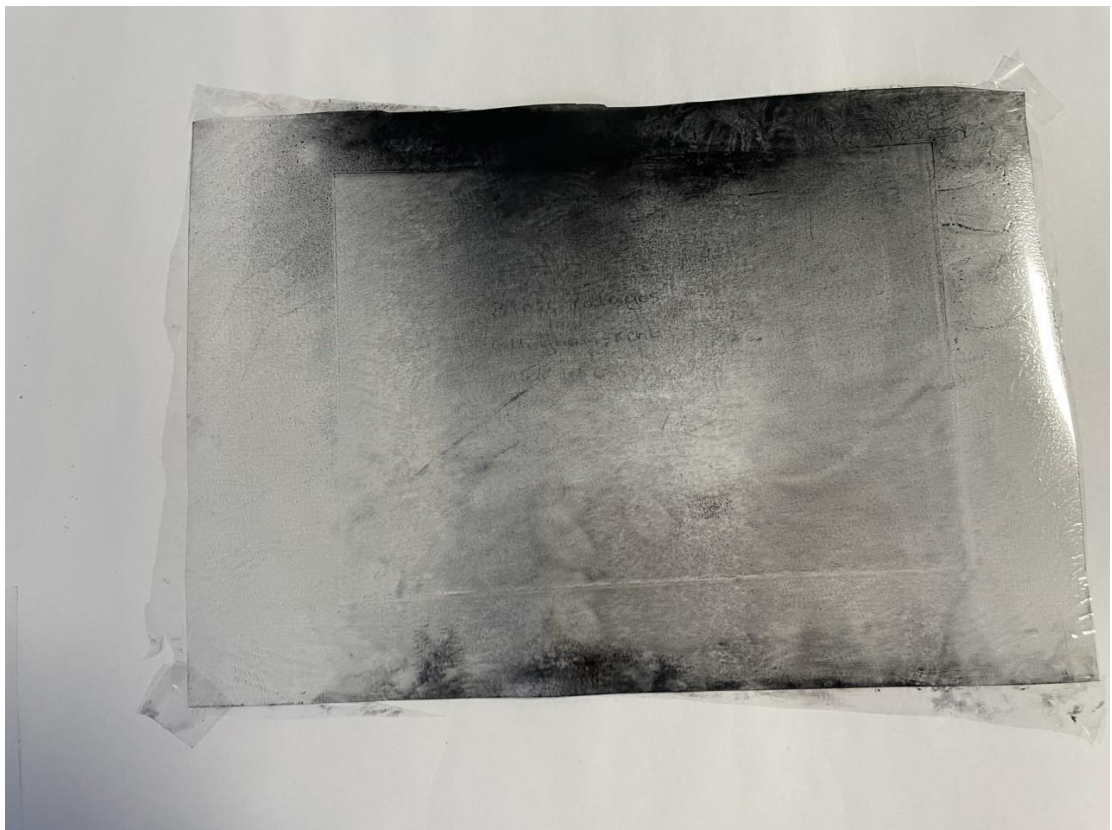


Figure 23 - Positive ESDA result (control document 1 repeat 3)

