

**The Detection of Simulated Clandestine Graves in an Arid Environment Using Unmanned
Aerial Vehicle Remote Sensing**

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Abstract

The Middle East has frequently suffered from armed conflicts that resulted in mass burials. However, the detection of graves in such an arid environment by deploying remote sensing payload on unmanned aerial vehicles (UAVs) has received little attention. This study used UAVs equipped with different sensors aimed at narrowing down the search area of possible simulated gravesites. It sought to detect variation in topsoil temperature and soil moisture between the simulated graves and their surroundings, detect surface anomalies both manually and automatically, find grave mounds using the digital elevation model and evaluate the use of normalised difference vegetation index (NDVI) in grave detection. The enclosed research area included both control and experimental graves and was imaged for 18 months. The results demonstrated the effectiveness of thermal imaging in detecting heat produced from buried sheep carcasses and detecting the change in grave soil moisture for 7 and 10 months, respectively. Moreover, the buried animals significantly influenced the topsoil temperature of the mass graves ($p = 0.044$). Meanwhile, the anomaly detection was possible for up to 18 months. Near-IR and red-edge bands were the most suitable for the manual detection (Near-IR 66.66%, red-edge 33.33%), whilst the best-performing automated method varied depending on the sensor used. Standard RXD (RXD) and Uniform Target Detector (UTD) algorithms were the most suitable methods for the RGB sensor (RXD 56.25%, UTD 43.75%). The best outcomes for the multispectral sensor were obtained using Hybrid of the RXD and UTD algorithms (RXD-UTD) (60%), UTD (26.67%) and RXD (13.33%). Despite the fact that the research took place in a very hot and dry environment, a high (0.33) difference in NDVI values was observed between the graves and their surroundings. The results from these cost-and time- effective search methods presented in this study affirm their potential for detecting burial sites in an arid environment.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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List of abbreviations

DEM – Digital elevation model

DN – Digital number

DSM – Digital surface model

DTM – Digital terrain model

EAAF – The Argentinian forensic anthropology team (Equipo Argentino de Antropología Forense)

FAFG – The Guatemalan forensic anthropology foundation

FIR – Far-infrared

FLIR – Forward-looking infrared

GAS – Global acquisition system

GCP – Ground control point

GLONASS – Global navigation satellite system

GPR – Ground-penetration radar

GSD - ground sampling distance

HSI – Hyperspectral imaging

ICC – International criminal court

ICJ – International court of justice

ICL – International criminal law

ICMP – International commission of missing persons

ICRC – International Committee of the Red Cross

ICTR – International criminal tribunal for Rwanda

ICTY – International criminal tribunal for the former Yugoslavia

IHL – International humanitarian law

LiDAR – Light detection and ranging

MIR – Mid-infrared

MSI – Multispectral imaging

NDVI – Normalised difference vegetation index

NGO – Non-governmental organisation

NIR – Near-infrared

PCA – Permanent court of arbitration

PHR – Physicians for human rights

POW – Prisoners of war

RGB – Red, Green and Blue

RXD – Reed-Xiaoli detector algorithm

RXD-UTD – Hybrid of the RXD and UTD methods

SAS – Sequential acquisition systems

Sfm – Structure-from-motion

SWIR – Short wave infrared

TI – Thermal imaging

TVDI – Temperature vegetation dryness index

UAV – unmanned aerial vehicle

UDHR – Universal declaration of Human Rights

UN – United nations

UTD – Uniformed target detector

2D – Two-dimensional

3D - Three-dimensional

Chapter 1 Introduction

1.1 Overview

In forensic science, remote sensing has been used in various cases to aid criminal investigation (Pringle et al., 2012b; Silván- Cárdenas et al., 2017; Blau et al., 2018; Murray et al., 2018; Butters et al., 2021; Silván-Cárdenas et al., 2021). One of the earliest examples, is the use of images obtained by a hot-air balloon in the city of San Francisco in 1906 which allowed the comparison between the houses that were affected by the earthquake and those that were deliberately set on fire by their owners to benefit from the insurance policy, (Brilis, 2000). Moreover, past research has demonstrated that remote sensing can detect burial sites. It was successful in detecting clandestine graves in tropical forests (Kalacska et al., 2009), mountainous terrain (Fernández-Álvarez et al., 2016), and in woodland (Pollard and Barton, 2013). However, only the costly hyperspectral imaging (HSI) has been used in arid environment. It successfully detected buried remains three months post-burial, and the useful wavelength intervals are mainly distributed along the spectral range of 700–1800nm (Silván-Cárdenas et al., 2017).

The proposed research was carried out in Kuwait, a country known for its arid environment, using remote sensing approaches. The small number of publications on grave detection in an arid environment was the impetus for conducting this research (see: Silván-Cárdenas et al., 2017; Dozal et al., 2018). The importance of detecting such burials arises from the fact that the Middle East, including Kuwait, is one of the world regions that has frequently suffered from armed conflicts that resulted in mass burials (Schuldenrein et al., 2017). However, the detection of clandestine graves in such an arid environment by deploying remote sensing payload on unmanned aerial vehicles has received little attention. At the same time, the geophysical techniques and the on-foot coverage of a large land area and thoroughly searching it for a possible burial site places a significant demand on both human and financial resources.

This research was conducted by simulating multiple occupied single graves and a mass grave in a fenced Kuwaiti desert area. Pigs have always been the first analogue choice to simulate human bodies when conducting forensic experiments; however, since pigs are not available in Kuwait, sheep were the closest equivalent available (Matuszewski et al., 2020). It is not the first time mammals, other than pigs, have been successfully used when conducting such experiments (Kalacska et al., 2009). Different sensors are introduced to detect those graves using remote sensing techniques that have never been used in such an arid environment, including high-resolution RGB, multispectral and

thermal. Such detection methods have been implemented in different environments to detect burial sites. However, in an arid environment, only HSI has been used (Kalacska et al., 2009; Silván-Cárdenas et al., 2017; Murray et al., 2018).

Therefore, this research sought to identify the usefulness of using RGB images to detect soil and terrain disturbances caused by the presence of graves in an arid environment. Moreover, RGB images are used to identify any surface elevation from burial mounds. Similarly, multispectral imaging was also used to detect disturbances caused by the presence of graves. Additionally, multispectral sensor is used to model and evaluate the use of normalised difference vegetation index (NDVI) in grave detection. Whilst not being commonly used in forensic science (Sobotkova and Ross, 2010; Blau et al., 2018), multispectral sensors are heavily used in agricultural research (Assmann et al., 2018) and archaeology (Winterbottom and Dawson, 2005). Implementing this technology in such environmental conditions is considered a new approach, and it is hoped that it will serve as a cost- and time-effective search method.

Moreover, this research explores a unique aspect by using a thermal sensor mounted on a UAV to detect the heat generated during the decomposition process of cadavers in a recent burial site in an arid environment, a topic that has not been previously studied. In addition, the results obtained from analysing the thermal imaging (TI) can potentially aid in assessing the soil moisture of the graves and the effect of the buried bodies on features of the soil (Hsu and Chang, 2019) .

Hence, the originality of the research lies in using the aforementioned imaging sensors mounted on UAVs to improve the current grave detection methods in an arid environment. Therefore, successfully implementing this technology in such harsh environmental conditions would benefit all the agencies involved in detecting burial sites. Furthermore, it will have a definite humanitarian impact in that it will give closure to the families of the people who are missing and presumed to be dead in many countries.

1.2 Aims, Objectives and Research Questions

This thesis aims to examine the effectiveness of using commercially available UAVs equipped with 4K RGB, thermal and multispectral sensors in narrowing down the search area of potential gravesites, both recent and old. The captured images will be analysed using multiple image processing software, which will prove the originality of using such technologies in an arid environment to help detecting burial sites. More precisely, the aims are to:

- Evaluate the use of a thermal sensor mounted on an unmanned aerial vehicle (UAV) to detect recent burials in an arid environment.
- Evaluate the use of a multispectral sensor mounted on a UAV to detect older simulated clandestine burials in an arid environment.
- Evaluate the use of a 4K RGB sensor mounted on a UAV to detect simulated clandestine burials in an arid environment.
- Develop a cost- and time-effective remote sensing burial detection method which can be used in an arid environment.

These aims will be achieved by undertaking an experiment to explore the physical changes in topsoil temperature and soil moisture. Furthermore, the effect of burying animals and how these features are affected over a period of time is what sought to be understood in this research. More specifically, the objectives are:

- To identify the optimal conditions for detecting the thermal signature of the graves. This will specifically address whether graves in arid environment can produce distinguishable temperatures and soil moisture when compared to their surroundings.
- To explore which wavelength bands across the electromagnetic spectrum is most suitable to detect landscape changes and soil disturbance created from graves in an arid environment.
- To study the period of time during which surface changes can be detected when 4K RGB, multispectral and thermal sensors are used in an arid environment.
- To investigate the effectiveness of using commercially available UAVs in forensic investigations.

Hence, and in order to achieve these goals, the thesis sought to answer three main research questions:

- Do graves in an arid environment have distinguishable temperatures and soil moisture on their surface compared to their surroundings? How long can these features be discerned using the thermal sensor deployed on the UAV?
- Can a multispectral sensor deployed on a UAV detect soil disturbance and surface anomalies produced by a grave in an arid environment? For how long would the sensor produce effective results?
- Can a 4K RGB sensor deployed on a UAV detect changes in surface height and surface anomalies produced by a grave in an arid environment?

The research undertaken allowed a holistic examination of the effectiveness of the proposed clandestine grave detection method in weather conditions characterised by very high temperatures. It is hoped that it will render forensic search teams worldwide with a better remote search approach, which will reduce the cost and time of the operation when dealing with vast areas in an arid environment.

1.3 Structure of the thesis

The thesis comprises six chapters, each serving a distinct yet interconnected purpose in the overall research narrative. Chapter 1 introduces the research topic, providing context, significance, and the research questions to be addressed. Chapter 2 provides an overview of the pertinent literature. As this thesis is a multidisciplinary research project combining several fields, the literature review covers the three major disciplines starting with an overview of remote sensing. The second part of the literature review provides an overview of methods used in detecting clandestine human burials. The final part of the literature review provides an overview of human rights violations and the legal framework surrounding mass graves. Chapter 3 presents the experiment setup of the research area, equipment used for on-ground measurement and analysis, type of UAVs deployed and their image capturing sensors, the image acquisition techniques, and finally, the tools used to process the captured images. Chapter 4 presents the results obtained from the on-ground observations and measurements. Moreover, it demonstrates the findings of image processing techniques using various image processing tools and software. Chapter 5 contains the discussion that evaluates the key findings from the experiment. In addition, the limitations of the thesis, future recommendations and directions for further work are presented. Chapter 6 provides the conclusion that assesses the main findings for each

research question and presents the implications of this research for forensic anthropology in particular and forensic sciences and human rights investigation.

1.4 Additional Considerations

The experimental research design included the use of legally purchased sheep from the local abattoir. Therefore, appropriate ethical approval in accordance with Liverpool John Moores University ethics committee (approval number CE_ASA/2020-4) was obtained on January 5, 2020 (see Appendix A). Furthermore, the use of animals in this research was conducted in compliance with the Animal (Scientific Procedure) Act 1986 which guides the use of live animals in unregulated and non-licensed teaching and research protocols (Animals (Scientific Procedures) Act 1986, 2014).

Chapter 2 Literature Review

2.1 Remote sensing

This chapter focuses on the issues surrounding the application and capability of UAV passive remote sensing technology. In passive sensing, the sensor detects the natural source of electromagnetic radiation reflected or radiated from the ground, atmosphere, and clouds (Schowengerdt, 2007). Then, the energy reflected into the atmosphere is detected and recorded by the remote sensing instrument. Still- images without flash, multispectral imaging (MSI) and thermal imaging TI all operate as passive sensors that use solar radiations as a source of illumination when capturing them (Schowengerdt, 1997). On the contrary, the active sensor uses its own energy source to illuminate the desired target to obtain its surface information and physical characterisation (Liu, 2016). Many factors must be considered when selecting the type of optical sensor when conducting a field experiment. The source of light, signal-to-noise ratio, temporal coverage, and ground resolution are essential elements that govern any operation (Okin and Roberts, 2004). The spectral band coverage differs from one sensor to another. The narrower the bands reflected from the solar spectrum to the sensor, the more information will be obtained for the desired target (Murray et al., 2018).

Remote sensing refers to the process of gathering information about object characteristics on the surface of the Earth through the use of data obtained from airborne or spaceborne platforms (Schowengerdt, 1997). The information is gathered using a radiation source that can be natural, emitted from the sun or artificial, launched from an airborne or spaceborne platform on a specific target of interest (Schowengerdt, 2007). Whether the radiations were reflected, scattered, absorbed, or transmitted from the surface of interest, the sensors can detect surface reflection spectra, gather surface information, and acquire their physical characteristics (Hsu and Chang, 2019). During this process sensors detect electromagnetic radiation and convert them into a physical value that can be processed and analysed using different sensors. Sensors can operate using either a global or sequential acquisition system depending on the method used in acquiring radiation. The former records an entire scene instantaneously, while the latter acquires point-specific information about the target. Photographic or television cameras are examples of the global acquisition system (GAS). Multispectral imaging (MSI), thermal imaging (TI), radars, lidars and sonars are samples of sequential acquisition systems (SAS).

2.1.1 UAV remote sensing

Nowadays, the use of multirotor and fixed-wing UAVs remote sensing platforms, similar to what is being used in this research, is heavily increasing due to the simplicity of their usage in acquiring high spectral and spatial resolution images when compared to satellite platforms. Planning flight surveys using such technology is considered more manageable than planning those surveys using other platforms. Such flight surveys are considered cost- and time-effective solutions and have been used in many fields, such as marine science, agriculture, search and rescue, geographic mapping, and forensic science. Nowadays, UAV remote sensing is heavily utilised due to its compatibility with different types of sensors and effectiveness compared to satellite platforms. It can overcome some significant limitations related to satellite platforms, including weather conditions such as cloud coverage, low temporal resolution, low spatial resolution, and invalid data bands (Fuentes-Peailillo et al., 2018). This is true since satellite platforms orbit thousands of kilometres in space from the target, which causes the limitations mentioned above. However, UAVs can be positioned at a shorter distance, usually meters above the target resulting in capturing images with higher spatial, spectral, temporal and radiometric resolutions. It is now possible to cover and capture images for a large land area in a single UAV flight without the cost and difficulties of human-crewed flights or the costly hyperspectral imagery. The use of UAVs has also eased the difficulties that sometimes accompany the on-foot search for clandestine graves. Examples of such difficulties can be in the form of a large search area which requires a lot of time and effort to search, or an area with rough, inaccessible terrain (Murray et al., 2018).

Meanwhile, there are plenty of considerations that governs any flight survey conducted and its outcome. The selection of flight plan, pixel resolution, flight height, and flight speed are important factors that define the success of any flight operation (Gowravaram et al., 2018). On some occasions, the systematic search method of the UAV also helps to detect evidence and potential gravesites that the human eye cannot detect while conducting the on-foot ground search. As a result, such technology saves time, reduces the human resources needed for the search, and reduces the operation cost. However, the limitation arises when covering vast areas since most multirotor UAVs are governed by a flight duration between 20 and 30 minutes. Hence, to maximise the aerial coverage of the research area, the UAV can either be flown at an increased height or higher speed. An example would be using a fixed-wing UAV, which can cover a larger area in a shorter time than a multirotor UAV (Assmann et al., 2018). However, flying the UAV at an increased height might influence the

obtained ground sampling distance (GSD) in an image, while the higher speed would affect its quality and blurriness.

2.1.2 The electromagnetic spectrum

The electromagnetic spectrum is the distribution of electromagnetic radiations according to their frequency or wavelength. The electromagnetic spectrum covers a range of radiations in the visible light (400-700 nm), near-infrared (NIR) light (700-1300 nm), mid-infrared (MIR) light (1300- 2500 nm), far-infrared (FIR) light (8-14 μm), and microwave (1 mm-1 m) (Campbell and Wynne, 2011).

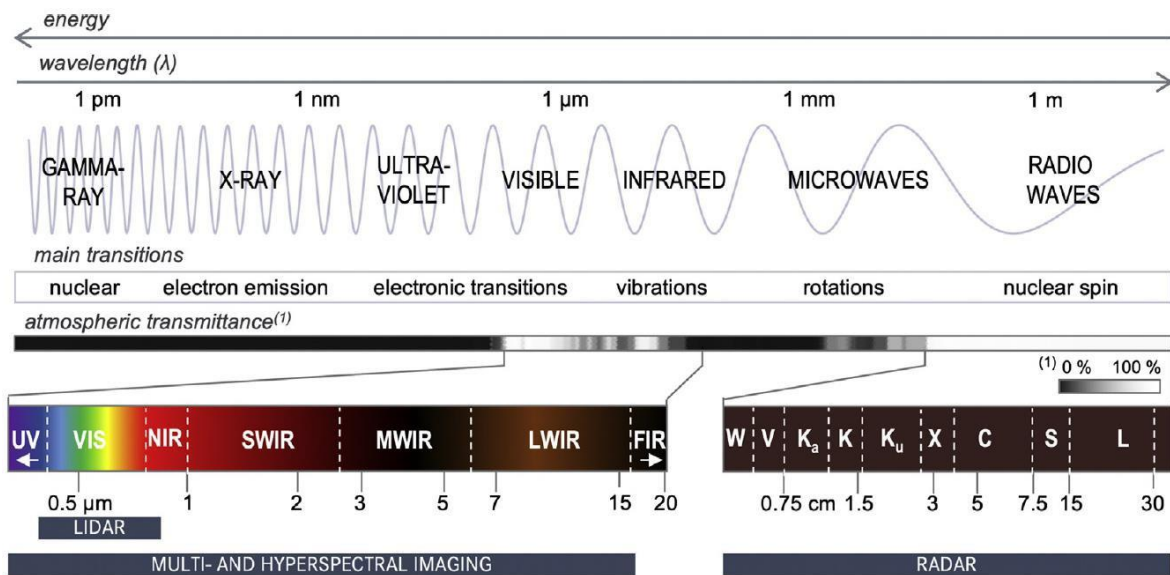


Figure 1 The electromagnetic spectrum (Booyesen et al., 2021).

For many years, researchers have shown interest in studying the electromagnetic spectrum and interpreting the associated radiation in many different fields (Blau et al., 2018; Hsu and Chang, 2019; Okin and Roberts, 2004). Earth remote sensing was first introduced in 1972 with the launch of the first Landsat Multispectral Scanner System, which had four 100 nm wide spectral bands and an 80 m pixel size (Schowengerdt, 1997). Nowadays, sampling the entire electromagnetic spectrum is manageable with the availability of systems that capture multiple bands and narrow pixel sizes ranging from less than 1 m up to 1000 m (Schowengerdt, 1997).

2.1.3 RGB sensor

Visible light can be divided into three segments known as the primary colours (Campbell and Wynne, 2011). Those colours are red, green and blue, and their signal peaks at 680 nm, 545 nm, and 440 nm, respectively (Liu and Mason, 2016). The colours are defined as such since no single primary

colour can be formed from a mixture of the other two primary colours. Also, when mixed in a precise proportion, these primary colours produce all the colours a person visualises. Finally, white light is formed when equal proportions of the three primary colours are combined (Campbell and Wynne, 2011).

Many commercially available UAVs are equipped with a very high-resolution RGB sensor. One of them is the Parrot ANAFI Thermal, equipped with a thermal sensor and an RGB sensor that has a photo resolution of 3264x2448. Additionally, it uses a Quad Bayer colour filter array which helps obtain a real-time high-definition resolution capture in photo and video modes. Such sensitivity captures difficult scenes with minimal loss of details (Parrot, 2020a). This makes the Parrot ANAFI Thermal a simple but powerful tool for assessing the analysis of the findings of topographic changes due to the high-resolution images captured by it. One of the applications of RGB image processing using photogrammetry software is generating a digital elevation model (DEM). Depending on the type and source of the DEM, the elevation values describe the ground surface excluding all objects above, which is known as the digital terrain model (DTM), or it represents the actual surface including all objects rising above the terrain, which is known as the digital surface model (DSM) (Aber, Marzolf and Ries, 2010).

2.1.4 Multispectral sensor

Spectral imaging is a form of imaging that uses multiple bands across the electromagnetic spectrum (Campbell and Wynne, 2011). It encompasses a broader capturing technique that goes beyond the visible spectrum (RGB) (Campbell and Wynne, 2011). Two main techniques are used to capture spectral imaging. The techniques are based on a similar principle and differ only in the number of channels captured. Those techniques are multispectral imaging (MSI) and hyperspectral Imaging (HSI). Multispectral sensors measure surface reflectance across space for multiple bands of wavelengths, consisting of at least two digital imaging systems capturing monochromatic imagery (Assmann et al., 2018). MSI, similarly to HSI, was initially introduced using satellite platforms. It collects data using broad spectral bands from the electromagnetic spectrum between the visible and NIR region (350 to 2500 nm) (Okin and Roberts, 2004). MSI typically captures between 4 to 15 wavebands with wavelength ranges as follows: blue (0.40– 0.58 μm), green (0.50– 0.65 μm), red (0.59– 0.675 μm), and near-infrared (NIR) (0.675– 0.85 μm) (Assmann et al., 2018). From the broad spectral bands collected, a georeferenced map is generated. With the development of sensing technology and the need for more convenient and portable remote sensing instrumentation than the

complicated satellite platforms, sensors for imaging spectroscopy using airborne platforms showed a significant advance in providing high spatial and spectral captured image resolution. It allows image acquisition covering hundreds of meters of land in a single flight. Two aspects need to be considered when capturing MSI to acquire the best possible images. The first one is to set the camera to have a side and front image overlapping by at least 75%. It will ensure fulfilling the required coverage of image overlapping between neighbouring images in order to provide the necessary data for the photogrammetry software to extract positioning information. The second aspect is the representation of the width in each pixel of the ground area, also known as ground sampling distance (GSD) (Assmann et al., 2018). The lower the GSD, the more details and information can be obtained from the image. Flight height and speed, in addition to sensor size, resolution, focal length, and trigger rate, govern the two aspects of MSI (Assmann et al., 2018). MS sensors are spectroscopic devices which require spatial calibration to obtain reliable spectral information. It is a crucial step since light intensity, sensor capability and hardware used are possible variations that might alter the actual obtained results of the data if not calibrated. In MS remote sensing, the calibration can be done prior to, after or during the flight to obtain the optimal lighting conditions of the captured images (Assmann et al., 2018). The Parrot Sequoia sunshine sensor, positioned on the upper part of the device, is an example of a spectral sensor which allows radiometric calibration of images (Gowravaram et al., 2018). It captures band wavelengths at green (530-570 nm), red (640-680 nm), red-edge (730-740 nm), and NIR (770-810 NM) (Assmann et al., 2018). Furthermore, it converts the digital number (DN) received by the sensor to absolute surface reflectance values using the calibration coefficient on reflectance targets representing a pixel in a known reflectance area (Assmann et al., 2018).

Regarding its photogrammetry application, MSI can be used to create a reflectance map of a selected area. A reflectance map is an orthomosaic monochromatic image, where each pixel on it is radiometrically calibrated, contains surface reflectance values ranging from 0 to 1, and shows a different amount of light and similar hue in a specific spectral band. It can calculate vegetation indices maps and extract the values of each pixel. An example of a vegetation index is the normalised difference vegetation index (NDVI), which is calculated using the spectral reflectance values corresponding to the calibrated near-infrared (NIR) and red spectral bands (Gowravaram et al., 2018). NDVI is a graphical indicator widely used in agriculture, biology, and other geosciences for monitoring vegetation and ecosystems (Baluja et al., 2012; Assmann et al., 2018; Gowravaram et al., 2018; Casamitjana et al., 2020). NDVI provides valuable information on vegetation vigour and

biomass, and its values always lie between -1 and 1 (Fuentes-Peailillo et al., 2018). It is calculated using the following equation:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Equation 1 where NIR is the calibrated wavelength value of the near-infrared spectral band and RED is the calibrated wavelength value of the red spectral band captured from a MSI.

There are seven classifications of urban cover according to NDVI values which are described in the following table (Korchagina et al., 2020).

Class	NDVI Range
Artificial materials (concrete, asphalt)	-0.5
Water	From -0.42 to -0.33
Snow, ice, dust, rocks	From -0.1 to 0.1
Clouds	0
Open soil	From 0.025 to 0.2
Sparse vegetation (shrubs, pastures)	From 0.2 to 0.5
High, dense vegetation (forest)	From 0.7 to 1

Table 1 The classification of urban covering according to NDVI values (Korchagina et al., 2020).

2.1.5 Hyperspectral Sensor

The originality of using HSI falls in the field of Earth science. HSI consists of hundreds of narrow (5-10 nm) and contiguous bands for each spatial sample that covers the entire reflected solar spectrum (0.4– 2.45 µm) (Campbell and Wynne, 2011). It aims to obtain an improved spectral resolution of a particular target of interest. The electromagnetic energy hits a pixel in the detector and generates a voltage which is measured and transformed into a Digital Number (DN), which ultimately converts to spectral radiance units via spectral calibration coefficients (Leblanc, Kalacska and Soffer, 2014). Based on its reliance on reflected light for its sensor readings, HSI only provides surface information without penetrating the ground. To reduce the dimensionality of HSI and choose the appropriate wavelengths for analysis is a process known as band selection (Dozal et al., 2018). Covering and

capturing the entire solar spectrum has drawbacks when considering HSI because it uses extensive capital and labour resources (Leblanc, Kalacska and Soffer, 2014).

Meanwhile, the application of hyperspectral image analysis when processed using photogrammetry software varies from anomaly detection, detecting of buried remains, plant monitoring and soil matrix analysis (Chein and Shao-Shan, 2002; Kalacska et al., 2009; Leblanc, Kalacska and Soffer, 2014; Dozal et al., 2018; Pádua et al., 2018; Silván-Cárdenas et al., 2021).

2.1.6 Thermal sensor

Thermal imaging is available in both airborne and ground-based configurations. It captures thermal emissions from a specific target and its reflected wavelength without needing visible light (DesMarais, 2014). The technology is site-specific in that elements such as soil moisture, solar intensity and heat transfer coefficients control its effectiveness (Davenport, 2001). It focuses on the heat difference between the target and its surroundings. The technology is helpful in specific contexts, such as clear weather conditions to obtain optimal results. However, misinterpreting results can play a significant role when using this technology in areas with similar thermal properties.

The outcome of capturing thermal images when processed using photogrammetry software has various applications. It has been extensively used in many fields, such as archaeology, in locating historic site remains (Casana et al., 2014). Furthermore, law enforcement and the military use this technology in their security and surveillance operations to identify and destroy hostile targets (Davenport, 2001). Moreover, it can be used to search for decomposition remains, estimate the water status of plants and detects cadaveric remains (Cohen et al., 2011; DesMarais, 2014; Butters et al., 2021).

2.2 UAV Photogrammetry

According to Aber, Marzolf and Ries (2010, p. 23), *photogrammetry* is "...the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena". Consequently, mapping an area using images captured by a UAV is known as UAV photogrammetry (Saifizi et al., 2020). UAV photogrammetry is a rapidly expanding field in close-range photogrammetry and has diverse applications in geomatics, construction, agriculture, disaster management, mining, infrastructure inspection and real estate (Saifizi et al., 2020). It entails utilising UAVs equipped with cameras to capture images of a specific area and then subsequently process them to map the area and turn 2D photos into 3D models

using a photogrammetry software package (such as Pix4mapper or Agisoft PhotoScan). Through this process, it can also generate orthomosaic maps and digital elevation models (DEMs) (Agüera-Vega, Carvajal-Ramírez and Martínez-Carricondo, 2017). An orthomosaic map is a large image with great detail and resolution made from combining many overlapping orthophotographs to construct drone-based reflectance maps of an area of interest. Meanwhile, the orthophotograph is an aerial photo that has been geometrically corrected for lens distortion, camera tilt, perspective, topographic relief and can be handled as a map (Booyesen et al., 2021). The advantages of UAV photogrammetry encompass its capacity to obtain high-resolution data with excellent spatial and temporal resolutions, accessibility and lower costs in comparison to traditional photogrammetry techniques.