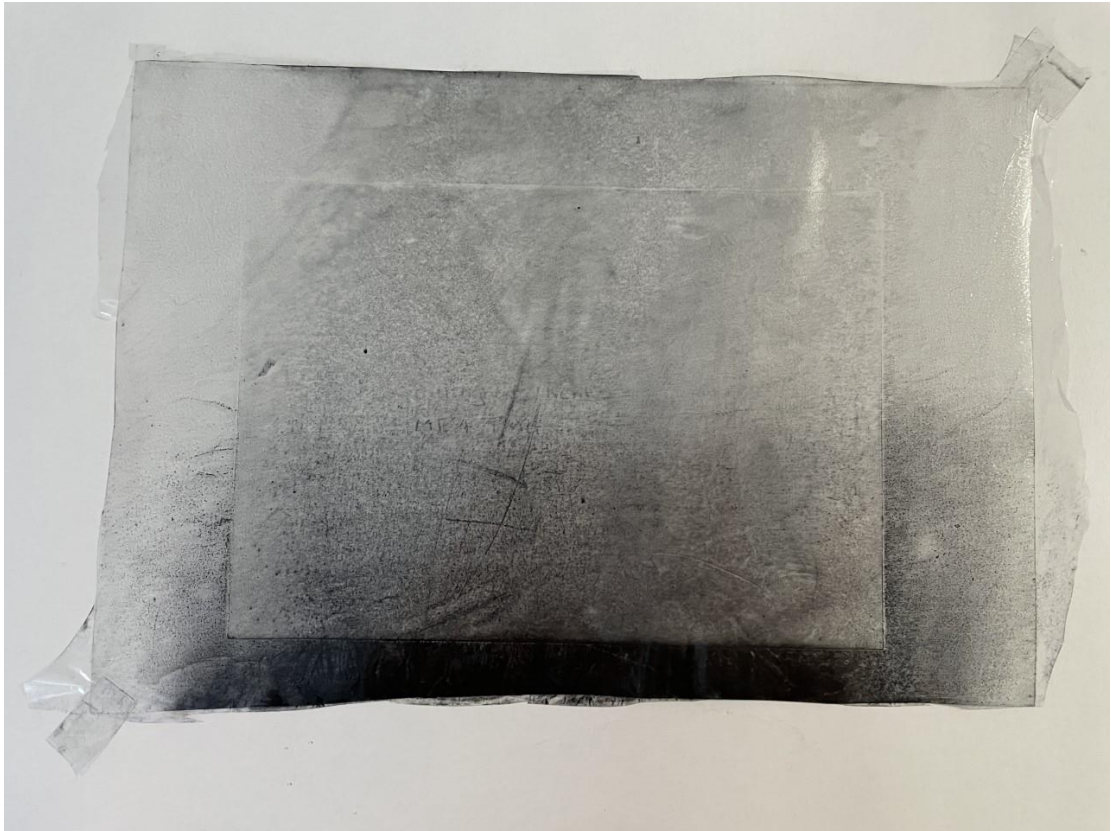


Figure 24 - Positive ESDA result (control document 2 repeat 1)



Figure 25 - Positive ESDA result (control document 3 repeat 1)

Figures 22 to 26 display the close-up images of each positive ESDA result from the control documents. These figures again highlight the varied quality of ESDA developed images.

Discussion

The results demonstrate that the control documents had the highest quantity of positive ESDA results, which was an expected result as there were no environmental factors affecting the unconcealed control documents. The only condition that also gave positive ESDA results were the documents that had been concealed in burial site one in plastic document wallets. This result could have been expected due to the plastic wallets being the most waterproof material and the detrimental effects of liquid as discussed by Radley (1993) in previous research. Therefore, also supporting the findings from Parsons, Sharfe, and Vintiner (2015) that the introduction of moisture to a document prior to ESDA analysis is detrimental to developing high quality images of the indented writing as it could potentially cause fibres to alter their structure and ultimately a deterioration in indentation detail. This highlights how moisture can be damaging to some types of forensic evidence as it compromises the ability to gain information from the indented writing on documents.

All experimental documents were flattened by a glass board promptly after being retrieved from the burial sites due to each one of the documents being crumpled to some degree. However, some of the documents were in worse condition than others, for example, both repeat documents retrieved from burial site two, one of the repeats from burial site three, and two of the repeats from burial site five all acquired some kind of tear to the paper. All the documents that were badly crumpled and had tears in produced zero positive ESDA results. These findings are consistent with Baier's (1983) findings where the documents with the most crumpled texture produced the worst quality ESDA results, even after they had been smoothed back out. These results were expected as the unconcealed control documents which had the best texture with no creases, crumples or tears produced the highest numbers of positive ESDA results, and the experimental documents with the best texture with the least damage were retrieved from burial site one in the plastic wallet documents and these produced some high quality ESDA results. This means the results were in accordance with Baier (1983), that texture of document is one of the most detrimental factors to ESDA analysis quality, which could help diminish some concerns about the validity of his study due to the belief there was a lack of complete control in the techniques used.

The findings reveal that although the control documents produced the highest quantity of positive ESDA results (five), the documents from burial site one produced the highest quality positive ESDA result that reached four on the employed scale representing excellent legibility. These results were not expected as the control documents were expected to have the highest quality ESDA results as they had not been subjected to the addition of moisture, texture damage, fingermarks or differences in soil pH. Thus, the highest quality image being produced by the experimental document retrieved from burial site one in plastic documents could be due to the ESDA technique being

potentially temperamental as the truth about the method is not completely understood owing to the several fundamental processes that occur (Pearse & Brennan, 1996). The experimental results also display how all the positive ESDA results developed were very varied when applied to an appropriate scale. This again could agree with previous studies that imply the ESDA procedure can be unpredictable and sometimes inconsistent. As these findings could also support Hall (1995) suggesting ESDA can be temperamental as he found that in various cases the results from the ESDA technique were not sufficient, thus, in these instances the conventional approach of utilizing oblique lighting could resolve the dilemma. As even though the unconcealed control repeats were handled and processed the exact same way, not all of the ESDA results were positive which is unexpected if the ESDA process and development remained consistent.

Based on the potential that the ESDA method can be temperamental, the findings could therefore also agree that new techniques need to be explored further to test if there are more advanced methods to offer improved results with higher validity. For example, Kalbitz, Scheidat, and Vielhauer (2016) recommended the application of industrial surface assessment methods instead to eliminate certain constraints of the ESDA method and, therefore, provide a more advantageous method.

There is a possibility the inconsistency in positive ESDA results could be due to human error during the ESDA procedure, for example, during the cascade development process. This possibility would agree with the argument that pouring the toner onto the plate to achieve an even development is typically subjective (Yaraskavitch *et al.*, 2008). Although, precautions were taken to avoid this possibility of human error, such as regulating the process by establishing a set number of passes of the toner that is poured over the mylar; in this study it was set at four. In addition to having no time delay between charging the mylar film and pouring the toner to develop the images. Regarding the charging process, it was again regulated by passing the corona wire over the film 10 times whilst being held consistently at around 5 cm above. Gloves were also worn at all times when handling the documents and carrying out the ESDA procedure to ensure there was no contamination of documents and no fingermarks were left on any of the documents which can interfere with the ESDA development process and effect quality of developed images and, therefore, the forensic evidential value of the ESDA. These measures were put in place to prevent the opportunity for human error to arise; however, it cannot completely eradicate it. Suggesting a potential limitation of this study could be human error.

The humidity in the laboratory where the experiment took place was 64% which was in line with previous research studies to produce high quality ESDA results. As some high quality developed images were produced from both the unconcealed control documents and the documents concealed in plastic wallets, the results support the findings of the study carried out by Daéid, Whitehead, and Allen (2008), as indentations were developed visibly in an environment with a relative

humidity higher than 60%. These results could also contradict the initial statement by Foster and Morantz (1979) that there is no evidence that humidity can affect the developed ESDA image. As it has now been found through many studies that humidity does influence the quality of ESDA results, the findings of this study could have had further influences than just the relative humidity at time of analysis that was noted, as Daéid, Hayes and Allen (2008) found that the environmental conditions of both the laboratory where the ESDA is employed and those to which the paper document involved are exposed, are of crucial significance when examining the variables that influence the ESDA procedure. Therefore, the individual humidity's that each of the documents were exposed to during the burial concealment may have affected the quality of the developed images, for example, as the plastic wallet material is the most impermeable, environmental factors such as humidity would have less interaction with the documents, so less influence on the documents and, thus, their resulting ESDA developed images, as seen in their high quality images.

The findings of this study provide support for the study conducted by Pearse and Brennan (1996), as they suggest a standard operating temperature of 20°C and a relative humidity of around 75% to be the optimal conditions when carrying out ESDA for the best quality results. The experimental conditions used to conduct the study were 15.7°C and 64% humidity, which allowed high quality developed images for both the unconcealed documents and documents concealed in plastic wallets, emphasising that approximations of these optimal conditions are still able to produce high quality results.