2.2.1 Image acquisition and processing

UAV image acquisition is a valuable technique that enables the efficient and cost-effective collection of aerial imagery. It can be captured either manually (while flying the UAV) or automatically (using photogrammetry software such as Pix4Dcapture). Pix4Dcapture is available to download free of charge and allows UAV flight planning for optimal area mapping and modelling. It is widely used in photogrammetry since it is compatible with the leading manufacturers of commercially available UAVs, such as Parrot and DJI. Also, it allows variability in choosing from different flight missions according to the operation needs. Whether it is a two-dimensional (2D) project or a three-dimensional (3D) project, the software can fulfil the requirements using the various flight mission options: Polygon (2D), Grid (2D), Double Grid (3D), and Circular (3D). In addition, the ability to customise each flight setting (the size of the mission, angle of the camera, image frontal and side overlaps, UAV speed, flight height, and the type of images captured, whether it is RGB, thermal, or multispectral) makes such software extensively used to plan flight missions and capture UAV images (Pix4D, 2022a). The image processing steps vary depending on the sensor type and software used. Figure 2 outlines the steps when processing Parrot Sequoia data with Pix4Dmapper.

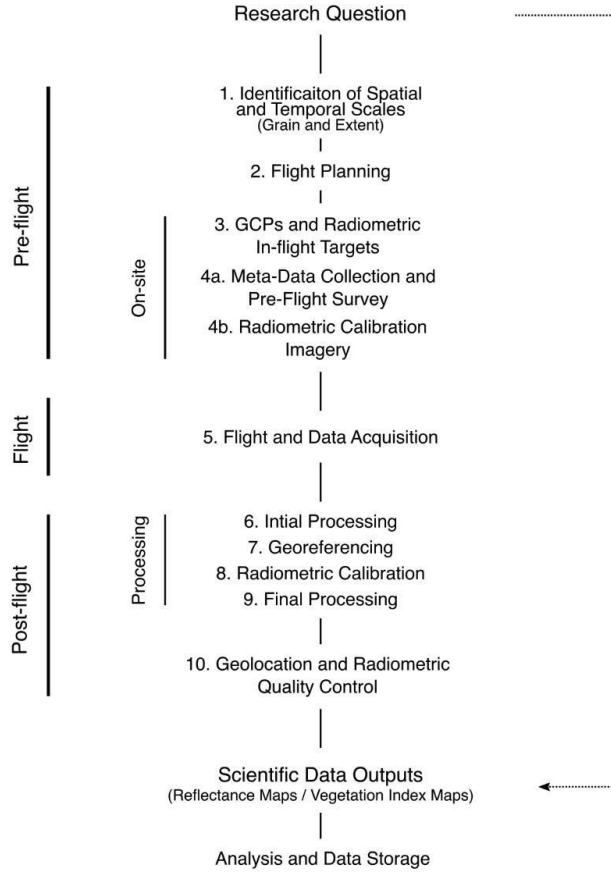


Figure 2 Overview of the proposed workflow for scientific data collection using multispectral drone sensors. The image is taken from (Assmann et al., 2018).

The initial step constructs a preliminary model of the surveyed area using structure-from-motion (SfM) algorithms. SfM is a computational technique that employs the relative position of pixels from overlapping images of a scene taken from various angles to construct 3D models and composite orthomosaic images (Assmann et al., 2018). Afterwards, ground control points (GCPs) are manually introduced in the georeferencing step to improve the precision of camera position and lens model parameters. A radiometric calibration follows that to convert at-sensor radiance (in the form of digital numbers (DNs)) to radiance values and subsequently reflectance values to overcome any differences in the ambient light of the captured images (Assmann et al., 2018). Finally, these inputs are integrated by the software in a final processing step resulting in the generation of the reflectance map and vegetation index map output.

2.2.2 UAV Image Calibration

In order to obtain robust results from MSI, a radiometric calibration of the images captured is

required. The calibration requires an image taken off the reflectance calibration target, immediately before or after each flight or during the flight, and a UAV equipped with a spectrometer and sunshine dual sensors. Consequently, the effect of the sun angle and illumination conditions is eliminated, and an absolute reflectance value is obtained (Assmann et al., 2018; Gowravaram et al., 2018). A simplified flow of the calibration process of an image captured using a UAV equipped with Sequoia, a multispectral sensor, is illustrated in Figure 3:

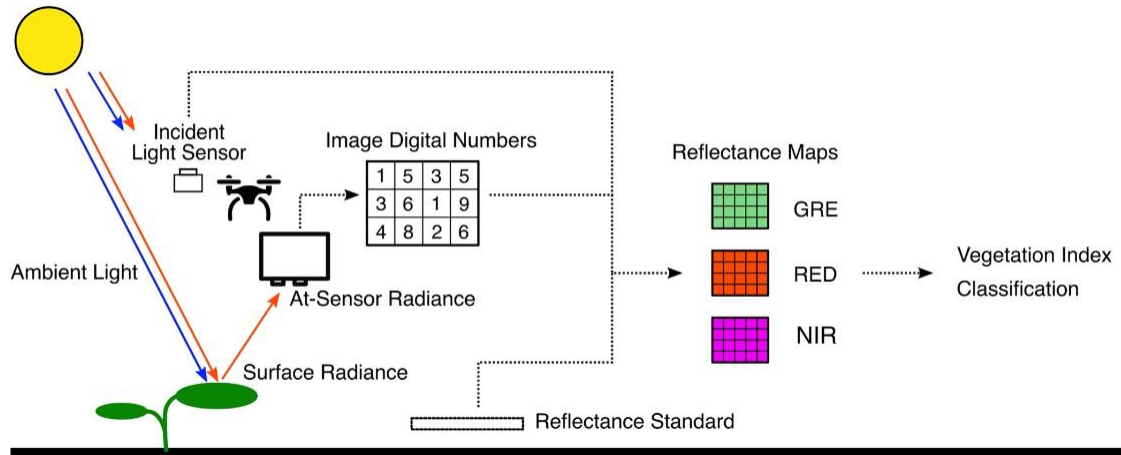


Figure 3 The workflow of calibrating MSI captured using the Sequoia multispectral sensor to generate a reflectance map. The image is taken from (Assmann et al., 2018).

To further illustrate the process, as the light hits an object on a surface, a radiance is reflected in the radiance sensor attached beneath the drone and each band reflected from the object is saved as a digital number (DN) in an image file. Afterwards, using an image captured from the calibration target right before or after the flight to match the weather and lighting conditions to the ones during the flight, those DNs are calibrated into reflectance maps using photogrammetry software for UAV mapping (such as Pix4DMapper). Finally, the calibrated spectral bands can be used to calculate vegetation indices or as direct inputs for classification.

The utilisation of UAV photogrammetry has been observed in various applications such the measuring of coordinates, quantification of distances, heights, areas and volumes. Moreover, it is used in generating orthophotographs, DEM, topographic and reflectance maps (such as thermal and NDVI maps) (Aber, Marzolff and Ries, 2010).

2.3 Clandestine Human Burials Detection

This section illustrates the methods used to detect and locate clandestine human burials. Information regarding clandestine graves relies on eyewitness testimony, which is considered the critical element

in locating them (Bor, 2018; Wright, 2010). Current practice in forensic archaeology suggests a phased approach in detecting burials in which the search moves from large-scale (macro-scale) remote sensing methods (Kalacska et al., 2009) to the application of medium-range geophysical technology (Pringle et al., 2012a) and, finally, a ground search (micro-scale) for a specific and defined area of interest (Skinner, Alempijevic and Djuric-Srejic, 2003). Recent advancements in remote sensing technologies and terrestrial survey techniques have enabled the transition from macro to micro scale analysis. Since each technique detects different properties in the material being examined, the use of multiple complementary methods is often required (Abate et al., 2019).

2.3.1 Remote Sensing

Remote sensing is considered the initial step in the search process, moving from a macro- to a micro-scale. One of the early uses of remote sensing in detecting and identifying burial sites was during the investigations for the International Criminal Tribunal for the former Yugoslavia (ICTY) when aerial and satellite images from the US government helped search for clandestine graves (Blau et al., 2018). The advantage of remote sensing technology lies in its non-invasive nature that covers a large area of interest in a short amount of time with minimal human and non-human resources (Blau et al., 2018). Different methods are available and have been previously used to assist the search for clandestine graves, which will be elaborated on in the following sections. The various photogrammetry software used in the current research to capture and process images of the research area will be discussed in Chapter 3 section 3.3.2.

The main objective of remote sensing is not to find the buried bodies; instead, it helps narrow down the search area of a burial site. It is used to interpret surface anomalies that might indicate a suspected burial site. Forensic archaeology techniques, such as trenching and probing methods, are then used to confirm the existence of any buried bodies (Haglund and Sorg, 2002). For optimal results, combining different techniques of remote sensing improves the success rate in detecting and identifying clandestine graves. However, each scenario is case-specific, and the techniques that might show a success rate of identification in one case might not be helpful in another.

2.3.1.1 Aerial Photography (RGB images)

Soil disturbance, vegetation changes and on-ground anomalies are some features an archaeologist needs to look for when interpreting aerial photography (Ruffell and McKinley, 2014). Comparing recently captured images to historical photographs of the same site can help identify potential

gravesite locations and their occurrence time (Pringle et al., 2012a). An essential consideration here is the location and the time of the day when capturing the image and the angle at which the sunlight hits the ground and casts a shadow on the landscape. Non-vegetated and open landscapes with no ground obstacles are always preferable when looking for clandestine graves compared to heavily vegetated lands (Murray et al., 2018). RGB sensors mounted on UAVs are considered very useful for monitoring topographic changes and locating soil disturbances related to burial sites (Silván-Cárdenas et al., 2021). Combining RGB imaging with image processing tools has successfully detected burial sites using different heights (Urbanová et al., 2017; Murray et al., 2018; Parrott et al., 2019). It proved that processing captured images from a low-cost UAV using just a laptop and MATLAB (a programming platform) can aid the detection of disturbed soil sites indicative of fresh clandestine graves, limit unnecessary footfall and minimise crime scene alteration (Parrott et al., 2019). Also, previously published literature proved the effectiveness of using the digital terrain model (DTM) and digital surface model (DSM) in detecting clandestine graves by identifying surface outliers related to grave mounds (Somma et al., 2018; Rocke, Ruffell and Donnelly, 2021). Such an approach successfully detected the outliers related to grave mounds of an adult and a child grave, hence being successful in large and small grave scenarios (Rocke, Ruffell and Donnelly, 2021). Moreover, in search areas where a recent grave is exposed to aerial viewing, the analysis of the landscape by means of high-resolution RGB aerial imagery and DTMs may be sufficient for search purposes; by contrast, if a burial is covered by the tree canopy, DTM and DSM viewshed analyses may be successful, as it is impossible to detect a burial with only high-resolution RGB aerial imagery (Somma et al., 2018). A limitation of RGB imaging is that the images are captured in three spectral bands, limiting the retrieval of the amount of information from those images (Silván-Cárdenas et al., 2017).

2.3.1.2 Multispectral Imaging

The use of MSI for detecting burial sites becomes very useful when combined with witness testimony to search a suspected area which might contain a burial site. That is because MSI records the spectral bands in specific multiple channels. On the contrary, the regular RGB camera lacks the sensitivity of MSI and records broad range spectral bands. Hence, MSI is considered a beneficial spectral imaging sensor to expose surface anomalies using different light reflectance sources invisible and unidentifiable to the human eye. Multispectral and hyperspectral imaging has shown its effectiveness in detecting buried remains using various animal remains such as cattle (Kalacska and

Bell, 2006; Kalacska et al., 2009), pigs (Leblanc, Kalacska and Soffer, 2014; Silván-Cárdenas et al., 2017), and rabbits (Ruotsala, 2016). However, its application to human remains has been less frequent (Blau et al., 2018; Corcoran et al., 2018). Sobotkova and Ross (2010) used MSI to identify burial mounds and subsurface remains that represent permanent settlements built from durable materials in Bulgaria and Italy. In both locations, archival multispectral satellite images available online were used (with 2.4 m spectral resolution for the site in Italy and 4 m spectral resolution for the site in Bulgaria). Several factors governed the successful approach of using MSI in both locations, such as the clear sky, open landscape and the nondeceptive geology of the area (Sobotkova and Ross, 2010). Additionally, detecting clandestine burials using their effects on vegetation using different vegetation indices has also been proven effective on numerous occasions (Assmann et al., 2018; Silván-Cárdenas et al., 2021; Rocke and Ruffell, 2022). Accurately quantifying and accounting for familiar sources of error and variation in multispectral data collection, such as radiometrically calibrating the sensor and flying the UAV in a clear sky, are among the factors that induced the success rate of using vegetation indices to detect burial sites (Assmann et al., 2018). Normalised difference vegetation index (NDVI) aided the analysis by distinguishing any anomaly in the captured images and identifying the suspected cause of this anomaly and the time it happened for both 16-year-old and recent graves (Rocke, Ruffell and Donnelly, 2021). MSI is very beneficial if the bands of interest are known. If not, then HSI would be a better instrument to use since it gathers a greater number of spectral bands.

2.3.1.3 Hyperspectral Imaging

The use of hyperspectral imaging (HSI) gained popularity in forensic science in various applications such as trace evidence analysis, bloodstain ageing, chemical identification, document analysis and artwork analysis (Leblanc, Kalacska and Soffer, 2014). Introducing HSI to the field of forensic science to detect burial sites showed promising results in many case studies. Kalacska and Bell (2006) proved the effectiveness of using HSI captured from a satellite with a spatial resolution of 15 m in the visible bands and 30 m in the short-wave infrared in identifying the location of the grave in Guatemala. The results from a study done in Costa Rica demonstrated that the reflectance spectra of the grave are readily distinguished from soil disturbance (i.e., false grave) for 16 months when HSI is used, with the optimal region for differentiating the spectra being the near-infrared plateau above 700 nm and between 550-700 nm (Kalacska et al., 2009). Another approach of using the HSI, which was also successful in detecting single graves, is to measure the relative distribution of hydroxyl (OH-)

ion that has a diagnostic absorption in the reflectance data at 2200 nm, which is indicative of the presence of clay which is expected to be shown on the surface of the grave (Leblanc, Kalacska and Soffer, 2014). In Mexico, the results from analysing the HSI indicated that such technology could succeed only after three months from burial, and the valuable wavelength intervals are mainly distributed along the spectral range of NIR (700-1000nm) and short-wave infrared 1 (SWIR1) (1001-1800 nm (Silván-Cárdenas et al., 2017). Actual graves could be distinguished from control graves (or false ones) using this technology, showing potential in the detectability of buried remains using HSI. The prime time for image acquisition is three months post-burial, and the best spectral bands to use are those that respond to the vegetation and the water content of the plants (Dozal et al., 2018). HSI usually comes with hardware calibration, correction, and processing challenges. It is also considered among the most expensive commercially available UAVs, with a market price of £36000 (Murray et al., 2018). Hence, a solid background in processing the obtained results and the available funding to purchase such UAV governs the feasibility of HSI to detect buried remains. Although some of the relevant spectral intervals are considered wide enough to be measured using MSI, it cannot substitute the use of HSI. This is true since the use of HSI is accompanied with the benefit of having several narrow intervals which favours the use of this technology over MSI (Silván- Cárdenas et al., 2017).

2.3.1.4 Thermal Imaging

Many UAVs with thermal sensors can detect evidence outside the range of human vision (Murray et al., 2018). The optimum time for conducting this type of imaging is when the temperature variance between the burial site and its surroundings is detectable. This occurs during sunrise and sunset in extremely hot weather conditions, or during the day or night in cooler weather conditions. This is true because the temperature of the surrounding environment would be lower than the grave containing the decomposed body, which produces heat that is easily captured at that time (Pringle et al., 2012b). Although this will be influenced by the local geology, groundwater level and soil type (Pringle et al., 2012b). This showed effectiveness only in the first month while the grave still produced decomposition heat (Bodnar et. al, 2019; Butters et. al, 2021). More specifically, flights taking place from day 6 to day 29 were most effective for identifying temperature differences between the burial site and its surroundings (Bodnar et. al, 2019). Another study showed that buried human bodies at a depth of 1.2 and 0.6 m began heating after four and two weeks, respectively (Johnson, Mikac and Wallman, 2013). Moreover, a study showed that during the decomposition process, the body temperature peak was captured two weeks post-burial (Amendt et al., 2017). Furthermore, previous

studies showed that large graves are more prone to show temperature variations than their surroundings compared to smaller single graves (Servello, 2010; Silván-Cárdenas et al., 2021).

Upon the completion of the decomposition process, the remaining bones will not generate any heat making this method only suitable for recent shallow fresh graves (DesMarais, 2014). This process can sometimes take 21 days (Lee et al., 2018) and, in other cases, can take up to nine months post-burial, depending on various factors such as the environment and the depth of the grave (Blau et al., 2018). The detection of heat difference between the graves and their surroundings is heavily dependent on the time since burial, the temperature differential between the remains and the adjacent soil, the size of the remains and the ability of the viewer to distinguish contrast in the image, which is dependent on adequate image resolution (Butters et. al, 2021). The use of thermal cameras may alert the search units of possible gravesites from the field thermal indications, which requires further on-foot confirmation.

2.3.1.5 Light Detection and Ranging (LiDAR)

LiDAR uses an active sensor remote sensing technology that emits its energy source to the target of interest to measure the distance to the earth and generate three-dimensional information about its shape and surface characteristics. Although it is outside the scope of this research, LiDAR has shown its efficiency in detecting and measuring localised elevation changes at human grave surfaces (Corcoran et al., 2018) and in distinguishing and identifying anomalies related to five out of the six human graves when compared to the undisturbed natural surrounding 16 months following interment (Blau et al., 2018). The use of a UAV coupled with a LiDAR sensor assists in the finding of clandestine graves and their related soil disturbance.

2.3.2 Geophysical Techniques

Over the years, geophysical methods have aided forensic search teams with their civil and criminal investigations (Ruffell and McKinley, 2005; Pringle et al., 2012a; Ruffell and McKinley, 2014; Fernández-Álvarez et al., 2016; Abate et al., 2019; Pringle et al., 2020). Geophysical methods are sensitive to noise and interference caused by cultural features, geological conditions, and solar activity (Davenport, 2001). Schultz (2007) and Abate et al. (2019) found that geophysical methods are not designed to provide an indefinite location of the grave or identify a body per se. Instead, such methods detect differences and anomalies inconsistent with undisturbed natural strata, such as variations in soil strata and human interventions.

2.3.2.1 Ground Penetration Radar

Widespread use of ground-penetrating radar (GPR) for archaeological purposes began in the early 1990s. GPR sends an energy pulse into the ground and records the reflections of subsurface features (Barone and Di Maggio, 2019). Multiple reflections from different depths can be distinguished by their time delay after the initial pulse. Thus, features buried deeper than other features in the ground will return echoes later than surface features. Uneven or disturbed surfaces can also produce reflections that indicate the presence of buried features. GPR has been used to detect graves and artefacts buried beneath the surface of the ground. A limitation of GPR is that it can only detect relatively shallow features. Graves less than 1.5 m deep can often be detected, but graves deeper than this may not be detectable.

Conducting a GPR survey over an archaeological site involves setting up a stationary antenna to transmit energy pulses into the ground. Each transmitter-receiver pair is set up at regular intervals across the surveyed area. The antennas are usually placed on 1-meter centres, although this spacing can be decreased for narrow areas or increased for vast areas. A recorder is used to record the strength and time of the reflections.

2.3.2.2 Electrical Resistivity

Electrical resistivity surveys are generally conducted using a borehole electrode array (Loke et al., 2020). Several electrodes are inserted into a borehole that has been drilled in the area of interest. The electrodes are spaced at regular intervals, and an electric current is injected into the ground through the electrodes. A recorder is used to measure the induced voltage on the ground surface between each pair of electrodes and measure how electricity flows through material. The data are then processed to produce a map of the resistivity of the subsurface (Loke et al., 2020). Electrical resistivity surveys can be used to detect buried bodies. Soils with high organic matter content (e.g., soils rich in decayed plant material) have low resistivity, while soils with little organic matter content have high resistivity. In addition, the presence of tissues and bones buried in the ground increase the local concentration of electrons. These conditions can result in electron migration within an affected area, which would produce a measurable change in the electrical resistivity of the soil. Hence, when an electrical current is passed through the soil, disturbances in the current flow indicate the presence of a potential burial (Pringle et al., 2020).

2.3.2.3 Magnetometry

Frequently used to detect the presence of graves and burial features in cemeteries, magnetometry detects changes in the magnetic field of the earth resulting from variations in soil chemistry associated with buried human remains (Buck, 2003). Magnetometers can also map underground drainage systems, locate subsurface utilities (e.g., water and sewer lines), and identify buried metallic objects. However, fences, metal grave markers and other metallic objects can produce erroneous readings, so care must be taken to avoid these features when conducting a magnetometry survey (Buck, 2003). A magnetometer is a device that measures the magnetic field of the earth. It consists of a sensor and a display or recorder. The sensor is usually in the form of a loop of wire suspended from a frame to maintain a constant distance from the ground. The magnetic field strength is displayed as an intensity reading on the recorder or as a voltage on display. The strength of the magnetic field decreases with increasing distance from the source. Mapping the variation in intensity or voltage over an area will reveal variations caused by buried features, which can then be correlated to specific sites.

2.3.3 On-Ground Search

Moving from the macro-scale to the micro-scale grave detection method, the terrestrial survey is usually preceded by a foot search (Abate et al., 2019). Different approaches can be made in this process depending on the area of interest and topography. Whether or not there are any natural barriers, the search team designs a search plan. In this phase, minimal unsophisticated equipment, such as a probe rod to test the soil, a shovel to dig any suspected shallow graves and a stick to move the vegetation for a better look at the area, are used. It may require increased human resources, depending on the area of interest and the timeframe for completing the mission.

2.3.3.1 Visual Foot Searches

In this search method, the team responsible for the on-ground search use nonintrusive techniques to locate human remains or various types of forensic evidence. Search team members are usually equipped with little more than a stick when conducting the search (Dupras et al., 2011). Foul odours, flies and other indicators of decomposition can help locate a body, but these are not always present. The greatest challenge faced by on-foot searchers is their inability to cover a large area quickly. Therefore, narrowing the search area is essential; hence, when searching large areas, it is usually divided into smaller zones, and a search pattern is chosen depending on the search area. Different

patterns are available; however, the three most effective patterns for visually searching the surface of an area on foot are a strip (or line) pattern, a grid pattern, and a spiral pattern (Dupras et al., 2011). Figure 4 illustrates the different types of pattern searches:

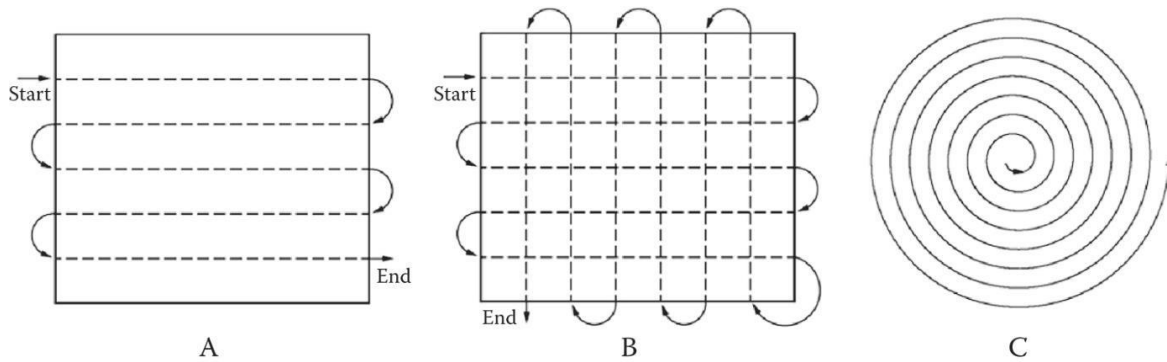


Figure 4 Search patterns: a) line or strip search, b) grid search, and c) spiral search. The image is taken from (Dupras et al., 2011).

If performed correctly in an open and unobstructed area, the strip (or line) pattern provides 100% coverage of the area of interest (Dupras et al., 2011). Search team members line up in a straight line, an arm's length away from each other, overlapping their fields of view. At a steady and controlled pace, the team members are constantly examining their surroundings and looking for clues that might lead them to a body, like soil disturbance, clothing, or personal belongings. A forensic anthropologist usually follows behind the line, examines any suspected finds that the searchers think might be a bone fragment, and confirms if it is human. However, the grid pattern searches the area of interest twice using two perpendicular strips (or lines) patterns for a 200% coverage. It is advantageous in uneven terrain, heavy bush or ground cover where it is not easy to examine the ground from one angle. Lastly, a spiral pattern works best when the searching area is small or on a hill, moving in decreasing or increasing concentric circles if the primary deposition site is known (Dupras et al., 2011).

2.3.3.2 Probing

Following the systematic foot search using one of the pattern search methods, probing is introduced to locate a clandestine grave and outline it. Bodies buried in shallow graves can often be located by pushing a pointed metal or fibreglass rod into the ground at regular intervals. It is used to identify the difference in the density of subsurface materials, where undisturbed areas will have a more rigid surface and will be harder to penetrate using the probe (Dupras et al., 2011). Locating a body through

probing is a slow process and can be problematic in areas with dense vegetation or rocky terrain. The most significant advantage of probing is that it does not require any special equipment, which is usually done using a metal rod. However, it can be challenging since successfully identifying a grave using probing can mistakenly be mixed with animal burrows, roots, and other natural features.

2.3.3.3 Cadaver dogs

Cadaver dogs are specially trained to assist in locating human cadavers by detecting the decomposition odour coming from them or their associated body parts and fluids (Dupras et al., 2011). Whenever cadaver dogs detect the odour of decomposing bodies, they indicate this to their handlers with a combination of signals, such as sitting down or scratching at the ground (Martin, Diederich and Verheggen, 2020). Pungent odours associated with decomposition also increase the likelihood that cadaver-sniffing dogs will be successful. A cadaver dog is not necessarily accurate in locating the exact spot of the buried body due to weather conditions such as high winds or heavy rains, which can interfere with the ability of the dog to detect a body (Dupras et al., 2011). Hence, searching the area where the cadaver dog has indicated is essential.

As with any other tool used in the search for human remains, cadaver dogs are not without drawbacks. The dogs may be led astray by other scents, such as decomposing animal carcasses (Dorriety, 2007). Dogs must be handled with care, and their handlers must be aware of the potential stress caused by working in such conditions. The effectiveness of a cadaver dog is ultimately limited by its training, handler and the conditions in which it works. Hasty or unfocused searches conducted by handlers who do not understand the limitations of cadaver dogs are likely to be unsuccessful (Dorriety, 2007).

2.4 Human Rights Violations and Laws Related to Mass Graves

Throughout the years, several authors and organisations have defined mass graves in various aspects depending on the interest of the author. Many defined it using the number of bodies buried (Mant, 1987; Skinner, 1987; Schabas, 2006), some by how the victims died (Haglund, Connor and Scott, 2001; Schabas, 2006), and others by the way the bodies are laid in the ground and whether or not there is a contact between the bodies (Mant, 1987; Haglund, Connor and Scott, 2001). Mass graves can emerge following the death of many people due to a ravaging pandemic, natural disasters or armed conflicts. For instance, 19733 mass graves spread over 388 sites were found in Cambodia, and over 2000 have been connected to the Spanish Civil war (Callamard, 2019). In addition, in April

2020, authorities in Rwanda discovered a valley dam that possibly could contain about 30000 bodies, of which 100 bodies may have been exhumed and were part of the 1994 Rwandan genocide (Pulla and Kalinganire, 2021).

Around the world, many populations have suffered from human rights violations throughout history. There are different types of human rights violations, and in this chapter, the focus is on the victims of crimes against international humanitarian law (IHL), international human rights law, and international criminal law (ICL). Specifically, cases related to victims buried in unmarked clandestine mass graves will be illustrated and discussed, covering all the measures followed against such human rights violation. Moreover, the role of a forensic investigation into mass graves and how to prove the occurrence of a human rights violation will be discussed in the following sections.

2.4.1 International Humanitarian Law

“International humanitarian law—also known as the law of war or the law of armed conflict— seeks to limit the effects of armed conflict by protecting persons who are not or no longer participating in the hostilities and restricting the means and methods of warfare” (Manual on human rights monitoring, 2001, p.12). It applies in situations of armed conflict. On 24 June 1859, in the aftermath of the battle of Solferino, Henry Dunant suggested establishing an organisation to help the wounded military personnel on the battlefield and guarantee their protection. The organisation he suggested was established in 1863 in Geneva and was called the International Committee of the Red Cross (ICRC), and his second suggestion was agreed upon and signed in 1864, which later marked the first Geneva Convention (Gasser, 1998). The three suggestions were as followed:

1. "That Governments should extend their patronage to Relief Committees which may be formed, and facilitate as far as possible the accomplishment of their tasks;
2. That in time of war the belligerent nations should proclaim the neutrality of ambulances and military hospitals, and that neutrality should likewise be recognized, fully and absolutely, in respect of official medical personnel, voluntary medical personnel, inhabitants of the country who go to the relief of the wounded, and the wounded themselves;
3. That a uniform distinctive sign be recognized for the Medical Corps of all armies, or at least for all persons of the same army belonging to this Service; and that a uniform flag also be adopted in all countries for ambulances and hospitals. " (Bugnion, 2012, p.1320)

Since 1949, the four Geneva Conventions, which construct what is known as Geneva Law, seek the legal protection of vulnerable armed forces and civilians which no longer act as a threat. The four Conventions are: on the care of the wounded and sick members of armed forces in the field, on the care of the wounded, sick and shipwrecked members of armed forces at sea, on the treatment of prisoners of war (POWs), and the protection of civilians in time of war.

War causes much destruction to society, the economy and the environment. Moreover, it is unfortunate that losing lives and capturing prisoners is unlikely to be avoided at war. Hence, many IHLs have been established to safeguard the rights of POWs. If any violation of these laws occurs, it is necessary to ensure that truth and justice are pursued. The 2006 Basic Principles of the United Nations (UN) obliged member States to provide any human rights violations which may have resulted in mass graves (Klinkner, 2017). Chapter XI from the 1949 Geneva Convention IV demands the proper burial of the deceased internees in a single marked grave unless the necessity of the graves was unavoidable. It also emphasises producing a death certificate for the deceased prisoners by a doctor showing the cause of death.

During armed conflicts, various organizations address issues related to the conflict using IHL. Since its establishment, IHL has been the frontline defence to all wounded and POWs. It tries to eliminate any human rights violations that might occur during an armed conflict. War is a horrible and out-of-control event that sadly occurs in the world. However, respecting and enforcing such laws among all states adds value to human life and protects their basic living needs. Following armed conflicts, the states involved have the right to know the truth about their civilian and armed prisoners and their fate. Whether they are still alive, buried in marked graves, or buried in unmarked clandestine mass graves.

2.4.2 International human rights law

“International human rights law lays down the obligations of governments to act in certain ways or to refrain from certain acts, in order to promote and protect human rights and fundamental freedoms of individuals or groups”. (United Nations, 2018). The United Nations Human Rights Council enforces International Human Rights Law all over the globe. The Universal Declaration of Human Rights (UDHR) is an essential document in human rights history as it outlines fundamental human rights protected universally. The document contains 30 articles detailing basic rights and fundamental freedoms every human should enjoy. Furthermore, it stipulates that every human being has achieved a common standard, thus, recognising that all beings are born free and equal in dignity and rights (Lattimer, 2018). This aspect is not dependent on any form of status, such as nationality, gender,

ethnicity, colour, or religion. As earlier stated, human dignity is the nature of a human being, and it became a modus of human existence, differentiating humans from other biological species. This means humans have a special right naturally earned due to their humanity. It is worth noting that human dignity does not end when one dies. Therefore, dead people have rights that require them to be treated with dignity (Matheson, 2017). Thus, corpses should be treated and disposed of with respect, meaning that the body should be kept in an environment that preserves it until it is buried or cremated. International human rights law states that the process from the death to the burial of an individual should promote human dignity and respect. The establishment of mass graves violates people's 'last rights' of dignified treatment of the lifeless body (Callamard, 2019). Geneva Conventions stipulate that the dead should be buried individually so long as the circumstances permit. Unmarked gravesites must also be protected to avoid disturbing the dead by excavating and destroying the grave. Unfortunately, mass graves are often left unpreserved, unprotected, unacknowledged, and destroyed. This violates international human rights law, which emphasises that graves (including mass graves) should be maintained, respected, and marked to be recognised consistently (Callamard, 2019). Therefore, international human rights law is essential and plays a significant role in maintaining these mass grave sites and assuring that the deceased get the proper burial they deserve, regardless of the death circumstances.

2.4.3 International criminal law

“International criminal law is a branch of international law that recognizes certain categories of very serious acts (war crimes, crimes against humanity, genocide, aggression) as international crimes and assigns individual criminal responsibility to perpetrators of such acts” (Manual on human rights monitoring, 2001, p.17). The first international tribunal establishment dates to 1945, which dealt with the World War II mass atrocities and human rights violations (Freeman, 2018). The Rome Statute, adopted at a diplomatic conference in Rome, Italy on 17 July 1998 and it entered into force on 1 July 2002 with the establishment of the International Criminal Court (ICC), categorised those war violations into war crimes, crimes against humanity, the crime of aggression or an act of genocide (Gaggioli, 2018). Where those humanitarian laws are violated and crimes are committed, ICL structures the legal framework to serve justice. At the international level, the ICC at the Hauge investigates and, where warranted, tries individuals charged with the gravest crimes of concern to the internationally community (Gaggioli, 2018). The Rome Statute organises and structures the foundation of this legal practice (United Nations, 1998). Through independent prosecution, the ICC aims to offer fair trials where the right of the defendants is upheld, victim voices are heard, and participating victims and witnesses are protected. Examples of such cases were those against the leaders and military personnel of the Former Yugoslavia, Rwanda and Sierra Leone, whom they were

brought to justice, after committing the four core crimes of the ICC against their people (Schabas, 2006).

2.4.4 The role of forensic investigation

The WWII tribunal demonstrated the effectiveness of evidence in a court of law, which proved the guilt of the Nazis for their crimes against the Jewish population and several other groups (Freeman, 2018). The Nazis early IBM computers, military records and war photographs turned from military tools into strong evidence presented in court (Freeman, 2018). Scientifically proven forensic evidence is considered the key element in the reliability of the evidence in a court of law. It adds probative value to the evidence at trial. The use of satellite imagery as evidence against war crimes and human rights violations has already been admitted and proven effective in cases at the ICC, International Court of Justice (ICJ), International Criminal Tribunal for the Former Yugoslavia (ICTY), International Criminal Tribunal for Rwanda (ICTR) and the Permanent Court of Arbitration (PCA) at The Hague (Wang et al., 2013). The court conviction verdicts of ICTY and ICTR relied on scientific expert testimony from various disciplines, including, and not limited to, sociology, archaeology, anthropology, pathology and psychology, all of which are seeking the truth of the war crimes committed (Freeman, 2018). Latin America, the former Yugoslavia, and Spain all showed successful effectiveness of the role of forensic science in excavating mass graves (Blau et al., 2018).

Several non-governmental organisations (NGOs) have a dedicated team of scientists, mainly forensic anthropologists and forensic archaeologists, who undertake global investigations in the aftermath of political violence. The Argentine Forensic Anthropology Team (EAAF), the Guatemalan Forensic Anthropology Foundation (FAFG), International Commission of Missing Persons (ICMP), Inforce Foundation in the U.K., the forensic unit of the International Committee of the Red Cross, the Humanitarian and Human Rights Resources Center of the American Academy of Forensic Sciences and Physicians for Human Rights (PHR) are among those NGOs who seek human rights justice in armed conflicts (Steadman and Haglund, 2005; Ubelaker, Shamlou and Kunkle, 2019). The most famous team among them is the EAAF (Equipo Argentino de Antropología Forense), established in 1984 and has worked in over 37 countries on four continents (Ubelaker, 2018). The collaboration of such NGOs and government agencies has proven to be a successful tool in bringing justice to the countries which suffered from war conflicts and human rights violations.

2.4.5 Why locating body remains is important

Many parts of the world have undergone political, ethnic or religious violence, leading to countless

disappearances and deaths (Schabas, 2006). Locating and recovering the remains of those missing persons has social, humanitarian and legal importance. The social benefit aspect of locating the missing people, which might take decades, translates into clearing the ambiguity their families live in, not knowing the fate of their beloved ones. Only then will the family members get closure for their missing relative and reach inner peace with themselves. As time passes, and without disclosing any information concerning the POWs after a conflict between two countries, those POWs are usually presumed dead. The ICRC Rule 117 coded the importance of returning human remains after armed conflicts. The Rule states, “*Each party to the conflict must take all feasible measures to account for persons reported missing as a result of armed conflict and must provide their family members with any information it has on their fate.*” (ICRC, 1949). When recovering the remains of the missing people following the international standards documented in the revised Minnesota Protocol, it helps the prosecution team convicting war criminals and support a lawsuit in a court of law (United Nations Department of Political Affairs, 1991; Office of the United Nations High Commissioner for Human Rights, 2017).

2.4.6 Future direction

The effectiveness of detecting clandestine graves in various environmental conditions using UAVs coupled with remote sensing technology has been increasingly discussed and described in the published literature. It is clear that not only the expensive hyperspectral imaging techniques are efficient when detecting clandestine graves. Also, the inexpensive RGB, multispectral and thermal sensors were successful in such burial detection when analysed using different image processing software. Such imaging techniques present cost- and time-effective techniques that are feasible by most agencies concerned with locating clandestine graves worldwide.

As stated earlier, various arid environment countries suffered from armed conflicts that resulted in many clandestine graves. Some of those countries lack the human and financial resources, which are crucial elements in any search mission for those graves. Current techniques for locating clandestine graves used in such an environment consist of manual ground searches and random hole digging using a heavy equipment vehicle. Moreover, cadaver dogs are used if the graves are suspected to be dug recently. Nevertheless, these approaches have their limitations. Therefore, a humanitarian and legal obligation constitutes the necessity of further imposing new methods of detection techniques in such an environment, which can help bring closure for the family of the victims and bring justice by prosecuting whoever is involved in such a horrific crime. Accordingly, and similar to its use in

different environments, a potentially cost-effective alternative could involve utilising RGB, multispectral and thermal sensors deployed on an unmanned aerial vehicle to aid this process in such a rigid environment.

Arid regions pose a challenge for traditional grave detection methods when introducing such sensors due to the lack of vegetation cover and vast soil exposure (Blau et al., 2018). Those challenges arise since there is no vegetation cover difference in the area, which can be easily detected using vegetation indices that can ease the process of narrowing down the search area for possible burial sites (Rocke and Ruffell, 2022). Hence, successfully implementing such technology holds significant importance in introducing an enhanced, efficient, timesaving, accessible and non-invasive grave detection method.

Chapter 3 Material and Methods

3.1 Research area

Kuwait is a country located in the north-western corner of the Arabian Gulf in the Middle East. It is a country known for its arid environment and a temperature of 53.9 °C recorded in July 2016, was the highest recorded temperature in Asia and the third hottest temperature ever recorded in the world (Merlone et al., 2019). Nevertheless, the winter is short and warm, with temperatures ranging from 7 °C to 25 °C, with a mean annual rainfall of 115 mm, the majority of which falls between October and December (Aljassar and Rao, 2010). A measured 30 m x 30 m plot of land in Jahra Pools Nature Reserve, an 18 km² restricted nature reserve located at Jahra town in the north of Kuwait (29.3621° N, 47.6931° E), was used for the research. An official permit was granted from the Environment Public Authority, a government authority responsible for managing the nature reserve (Appendix C). The site consists of dry, rough, uniform soil with no vegetation cover. This site was chosen following the description of (Schuldenrein et al., 2017) of mass grave location and features such as being remote with minimal susceptibility to degradation, erosion, and exposure. A location with these characteristics resembles the landscape of previously excavated mass graves from the Gulf War. An essential factor in post-burial image analysis is the undisturbed topography of the enclosed area prior to the research. The research area was fenced to ground level. Usually, when fencing an area to secure it from any animal intrusion, the fence is dug below ground level. However, for the purpose of this research, the fence was only set at ground level without digging it below that. This was done to avoid human intrusion while keeping the scavenger element in place. Hence, the experiment contributes to all the natural factors in the real world.

3.2 The graves and animals used

Pigs have always been the first choice as an analogue to humans when conducting a forensic experiment as they possess similar chemical composition, size, tissue-to-body fat ratios, and skin/hair type to humans (Pringle et al., 2012a). However, pigs are not available in Kuwait due to religious reasons. Various mammals, besides pigs, have been previously introduced as human analogues when conducting such experiments (Catts and Goff, 1992; Teo et al., 2013; Matuszewski et al., 2020; Kislov et al., 2022). For this research, sheep were chosen as analogues to humans for various reasons. The first one was the price of the carcasses. The average cost of the sheep was within the

available budget for purchasing the human analogue. The second reason was the weight of the sheep, which falls within the recommended carcass weight for experimental studies when a human analogue is used and within the average weight of an adult human torso of 22 to 35 kg (E P Catts and Goff, 1992; Kalacska et al., 2009; DesMarais, 2014). Lastly, the sheep blood matches the tissue properties of the human blood (Kislov et al., 2022). Hence, ten freshly slaughtered and skinned sheep were purchased from a local slaughterhouse. The internal organs of the sheep were kept intact, and each sheep was separately wrapped in a plastic bag and transferred to the research area to get buried. An ethical approval was obtained for the use of the animals which was mentioned in Chapter 1 section 1.4. The average weight of the sheep was 32 kg.

A total of six graves were simulated for the purpose of the present research. All graves were at least 5 m apart to avoid cross-contamination or interference from the decomposition fluids of the buried animals (Teo et al., 2013, p.78). Figure 5 shows an overview image taken by the UAV using the 4K RGB sensor one day post-burial.

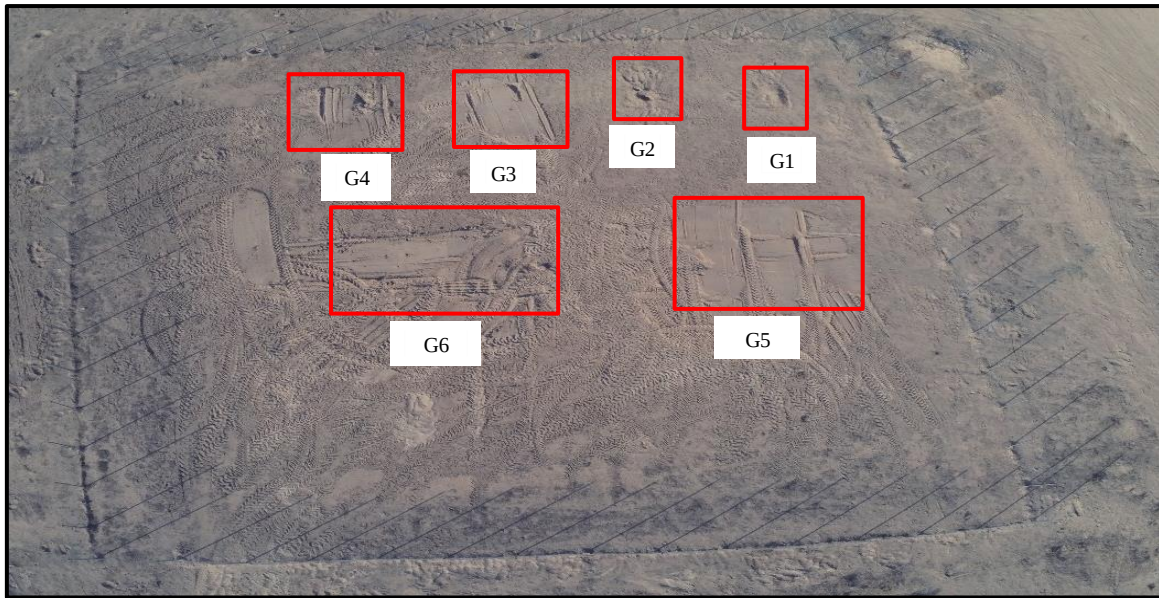


Figure 5 The research area containing the six graves captured one day post-burial using the Parrot ANAFI Thermal.

The graves were classified as hand-dug shallow graves (50-60 cm) or machine-dug deep graves (100-150 cm). Although it is expected that old mass graves that were dug more than 30 years ago, such as the ones from the 1990 Gulf War, would not be detectable using the proposed technology, the depth of the graves at 150 cm (see Figure 6) was chosen to resemble similar conditions of the graves excavated following the 1990 Gulf War (Al-Dossari, 2018). This would aid in the determination of the useful timeframe to detect changes by using this technology in these specific conditions. The

graves were excavated and backfilled either by a hand tool (shovel) or using a machine (a rented Caterpillar backhoe loader with a bucket size of 60 cm and loader size of 240 cm).



Figure 6 The depth of the mass grave being monitored during the excavation by the backhoe.

Three out of the six graves served as control graves, simulating soil disturbance caused by factors other than being a burial site, such as digging related to construction. The first one was a single shallow (50-60 cm) hand-dug grave (G1), the second one was a single deep (100-150 cm) grave dug with a backhoe (G3), and the last one was a deep mass grave (G5) dug with a backhoe. Therefore, the control graves were all empty and did not contain any remains. The following ground view image was taken upon the completion of the graves backfilling on the first day (Figure 7).



Figure 7 A ground view of the research area captured upon the completion of the backfilling of the graves.

The experimental graves had single or multiple sheep buried in them at various depths, all facing southwest, with some added content included in the graves. Cloths, placed on top of the sheep, and 9 mm handgun shell cases, placed around the sheep, were added to the experimental graves to make them resemble a real-life scenario (see Figure 8 and Table 2 for more information about the added content). These inclusions will also be useful when the grave is excavated in the future for training purposes. Such variation in graves depth was chosen to simulate actual graves excavated in the past and to study whether depth influences the results in the control and experimental graves. The first experimental grave was a hand-dug shallow grave with a single sheep (G2). The second grave was a deep grave dug with a backhoe (G4), also with a single sheep. All the single graves had a dimension of 2.5 m (length) by 1 m (width). The last grave would be the mass grave with a dimension of 5 m (length) by 2 m (width) and 1.5 m in depth and was occupied by eight sheep (G6) (see Figure 8).



Figure 8 An overview of the carcasses inside the experimental mass grave with the clothing items, prior to backfilling the grave.

Before backfilling the graves, digital images of the graves were taken using a Canon EOS 90D DSLR camera with an 18-55 mm lens. It took four hours and forty-four minutes (05:05-09:49 am) to complete setting up the experimental site, which included all the digging work, placing the cadavers and extra contents in the graves, taking pictures of the graves and the backfilling. Table 2 below illustrates a summary of grave-related information.

Table 2 Set-up for the control and experimental graves for the present study

Grave	Single/Mass Grave	Method of Digging	Size (m)	Depth (cm)	Grave Content	Control/Experimental
G1	Single	Hand dug	2x1	30	N/A	Control
G2	Single	Hand dug	2x1	40	1 sheep 2 shell cases	Experimental

					1 cotton grey sweater	
G3	Single	Machine dug	2x1	60	N/A	Control
G4	Single	Machine dug	2x1	80	1 sheep 2 shell cases 1 cotton purple-pinkish pants	Experimental
G5	Mass	Machine dug	2x5	150	N/A	Control
G6	Mass	Machine dug	2x5	145	8 sheep 2 shell cases 1 blue denim jeans 2 cotton grey socks 1 cotton black dress (women) 1 cotton white underwear (baby)	Experimental

3.3 Data Collection

Prior to each day of data collection, meteorological information was checked to ensure that it would be suitable to go to the field and collect the on-ground data and ideal for flying the UAVs and collecting the data aerially. In this regard, the weather conditions, wind speed and direction, humidity, highest and lowest air temperatures, and sunrise and sunset timings were checked. Once in the field the next morning, these data were recorded. The following table indicates the recorded meteorological observations before commencing data collection during the experiment period.

Table 3 Meteorological data recorded during the research period.

Day measured	Weather condition	Wind speed and direction (km/h)	Humidity (%)	Sunrise time	Sunset time	Highest temperature (°C)	Lowest temperature (°C)
1 day before	Sunny	W 20	12	5:13	18:31	48	28
Same day	Sunny	W 23	14	5:14	18:32	47	34
1 day PB	Sunny	21	19	5:15	18:33	47	33
3 days PB	Mostly sunny	16	28	5:16	16:32	44	31
1 week PB	Mostly sunny	S/SW 8	24	5:16	18:25	44	31
2 weeks PB	Sunny	W/SW 10	18	5:21	18:19	46	29
3 weeks PB	Sunny	16	19	5:25	18:12	47	31
1 month PB	Sunny	W/NW 10	16	5:30	18:00	48	29
2 months PB	Sunny	W 10	26	5:44	17:23	37	21

3 months PB	Sunny	N 5	84	6:08	16:56	34	21
6 months PB	Sunny	W 8	92	6:31	17:32	25	11
7 months PB	Sunny	W 6	50	6:02	17:53	29	13
9 months PB	Sunny	W 11	28	4:59	18:29	40	24
10 months PB	Sunny	W/SW 8	23	4:49	18:51	47	31
11 months PB	Sunny	W 11	24	5:05	18:46	49	33
12 months PB	Sunny	SW 5	52	5:21	18:23	44	29
15 months PB	Sunny	SE 11	51	6:13	16:52	28	16
18 months PB	Sunny	SE 10	61	6:33	17:30	19	11

PB: Post-burial.

Soil temperature, soil moisture, and landscape changes (including grave mound height and observation of the vegetation) were all recorded both on-ground and by aerial survey. The aerial survey used 4K RGB, MSI and thermal sensors. A total of 18 sets of data, both on-ground and aerial, were collected throughout the experiment period, which lasted for 18 months. Data collection was conducted one day before the burial, the day of burial, and then one, three and seven days post-burial. Afterwards, data were collected weekly for three weeks. Next, the data were collected monthly until one year post-burial except for the fourth, fifth and eighth months due to government restrictions related to the COVID-19 pandemic, and the thirteenth, fourteenth, sixteenth and seventeenth months due to being in Liverpool. Lastly, data were collected in the fifteenth and eighteenth months. Details of the data collected are presented in Table 4:

Table 4 Data collection information.

Day of data collection	Date	On-ground data	Aerial survey data
1 day before	08/08/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI

Same day	09/08/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
1 day PB	10/08/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
3 days PB	12/08/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
1 week PB	15/08/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
2 weeks PB	23/08/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
3 weeks PB	30/08/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
1 month PB	09/09/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI

2 months PB	09/10/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
3 months PB	09/11/2020	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
6 months PB	09/02/2021	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
7 months PB	09/03/2021	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
9 months PB	12/05/2021	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
10 months PB	15/06/2021	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
11 months PB	15/07/2021	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI

12 months PB	21/08/2021	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
15 months PB	17/11/2021	Soil Sample Soil Temperature Landscape changes	RGB/TI/MSI
18 months PB	06/02/2022	Soil Sample Soil Temperature Landscape changes	RGB/TI

PB: Post-burial, RGB: Red, green and blue, TI: Thermal imaging, MSI: Multispectral imaging.

3.3.1 On-ground

In the process of locating a clandestine grave, once the search area is identified based on witness accounts, confessions, police intelligence or by any other means, usually an on-ground search would be the first approach for the investigators (Larson, Vass and Wise, 2011). In this grave detection process, the methods used depend on various elements such as the terrain, environment, vegetation cover and soil type. The investigators choose the most suitable methods in their on-ground search based on these elements. Visual examination of the ground and the surrounding vegetation, probing, ground penetrating radar, thermal scans and cadaver dogs are some of the methods used in an on-ground search (Larson, Vass and Wise, 2011). In this research, temperature measurements of the graves, the soil moisture of the graves and landscape changes were the methods used to aid the detection of the simulated clandestine graves.

3.3.1.1 Temperature measurement

The on-ground soil temperature of the graves and their surrounding area was recorded using a handheld infrared thermometer (model: Lutron TM-919AL) with an accuracy of 0.1 °C and a temperature measuring range of -20 °C to 400 °C (see Figure 9).



Figure 9 Handheld thermometer model: Lutron TM-919AL.

3.3.1.2 Soil Moisture

To measure soil moisture, a sample from each grave was collected and weighed using an analytical laboratory scale with a ceramic load sensor (see Figure 10).



Figure 10 The analytical laboratory scale used for measuring the soil samples.

Samples were then placed inside a laboratory oven (SHEL LAB 1370 GX) for 24 hours and then reweighed to quantify the moisture (see Figure 11).

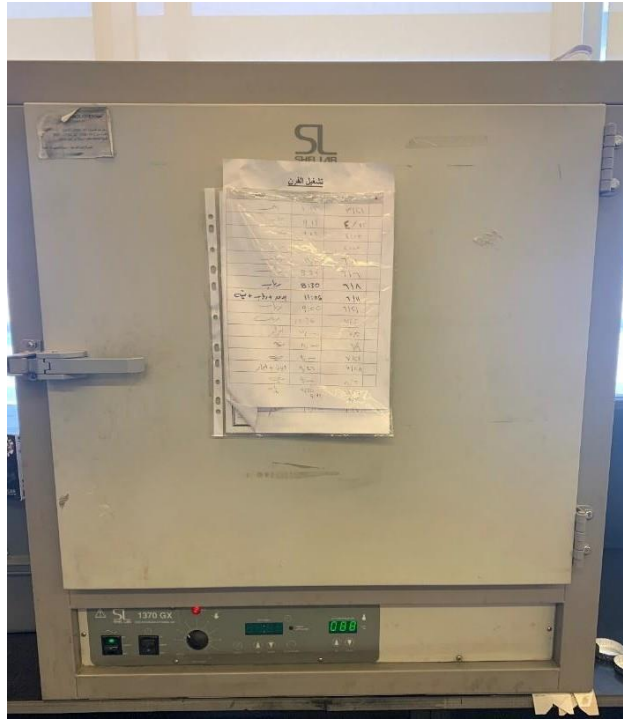


Figure 11 The laboratory oven (SHEL LAB 1370 GX) used to dry the soil samples.

3.3.1.3 Landscape Changes

The physical characteristics of vegetation were recorded throughout the research period for all graves and their surroundings. These included vegetation height and grave height. Here, the grave height has to do with the backfilling of the grave and is measured from the ground to the highest point of the grave. The data were recorded throughout the experiment using a measuring tape. Moreover, grave-edge cracks and soil crusting were also noted throughout the research period.

3.3.2 Aerial Survey

In clandestine grave detection, remote sensing proved to be advantageous because it does not involve terrain disturbance caused by a foot search or geophysical techniques (Murray et al., 2018; Silván-Cárdenas et al., 2021). Additionally, it helps to reduce the search time while increasing the area of exploration. For this research, two quadcopters (four propellers) UAVs were used to capture three sets of images: RGB, MS, and TI. Prior to commencing any flight, a flyer ID was obtained from the UK Civil Aviation Authority (Appendix B). Data acquisition always took place at the same time of the day for all operation days, which was at sunrise; hence, there was little variation in the sun

position as sunrise varies each day (see: Dozal et al., 2018). Prior to any mission, an environmental consideration always takes place in which the weather forecast is checked for wind speed and sky clarity. Objects must remain in the same place relative to each other to achieve an accurate reconstruction; hence, days with strong winds that can move objects from their original places were avoided. In addition, cloudy days were avoided as well since clouds can cast discrete shadows, causing different lighting conditions over the area of interest and ultimately degrading the reconstruction process.

Parrot Anafi Thermal UAV was used for the 4K RGB and TI image acquisition. The UAV weight (including propellers and excluding the battery) is about 320 g, with a dimension of 242 x 315 x 64 mm (see Figure 12). The maximum speed is 54 km/h, with wind resistance and wind gust resistance of 50 and 80 km/h, respectively. It has a GPS installed (U-BLOX UBX-M8030 GPS), and a precise Return Home feature activated automatically, so that the UAV returns to the flying position (where the UAV took-off) when the remaining battery level is running low. The maximum flight time of the UAV is approximately 26 minutes. A single person can operate this UAV to capture the image data. The UAV is equipped with a forward-looking infrared (FLIR) Lepton 3.5 microbolometer (radiometric) sensor for IR temperature image capturing and with a SONY IMX230 1/2.4" sensor for the visible imaging (4K RGB), with a resolution of 1440x1080 for both photo and video. The visible sensor has a resolution of 16 megapixels (4608x3456) for the photo resolution and 4K Cinema (4096x2160) for the video resolution (Parrot, 2020a).



Figure 12 Parrot Anafi Thermal UAV (Parrot, 2020a).

Parrot Bluegrass was used for the MSI image acquisition (see Figure 13). The UAV weight (including propellers and excluding the battery) is about 1850 g with a dimension of 500 x 440 x 120 mm. It can travel for 2 km in an unobstructed area free of interference with a wind resistance capability of 46 km/h. The maximum flight time of the UAV is approximately about 25 minutes. It has a built-in Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS). A single person can operate this UAV to capture the image data. The UAV comes with a preinstalled front 16-megapixel RGB camera, which shoots both still and video in full HD (1080p). It is also equipped

with a Parrot Sequoia multispectral sensor, which captures images in RGB with a 4608×3456 sensor and in green, red, red-edge and NIR wavelengths with a resolution of 1280×960 . It also comes with a fully-integrated sunshine sensor that captures and logs the lightning conditions for calibration purposes to ensure the digital number (DN) obtained is an accurate representation of the captured images on the day (Parrot, 2020b).