The effect of how the temperature influences the ESDA developed images was also discussed by Pearse and Brennan (1996), where they stated even if relative humidity is low, a high temperature allows the atmosphere to retain sufficient water vapour to make the paper document a conductor, producing high quality ESDA results. The temperature values measured at each burial site, all had similar differences in temperature from initial measurement to measurement at time of document retrieval. Suggesting that only the temperature of the laboratory where the ESDA analysis is taking place is important, as the documents concealed in the plastic wallets had very similar differences in temperature values to all the other experimental conditions, yet still produced the highest quality results, indicating other factors to be more influential to the ESDA analysis. These findings could, therefore, provide some agreement to the statement by D'Andrea *et al.* (1996) that temperature only has a minimal influence on the quality of ESDA.

During the study, the pH values of the soil from each burial site was established at the time of burial and again at time of document retrieval. It was observed that each one of the burial site's soil increased in pH in the time interval between burial and retrieval of documents and therefore became more basic. Although there was a common increase in pH values for each burial site, the increases were all minimal with the largest increase being 1.14. The pH change for the soil in

burial site one where the experimental documents in plastic wallets produced the only positive ESDA results was 0.71 which is a very small increase. Even though there was an increase in pH of the soil, the plastic wallets were the most waterproof and impermeable experimental material in the study which meant the documents in burial site one had the least interaction with the soil, hence less subjected to effects due to pH. This could potentially explain why it was the only experimental condition to produce positive ESDA results comparable to the control documents which were not exposed to any change in pH. All other experimental conditions produced only negative ESDA results, and this could be due to having higher exposure to the soil pH change. Although the reasons behind how the pH affects the documents to alter the ESDA results are still unknown, the results can be supported through other studies into how pH has affected different types of forensic evidence, and specifically how soil pH can interfere with forensic evidence. Young *et al.* (2014) carried out a study on how soil pH can affect forensic evidence in the manner of DNA extraction from forensic soil samples. The results showed that the pH of the soil is possibly the element that can interfere with the DNA adsorption to clay minerals the most. Cai *et al.* (2006) also found a rise in DNA adsorption on soils with low pH. Further reiterating how pH, particularly soil pH, can interfere with forensic evidence, which can also be seen in this experimental study as the only experimental condition to produce positive ESDA result was the one which had least interaction with the soil and therefore change in pH. The experimental results could also agree with an additional study into the effects of soil pH on pollen deterioration (Phumphumirat, Mildenhall, & Purintavaragul, 2009). The findings revealed how certain types of pollen's deterioration can be influenced by soil pH, emphasising the potential detrimental effect of pH on different of types of evidence (Phumphumirat, Mildenhall, & Purintavaragul, 2009). However, for the study by Phumphumirat, Mildenhall, and Purintavaragul, (2009), the outcomes discovered that the pollen deterioration occurred more gradually in alkaline soil, which contradicts the experimental findings as the documents that were more exposed to the soil with rising pH over time (becoming more alkaline) caused degradation to the documents, and therefore signifying that more alkaline soil can also be detrimental to certain types of forensic evidence.

So, although there were some limitations to the study such as potential human error during the procedure and also potential subjectivity when comparing results to an already established scale, the results obtained were in accordance with many of the studies discussed, into how environmental factors can be found to alter forensic evidence.