Figure 13 Parrot Bluegrass UAV (Parrot, 2020b).

Both UAVs were linked to the Pix4Dcapture mobile application to plan flight missions and capture images, which was previously discussed in Chapter 2 section 2.2.1. A double-grid flight mission option was chosen to cover the research area thoroughly and allow 3D mapping. Figure 14 below shows how a double grid mission operates.

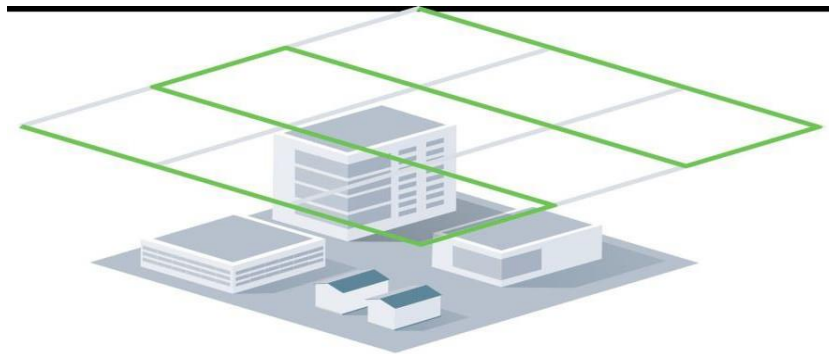


Figure 14 An example of what the double grid flight mission entails can be seen in a preview of the flight pattern, which involves flying two perpendicular grids over the same area. The image was taken from (Pix4D, 2022b).

In addition to the enclosed research area, the camera was set to capture a meter beyond the extent of the research area to ensure no deterioration in the captured images of the research area that might affect its quality and actual representation. Since the UAVs are not compatible with flying above 40°C temperatures based on the flight manual, only a single image was captured on the days mentioned in Chapter 3 section 3.3. Previous literature suggested that heights of 50 ft (15 m) and 100 ft (30 m) are ideal for aiding the investigation of a potential gravesite when a thermal UAV is used (Bodnar et. al, 2019). However, large area coverage with such heights would take a long time and

multiple visits may be needed to conduct the initial investigation. Hence, images were captured at different altitudes to explore the ultimate height that covers the most area possible in a single flight while maintaining a clear ground sampling distance of the research area. Those altitudes are 100 m, 80 m, 50 m, 30 m and 10 m. The higher the altitude of the UAV, the higher the ground sampling distance (GSD) of the obtained image. The minimum recommended GSD is 10 cm/pixel for the RGB images, whilst the thermal images have no specific recommendation for the GSD. If the obtained images are blurry or poorly exposed, then the shutter speed or ISO is set to a fixed value to correct the image exposure and control the sensitivity of the sensor to the incoming light (Pix4D, 2022b).

The captured images were then transferred to the photogrammetry software Pix4Dmapper to generate different orthorectified outputs mentioned in Chapter 2 section 2.2. The usefulness of the output is directly related to the number of image overlaps, the image content, the resolution of the images and the processing options. This orthorectified generation involves a three-step processing method. The first step is generating a sparse point cloud using Sfm algorithms, which establish a relationship between the geo-tagged captured images by matching the tie points in multiple images, hence estimating its three-dimensional positions. The second step is generating a dense point cloud of the area. Lastly, these dense point clouds are submitted to a noise-filtering process and then interpolated using a triangulation algorithm to compute the required orthorectified outputs (Pádua et al., 2018; Pix4D, 2022b).

3.3.2.1 4K RGB Images

Prior to the first flight on the day of image acquisition, the Parrot ANAFI Thermal UAV compass and gimbal were calibrated using the calibration option available in the factory flight mission management software Parrot FreeFlight6. Afterwards, the UAV was linked to Pix4Dcapture software to plan and capture RGB images of the research area, which were then transferred to Pix4Dmapper software for the initial processing of the images. The camera parameters and technical options were set on the recommended 80% frontal and 70% side image overlapping. Additionally, the gimbal holding the camera is tilted to a 90° angle parallel to the ground, and a UAV speed fluctuating between two and 8 m/s when capturing RGB images using Pix4Dcapture (Pix4D, 2022a). These settings were similar in all flights at various heights where the images were captured. Then, images were downloaded from the UAV to a hard drive and transferred to Pix4Dmapper for the initial processing phase. The software parameters were set to extract a RGB orthomosaic image, DTM and DSM from the research area. The multiple band orthomosaic was then exported to ENVI by

L3HARRIS, an image processing and analysis software, to automatically detect surface anomalies using the RX Anomaly Detection tool (Exelis Visual Information Solutions, 2020). The tool implements the workflow of the Reed-Xiaoli Detector (RXD) algorithm, which extracts targets that are spectrally distinct from the image background in a multiband image, an algorithm developed by Reed and Yu (Reed and Yu, 1990). It uses the pixel currently being processed as the matched signal and the sample covariance matrix to account for the sample spectral correlation; hence, the matched signals vary pixel-by-pixel, and bad pixels appear anomalous (Chang and Chiang, 2002). A bad pixel is a pixel in a digital image with some noisy, dead or poor signal-to-noise performance different from the rest of the recorded image sequence, resulting in a digital image that does not function correctly; hence an artefact or anomaly is detected in the image (Meng et al., 2010). The detection of such anomalies increases when the anomalous targets are considerably smaller than the background. Since the images produced by the RXD are generally grayscale, the target detection and discrimination are carried out by visual inspection (Chang and Chiang, 2002).

Three anomaly detection methods are available to choose from in ENVI RX Anomaly Detection tool based on the chosen algorithm: RXD, Uniform Target Detector (UTD), and a hybrid of the RXD and UTD methods (RXD-UTD) (Reed and Yu, 1990; Chang and Chiang, 2002). RXD is the standard RXD algorithm, which is calculated using the following equation:

$$\delta_{RXD}(r) = (r - \mu)^T K_{L \times L}^{-1} (r - \mu)$$

Equation 2 Where r is the sample vector, m is the sample mean, and $KL \times L$ is the sample covariance matrix.

Alternatively, UTD extracts background signatures as anomalies and is defined using $(1 - \mu)$ as the matched signature rather than $(r - \mu)$. Furthermore, it uses the unit vector rather than a sample vector from the data, as with RXD. Lastly, RXD-UTD, a variant of the UTD approach, uses $(r - 1)$ as the matched signature. This UTD and RXD subtraction suppresses the background and enhance anomalies. Therefore, it is suitable for situations where the anomalies have an energy level comparable to or less than the background, in which the features or patterns under investigation in an image are not easily distinguishable from the background (Reed and Yu, 1990; Chang and Chiang, 2002).

Yet, the DTMs and DSMs are exported to Esri ArcMap application, a geospatial processing software designed by ArcGIS Desktop, to view and manually detect surface anomalies and to calculate the DEMs of the research area (ESRI, 2002).

3.3.2.2 Thermal Images

Past research demonstrated that the highest carcass temperature was recorded in the first two weeks (Bodnar et. al, 2019; Butters et al., 2021)); hence the initial plan was to capture thermal images of the research area twice daily for the first two weeks, then a single capture for the following weeks. The first set of images would be in the early hours of the day, and the second set of images would be at sunset to explore the effect of ambient temperature variance on graves in the desert. However, the temperatures recorded for the first two weeks, around sunrise and sunset, were just below 40 °C, the maximum temperature to operate a UAV. Hence, the temperature variance will not be present; therefore, only one set of images at sunrise will be captured.

Similarly, to the RGB image acquisition, the Parrot ANAFI Thermal UAV compass and gimbal are both calibrated the same way, which was mentioned above. Afterwards, the UAV was also linked to Pix4Dcapture software to plan and capture thermal images of the research area. The camera parameters were set on the recommended 90% frontal and side images overlapping, 90° camera gimbal angle, and a UAV speed fluctuating between 2 and 8 m/s when thermal images were captured (Pix4D, 2022a). These settings were the same in all flights at various heights where the images were captured. Once finished with the capturing step, images were downloaded from the UAV to a hard drive and then transferred to Pix4Dmapper for the initial processing phase. Next, the Pix4Dmapper processing tool was set only to extract the thermal orthomosaic image of the research area. It was then exported and used with image processing and analysis software ENVI by L3HARRIS (Exelis Visual Information Solutions, 2020) and geospatial processing software ArcGIS Desktop using its Esri ArcMap application for image analysis and calculating soil moisture (ESRI, 2002).

3.3.2.3 Multispectral Images

A Parrot Bluegrass UAV was used to capture the required multispectral images. It was done using the same process as capturing the RGB and thermal images. First, the UAV was linked to Pix4Dcapture, where both the UAV and the Sequoia multispectral sensor are calibrated. The UAV is calibrated using special onscreen guided manoeuvres, which involve manually rotating the UAV on the Z, Y and X axes, whilst the multispectral sensor calibration follows two steps. The first step is to capture an image of a calibration target that comes with the UAV prior to the first flight on the day of image acquisition. The image should be taken one meter away from the target and not facing the sun. In addition, the target must be level with the ground, aligned to the North to avoid artefacts when sun angle correction is applied and not affected by any shadow or reflection. Once this calibration step is

completed, the software is used to plan and capture multispectral images of the research area.

The camera parameters were set on the recommended 80% frontal and side image overlapping, 90° camera gimbal angle, and a UAV speed fluctuating between 2 and 8 m/s when multispectral images were captured (Pix4D, 2022a). These settings were similar in all flights at various heights where the images were captured. Once finished with the capturing step, images were downloaded from the UAV to a hard drive and then transferred to Pix4Dmapper for the initial processing phase.

Next, the Pix4Dmapper processing tool was set to compute the multispectral orthomosaic images and the index map of the NDVI of the research area. The single-band MS orthomosaics were then exported to ENVI v.5.6 by L3HARRIS to combine them into a multiple-band orthomosaic image using the Layer Stacking tool (Veerendra, Latha and GP, 2014). Then, the stacked image was processed using the Anomaly Detection tool in ENVI to detect surface anomalies automatically. In addition, the Esri ArcMap application was used to preview and manually detect surface anomalies of the single-band MS orthomosaics by visualising the image and looking for the outplaced pixels in the image.

Chapter 4 Results

This chapter presents the results of the on-ground and all three remote sensing data sets analyses described in Chapter 3. A comparison analysis was conducted between the control and experimental graves for each type of set of graves. Specifically, the results of G1 were compared with G2, G3 with G4, and G5 with G6.

On-ground results explored the variation in temperature and soil moisture of the graves which was measured using a handheld thermometer and through weighing the difference in soil samples, respectively. Also, graves heights were measured using a measuring tape each time the data were collected. Moreover, observations were made for any botanical changes or scavenger intrusions in the research area. Furthermore, soil crusting and grave-edge cracks were also noted and documented throughout the process.

Contrarily, the same on-ground observations were explored and analysed using remote sensing technology. Three different sensors deployed on two multirotor UAVs were used to extract certain features from the obtained orthomosaics maps using different software to fulfil the analysis requirements. First, the on-ground results will be illustrated in section 4.1, followed by the aerial results in section 4.2.

4.1 On-ground results

In most situations, the initial approach that forensic investigators usually employ to find a clandestine grave starts with an on-ground landscape survey (Abate et al., 2019). This survey includes, but is not limited to, identifying surface anomalies, looking for differences in the height of the plants and grave mounds and exploring any animal activity and scavenging (Dupras et al., 2011). In this research, the on-ground survey explored the differences in the temperature and soil moisture of the graves, as well as landscape changes. The following section illustrates the on-ground findings.

4.1.1 Temperature measurement

The on-ground temperature measurement was conducted by using the hand-held device mentioned in Chapter 3 section 3.3.1.1. It was recorded throughout the research period, and below is a comparison between the recorded temperatures.

Graves 1 and 2

The temperature of G2 (experimental hand-dug grave) displayed higher surface temperatures in 12 of

the total 18 recorded temperatures than that of G1 (control hand-dug grave). The highest temperature difference measured between the graves was 0.8 °C, which was the day after commencing the burials. G2 recorded a temperature of 37.8 °C, while G1 recorded a 37 °C. Meanwhile, the area surrounding the graves had higher surface temperatures than the graves in 12 of the 18 recorded temperatures. The highest temperature difference measured between the graves and their surroundings was also recorded on the first day after commencing the burials. On that day, the recorded temperature of G1, G2 and their surroundings were 37 °C, 37.8 °C and 38.6 °C, respectively. Table 5 and Figure 15 illustrate the measured on-ground temperatures for G1, G2 and their surroundings throughout the experiment period.

Table 5 On-ground temperature comparison between G1, G2 and their surroundings. PB: Post-burial, G1: Grave 1, G2: Grave 2.

Day measured	G1 on-ground temperature (°C)	G2 on-ground temperature (°C)	Surrounding temperature (°C)
1 day before	32	31	31.5
Same day	40.5	40.8	40.9
1-day PB	37	37.8	38.6
3 days PB	37.3	37	37.8
1-week PB	28.5	28.7	29.2
2 weeks PB	28.8	29	29.4
3 weeks PB	28.1	28.7	29.2
1-month PB	30.5	30.7	30.6
2 months PB	21.9	21.3	22
3 months PB	24.2	23.9	24.3
6 months PB	6.7	6.4	6.9
7 months PB	9.3	9.6	9.2
9 months PB	22.8	22.3	23.1
10 months PB	30.7	30	30.4
11 months PB	32.7	32.8	33.2
12 months PB	31.3	31.5	32.1
15 months PB	8.4	8.9	8.7
18 months PB	3.1	3.4	3.2

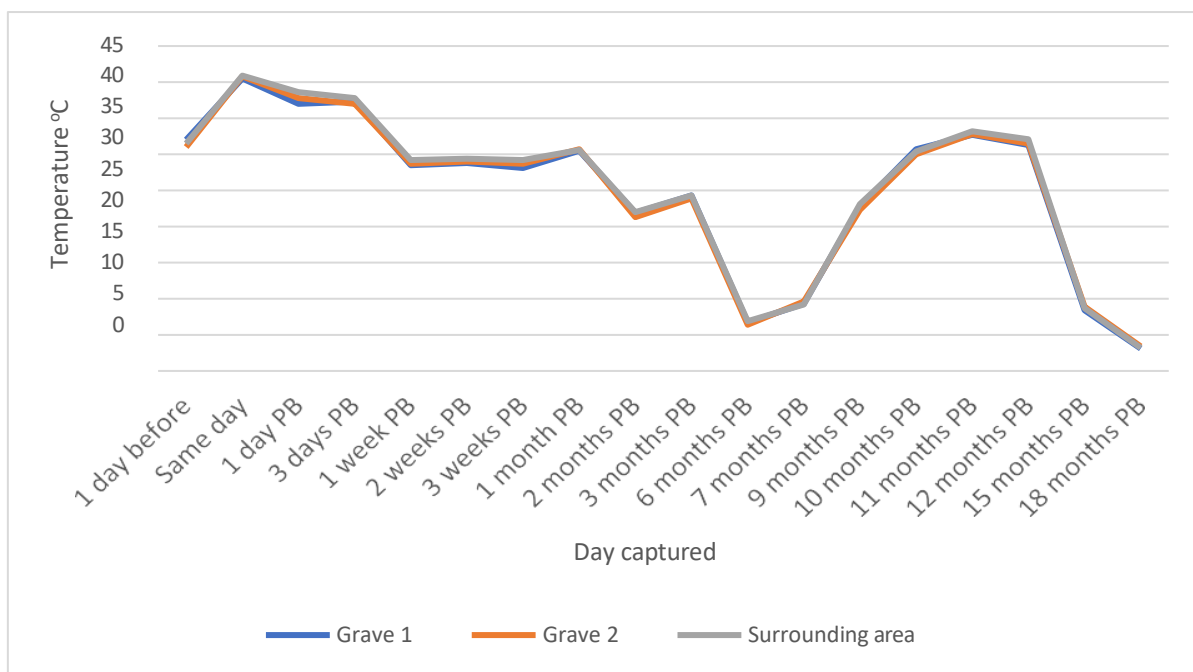


Figure 15 On-ground temperature comparison between G1, G2 and their surroundings. PB: Post-burial, G1: Grave 1, G2: Grave 2.

Graves 3 and 4

The on-ground temperature of the surrounding enclosed area was always higher than that of both graves, except for the recorded temperatures one- and two-weeks post-burial, the third, seventh, tenth, fifteenth- and eighteenth-months post-burial. The measured temperature of G3 (control machine dug grave) was higher than G4 (experimental machine dug grave) on six occasions; the rest showed higher temperature values for the experimental grave. The highest temperature difference between the graves was 4 °C recorded two weeks post-burial. On that same day, the highest temperature difference between the graves and their surroundings was also recorded, in which the temperature of G4 was higher than the surrounding temperature by 2.6 °C. Table 6 and Figure 16 illustrate the measured on-ground temperatures for G3 and G4 throughout the experiment period and the temperature of their surroundings.

Table 6 On-ground temperature comparison between G3, G4 and their surroundings. PB: Post-burial, G3: Grave 3, G4: Grave 4.

Day measured	G3 on-ground temperature (°C)	G4 on-ground temperature (°C)	Surrounding temperature (°C)
1 day before	31.2	31	34
Same Day	42.8	41.6	44.2
1 day PB	38.6	38.1	39.7
3 days PB	36.6	37.5	39.9

1 week PB	29.7	31.6	30.2
2 weeks PB	30	34	31.4
3 weeks PB	28.2	29.8	30.2
1 month PB	33.1	32.2	34.6
2 months PB	21	21.9	23.4
3 months PB	23.8	24.7	24.1
6 months PB	7.3	7.1	7.9
7 months PB	10.8	11.3	11.2
9 months PB	23.9	23.8	24.1
10 months PB	30.3	30.9	30.4
11 months PB	32.3	32.4	33.2
12 months PB	31.6	31.3	32.1
15 months PB	8.7	9	8.7
18 months PB	3.2	3.4	2.9

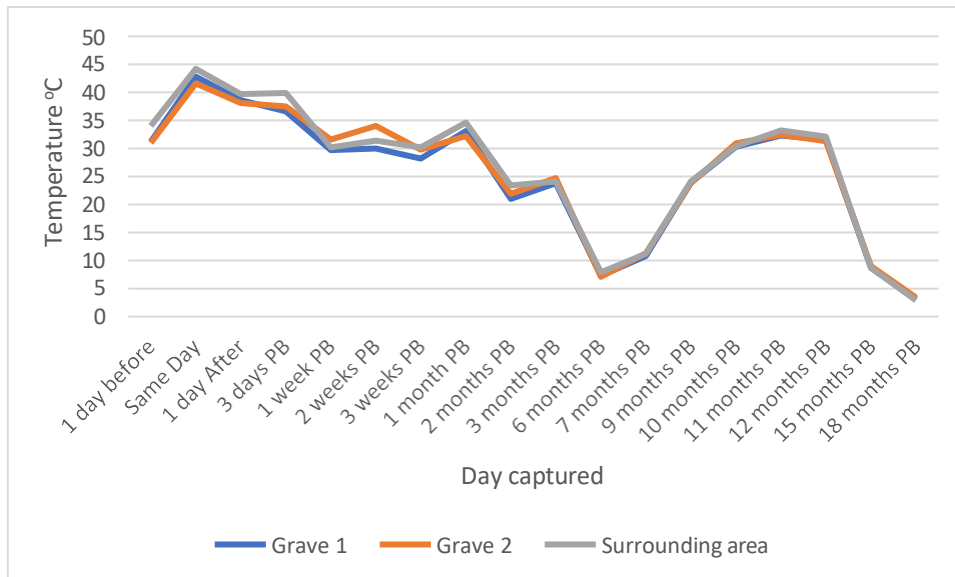


Figure 16 On-ground temperature comparison between G3, G4 and their surroundings. PB: Post-burial, G3: Grave 3, G4: Grave 4.

Graves 5 and 6

When compared to their surroundings, the recorded temperatures showed that the surrounding areas of the graves were warmer than the graves for the first two months. Afterwards, from the third month post-burial up until the seventh month, the temperatures of the graves encountered an increase in temperature and were higher than their surroundings. From the ninth month onwards, the recorded temperature of the enclosed research area was almost at the same level. The measured temperature of G5 (control mass grave) was higher than G6 (experimental mass grave) on seven occasions: the day of the burial, one day and three days post-burial, three weeks post-burial, and then the tenth, eleventh- and twelfth-months post-burial. Hence, the experimental grave was higher in temperature

than the control grave on the other 11 occasions. The highest difference between the graves was in the seventh month when G6 was higher than G5 by 3.7 °C. Table 7 and Figure 17 illustrate the measured on-ground temperatures of both graves and their surroundings throughout the experiment period.

Table 7 On-ground temperature comparison between G5, G6 and their surroundings. PB: Post-burial, G5: Grave 5, G6: Grave 6.

Day measured	G5 on-ground temperature (°C)	G6 on-ground temperature (°C)	Surrounding temperature (°C)
1 day before	39.2	39.1	41.5
Same day	41.8	42.6	44.2
1 day After	42.8	42	44.7
3 days PB	43.5	42	44.9
1 week PB	28	28.1	29.2
2 weeks PB	29.6	31	31.4
3 weeks PB	29.9	29.7	31.2
1 month PB	32.6	33.6	34.6
2 months PB	21.9	22.1	23.4
3 months PB	23.8	25.7	23.1
6 months PB	6.3	8.3	5.4
7 months PB	9.7	13.4	9.2
9 months PB	23.7	23.9	24.1
10 months PB	30.3	30.1	30.4
11 months PB	33.2	32.9	33.2
12 months PB	30.9	30.7	31.1
15 months PB	28.3	28.5	28.7
18 months PB	3.1	3.2	2.9

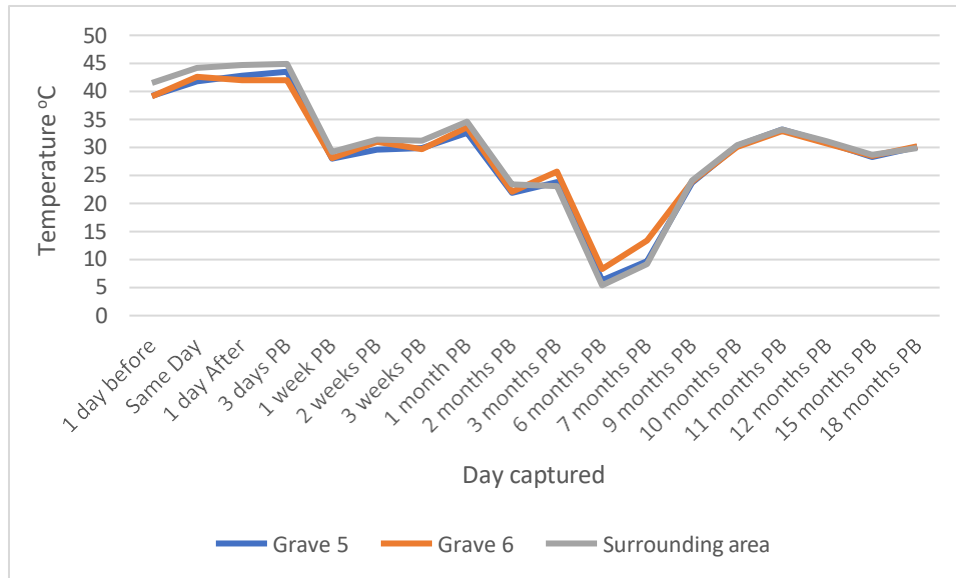


Figure 17 On-ground temperature comparison between G5, G6, and their surroundings. PB: Post-burial, G5: Grave 5, G6: Grave 6

4.1.2 Soil Moisture

The soil moisture was calculated using the method mentioned in Chapter 3 section 3.3.1.2, one- week post-burial until the end of the experiment, which is 18 months post-burial. A comparison between the graves and their soil moisture is illustrated below, showing recorded differences.

Graves 1 and 2

Out of the 14 calculated soil moisture samples of G1 (control hand-dug grave) and G2 (experimental hand-dug grave), G1 was higher than G2 11 times. The highest calculated difference between G1 and G2 soil moisture percentage was in the tenth month, where G2 was higher than G1 by 1.2%. Table 8 and Figure 18 illustrate the calculated soil moisture percentages of G1 and G2 throughout the experiment.

Table 8 The calculated soil moisture percentage for grave 1 (G1) and grave 2 (G2). PB: Post-burial.

Day measured	G1 soil moisture percentage	G2 soil moisture percentage
1-week PB	2.29	3.18
2 weeks PB	2.33	2.25
3 weeks PB	2.59	2.25

1-month PB	2.82	2.48
2 months PB	3.17	3.02
3 months PB	2.25	1.39
6 months PB	4.18	3.42
7 months PB	3.31	3.04
9 months PB	3.27	2.91
10 months PB	3.39	2.19
11 months PB	2.91	1.89
12 months PB	1.79	0.84
15 months PB	2.1	2.97
18 months PB	2.08	2.34

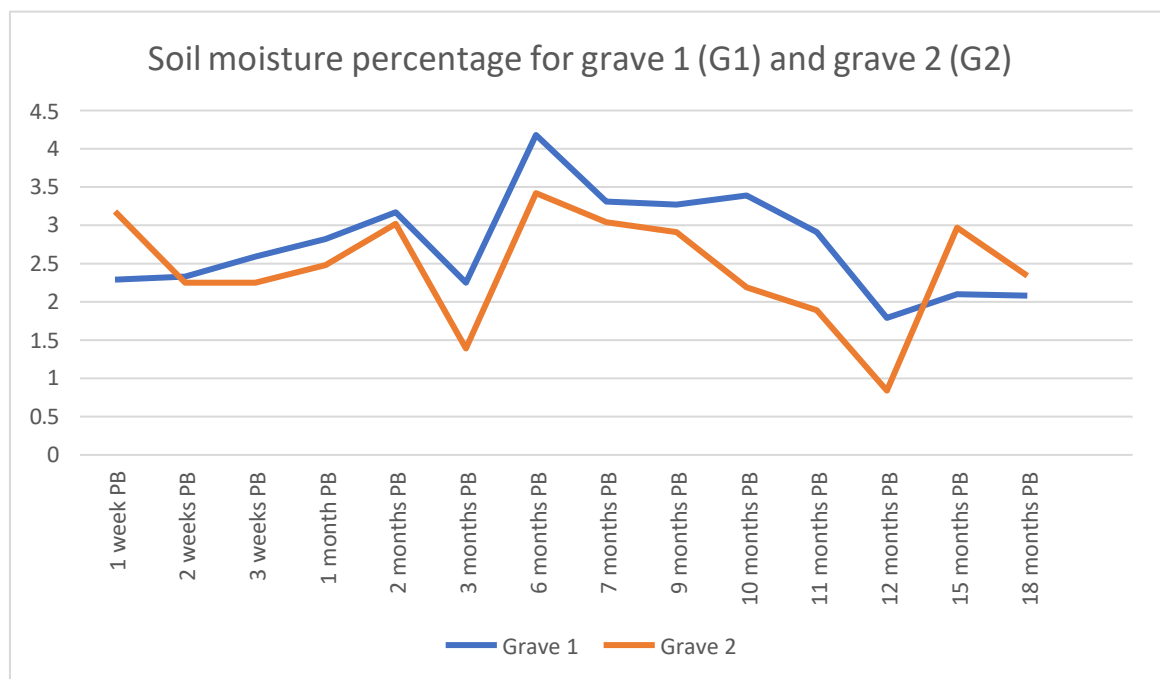


Figure 18 Soil moisture percentage for grave 1 (G1) and grave 2 (G2). PB: post-burial.

Graves 3 and 4

Out of the 14 calculated soil moisture samples of G3 (control machine dug grave) and G4 (experimental machine dug grave), the graves were equal in the number of times when each had a higher soil moisture percentage. There was no large variation between the soil moisture percentages during the experiment. The highest calculated difference between G3 and G4 soil moisture percentage was in the fifteenth month, where G3 was higher than G4 by 0.88%. Table 9 and Figure 19 illustrate the calculated soil moisture percentages of G3 and G4 throughout the experiment.

Table 9 The calculated soil moisture percentage for grave 3 (G3) and grave 4 (G4). PB: Post-burial.

Day measured	G3 soil moisture percentage	G4 soil moisture percentage
1-week PB	1.94	2.08
2 weeks PB	2.62	2.11
3 weeks PB	1.75	2.35
1 month PB	1.98	2.58
2 months PB	2.15	2.12
3 months PB	1.92	2.28
6 months PB	3.8	4.11
7 months PB	1.99	2.11
9 months PB	2.36	2.01
10 months PB	2.37	2.53
11 months PB	1.7	1.51
12 months PB	0.9	0.72
15 months PB	2.97	2.09
18 months PB	2.19	2.04

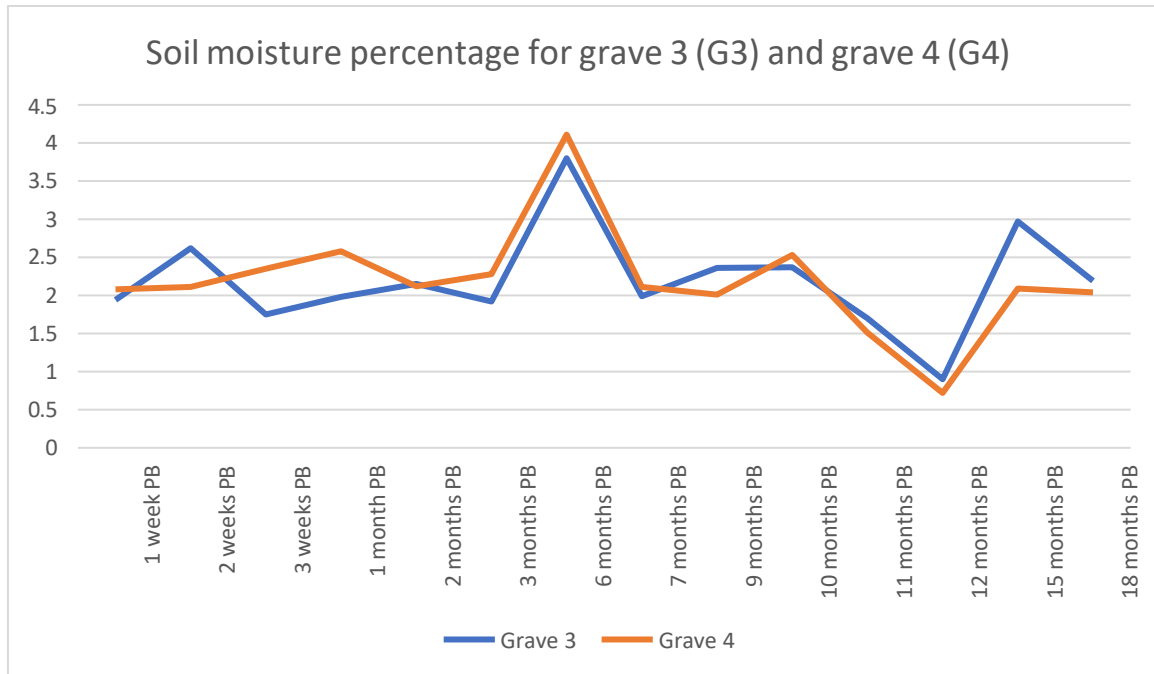


Figure 19 Soil moisture percentage for grave 3 (G3) and grave 4 (G4). PB: post-burial.

Graves 5 and 6

The soil moisture of G6 (experimental mass grave) was higher than G5 (control mass grave) throughout the research period (see Table 10 and Figure 20), which is in line with previously published literature (Blau et al., 2018). The highest calculated difference between G5 and G6 soil moisture percentage was in the sixth month, where G6 was higher than G5 by 2.77%.

Table 10 The calculated soil moisture percentage for grave 5 (G5) and grave 6 (G6). PB: Post-burial.

Day measured	G5 soil moisture percentage	G6 soil moisture percentage
1 week PB	1.85	2.35
2 weeks PB	1.65	2.13
3 weeks PB	1.38	2.43
1 month PB	1.61	2.66
2 months PB	1.26	2.5
3 months PB	1.7	2.6
6 months PB	2.11	4.88
7 months PB	1.76	2.62
9 months PB	2.04	2.7

10 months PB	1.86	2.65
11 months PB	1.49	2.38
12 months PB	0.91	1.35
15 months PB	2.28	3.25
18 months PB	2.37	2.99

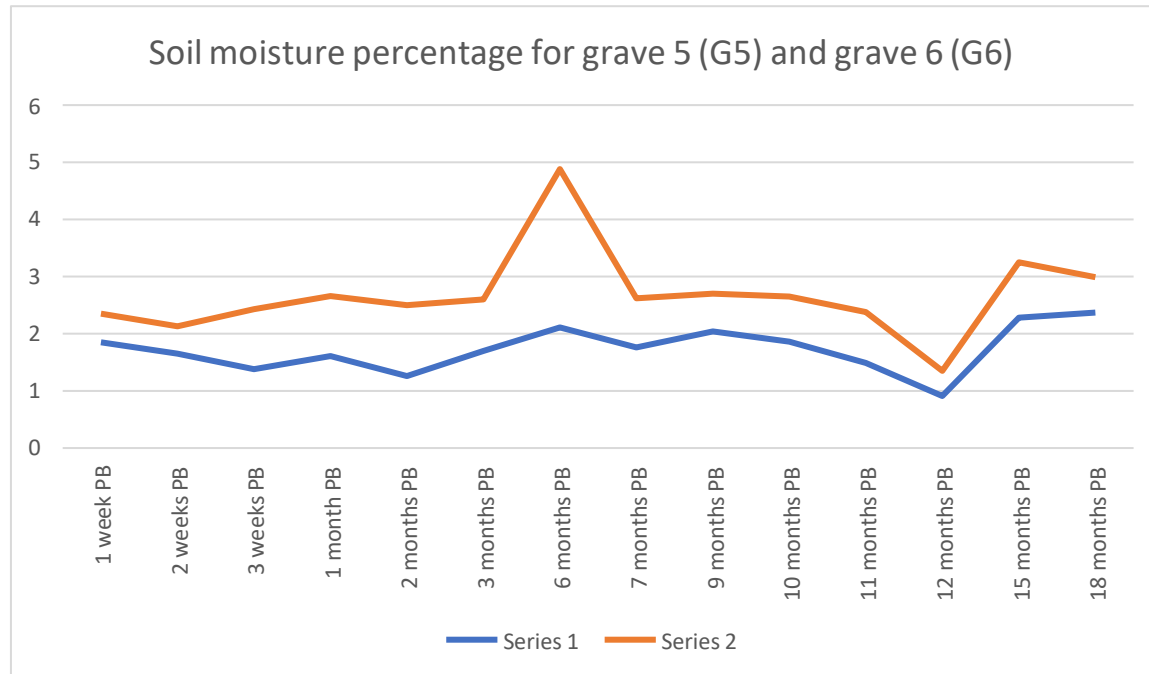


Figure 20 Soil moisture percentage for grave 5 (G5) and grave 6 (G6). PB: post-burial.

4.1.3 Landscape Changes

Since the research area was enclosed and fenced, any landscape changes in the research area had to be caused by a natural process or by scavengers. Therefore, a thorough survey of the enclosed area took place on every site visit. Notes were taken for landscape changes in the research area that differed from previous data collection dates. The main objective of this observation was to notice the botanical changes in the research area, grave elevation loss and any scavenger intrusion.

Observation of the vegetation

When conducting the on-ground survey, only G6 showed signs of soil crusts formation on its surface just one week into the experiment. A soil crust is a shallow hard layer formed on the surface

of the soil due to rapid drying caused by suctioning its wetness from the underlying layers (Awadhwal and Thierstein, 1985). It increased throughout the weeks and lasted until the sixth-month post-burial (see Figure 21). Grave-edge cracks of both G5 and G6 started showing just seven days post-burial. The graves had clearly defined grave-edge cracks by the sixth month, which were as wide as 1.5 cm. Those cracks almost disappeared for G5 on the fifteenth month post-burial and for G6 on the last survey, which was conducted on the eighteenth month.



Figure 21 An overview of Grave 6 (framed in black) taken on the sixth month post-burial showing the soil crust formation on its surface (framed in red).

The first-time vegetation growth was noticed and recorded was during the on-ground survey in the sixth month post-burial. Almost all the enclosed research areas showed a sign of vegetation growth; however, the observation of the vegetation showed a clear difference in the vegetation growth between the graves and their surroundings. The single graves (G1, G2, G3 and G4) were in line with the research area in the colour of the vegetation but differed in their height. The graves had higher vegetation compared to their surroundings. On the other hand, the mass graves vegetation was greener and showed more vegetation growth than the surroundings. G6 vegetation growth reached 18.3

cm, while G5 reached 15.6 cm (see Figures 22a and 22b). This trend lasted up to the seventh month post-burial.

a)



b)



Figure 22 Vegetation difference between a) G5 and b) G6 in the seventh month post-burial.

By the ninth month, only the mass graves had dry vegetation on their surface, which also lost most of their height. G6 highest vegetation was 13 cm and G5 was 9 cm. Going through the tenth month, only G6 showed some dry vegetation on its surface, and G5 lost most of its vegetation. This dryness and loss of vegetation lasted until the fifteenth month. The last survey showed the regrowth of the vegetation inside the enclosed research area; however, all of it was in line with the nature. That is, there was not a distinguishable difference between the regrowth of vegetation on the surfaces of the graves when compared to their surroundings (see Figure 23).



Figure 23 An overview of the enclosed area taken 18 months post-burial.

Grave elevation

The on-ground grave height measurement using the measuring tape showed a loss of elevation of the graves as the days passed. G2, G4, and G6 encountered a swift elevation loss the first three days post-burial. These graves all contained sheep carcasses. Following those three days, all graves showed a steady trend of elevation loss. Table 11 shows the measured height of each grave throughout the research period, with 1 representing the ground surface.

Table 11 On-ground grave height measurement in centimetre. PB: post-burial.

Day measured	G1	G2	G3	G4	G5	G6
Same day	12	18	3	0	6	17
One day PB	8.5	6	0	0	6	7
3 day PB	9	-8	0	-9	6	5
1 week PB	8	-10	0	-9	4	5
2 weeks PB	8	-10	0	-11	4	5
3 weeks PB	8	-8	0	-10.5	4	4
1 month PB	8	-10	0	-11	4	4
2 months PB	8	-10	-1	-12	4	3
3 months PB	7	-10	-2	-12	3	3
6 months PB	5.5	-6	-5.5	-10	0	4
7 months PB	5.5	-8	-6	-8	0	3
9 months PB	5	-3	-5.5	-9	0	3
10 months PB	3	-2	-2.5	-5.5	0	2
11 months PB	3	-1.5	-2	-4.5	0	2
12 months PB	2.5	-1.5	-1.5	-4.5	0	2
15 months PB	2	-1	-1	-2	0	1
18 months PB	1	-1	-1	-1	0	1

Scavenger intrusion

On the first-day post-burial, scavengers were able to dig through G2 (hand-dug single grave) and feed on the buried carcass without fully exposing it. In addition, scavenger tracks were noticed around all graves, and evidence of digging could be seen (see Figure 24).



Figure 24 An overview of grave 6 showing tracks and digging marks of the scavenger.

On the third day post-burial, scavengers were able to dig most of the carcass out of G2 and partially expose the carcass buried in G4 (machine-dug single grave) and devour some of its body parts. Going into the first-week post-burial, G2 was almost entirely exposed, and scavengers managed to pull out the carcass, that showed signs of decomposition and insect inhabitation. On the other hand, G4 was uncovered by the scavengers and the carcass was devoured. By the third week, the scavengers were able to devour most of the carcass in G2 and G4, while G4 showed signs of

decomposition and insect inhabitation on its carcass. Scavengers did not manage to reach into G6 and dig out the buried carcasses being buried in a deeper grave.

4.1.4 Summary of on-ground findings

The on-ground data analysis explored the effect of buried carcasses and grave size on topsoil temperature, soil moisture and landscape changes. The on-ground temperature of the surrounding enclosed area was always higher than that of all graves. The on-ground temperature of the control graves was always higher than the experimental ones. The mass graves analysis showed that the buried carcasses did influence the obtained results for both the topsoil temperature and soil moisture. The empty grave (G5) was higher than the experimental grave (G6) in topsoil temperature 12 out of 18 times in which the temperature was measured. The highest topsoil difference G6 had on G5 was in the seventh month, which was by 2.2 °C.

On the other hand, the soil moisture of G1 and G6 were more frequently higher than G2 and G5, respectively, whilst G3 and G4 shared an equal number of times where one grave was higher than the other. More precisely, when comparing the soil moisture of the mass graves, the soil moisture of G6 was always higher than G5 throughout the experiment, with 2.77% being the highest difference between them.

Regarding the landscape changes, G6 was the only grave showing soil crust on its surface. In addition, both G5 and G6 had clearly defined grave-edge cracks, which were visible to the fifteenth- and eighteenth-months post-burial, respectively. Moreover, all graves had higher vegetation growth when compared to the surroundings, with G5 and G6 showing the highest growth and reaching a maximum height of 15.6 cm for G5 and 18.3 cm for G6. Furthermore, all graves had a steady trend of elevation loss, except for the first three days, when the graves with carcasses buried in them encountered a swift elevation loss. Lastly, scavengers successfully dug out the buried carcasses in G2 and G4 but not G6.

4.2 Aerial survey

As discussed in the preceding chapter, the analysis of captured images depends on the type of sensor used. Captured images were analysed using a variety of image processing software that are commercially available, some of which are licensed while others are free to use. For the purpose

of the study, the following flowchart illustrates the different types of software used for spatial data analysis in order to extract the required features (see Figure 25). The specialised software aids the process of detecting possible burial sites in an arid environment by highlighting the differences between the experimental and control graves. The same analysis was done for the images captured at five different heights mentioned in Chapter 3 section 3.3.2. During the analysis, it became apparent that the ultimate height, which maintained a clear GSD and had the most relevant discernible when compared to the on-ground results, was 30 m high. Henceforth, all aerial analyses listed will represent the obtained results at 30 m.

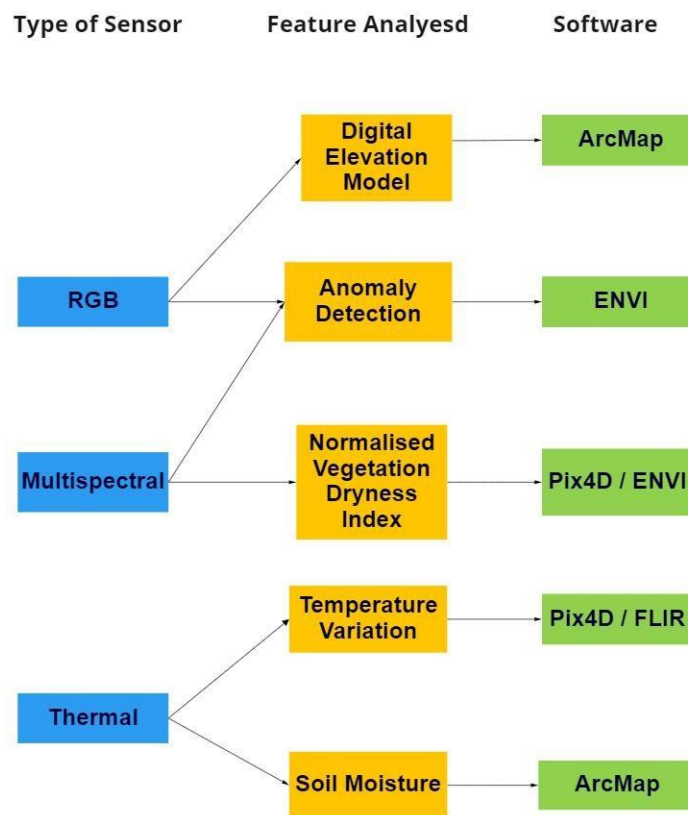


Figure 25 Flowchart of imaging sensors, feature analysed and the relevant software used in spatial analysis.

4.2.1 4K RGB Imaging

Parrot ANAFI Thermal was used to capture 4K RGB images of the research area, which were then merged into a single orthomosaic using Pix4Dmapper. This orthomosaic is used to spatially analyse the research area, calculate the DEM and detect anomalies.

Through the image processing steps, in addition to creating an orthomosaic, Pix4Dmapper allows the extraction of the DTM and DSM layers. As mentioned in Chapter 2 section 2.2.2, DTM represents the ground surface excluding all objects above, whilst DSM represents the actual surface, including all objects rising above the terrain. Hence, DEM is calculated using the Raster Calculator option available in ArcMap Spatial Analyst Tools by subtracting the DTM layer from the DSM layer.

An average of the obtained DEM values from the surfaces of the graves was calculated, which indicates the height of the graves. The results showed a loss of elevation as the days passed. The experimental graves showed a sharp elevation loss the first three days post-burial. Afterwards, all graves showed a steady trend of elevation loss. The following table illustrates the height of the graves measured on-ground, using a measuring tape placed on the centre of the grave and flattened against the ground surface, and the height of the graves, calculated from the DTM and DSM layers throughout the experiment.

Table 12 Graves height measurement obtained from the DEM and their relevant on-ground measurement in centimetre. DEM: Digital elevation model, PB: post-burial.

Day measured	Height measured	G1	G2	G3	G4	G5	G6
Day of digging	On-ground	12	12.5	3	0	6	17
	DEM	12.6	13.7	3.9	2.5	7.9	13.9
1 day PB	On-ground	12	6	0	0	6	7
	DEM	11.9	7	1	2.5	7	7
3 days PB	On-ground	10.8	-8	0	-9	6	5
	DEM	11.5	1	1	0	7	7
1 week PB	On-ground	8	-10	0	-9	4	5
	DEM	11	3	0	0	3.6	8.3
2 weeks PB	On-ground	8	-10	0	-11	4	5
	DEM	10	3	1	1	1	1

3 weeks PB	On-ground	8	-8	0	-10.5	4	4
	DEM	10	1	1	1	3	7
1 month PB	On-ground	8	-10	0	-11	4	4
	DEM	11	0.7	2.7	1	2.7	6.4
2 months PB	On-ground	8	-10	-1	-12	4	3
	DEM	10	0.7	1.7	0.6	8	6.5
3 months PB	On-ground	7	-10	-2	-12	3	3
	DEM	9.3	1.1	1.6	0.3	4	5.7
6 months PB	On-ground	5.5	-6	-5.5	-10	0	4
	DEM	7.9	1.2	1.2	0.2	1.2	5.9
7 months PB	On-ground	5.5	-6	-6	-8	0	3.2
	DEM	7.6	1.5	3.5	0.5	3.5	5.2
9 months PB	On-ground	5	-3	-5.5	-9	0	3
	DEM	7.2	1.5	3.5	0.5	2.2	4.1
10 months PB	On-ground	3	-2	-2.5	-5.5	0	2
	DEM	4.2	1.3	1.3	0.3	3.6	4.2
11 months PB	On-ground	3	-1.5	-2	-4.5	0	2
	DEM	2.8	1.3	1.3	1.3	2.7	3.5
12 months PB	On-ground	2.5	-1.5	-1.5	-4.5	0	2
	DEM	2	1.8	1.8	1.2	2.4	3.2

15 months PB	On-ground	2	-1	-1	-2	0	1
	DEM	2.6	1.2	1.2	1.2	1.4	2.5
18 months PB	On-ground	1	-1	-1	-1	0	1
	DEM	2.7	1.3	1.3	1.3	1.6	2.1

Figure 26 shows a sample of the DEM map calculated two months post-burial.

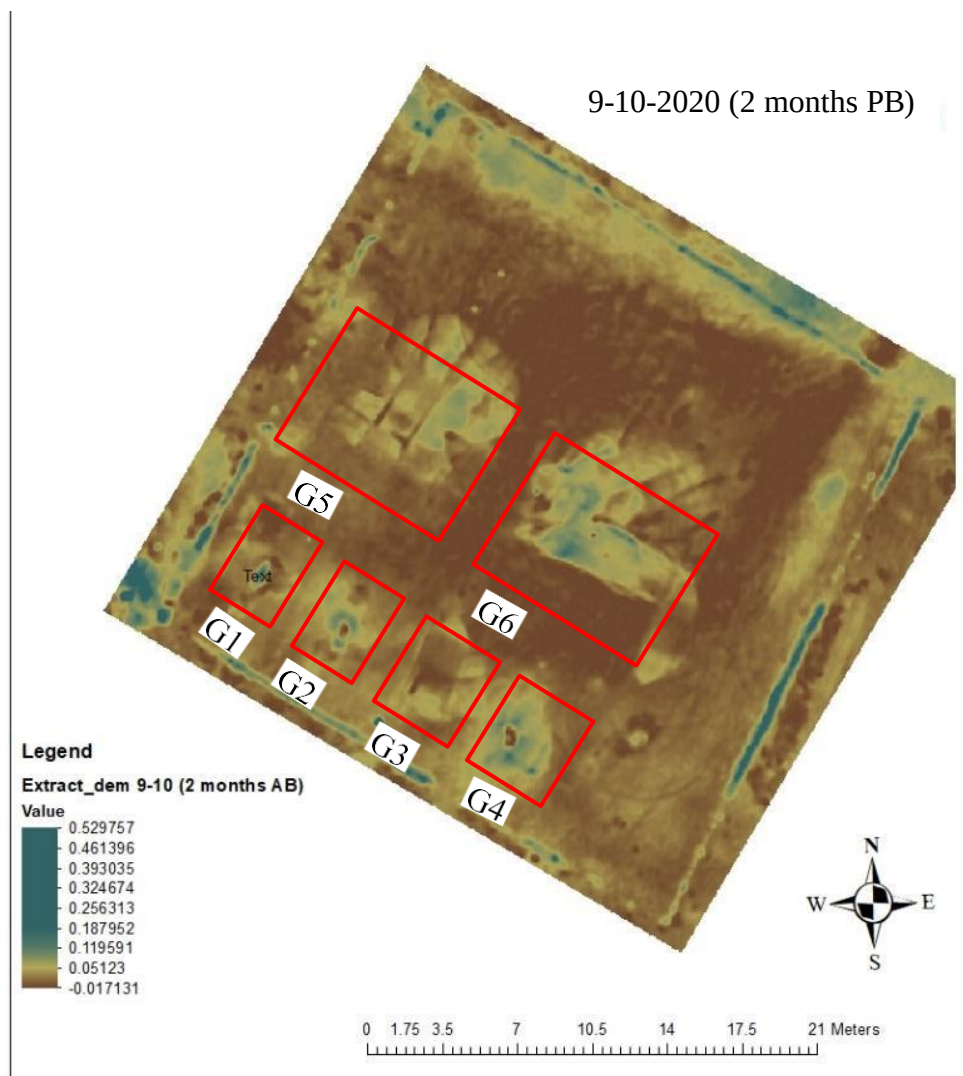


Figure 26 The DEM map of the research area calculated two months post-burial.

On the other hand, anomaly detection was explored and tested using manual and automated methods on both 4K RGB and MS images. In this section, only the anomaly detection results of 4K RGB images are discussed, whilst the MSI anomaly detection results are discussed in section 4.2.3.1.

The manual method is conducted by macroscopically visualising any anomalies in the extracted orthomosaic of the research area that might indicate the location of the graves without using any enhancement methods, colouring tools, or specialised computer software. It includes targeting surface features such as soil disturbance and differences in vegetation distribution. For the first three months, soil disturbance could be clearly detected when viewing the images of the research area. The following figure shows the soil disturbance which can be detected when visualising the research area three months post-burial.

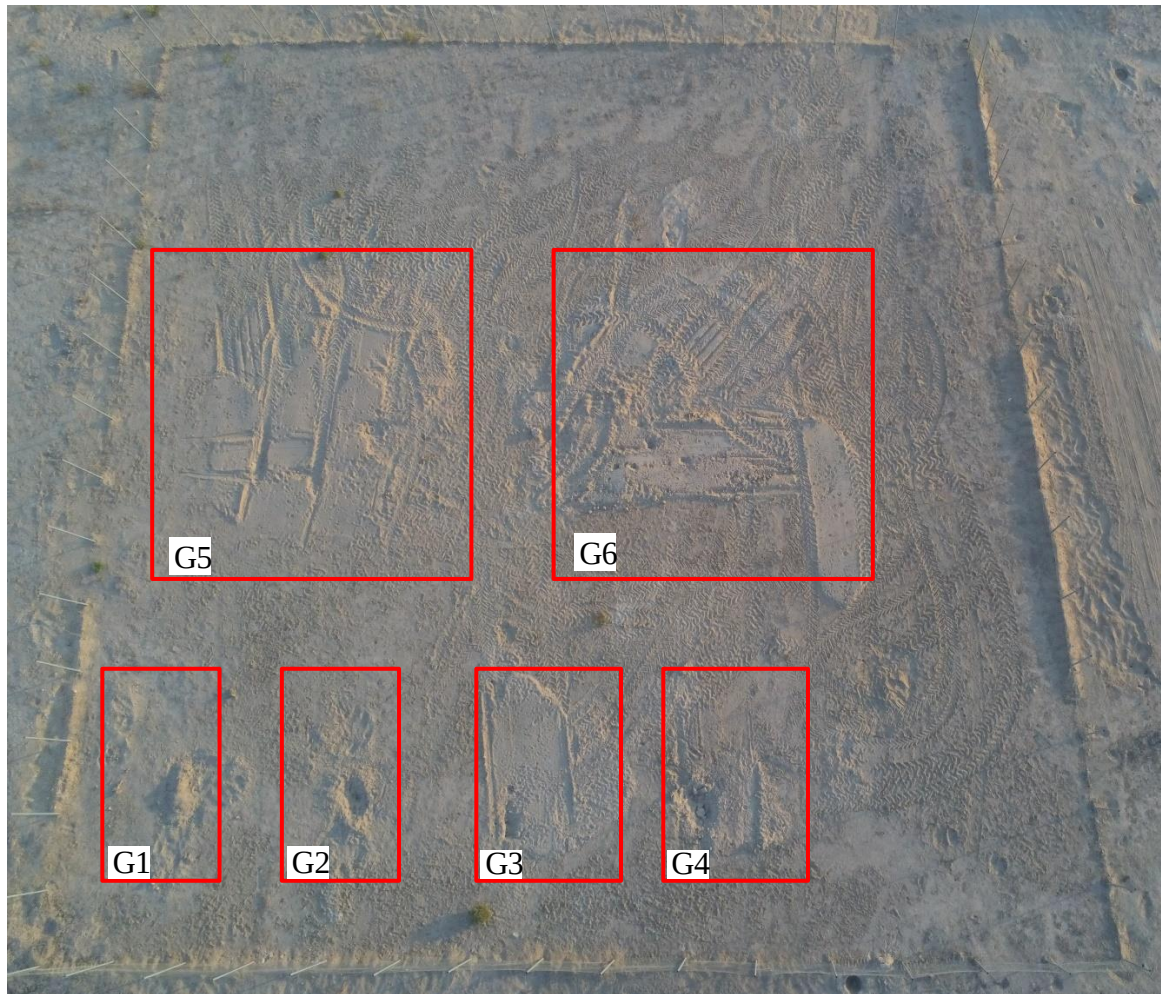


Figure 27 4K RGB overview image of the research area captured three months post-burial.

Toward the sixth and seventh months, the soil disturbance is visible in G5 and G6. In addition, the vegetation growth and distribution are very distinguishable when comparing G5 and G6 with the research area. Figure 28 below illustrates the appearance of vegetation growth on the graves when compared to their surroundings.