Conclusion

The investigation aimed to establish which materials are most effective at preserving documents from burial concealment for ESDA analysis. The results were that some materials were found to work better at preserving documents in a burial setting for ESDA analysis. Only the plastic wallets preserved the documents to a high enough standard that allowed for multiple positive results of high quality. The control documents produced the highest quantity of ESDA results with five positive results. The quality of all the positive ESDA results were very varied for both experimental results and control results, however, the experimental condition of documents buried in plastic wallets produced the highest quality ESDA result. This was an unexpected finding as the controls were assumed to obtain both the largest quantity and also highest quality of ESDA results due to the fact they remained untampered in every way. Therefore, it was concluded that the ESDA technique could have limitations such as being temperamental. There is a slight possibility that the inconsistency in the positive results could be due to the chance of human error when carrying out the ESDA procedure. However, provisions were put in place to reduce these chances by highly regulating the procedure across all conditions. Five out of the six experimental conditions produced no positive ESDA results. Two of these experimental conditions allowed degradation of the documents so both retrieval and ESDA analysis were not viable. The other three experimental conditions allowed for retrieval and ESDA analysis, yet only yielded negative results. It was concluded that these negative results were due to their materials being less waterproof and more permeable, therefore allowing the detrimental factors of moisture and soil pH to interact with the documents. These factors in turn enable damage of the documents, resulting in poor document texture, another limiting factor for ESDA analysis. This research is valuable as it tests the limits of the ESDA technique in conjunction with forensic archaeology, as it combines two forensic fields that are usually considered as individual disciplines. The results indicate the types of materials that preserve documents more effectively to allow for the best quality ESDA results, and thus the highest forensic evidential value. Therefore, it can be assumed that more waterproof and impermeable materials have been found to preserve documents the best for the highest quality ESDA analysis.

Future research

One advancement could be to experiment using several different types of paper, as in this study only one paper type was used (Wilko A4 white 'everyday paper', 75 grams per square meter). When it has been found that previous studies where multiple paper types were used, they all offered slightly differing outcomes depending on the paper type. For example, Pearse and Brennan (1996) discovered that ESDA's capability to visualise latent pressure designs is conditional on the paper type, amongst other factors. Therefore, in this study it would be valuable to know if different types of paper can withstand the potential changes that occur during the burial concealment process, for example introduction of moisture, change in soil pH and changes in texture. To then assess whether they allow for better quality results or if these factors affect all paper types and, hence, the outcome of the ESDA developed images.

An additional advancement for this study would be to repeat it, but experiment using different writing implements, for example, different types of pens and even pencils to investigate whether it has an influence on the quality of ESDA developed images.

Since the 70's there has been little exploration into utilising computers to enhance and automate the analysis achieved by forensic document analysts (Srihari & Leedham, 2003). As the majority of the exploration was focused on pattern detection methods for extracting static and dynamic characteristics from handwriting and handwritten signatures in addition to improving quality of document images and ESDA lifts (Srihari & Leedham, 2003). These were all recognised as mainly software implements to aid a document examiner instead of creating any scientific foundation for their work (Srihari & Leedham, 2003). It is not feasible to obtain comprehensive quantitative information concerning the impression generated by a writing implement such as deepness, variations or profiles through ESDA (Kalbitz, Scheidat, & Vielhauer, 2016). Due to these constraints, Kalbitz, Scheidat, Vielhauer (2016) advised the use of industrial surface assessment procedures to obtain forensic handwriting traces as an alternative. These methods are optical 2D/3D sensor mechanisms that are contactless and non-destructive that offer intensity and topography data in the nanometre range in high resolution quality and are centred on the chromatic white-light technology (Kalbitz, Scheidat, & Vielhauer, 2016). It works by utilising the effect of chromatic aberration of optical lenses to measure the distance between sensor and object (Kalbitz, Scheidat, & Vielhauer, 2016).

Only six experimental conditions plus controls were investigated in this study, and although the conditions were created using a range of different materials offering differing qualities, even more could be added, and investigated. This would allow for a larger quantity of results and to potentially identify additional conditions that would allow for positive ESDA results, as most of the results produced were negative. Being able to assess whether there are additional materials that

would preserve the paper documents at a high enough standard to allow for positive ESDA results could enhance the forensic value of the study. As crime scenes can be so individualised and could comprise of a large range of materials that in turn could create these different conditions (Mokwena, 2012).

The documents were buried in their separate materials for a time period of one month due to time constraints, this time frame offered enough time for the complete degradation of the documents in paper envelopes in burial site four and the isolated documents in burial site six. However, during this time period, there were only very small changes in pH. Hence, one potential advancement to this investigation could be to use an extended time period for the burial, enabling a greater potential change in soil pH. This could then allow for investigation into the effect of larger changes in soil pH on documents and consequently their analysis by ESDA.