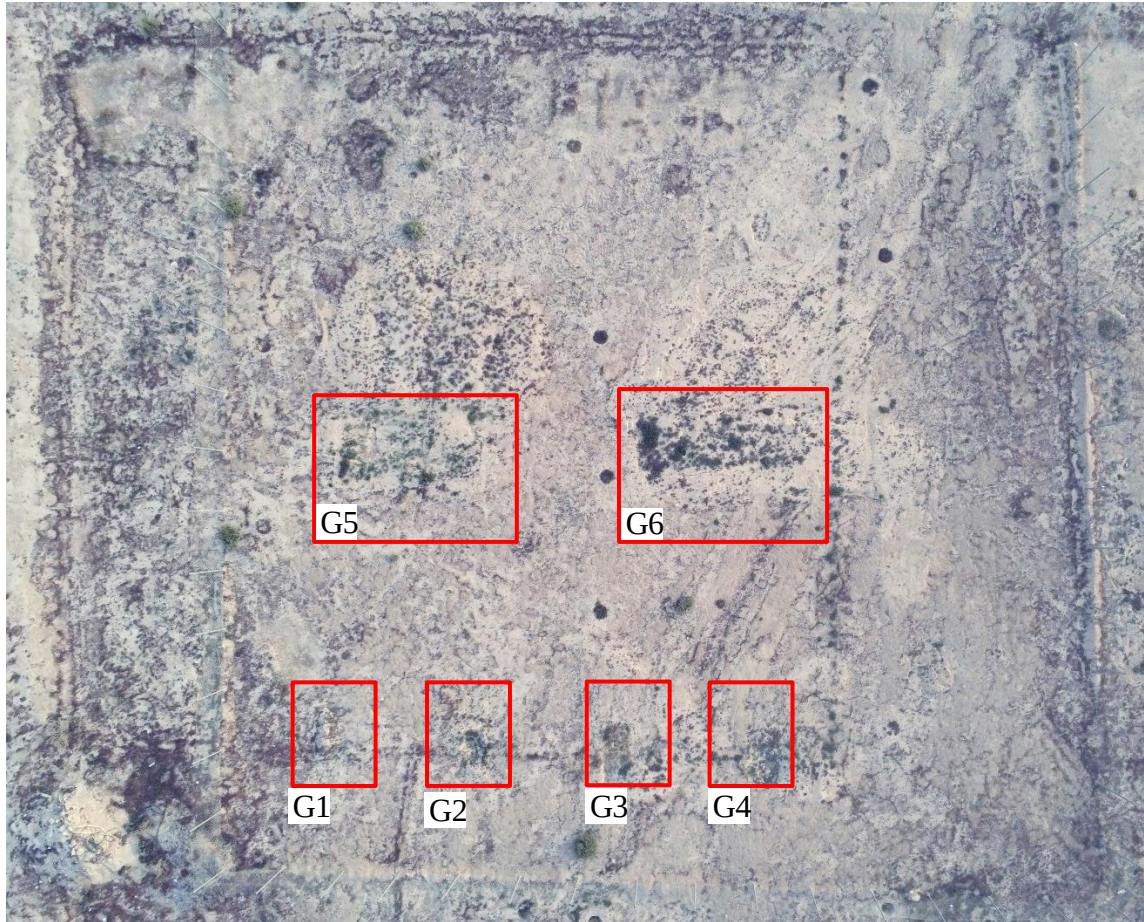


Figure 28 4K RGB overview image of the research area captured seven months post-burial.

By the ninth month, most of the vegetation dried and fewer topographic features were visually detectable when exploring the area. Only G5 and G6 show some soil disturbance and dried vegetation which can be detectable by the naked eye (see Figure 29).



Figure 29 4K RGB overview image of the research area captured nine months post-burial.

The captured images of the tenth, eleventh, twelfth and fifteenth months showed a clear view of all soil disturbance on the grave surfaces, except for G4. However, no sign of vegetation could be found. Lastly, the images captured in the eighteenth month did not show any type of soil disturbances or indications that could be used to locate the graves (see Figure 30).

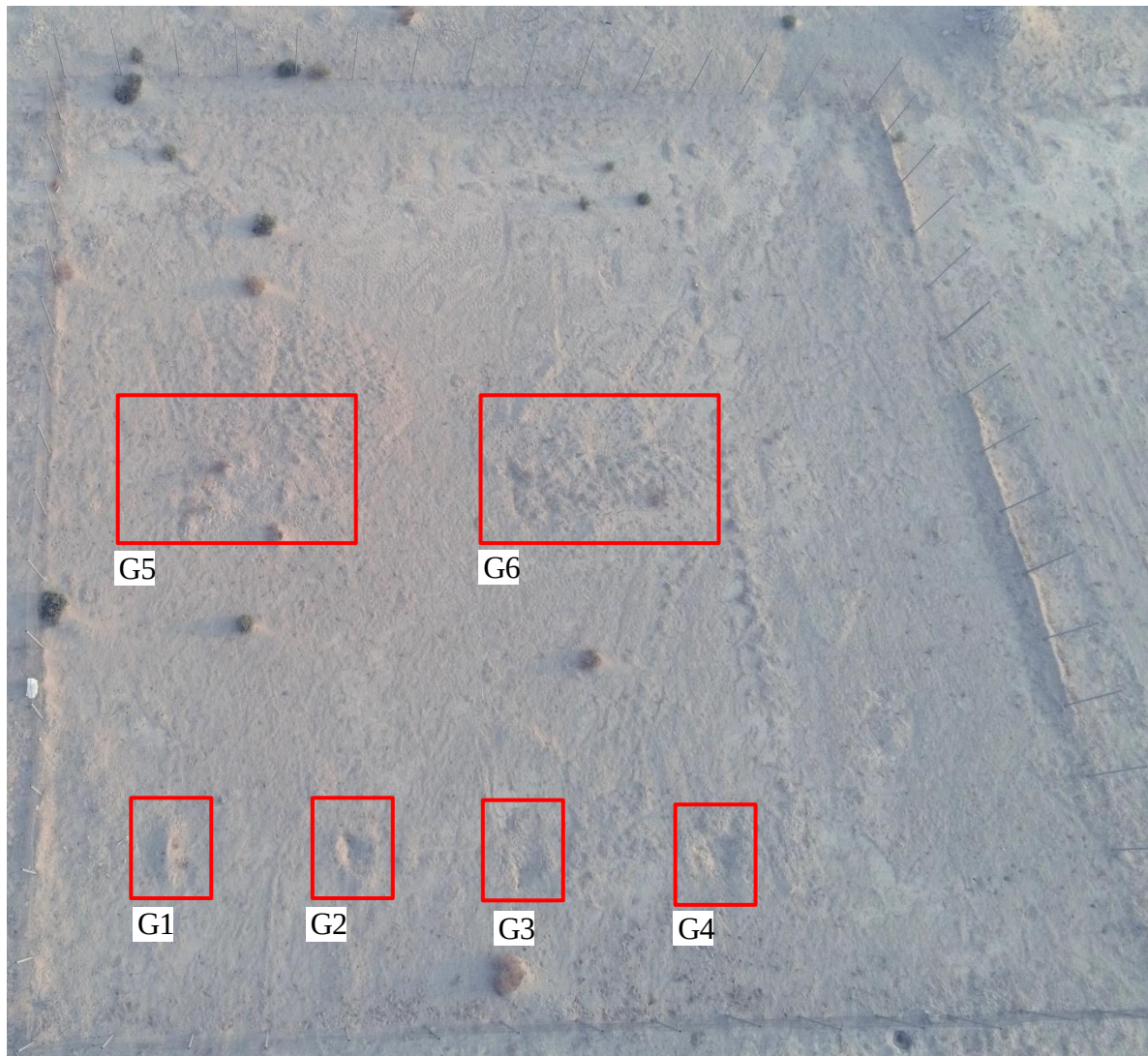


Figure 30 4K RGB overview image of the research area captured 15 months post-burial.

The automated anomaly detection method undertaken using the RX Anomaly Detection Tool in ENVI (Exelis Visual Information Solutions, 2020) involved the use of an algorithm which extracts targets that are spectrally distinct from the image background (Veerendra, Latha and GP, 2014). It proved to be successful, in almost the entire period of the experiment, when analysing the images captured in 4K RGB. This is true because it was able to identify soil disturbances related to the location of the graves by identifying bad pixels in the captured images, as explained in Chapter 3 section 3.3.2.1. The most suitable type of detector varied depending on the time of year and whether the area was vegetated or not. For the first two months, the RXD anomaly detection method proved to be the most successful tool. All graves were distinguished except for the first month, where G3 and G6 were not detectable (see Figure 31).

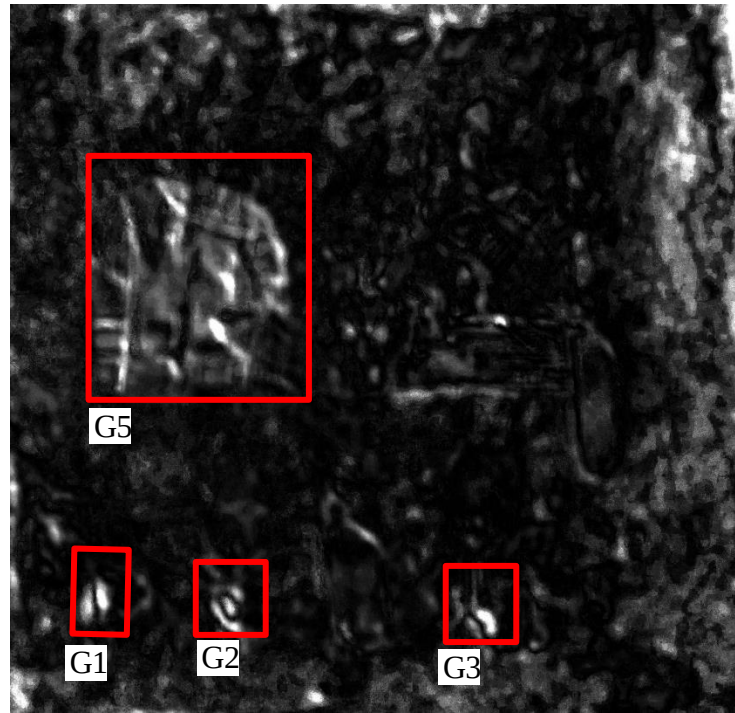


Figure 31 The application of the RXD anomaly detection method on the 4K RGB image, one month post-burial.

UTD was the best detection method in the RX Anomaly Detection tool from the third to the twelfth month of post-burial images. During this period, the level of detection was decreased when images from the third, sixth and ninth months got analysed. Their analysis showed some differences between the graves and the surrounding area; however, it was not as clear as the obtained results from the first two months. G3 was not detectable in the third month. G2 and G4 were not detectable in the sixth-month results. G1, G2 and G4 were not detectable in the ninth month (see Figure 32).

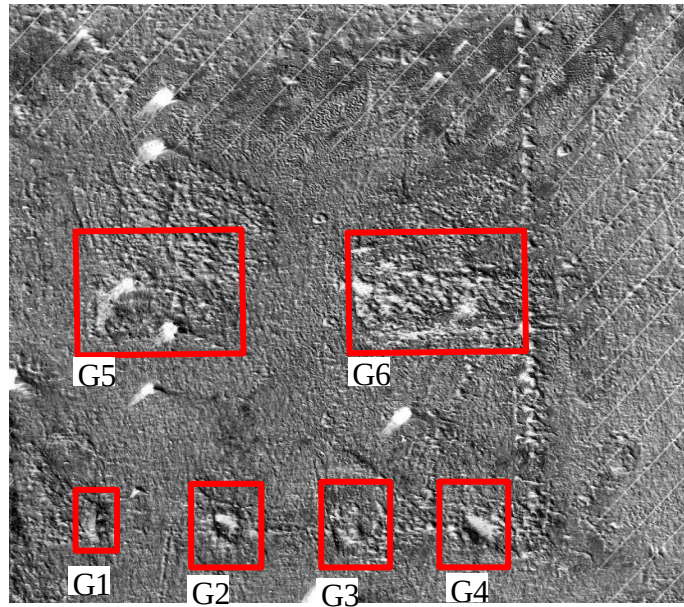


Figure 32 The application of the UTD anomaly detection method on the 4K RGB image, ten months post-burial.

The last two datasets analysed, which were for the fifteenth and eighteenth months, adapted best with the RXD method of detection. The fifteenth month result allowed only the detection of G1, G4, G5 and G6. On the other hand, all graves were visual in the eighteenth month dataset (see Figure 33).

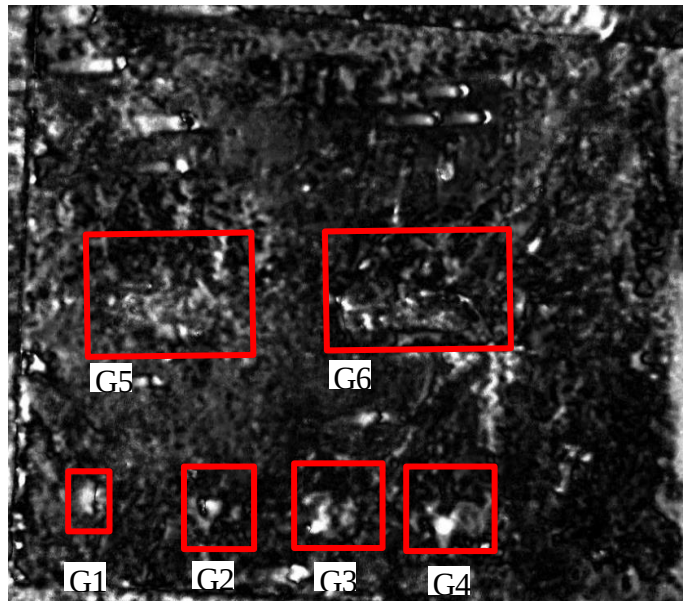


Figure 33 The application of the RXD anomaly detection method on the 4K RGB image, 18 months post-burial.

Table 13 illustrates the method of detection used and which graves were detectable when the RX Anomaly Detection tool was used.

Table 13 The graves which were detected when applying the RX Anomaly Detection Tool on 4K RGB images. PB: post-burial.

Collection date	Method of detection	G1	G2	G3	G4	G5	G6
10-08-2020 (1 day PB)	RXD	✓	✓	✓	✓	✓	✓
12-08-2020 (3 days PB)	RXD	✓	✓	✓	✓	✓	✓
16-08-2020 (7 days PB)	RXD	✓	✓	✓	✓	✓	✓
23-08-2020 (14 days PB)	RXD	✓	✓	✓	✓	✓	✓
30-08-2020 (21 days PB)	RXD	✓	✓	✓	✓	✓	✓
09-09-2020 (1 month PB)	RXD	✓	✓		✓	✓	✓
09-10-2020 (2 months PB)	RXD	✓	✓	✓	✓	✓	✓
09-11-2020 (3 months PB)	UTD	✓	✓		✓	✓	✓
09-02-2021 (6 months PB)	UTD	✓		✓		✓	✓
10-03-2021 (7 months PB)	UTD	✓	✓	✓	✓	✓	✓
10-05-2021 (9 months PB)	UTD			✓		✓	✓
15-06-2021 (10 months PB)	UTD	✓	✓	✓	✓	✓	✓
15-07-2021 (11 months PB)	UTD	✓	✓	✓	✓	✓	✓
21-08-2021 (12 months PB)	UTD	✓	✓	✓	✓	✓	✓
17-11-2021 (15 months PB)	RXD	✓			✓	✓	✓
06-02-2022 (18 months PB)	RXD	✓	✓	✓	✓	✓	✓

4.2.1.1 Summary of results pertaining to the use of a 4K RGB sensor to locate clandestine graves

The 4K RGB sensor was used to investigate whether variations in DEM and anomaly detection could aid in detecting the graves in the enclosed area. Firstly, the DEM was calculated using a tool available in ArcMap Spatial Analyst Tools by subtracting the DTM layer from the DSM layer. The DEM approach successfully distinguished G1, G2, G5 and G6 height differences when compared to their surroundings. The method was successful in detecting height differences as low as 1 cm. The backhoe flattened the surface of G3 and G4 upon refilling them, which is why the graves did not have any height differences from the surroundings.

The manual imagery inspection for soil disturbances on the graves proved to be a successful method for 15 months post-burial, apart from the disturbance on G4, which was visible until the ninth month only. In opposition, the automated anomaly detection carried out using the RX Anomaly Detection Tool accurately detected the disturbances on the graves throughout the research period. It is worth mentioning that the detectability of soil disturbance on the graves was not possible for all graves at all times. Out of the 16 images analysed, it was possible to detect all graves 11 times. Then, five graves were detected two times, four graves were detected two times and three graves were detected once. Regarding the best detection tool, RXD was the most successful tool used for the first two months. Afterwards, UTD was the most appropriate tool until the twelfth month. Lastly, RXD accurately detected the disturbance once again for the fifteenth and eighteenth months.

4.2.2 Thermal Imaging

Parrot ANAFI Thermal was used to capture thermal images of the research area, which were then merged into a single orthomosaic using Pix4Dmapper. The outcome of the captured images was used to measure the temperature variation between the graves and to calculate the soil moisture using the relevant formula. The temperature variation between the graves and the undisturbed research area within the enclosure was analysed using the FLIR Tools by creating a heat map of the area and quantifying the temperature of the graves (FLIR Systems Inc, 2015).

Graves 1 and 2

The temperature that was recorded using the thermal sensor deployed on the UAV (hereafter referred

to as aerial temperature) of the surrounding enclosed area was always higher than that of both graves, except for three occasions. When analysing the captured images, there was a very slight visible difference between the G1 (control hand-dug single grave) and G2 (experimental hand-dug single grave). The temperature of G1 was higher than G2 nine out of 18 times when images were captured. This includes the highest difference between the temperature of the graves (0.6 °C) recorded six months post-burial. In the other nine recordings, G2 was higher than G1 on seven occasions, whilst having equal temperatures on the other two occasions. Table 14 and Figure 34 show the captured temperatures of the graves and their surroundings throughout the experiment period.

Table 14 The captured temperature of G1, G2 and their surrounding throughout the experiment period. PB: post-burial.

Day measured	G1 aerial temperature (°C)	G2 aerial temperature (°C)	Surrounding temperature (°C)
1 day before	31.2	31.4	31.5
Same day	39	38.9	40.9
One day PB	37.7	37.5	38.6
3-day PB	37.2	36.8	37.8
1-week PB	28.2	28.2	29.2
2 weeks PB	28.4	28.6	29.4
3 weeks PB	28.2	28.3	29.2
1-month PB	30.3	30.1	30.6
2 months PB	21.4	21.1	22
3 months PB	24.1	24.1	24.3
6 months PB	6.8	6.2	6.9
7 months PB	9.9	9.8	9.2
9 months PB	23	22.7	23.1
10 months PB	30.4	30.5	30.4
11 months PB	32.4	32.2	33.2
12 months PB	31.1	31.3	32.1
15 months PB	8.7	8.9	8.7
18 months PB	2.9	3	3.2

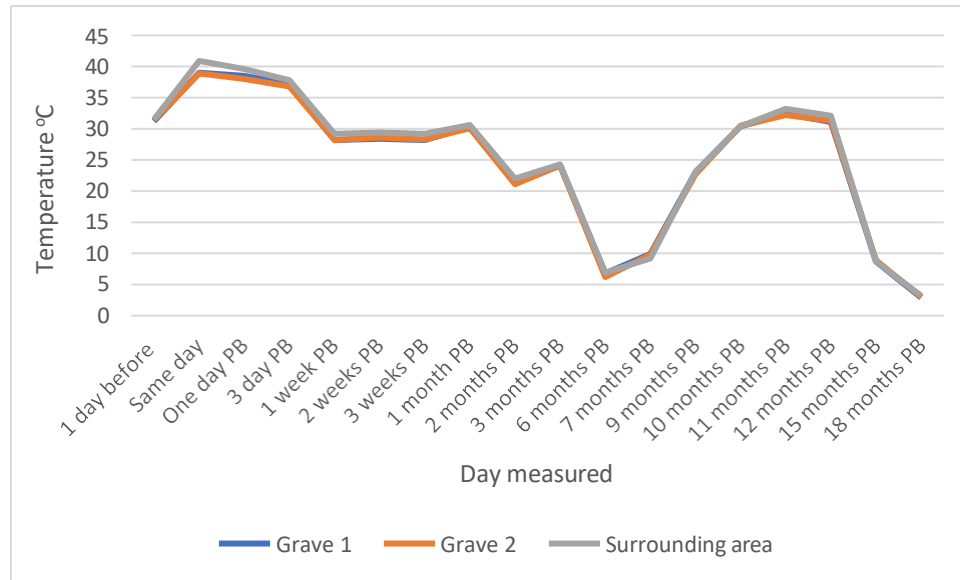


Figure 34 The captured temperature of G1, G2 and their surrounding throughout the experiment period.

Graves 3 and 4

The aerial temperature of the surrounding enclosed area was always higher than that of both graves, except for the third, tenth, fifteenth- and eighteenth-months post-burial. When analysing the captured thermal images, there was not much difference between the G3 (control machine-dug single grave) and G4 (experimental machine-dug single grave). The temperature of G4 was always higher than G3, and the highest difference between the graves was captured on the second week with a 1.2 °C difference. Table 15 and Figure 35 illustrate the captured aerial temperatures for G3 and G4 throughout the experiment period and the temperature of their surroundings.

Table 15 The captured temperature of G3, G4 and their surrounding throughout the experiment period. PB: post-burial.

Day measured	G3 aerial temperature (°C)	G4 aerial temperature (°C)	Surrounding temperature (°C)
1 day before	31.1	31	34
Same day	37.9	39.2	44.2
1-day PB	37	37.8	39.7
3-day PB	35.8	36.7	39.9
1-week PB	28.1	28.8	30.2
2 weeks PB	27.7	28.9	31.4
3 weeks PB	27.8	28.4	30.2
1-month PB	29.8	30.2	34.6
2 months PB	20.7	21.2	23.4
3 months PB	24	24.4	24.1

6 months PB	6.2	6.5	7.9
7 months PB	10	10.1	11.2
9 months PB	23.1	23.4	24.1
10 months PB	30.7	31.1	30.4
11 months PB	32.2	32.3	33.2
12 months PB	31.4	31.5	32.1
15 months PB	8.8	9	8.7
18 months PB	3	3.5	2.9

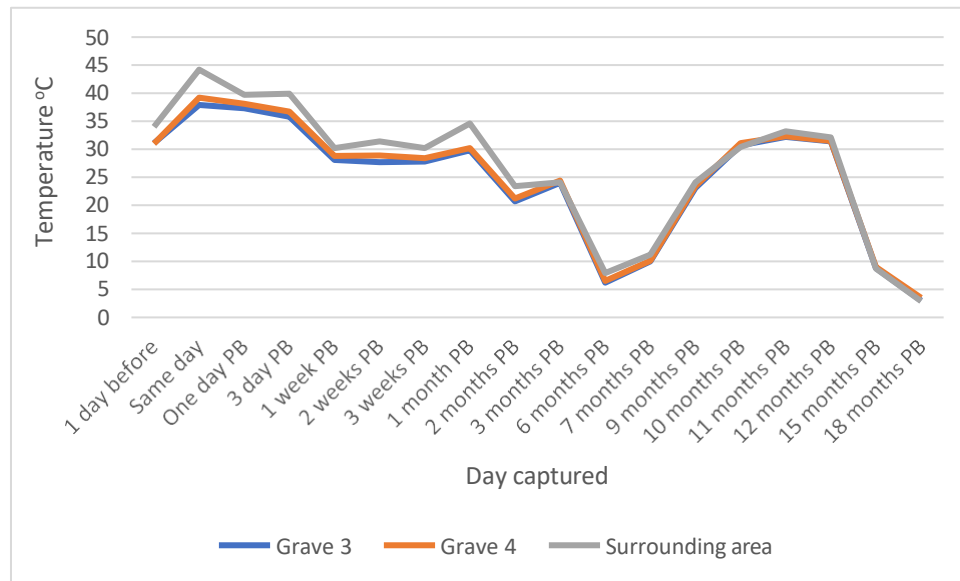


Figure 35 The captured temperature of G3, G4 and their surrounding throughout the experiment period.

Graves 5 and 6

When analysing the captured images, there was a visible difference between the temperature of G6 (experimental mass grave), G5 (control mass grave) and their surroundings. The temperatures of G6 and G5 were almost equal to each other in most of the times when the temperatures were recorded, except for the third, sixth and seventh months. The seventh month captured thermal images showed that G6 was higher than G5 with a noticeable difference of 3.3 °C (see Figure 36).

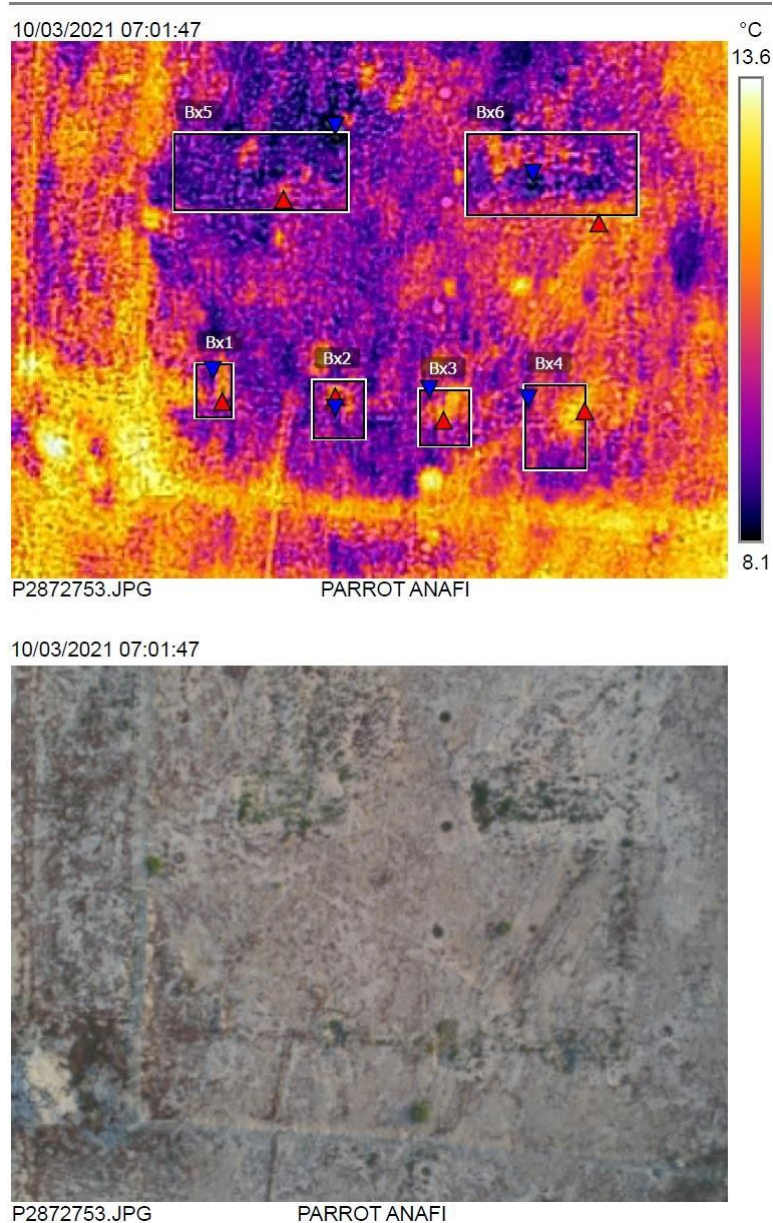


Figure 36 FLIR Thermal Studio Suite result view of the six graves which was captured 7 months post-burial.

The temperature of G6 and G5 were consistently lower than the surrounding area temperature for the first two months. However, on the third-month post-burial, the temperature of G6 was higher than that of G5 and their surroundings, which were almost equal to each other. This trend continued from the third to the seventh month. Table 16 and Figure 37 show all the recorded temperatures of G5, G6 and their surroundings.

Table 16 A comparison between the captured temperature of G5 and G6 using the ANAFI Thermal. PB: post-burial.

Data measured	G5 aerial temperature (°C)	G6 aerial temperature (°C)	Surrounding temperature (°C)
Same day	36.4	36.2	43.3
1-day PB	36.8	37.1	38.8
3 days PB	35.9	36.2	38.4
1-week PB	27.6	28.8	29.2
2 weeks PB	29.1	30	31.4
3 weeks PB	29.3	29.9	31.2
1-month PB	31.5	32.2	34.6
2 months PB	21.5	21.9	23.4
3 months PB	23.5	25.4	23.1
6 months PB	5.8	7.9	5.4
7 months PB	9.5	12.8	9.2
9 months PB	23.2	23.6	24.1
10 months PB	29.4	29.1	30.4
11 months PB	32.7	32.5	33.2
12 months PB	30.1	30.3	31.1
15 months PB	27.6	28.8	28.7
18 months PB	2.9	3	2.9

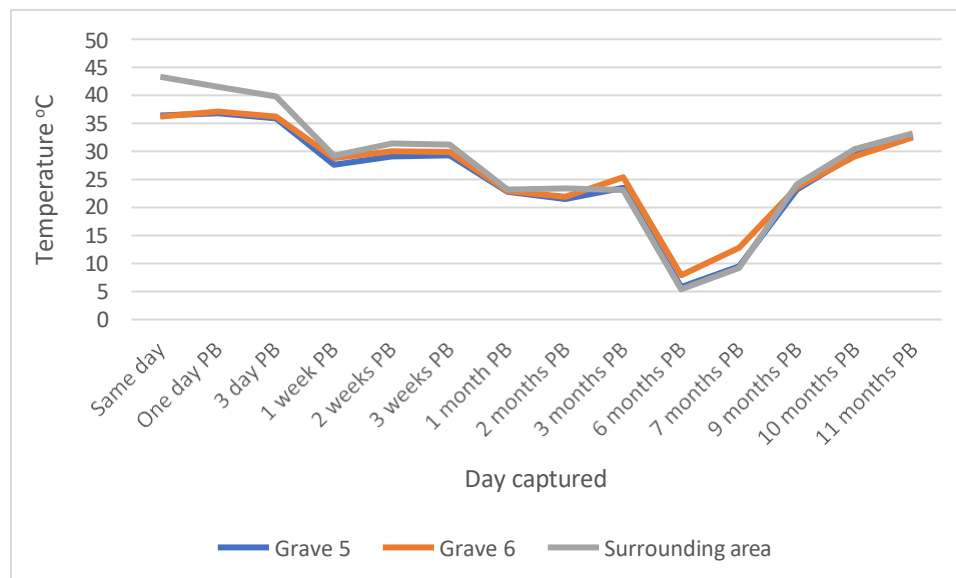


Figure 37 The temperature measured for G5 and G6 using the ANAFI Thermal, compared to their surroundings. PB, post-burial.

Another aspect considered when analysing the thermal images was the topsoil soil moisture. The study of soil moisture with UAVs is considered more advantageous than the costly conventional platforms such as satellites since UAVs can have higher spatial resolution resulting from flying at lower heights closer to the area of interest (Casamitjana et al., 2020). The orthomosaics created from the captured thermal images are used to calculate the soil moisture using the geospatial processing software ArcMap. It is calculated using the temperature vegetation dryness index (TVDI) formula (Chen et al., 2015):

$$TVDI = \frac{T_s - T_{smin}}{T_{smax} - T_{smin}}$$

Equation 3 where T_s is the temperature at a specific pixel, T_{smin} is the lowest temperature of the area of interest, and T_{smax} is the highest temperature of the area of interest.

ArcGIS Desktop software, through its Esri ArcMap application, was used to extract the T_s of each pixel in the thermal images and to calculate its relevant soil moisture resembled in the TVDI (ESRI, 2002). First, a shape file is drawn around each grave in preparation for each feature extraction. Then, the Spatial Analyst Tools – Extract by Mask feature available in the geospatial processing software was used to extract the T_s for all the pixels inside the graves and the surrounding area. Afterwards, the TVDI for the extracted points was calculated using the abovementioned formula. The Map Algebra tool - Raster Calculator feature available in Esri ArcMap was used to implement the formula.

TVDI ranges from 0 to 1, where 0 represents the highest water content point, and 1 is the lowest. There was a visible difference in soil moisture between the graves and the surrounding area that could be visualised from the TVDI index maps. The soil moisture of all graves could be visually distinguished from the enclosed area for the first month. Afterwards, only G5 and G6 showed a visible difference between them and the surroundings. Figure38 shows the calculated index map of the TVDI for the research area in the seventh month.

TVDI map seven months post-burial

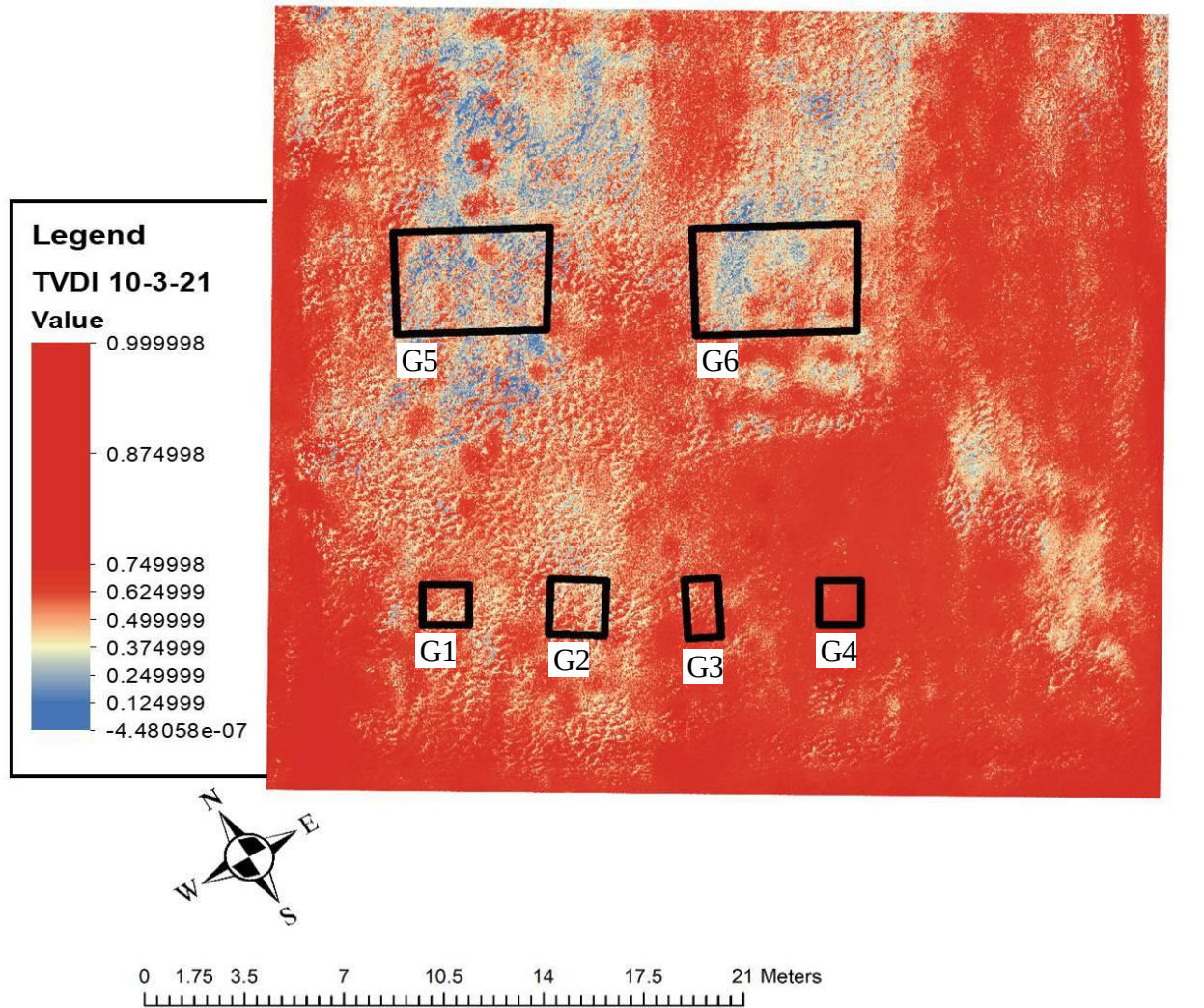


Figure 38 Calculated index map of the TVDI for the research area on the seventh month, where the blue area marks both the experimental and control mass graves.

This difference was detectable until the tenth month post-burial. After the tenth month, the TVDI index map levelled up, and there was no sign of soil moisture difference between the graves and the enclosed area. For the time when the soil moisture of the mass graves was visually distinguishable, and when compared to the surroundings, it always showed higher moistness levels. Table 17 illustrate the descriptive statistics of the TVDI, which is automatically calculated using the Zonal Statistics as Table method available in ArcMap Spatial Analyst Tools, along with its relevant index map, seven months post-burial. This method automatically calculates a selected minimum, maximum, range and mean values of the area based on the information available in the input image.

Table 17 The minimum, maximum, range and mean TVDI values of the graves and the surrounding area calculated seven months post-burial.

Data measured	Minimum	Maximum	Range	Mean
G1	0.16	0.60	0.45	0.30
G2	0.18	0.59	0.41	0.29
G3	0.15	0.65	0.50	0.32
G4	0.15	0.71	0.56	0.37
G5	0.04	0.57	0.53	0.24
G6	0.02	0.58	0.56	0.25
Surrounding Area	0.44	0.99	0.95	0.33

4.2.2.1 Summary of results pertaining to the use of a thermal sensor to locate simulated clandestine graves

The use of a thermal sensor to aid the detection of the simulated graves was achieved through the analysis of the captured thermal images by the Parrot ANAFI Thermal to ascertain whether there is any temperature variation between the temperatures and soil moisture of the graves and their surroundings. The outcome of the analysis was evaluated based on the type of grave. That is, whether it was a single grave or a mass grave, or if the grave was occupied or not. Hence, G1 and G2, G3 and G4, and G5 and G6 were compared.

For G1 and G2, the grave temperature analysis outcome was heavily affected by scavenger intrusions. Regarding G3 and G4, the temperature of G4 was always higher than G3. Lastly, G6 was always higher than G5 until the tenth month post-burial when G5 got higher by 0.3 °C. Afterwards, the temperature of the graves almost levelled up. The highest temperature difference was recorded in the seventh month when G6 was warmer than G5 by 3.3 °C. After that, the

temperature of G6 and G5 were consistently lower than the surrounding area temperature, except for the third month post-burial when G6 was higher than G5 and the surrounding.

With the advantage of having more spatial resolution than satellite platforms, the measured soil moisture from the captured thermal images by the UAV showed promising results. For the first month, all graves showed visual differences in soil moisture when visualising the TVDI map. Afterwards, only the mass graves had higher soil moisture than the surrounding, which lasted up until the tenth month post-burial.

4.2.3 Multispectral Imaging

Parrot Bluegrass, coupled with a Parrot Sequoia sensor, was used to capture MS images of the research area. As mentioned in Chapter 2 section 2.2.2, an image of the calibration reflectance targets is captured prior to any flight mission. Once the images are captured, and similarly to the 4K RGB image analysis process, images are merged into an orthomosaic using Pix4Dmapper. One crucial step in this processing step is the calibration of each band, done using the image of the calibration target. Once uploaded to Pix4Dmapper, the software identifies each band, allowing each band to merge. Hence, Pix4Dmapper allows the extraction of four individual orthomosaics that are spectrally different. Each spectral band of the Red, Green, red-edge and NIR has its orthomosaic. One option enabled when analysing the MSI is the index calculation of the NDVI, which was thoroughly discussed and explained in Chapter 2 section 2.2.1. The extracted orthomosaics are then used to analyse the research area and detect surface anomalies spatially. The anomaly detection is done using the manual detection method and the automated RX Anomaly Detection tool by ENVI.

When examining the images manually and trying to identify any surface anomalies that could help in the process of grave detection, the results revealed that the NIR and red-edge wavelengths had the most details that could aid this process. The NIR output had the best band to visualise the surface anomalies in 10 of the 15 data sets collected. The red-edge was the best detection method for the other five data sets, in which the NIR band was the second-best. Meanwhile, throughout the research, the Green band had the lowest detection rate among all the spectral bands showing the least amount of information on the images. Table 18 indicates the arrangement level of the bands most suitable for each data collection date.

Table 18 The arrangement level of the bands which indicates the best method of detection. PB: post-burial.

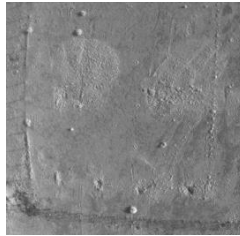
Collection Date	Bands detection Level			
	High _____ Low			
10-08-2020 (1-day PB)	Red-Edge	NIR	Red	Green
12-08-2020 (3 days PB)	Red-Edge	NIR	Red	Green
16-08-2020 (7 days PB)	Red-Edge	NIR	Red	Green
23-08-2020 (14 days PB)	NIR	Red	Red-Edge	Green
30-08-2020 (21 days PB)	NIR	Red-Edge	Red	Green
09-09-2020 (1-month PB)	NIR	Red	Red-Edge	Green
09-10-2020 (2 months PB)	NIR	Red	Red-Edge	Green
09-11-2020 (3 months PB)	NIR	Red	Red-Edge	Green
09-02-2021 (6 months PB)	NIR	Red-Edge	Red	Green
10-03-2021 (7 months PB)	NIR	Red-Edge	Red	Green
10-05-2021 (9 months PB)	NIR	Red-Edge	Red	Green
15-06-2021 (10 months PB)	Red-Edge	NIR	Red	Green
15-07-2021 (11 months PB)	NIR	Red-Edge	Red	Green
21-08-2021 (12 months PB)	Red-Edge	NIR	Red	Green
17-11-2021 (15 months PB)	NIR	Red-Edge	Red	Green

The following figures present the different types of results obtained when viewing the reflectance map of the different bands, captured on the seventh month using the multispectral sensor and 4K RGB:

a) RGB



b) NIR



c) red-edge



d) Green



e) Red

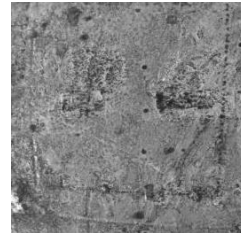


Figure 39 The different bands of MSI captured for the same image frame in the seventh month post-burial: (a) RGB (b) NIR (c) red-edge (d) Green (e) Red.

Similarly, to the results obtained from the 4K RGB image analysis, the automated anomaly detection method ran on the MSI using the RX Anomaly Detection Tool in ENVI (Exelis Visual Information Solutions, 2020) proved successful for almost the entire period of the experiment. As was found with the 4K RGB images, the results of the first two months showed high detectability levels of all graves when analysed (see Figure 40). In those two months, day one and day three post-burial showed that UTD was the best detection method, whilst days 7, 14, 21, 30 and 60 post-burial were best detected using the RXD-UTD.

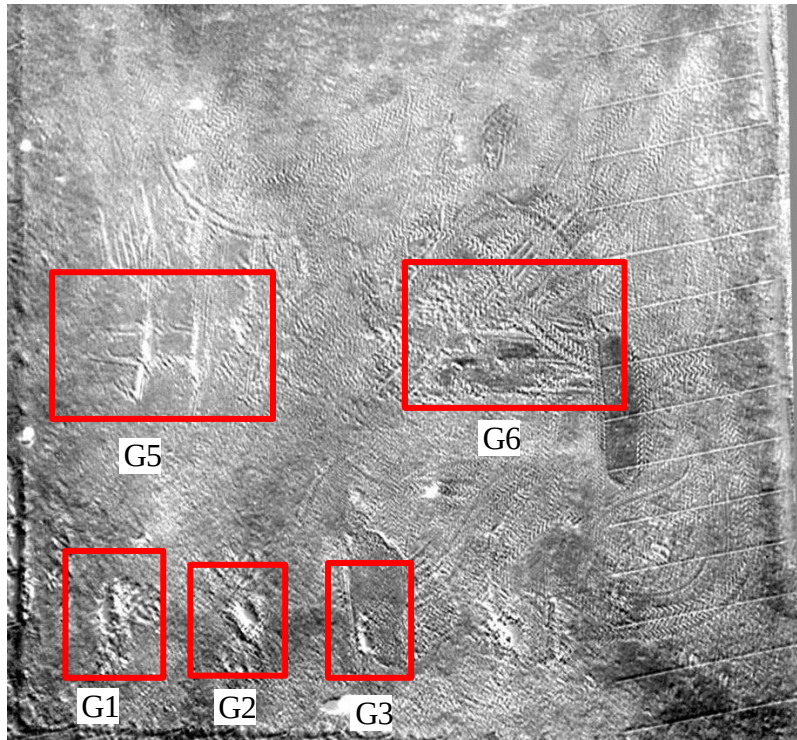


Figure 40 The application of the RXD-UTD anomaly detection method on the MSI image, two months post-burial.

The third month was not as clear as the previously analysed data. Using the RXD-UTD, only graves 1, 2 and 5 were detectable (see Figure 41).

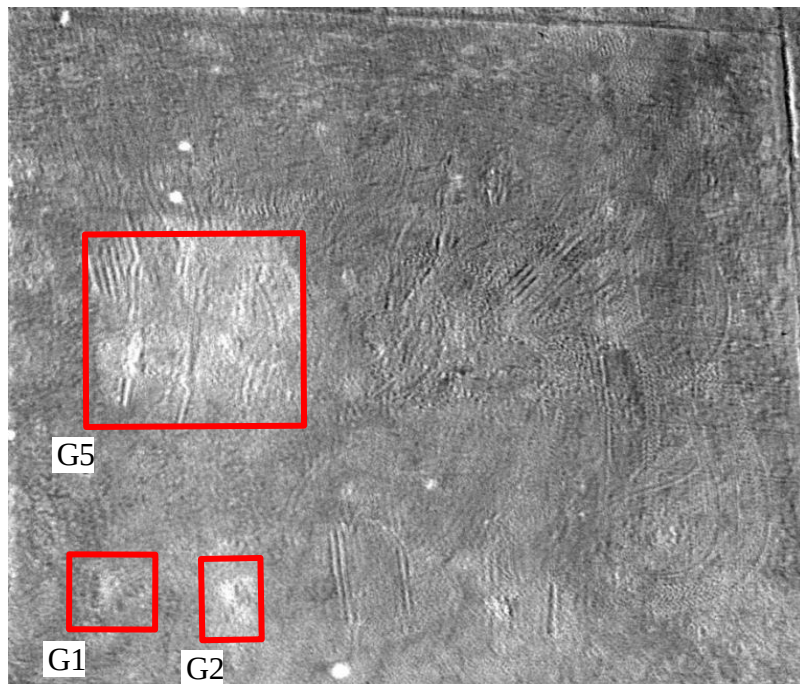


Figure 41 The application of the RXD-UTD anomaly detection method on the MSI image, three months post-burial.

The anomaly detection of the sixth and seventh months was performed and showed that the RXD was the best method of detection, and all graves were detectable. The analysis results of the ninth-month anomaly detection process had lower rates, with the RXD-UTD being the best method of detection for the grave, excluding G5, which was not detectable. The tenth-month anomaly detection results were not expected. It is the only month that did not show any signs of anomaly detection around any of the graves. The eleventh-month anomaly detection was not very clear. The RXD-UTD method of detection was the most suitable for the images captured this month, and all graves were detected except for G6. The twelfth-month results were apparent and easy to visualise, with RXD-UTD being the best anomaly detection mode (see Figure 42).

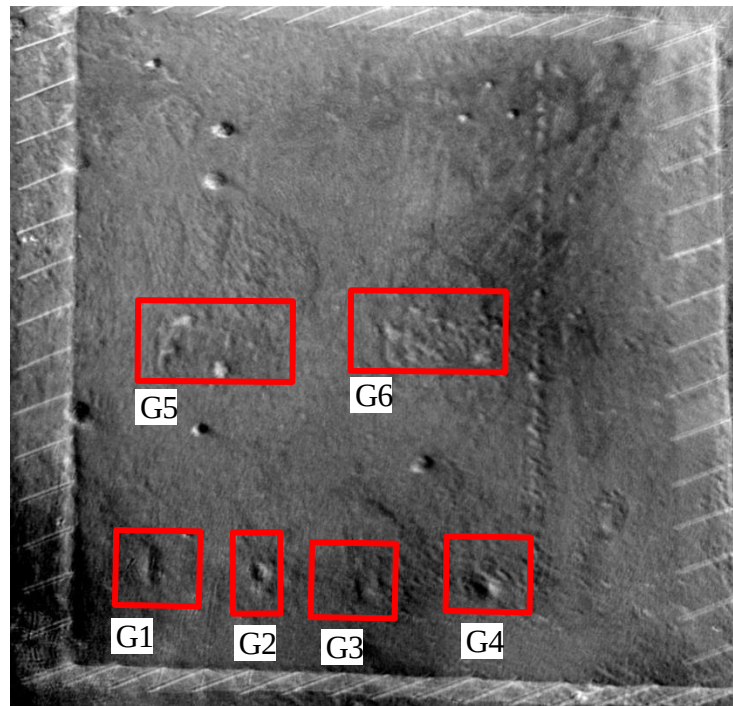


Figure 42 The application of the RXD-UTD anomaly detection method on the MSI image, twelve months post-burial.

The fifteenth-month post-burial anomaly detection showed that UTD is the most suitable detector, with some defects in the result. The image was blurry, with some noise that caused a variation in brightness and colour information (see Figure 43).

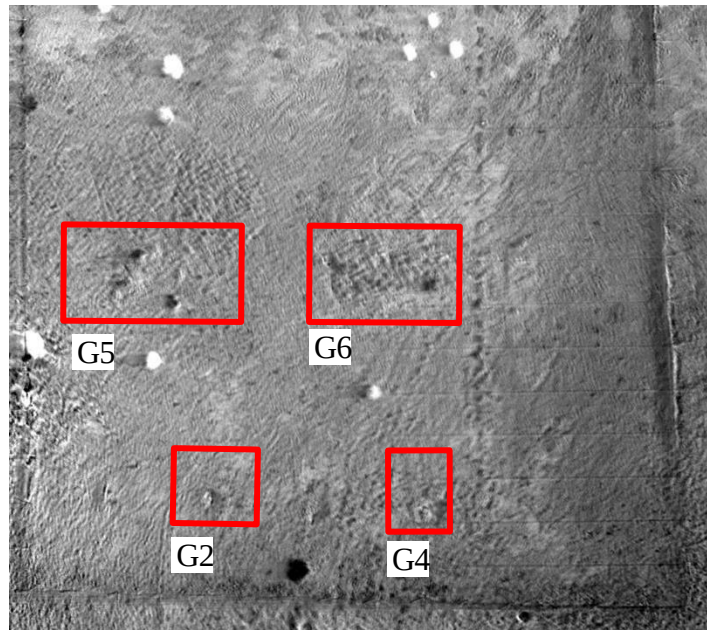


Figure 43 The application of the UTD anomaly detection method on the MSI image, 15 months post-burial

The eighteenth-month images were not captured due to an error with the UAV connection with the Pix4Dcapture software. Table 19 illustrates the method of detection used and which graves were detectable when the RX Anomaly Detection tool was used on the MSI.

Table 19 The graves which were detected when applying the RX Anomaly Detection Tool on MSI. PB: post-burial.

Collection date	Method of detection	G1	G2	G3	G4	G5	G6
10-08-2020 (1 day PB)	UTD	✓	✓	✓	✓	✓	✓
12-08-2020 (3 days PB)	UTD	✓	✓	✓	✓	✓	✓
16-08-2020 (7 days PB)	RXD- UTD	✓	✓	✓	✓	✓	✓
23-08-2020 (14 days PB)	RXD- UTD	✓	✓	✓	✓	✓	✓
30-08-2020 (21 days PB)	RXD- UTD	✓	✓	✓	✓	✓	✓
09-09-2020 (1 month PB)	RXD- UTD	✓	✓	✓	✓	✓	✓
09-10-2020 (2 months PB)	RXD- UTD	✓	✓	✓		✓	✓
09-11-2020 (3 months PB)	RXD- UTD	✓	✓			✓	

09-02-2021 (6 months PB)	RXD	✓	✓	✓	✓	✓	✓
10-03-2021 (7 months PB)	RXD	✓	✓	✓	✓	✓	✓
10-05-2021 (9 months PB)	RXD- UTD	✓	✓	✓	✓		✓
15-06-2021 (10 months PB)	UTD						
15-07-2021 (11 months PB)	RXD- UTD	✓	✓	✓	✓	✓	
21-08-2021 (12 months PB)	RXD- UTD	✓	✓	✓	✓	✓	✓
17-11-2021 (15 months PB)	UTD		✓		✓	✓	✓

MSI has many benefits for vegetation monitoring compared to traditional 4K RGB images (Assmann et al., 2018). As stated in section 2.2, NDVI is mainly used in agriculture, biology and other geosciences as a standardised way to measure healthy vegetation. However, here NDVI index is applied as an explanatory contribution in bare-soil soil moisture estimation, similar to experimental conditions that have been previously conducted since the research is carried out in a desert environment lacking vegetation cover (Casamitjana et al., 2020). The closer the number is to 1, the higher the indication that the soil is moist. For the radiometric processing and calibration, the spectral bands were set to 0.172, 0.215, 0.266 and 0.369 for green, red, red-edge and NIR, respectively (Franzini et al., 2019).

During the study period, there were sequential and spatial changes in the normalised difference vegetation index (NDVI) values for all six graves. For the first three months, based on the obtained values of NDVI, all six graves were categorised under the open soil class following the classification mentioned in Chapter 2 section 2.1.4. The NDVI values for the graves in the sixth, seventh and ninth months were all classified under the sparse vegetation (shrubs and pastures) class. The tenth month NDVI values showed the single hand-dug graves (G1 and G2) falling under the open soil class and the other four graves maintaining their level at the sparse vegetation class. In the following month, the NDVI values for the graves were still the same, with the only difference being that the control single machine-dug grave (G3) fell to the open soil class. The one-year data collection showed that only the mass graves (G5 and G6) had NDVI values to be classified under the sparse vegetation class,

while the remaining graves all fell under the open soil class. The NDVI values of all graves in the fifteenth and eighteenth months were classified as open soil class. Finally, when the NDVI values of the graves were compared to the surroundings, there was a minor difference between them. This difference was only noticed within the mass graves values compared to the surroundings. Table 20 illustrates the obtained NDVI values of all graves throughout the 18 month research period, along with the highest and lowest NDVI values recorded for the surroundings.

Table 20 NDVI values for all graves throughout the research period, along with the highest and lowest NDVI values of the surrounding area. PB: Post-burial.

Collection Date	Highest Value	Lowest Value	G1	G2	G3	G4	G5	G6
12-08-2020 (3 days PB)	0.19	0.03	0.04	0.04	0.08	0.07	0.1	0.15
16-08-2020 (7 days PB)	0.17	0.03	0.04	0.04	0.09	0.08	0.15	0.16
23-08-2020 (14 days PB)	0.12	0.02	0.03	0.04	0.07	0.09	0.15	0.17
30-08-2020 (21 days PB)	0.12	0.02	0.02	0.02	0.03	0.04	0.09	0.12
09-09-2020 (1 month PB)	0.14	0.04	0.02	0.02	0.03	0.04	0.1	0.13
09-10-2020 (2 months PB)	0.2	0.06	0.06	0.07	0.07	0.08	0.19	0.2
09-11-2020 (3 months PB)	0.17	0.06	0.07	0.07	0.09	0.08	0.16	0.17
09-02-2021 (6 months PB)	0.49	0.2	0.25	0.27	0.31	0.32	0.42	0.48
10-03-2021 (7 months PB)	0.56	0.3	0.23	0.24	0.29	0.31	0.4	0.56
10-05-2021 (9 months PB)	0.43	0.2	0.2	0.2	0.25	0.27	0.38	0.42
15-06-2021 (10 months PB)	0.35	0.12	0.14	0.13	0.2	0.22	0.31	0.34
15-07-2021 (11 months PB)	0.32	0.08	0.09	0.08	0.19	0.21	0.25	0.3
21-08-2021 (12 months PB)	0.21	0.05	0.07	0.08	0.12	0.14	0.21	0.21

17-11-2021 (15 months PB)	0.18	0.04	0.06	0.06	0.09	0.07	0.15	0.16
06-02-2022 (18 months PB)	0.35	0.07	0.07	0.07	0.09	0.08	0.17	0.18

4.2.3.1 Summary of results pertaining to the use of a multispectral sensor to locate clandestine graves

Parrot sequoia, a multispectral sensor, was the primary sensor used to calculate the NDVI of the research area. In addition, it captured the research area with four spectrally different bands, which are Red, Green, red-edge and NIR, that are used to detect surface anomalies manually and automatically. Upon analysing the images, it was shown that NIR and red-edge were the most suitable wavelengths for manual anomaly detection throughout the research due to having the best outcome that details the graves in 10 out of 15 data sets captured with the MSI. Alternatively, when MSI is used, the automated anomaly detection method was able to successfully detect surface anomalies in all graves in 10 out of 15 data sets captured. In the other five data sets, the anomaly detection method successfully detected between four and five surface anomalies on the graves. UTD was the best detection method for the first three days, and then RXD-UTD was favoured until the end of the third month. The most successful method of the sixth and seventh months was the RXD. By the ninth month, RXD-UTD was again the best method to use and maintained this detection level until the twelfth month post-burial. Lastly, UTD was the best method used for the fifteenth month. The eighteenth-month results were inconclusive when analysed for surface anomaly detection.

MSI was used to explore whether variations in NDVI over time could help detect the location of a grave in an arid environment lacking dense vegetation. When the same group of graves were compared, they showed little difference when measuring their NDVI. Generally, the graves had modest differences in NDVI values compared to their surroundings.

4.3 Statistical analysis

In addition to the abovementioned photogrammetric results obtained from the various software used both for the on-ground and the aerial data, descriptive statistics using SPSS (IBM, 2021) and percentage analysis were also used to evaluate and present the on-ground and aerial data. A series of one-way and two-way ANOVA were conducted based on the type of graves and whether the data

was from an on-ground or aerial method. The goal was to statistically determine whether the distribution of the categorical variables (UAV height, number of carcasses buried and the size of the grave) for each set of graves (G1 and G2, G3 and G4, G5 and G6) have a measurable effect on the dependent variables which are the graves soil moisture (on-ground) and temperature (both on- ground and aerial). Lastly, a correlation test was run to examine the relationship between the on- ground and the aerial temperatures of the graves and their on-ground soil moisture.