There is insufficient knowledge on forensic document examination in relation to forensic burials as these subjects are usually dealt with as two separate disciplines within forensic science which makes it hard to draw conclusions when they are merged together as seen in this investigation. To develop this study further, additional preliminary studies could be carried out into more general research linking the two disciplines in order to gain a wider range of knowledge. The knowledge gained from this could then be applied to more complex studies.

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Appendices



Figure 26 - Image showing the preparation of documents for burial site 1 in plastic wallets



Figure 27 - Image showing the preparation of documents for burial site 2 in a children's raincoat



Figure 28 - Image showing the preparation of documents in burial site 3 in a pair of jeans (front pocket)



Figure 29 - Image showing the preparation of documents in burial site 3 in a pair of jeans (back pockets)

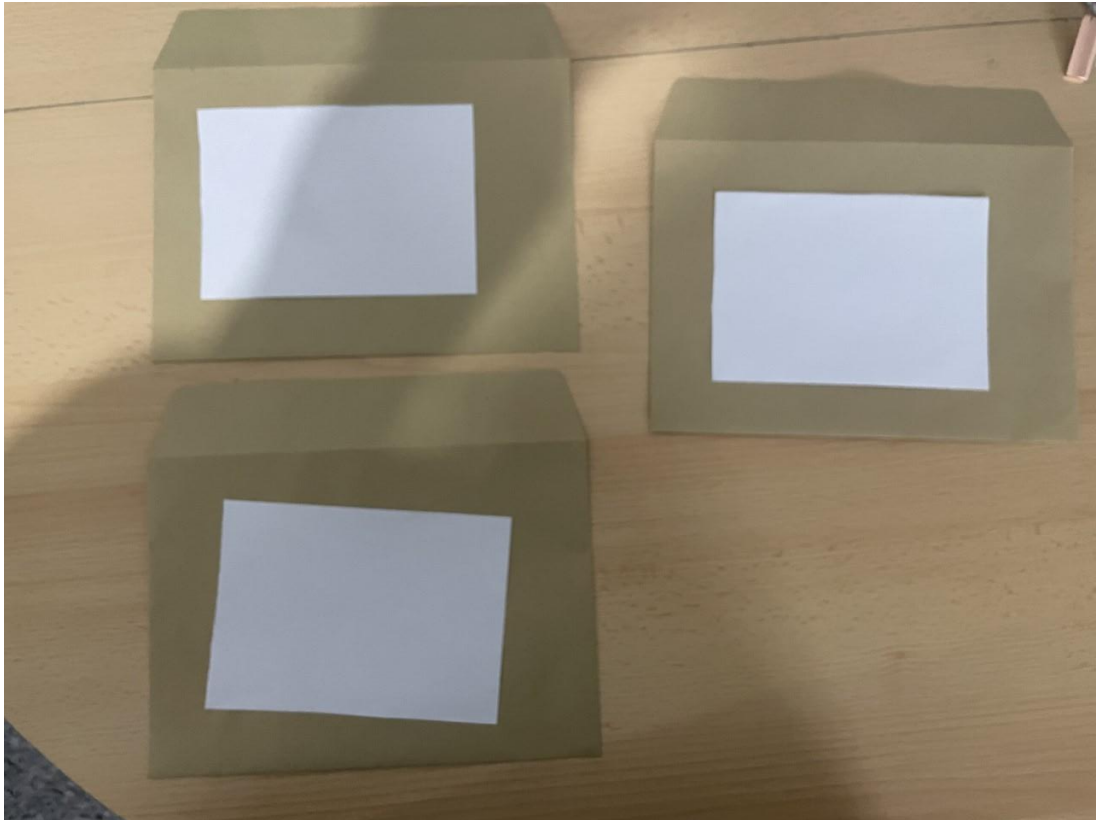


Figure 30 - Image showing the preparation for documents in burial site 4 in paper envelopes



Figure 31 - Image showing the preparation of burial site 5 in bubble envelopes