4.3.1 Graves 1 and 2

Grave 1 and grave 2 are hand-dug single graves in which grave 1 is a control grave with no sheep buried in it, and grave 2 is an experimental grave with one sheep buried. When running the two- way ANOVA test, it was found that there is an insignificant effect of height on the aerial temperature within the range tested (p-value = 0.747). Additionally, there is an insignificant effect of the buried sheep on the measured temperature (p-value = 0.937) (see Table 21).

Table 21 The results of ANOVA for the temperature of G1 and G2 captured aurally.

Dependent Variable: aerial temperature						
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	25.790	2.378	10.845	.000	21.075	30.505
height	-.020	.063	-.324	.747	-.145	.104
[number_of_sheep=1]	-.163	2.051	-.079	.937	-4.231	3.905
[number_of_sheep=0]	0 ^a	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

Likewise, when analysing the on-ground temperature, the results showed that there is an insignificant effect of the number of sheep buried on the recorded temperature (p-value = 0.641) (see Table 22).

Table 22 The results of ANOVA for the temperature of G1 and G2 captured on-ground.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	24.339	1	24.339	.218	.641
Within Groups	11807.786	106	111.394		
Total	11832.125	107			

Dependent variable: On ground _temperature.

Additionally, the number of sheep buried had a significant effect on soil moisture where the p- value was 0.04 (see Table 23).

Table 23 The results of ANOVA for the soil moisture of G1 and G2.

soil_moisture	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.990	1	1.990	4.345	.040
Within Groups	37.558	82	.458		
Total	39.549	83			

Dependent variable: Soil_moisture.

A correlation test was conducted to test the relationship between the on-ground and the aerial temperatures with the on-ground soil moisture. The results showed a statistically significant negative correlation between aerial temperature and soil moisture (p-value = 0.003). The correlation between aerial temperature and soil moisture was -0.325 (see Table 24).

Table 24 The correlation results between aerial temperature and soil moisture of G1 and G2.

		aerial temperature	soil moisture
aerial_temperature	Pearson Correlation	1	-.325**
	Sig. (2-tailed)		.003
	N	108	84
soil_moisture	Pearson Correlation	-.325**	1
	Sig. (2-tailed)	.003	
	N	84	84

**. Correlation is significant at the 0.01 level (2-tailed).

Meanwhile, the on-ground temperature showed an insignificant correlation when run against the on-ground soil moisture, with a significance value of 0.053 (see Table 25).

Table 25 The correlation results between on-ground temperature and soil moisture of G1 and G2

		on_ground_temperature	soil moisture
on_ground_temperature	Pearson Correlation	1	-.212
	Sig. (2-tailed)		.053
	N	108	84
soil_moisture	Pearson Correlation	-.212	1
	Sig. (2-tailed)	.053	
	N	84	84

The percentage analysis of the on-ground temperature of graves 1 and 2 showed that out of the 18 sets of images collected, the experimental grave was higher on only seven occasions compared to the control grave (38.89%). Meanwhile, the control grave was higher than the experimental grave nine times (50%). Lastly, the temperature of the graves was equal to each other two times (11.11%).

4.3.2 Graves 3 and 4

Graves 3 and 4 are machine-dug single graves in which grave 3 is a control grave with no sheep buried in it, and grave 4 is an experimental grave with one sheep buried. When running the two-way ANOVA test, it was found that within the range tested, height has an insignificant effect on aerial temperature (p-value = 0.698). Similarly, the buried sheep also had an insignificant effect on aerial temperature (p-value = 0.841) (see Table 26).

Table 26 The results of ANOVA for the temperature of G3 and G4 captured aerially.

Dependent Variable: aerial temperature						
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	25.630	2.381	10.767	.000	20.910	30.351
height	-.024	.062	-.389	.698	-.148	.099
[number_of_sheep=1]	.408	2.031	.201	.841	-3.620	4.435
[number_of_sheep=0]	0 ^a	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

Also, the one-way ANOVA test result showed that the number of carcasses buried had an insignificant effect on the on-ground temperatures of graves 3 and 4 (p-value = 0.581) (see Table 27).

Table 27 The results of ANOVA for the temperature of G3 and G4 captured on-ground.

on_ground_temperature					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	38.844	1	38.844	.307	.581
Within Groups	13403.572	106	126.449		
Total	13442.416	107			

Dependent variable: On_ground_temperature.

When testing the effect of the number of carcasses buried in the grave on soil moisture, the result showed an insignificant effect (p-value = 0.859) (see Table 28).

Table 28 The results of ANOVA for the soil moisture of G3 and G4.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.016	1	.016	.032	.859
Within Groups	42.359	82	.517		
Total	42.375	83			

Dependent variable: Soil_moisture.

Lastly, the relationship between the calculated soil moisture and the on-ground and the aerial temperatures was tested using a correlation test, and both results showed a statistically significant correlation between them (p-value = 0.000). The correlation between aerial temperature and soil moisture is -0.415, which means there is a negative relationship between them (see Table 29).

Table 29 The correlation results between aerial temperature and soil moisture of G3 and G4.

		aerial temperature	soil moisture
aerial_temperature	Pearson Correlation	1	-.415**
	Sig. (2-tailed)		.000
	N	108	84
soil_moisture	Pearson Correlation	-.415**	1
	Sig. (2-tailed)	.000	
	N	84	84

**. Correlation is significant at the 0.01 level (2-tailed).

On the other hand, the correlation between on-ground temperature and the soil moisture is -0.324, which means there is a negative relationship between them (see Table 30).

Table 30 The correlation results between on-ground temperature and soil moisture of G3 and G4.

		on_ground_temperature	soil moisture
on_ground_temperature	Pearson Correlation	1	-.324**
	Sig. (2-tailed)		.003
	N	108	84
soil_moisture	Pearson Correlation	-.324**	1
	Sig. (2-tailed)	.003	
	N	84	84

**. Correlation is significant at the 0.01 level (2-tailed).

The percentage analysis of the on-ground temperature of graves 3 and 4 showed that out of the 18 sets of images collected, the experimental grave was higher on only six occasions compared to the control grave (33.33%). Meanwhile, the control grave was higher than the experimental grave 12 times (66.66%).

4.3.3 Graves 5 and 6

Graves 5 and 6 are machine-dug mass graves in which grave 5 is a control grave with no sheep buried in it, and grave 6 is an experimental grave with eight sheep buried. When running the two-way ANOVA test, it was found that height has an insignificant effect on the aerial temperature within the range tested (p-value = 0.985). However, the carcasses buried in the experimental grave showed a significant effect on the aerial temperature (p-value = 0.044) (see Table 31).

Table 31 The results of ANOVA for the temperature of G5 and G6 captured aially.

Dependent Variable: aerial temperature						
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	22.343	2.332	9.580	.000	17.718	26.968
height	.001	.061	.019	.985	-.120	.122
[number_of_sheep=8]	4.054	1.990	2.037	.044	.108	8.000
[number_of_sheep=0]	0 ^a	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

On the other hand, a one-way ANOVA test showed that the number of carcasses significantly affected the on-ground temperature with a p-value of 0.029 (see Table 32).

Table 32 The results of ANOVA for the temperature of G5 and G6 captured on-ground.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	611.279	1	611.279	4.897	.029
Within Groups	13231.056	106	124.821		
Total	13842.335	107			

Dependent variable: On ground _temperature.

When running the one-way ANOVA on the on-ground soil moisture against the number of carcasses buried, the results showed that they are significantly affected by each other (p-value = 0.000) (see Table 33).

Table 33 The results of ANOVA for the soil moisture of G5 and G6.

soil_moisture					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	15.207	1	15.207	74.762	.000
Within Groups	16.679	82	.203		
Total	31.885	83			

Dependent variable: Soil_moisture.

Lastly, a correlation test was run on the aerial temperature and soil moisture, and the results showed a statistically significant correlation between them (p-value = 0.001). The correlation between aerial temperature and soil moisture is -0.359 (see Table 34).

Table 34 The correlation results between aerial temperature and soil moisture of G5 and G6.

		aerial temperature	soil moisture
aerial_temperature	Pearson Correlation	1	-.359**
	Sig. (2-tailed)		.001
	N	108	84
soil_moisture	Pearson Correlation	-.359**	1
	Sig. (2-tailed)	.001	
	N	84	84

** Correlation is significant at the 0.01 level (2-tailed).

Also, the on-ground temperature showed a statistically significant correlation when run against the soil

moisture (p-value = 0.000). The correlation between on-ground temperature and soil moisture is -0.539, meaning there is a negative relationship between them (see Table 35).

Table 35 The correlation results between on-ground temperature and soil moisture of G5 and G6.

		on_ground_temperature	soil moisture
on_ground_temperature	Pearson Correlation	1	-.539**
	Sig. (2-tailed)		.000
	N	108	84
soil_moisture	Pearson Correlation	-.539**	1
	Sig. (2-tailed)	.000	
	N	84	84

** . Correlation is significant at the 0.01 level (2-tailed).

The percentage analysis of the on-ground temperature of graves 5 and 6 showed that the experimental grave was always higher than the control (100%).

4.3.4 Summary of the statistical analysis

Using SPSS, one-way and two-way ANOVA descriptive statistics were introduced to analyse the results. The effect of the size of the grave (single or mass grave) and the number of buried carcasses (none, one, or eight sheep) on the on-ground temperature, the aerial temperature and the on-ground soil moisture were tested. Also, the effect of the height of the UAV on the temperature of the graves, which was captured using the thermal sensor deployed on the UAV, was explored. Additionally, a correlation test was introduced to investigate the relationship between the on-ground and the aerial temperatures of the graves when run against the on-ground soil moisture. Within the range tested, height had an insignificant effect on the recorded aerial temperature for all graves. For G1, G2, G3 and G4 the buried carcass had an insignificant result on both the on-ground and the aerial temperatures. However, when testing the effect of buried carcasses on G5 and G6, the results showed that buried carcasses do influence the recorded on-ground and aerial temperatures.

On the other hand, the buried carcasses did influence the results of the on-ground soil moisture for G1, G2, G5 and G6 but not for G3 and G4. Lastly, G1 and G2 demonstrated a significant negative correlation only between the aerial temperatures and the on-ground soil moisture. Meanwhile, G3, G4 G5 and G6 demonstrated a significantly negative correlation for both the on-ground and aerial temperatures when compared to the on-ground soil moisture.

4. 4 Chapter summary

This chapter presented on-ground and aerial survey results and statistical analysis. The data collected on-ground served as a reference for validating the findings from the aerial survey. Afterwards, both results were statistically analysed and interpreted. The results provided valuable insight into the effect of buried carcass and grave size on topsoil temperature, soil moisture and landscape changes.

First, the on-ground temperature of the surrounding enclosed area was always higher than that of all graves, whilst the aerial survey varied in the number of times the graves were higher than their surroundings. For example, G1 and G2 were higher than their surroundings on 3 occasions, G3 and G4 were higher on 4 occasions and G5 and G6 were higher on 6 occasions.

Second, the on-ground temperature of the control graves was always higher than the experimental ones. The aerial survey did not have any specific trend in the number of times any of the graves was higher than the other. In the hand-dug graves (G1 and G2), the experimental grave was higher than the control one on 7 occasions out of the 18 collected. However, the experimental graves were more frequently higher than the control ones in the machine-dug graves. In G3 and G4, the experimental grave was always higher than the control one, whilst in G5 and G6, the experimental grave was higher on 12 occasions.

On the other hand, the soil moisture comparison differed between the two approaches. For the on-ground, the control and the experimental graves of each method of digging were compared. Whilst in the aerial survey, the thermal image of the entire research area was analysed, and the TVDI map was generated. For the on-ground, G1 and G6 were more frequently higher than G2 and G5, respectively, whilst G3 and G4 shared an equivalent number of times where one grave was higher than another. More precisely, the soil moisture of G1 was higher than G2 on 15 occasions, and G6 was always higher than G5 throughout the experiment. On the other hand, the aerial survey indicated that the soil moisture of all graves was higher than their surroundings for the first month. Afterwards, only the mass graves were moister than the surroundings, and this trend lasted until eventually levelling up by the tenth month post-burial.

Regarding the landscape changes, only the vegetation cover and the height of the grave mounds were explored both on-ground and through the aerial survey. The rest of the landscape feature changes, such as grave-edge detection and anomaly detection, were explored either by on-ground methods or using the remote sensing approach due to the technicality and approachability of the required feature

analysis. To summarise the finding of the features analysed both on-ground and through the aerial survey, both methods revealed that all graves showed elevation loss as time passed. The experimental graves showed a higher rate of elevation loss for the first three days as a result of the graves being dug by the scavengers while attempting to devour the buried carcasses, followed by a steady trend of elevation loss. Moreover, on the features that were analysed using both methods, a vegetation cover difference was detected between the graves and their surroundings which started to appear by the sixth month post-burial. The vegetation of the mass graves was greener and denser than the single graves compared to their surroundings. By the ninth month post-burial, the vegetation got dried out, and images captured in the tenth month did not show any difference in the vegetation cover when explored through the aerial survey.

The features analysed on-ground were grave-edge detection, soil crust formation, vegetation height on the graves and scavenger intrusion. Therefore, the grave-edge detection was only visible with the mass graves, which lasted up to the twelfth month post-burial for the control grave and up to the fifteenth month for the experimental grave. Moreover, the soil crust formation was only visible on the experimental mass grave surface. Lastly, for the on-ground analysis, all graves had a clear vegetation height difference compared to their surroundings, with the mass graves exceeding the height of the single graves.

On the other hand, the features analysed only by the aerial survey were identifying surface anomalies and generating the NDVI index map. The surface anomalies were detected using manual and automatic approaches with the aid of two sensors deployed on different UAVs. The manual method using the 4K RGB sensor was successful for 15 months for all graves apart from G4, which was visible until the ninth month. Meanwhile, the MSI manual detection method showed that NIR and red-edge are the most suitable wavelengths to identify the surface anomalies in the presented research conditions, and it was successful throughout the experiment period. As far as the automated detection method, both the 4K RGB and MSI outcomes varied in the number of graves identified in each data set collected but successfully detected multiple graves throughout the research period. Regarding the best detection method, RXD was linked with the 4K RGB, while RXD-UTD was with the MSI. Using the MSI, the NDVI map interpretation showed a small, but detectable, variation in the obtained values of the graves compared to their surroundings. Hence, this approach indicates its usefulness in aiding the grave detection method in an arid environment.

Lastly, the statistical analysis performed using SPSS revealed that, within the range tested, drone

height had an insignificant effect on the recorded aerial temperature for all graves. Additionally, the buried carcasses had an insignificant effect on the on-ground and aerial temperatures of the single graves while influencing the topsoil temperatures of the mass graves. Moreover, the buried carcasses significantly affected the measured on-ground soil moisture for all graves except for G3 and G4.

Chapter 5 Discussion

The thesis had four primary research aims mentioned in Chapter 1 section 1.2. It sought to monitor topsoil temperature, soil moisture, vegetation cover and soil disturbances in an area with multiple graves over extended periods. First, the thermal image analysis evaluated the use of a thermal sensor mounted on an unmanned aerial vehicle to detect recent burials in an arid environment exploring topsoil temperature and soil moisture of the graves. Additionally, the multispectral image analysis evaluated the use of multispectral imaging in detecting surface anomalies that could indicate the presence of a not recent clandestine grave, and the usefulness of using the NDVI in the process. Lastly, to develop a cost- and time-effective burial detection method which can be used in an arid environment, the use of a 4K RGB sensor was also introduced. Moreover, the 4K RGB image analysis results sought to help detect surface anomalies, measure the digital elevation model of the enclosed research area and visually explore the landscape changes. In order to validate the aerial findings, on-ground sampling and survey were also conducted to correlate the aerial and on-ground findings.

Kalacska et al. (2009), Norton (2010), Leblanc et al. (2014) and Corcoran et al. (2017) have demonstrated the potential for remote sensing to detect graves on various airborne platforms, mainly focusing on using the costly hyperspectral imaging techniques. However, the ultimate goal of this research was to establish a reliable method for detecting clandestine graves in an arid environment using low-cost commercially available UAVs equipped with remote sensing technology. This will allow law enforcement agencies worldwide, who cannot afford the cost of using the expensive detection methods in the previous studies done in this matter, to use an affordable remote sensing technique which can aid their clandestine grave detection methods. The following sections explain and elaborate on the findings of each sensor used in the experiment and compare them to their relevant on-ground findings. The implication of both the on-ground and aerial results is explicitly discussed within the specific domain of grave detection in an arid environment.

5.1 Thermal imaging

The rationale to use thermal sensors in detecting clandestine graves emerges from the fact that the decomposition of humans, or their analogues for such research purposes, creates a discoverable and distinguishable temperature on the surface of the grave when compared to its surroundings (Larson, Vass and Wise, 2011; Pringle et al., 2012b; Bodnar et. al, 2019). Whether using thermal imaging to

detect thermal characteristics of disturbed soils or to detect the remains directly, in both cases, the technology proved its effectiveness numerous times (Servello, 2010; DesMarais, 2014; Johnson and Wallman, 2014; Amendt et al., 2017; Blau et al., 2018; Lee et al., 2018; Murray et al., 2018; Bodnar et al., 2019; Butters et al., 2021; Silván-Cárdenas et al., 2021). For example, the results of Bodnar et al. (2019) and Butter et al. (2020) showed that the technology effectively detects dead pigs on the surface or even concealed in various ways, for as long as 29 days. Meanwhile, the recorded on-ground temperature using the handheld infrared thermometer (model: Lutron TM- 919AL) and the recorded temperature using the thermal sensor deployed on the UAV (hereafter referred to as aerial temperature) of the research area, differed in their detectability levels and periods depending on the grave type and method of detection. Here, the thermal image analysis evaluated the use of a thermal imaging camera mounted on an unmanned aerial vehicle to detect recent burials in an arid environment by exploring the topsoil temperature and the relative soil moisture of the graves. The results were explored based on the digging method of the graves.

For the hand-dug single graves, the results concluded that there was a slight temperature difference between the control (G1) and experimental (G2) graves and their surroundings throughout the research period. That is true since only a 1.9 °C and 1 °C temperature difference was recorded aurally the day of the burial between G1 and G2 when compared to their surroundings. This difference can be related to the digging and backfilling of the grave. Moreover, the results of the graves were also barely distinguishable compared to each other. The highest difference between the graves was 0.8 °C and 0.6 °C for the on-ground and aerial recordings, respectively. Furthermore, examining the highest temperature difference between the graves and their surroundings, the on-ground temperature records showed that G2 had the highest difference compared to the surroundings with a 0.8 °C difference, whilst the aerial temperature outcomes showed that both graves were 1 °C lower than their surroundings when exploring the difference between them. This lack of temperature variation between the graves and their surroundings can be related to the fact that scavengers were able to reach the buried sheep in G2 as early as the first day post-burial. Additionally, the whole sheep was pulled out two weeks post-burial. Hence, the heat factor from the decomposition process that was expected to affect the temperature of the experimental grave got eliminated. That resulted in having almost the same temperature for both graves when compared to their surroundings. Therefore, it can be concluded that aerial temperatures are not highly informative for our research conditions in G1 and G2.

Regarding the machine-dug single graves (G3 and G4), the temperature of the graves varied when compared to their surroundings, both on-ground and aerially. From the total of 18 datasets collected, the surrounding area was higher in temperature than the on-ground grave temperatures on 10 occasions and higher than the aerial temperature on 14 occasions. On the second week post-burial, the temperature of the experimental grave captured on-ground showed the highest difference between the graves and their surroundings, being higher than the surroundings with a temperature difference of 2.6 °C. On the other hand, the aerial temperature records revealed that the temperature of the experimental grave had the highest difference in temperature when compared to the surroundings, by being higher than the surrounding with a difference of 0.7 °C, recorded on the tenth month post-burial. When comparing the on-ground recorded temperature of both graves, the experimental grave had higher temperature values than the control grave in 11 out of the 18 datasets collected, with 4 °C being the highest difference between them recorded two weeks post-burial. This difference can be explained and related to the decomposition process of the carcass in G4, which causes an increase in the temperature of the body and ultimately increases the temperature of the grave. Meanwhile, the aerial results showed that the experimental grave temperature was always higher than the control one. However, these temperatures were mostly slightly different, with the highest difference between them being 1.2 °C, recorded in the second week post-burial. That is similar to what has been published, showing that all carcasses demonstrated an increase in temperature over the first two weeks of decomposition for the shallow graves (Johnson, Mikac and Wallman, 2013; Bodnar et. al, 2019). This increase in temperature relates to the heat emitted by insects and bacterial activity on the decomposing remains (Butters et al., 2021). Unlike the case with the hand-dug single graves where the carcass was pulled out entirely from the experimental grave, the scavengers could devour some of the carcass buried in G4 by the third week, and the carcass was never removed from the grave, resulting in the decomposition process taking place inside the grave. That might give the advantage of detecting temperature differences between the graves or when compared to the surroundings, regardless of the scavenger intrusion.

Unlike the single graves, where it was found that the highest temperature difference between the graves was on the second week post-burial, the machine-dug mass graves (G5 and G6) encountered a lengthier period of temperature variation between the graves and their surroundings, which lasted until the seventh month post-burial. It was noticed that the temperature of the experimental machine-dug mass grave (G6) started to show higher temperature rates than both the control machine-dug mass grave (G5) and their surrounding from the third month post-burial, and it peaked in the seventh month

post-burial. On that month, the on-ground and aerial temperature data indicated that the experimental grave was higher than the surroundings by 4.2 °C for the on-ground temperature and 3.6 °C for the aerial temperature. Nonetheless, the on-ground and the aerial temperature of the graves indicated that the experimental grave was higher than the control one most of the time, with also the seventh month data showing the highest difference between the graves. The on-ground measures demonstrated an increase of 3.7 °C between the graves, whilst the aerial ones demonstrated an increase of 3.3 °C. This delay in capturing the highest temperature difference in the mass grave, which was in the seventh month, can be associated with the fact that the sheep in the experimental grave were buried at a 1.5 m deep grave. As reported to occur in previous studies, carcasses buried in such depth have a slower decomposition rate than that needed in a shallow grave (Rodriguez and Bass, 1985; Johnson, Mikac and Wallman, 2013; Teo et al., 2013). Thus, when capturing the temperature of the graves in the following months, the levelling of the recorded temperature of the control and the experimental graves indicates that the buried animals in G6 used all the atmospheric, iron and oxygen bound, and the process of putrefaction completed.

The ambient temperature in the study by Bodnar et al. (2019) ranged between 15-27 °C, while that of Butter et al. (2020) ranged between 4.1-38.6 °C. Moreover, in Butter et al. (2020), the difference between remains and adjacent soil temperatures ranged between 4.3-12.1 °C and 2-5 °C in Bodnar et al. (2019). When comparing the research findings to Bodnar et al. (2019) and Butter et al. (2020) the presented ambient temperature ranged between 11-49 °C, and the difference between temperatures of the graves topsoil and the surrounding area ranged between 0.6-3.7 °C. Although the present research environment is considered one of the hottest in the world, it was possible to detect a 3.7 °C temperature difference between the graves and their surroundings. Whilst it is not as high as seen in the other experiments (Lee et al., 2018; Murray et al., 2018; Silván-Cárdenas et al., 2021), detecting this temperature difference in such a harsh environment using low cost, off the shelf equipment is considered to be a major breakthrough in grave detection methods. Moreover, the detectability of this temperature difference was more efficient with the mass graves, supporting the theory that remote sensing works more efficiently and easier with detecting larger graves than smaller ones (Pringle et al., 2012b).

Whereas the statistical analysis conducted in section 4.3 showed that height had an insignificant effect on the recorded temperature for all graves within the range of height tested, the recorded GSD for the captured images, even the ones captured at 100 m, all fell within the recommended 10

cm/pixel (Pix4D, 2022b). Additionally, soil temperatures were below air temperature most of the time, which optimises the effectiveness of using thermal imaging analysis. Hence, the captured images at different heights could all be used to detect the thermal differences between the graves and their surroundings. On the other hand, the number of buried carcasses and the size of the grave did affect the obtained results of the topsoil temperatures of the graves. Therefore, the presented data suggest that the bigger the size of the grave and the number of buried carcasses, the better chance of the thermal detectability of the graves, thus supporting the findings of earlier studies (Silván-Cárdenas et al., 2021). Hence, the research findings were in line with similar studies (see: Bodnar et. al, 2019; Butters et al., 2021; Silván-Cárdenas et al., 2021) in supporting the fact that there would be a distinguishable surface temperature difference between the control and experimental graves when analysing the findings of the research area.

Thermal imaging was also used to detect changes in soil moisture levels using the temperature vegetation dryness index (TVDI), which seeks to provide information about the existence of a burial site in an arid environment. Previous publications (see: Chen et al., 2015; Shi et al., 2020; Gu et al., 2021) explored the use of the TVDI, mainly in agriculture, to estimate soil moisture, monitor drought and calculate surface water content. Meanwhile, implementing it in calculating soil moisture in an arid environment to aid criminal investigations, particularly the detection of clandestine graves, is considered a new application. The results of the present research support the findings of (Dozal et al., 2018), which concluded that the decomposition of buried carcasses affects vegetation structure and soil composition and that such an effect can be used to detect clandestine graves. That is, when calculating the TVDI of the research area, it was possible to distinguish all graves from their surroundings by being moister from their surroundings for the first month. Afterwards, only the mass graves showed signs of soil moisture differences which lasted for 10 months post-burial. Those results were associated with the aerially captured temperatures of the graves, in which the temperature difference between the graves and their surroundings was also detectable for seven months post-burial.

Moreover, when evaluating the results of the measured on-ground soil moisture of the graves compared to the on-ground and aerial topsoil temperatures of the graves, the results showed a significant negative correlation between the temperature of graves and their soil moisture. G1 and G2 only demonstrated a significant negative correlation between the aerial temperatures and the on-ground soil moisture. Meanwhile, graves G3, G4, G5, and G6 demonstrated a significantly negative

correlation for both the on-ground and aerial temperatures compared to the on-ground soil moisture. Consequently, it was concluded that the size of the grave, the method of digging and the buried carcasses did influence the obtained soil moisture results. That is, a larger and deeper grave with more carcasses buried in it results in having a higher moisture content for a more extended period of time.

To explore the reliability of using the TVDI as a soil moisture estimation method and ultimately using the results to help detect clandestine graves, the soil moisture estimations using the TVDI formula were compared with on-site soil moisture measurements. For the single graves, the on-ground measurements did not show a major difference between the control and experimental graves. However, the aerial survey results separated the single graves from their surroundings and detected a difference between them until the first-month post-burial. This is mainly related to the fact that scavengers were able to reach for the buried carcasses in the single experimental graves, causing the similarity between the on-ground soil moisture measurements of the single graves. On the other hand, both methods of measurement showed that the experimental mass grave (G6) always had a higher moisture content than the control mass grave (G5) and the surrounding area throughout the research period, which is in line with previously published literature (Blau et al., 2018). This high moistness can be explained mainly because of the existence of the buried carcasses in the experimental mass grave and the presence of clothing with the carcasses, which retains the moisture released from the decaying process, thus creating a consistent wet environment (Teo et al., 2013). Furthermore, the aerial survey detected the soil moisture difference between the mass graves and their surroundings for 10 months, whilst the on-ground method showed a variation until the last data set was obtained (18 months). Although the highest calculated difference between G5 and G6 on-ground soil moisture percentage was in the sixth month, where G6 was higher than G5 by 2.77%, the following months also showed a difference between the soil moisture of the graves that ranged between 0.44% and 0.97%. Hence, the aerial survey using the thermal imaging camera, which is used to calculate the TVDI, could aid the search plan of clandestine graves in an arid environment for almost 10 months post-burial, depending on the size of the grave, the method of digging and how many bodies are buried in the grave.

5.2 Multispectral imaging

Multispectral imaging has been widely used in agriculture to monitor vegetation and calculate vegetation indices (Baluja et al., 2012; Assmann et al., 2018). In the year of 2002, a revolutionary

search method was introduced to the field of forensic science in which multispectral data with a resolution of 15 m/pixel from the ASTER satellite was used to detect a mass grave in Guatemala during a retrospective study (Rocke and Ruffell, 2022). Since then, the use of multispectral and hyperspectral imaging to locate clandestine burials is a well-documented area within forensic science and has been suggested as a helpful technique (Kalacska et al., 2009; Leblanc, Kalacska and Soffer, 2014; Silván-Cárdenas et al., 2017; Blau et al., 2018; Corcoran et al., 2018; Dozal et al., 2018; Murray et al., 2018).

Although hyperspectral imaging has the potential of greater anomaly detection in soil and vegetation than the multispectral data, it is accompanied by much more complex computation and algorithms which cannot be operated by untrained individuals, such as police officers and rescue personnel that usually lack the specialised knowledge required by such technology (Rocke and Ruffell, 2022). On the other hand, the operation of the commercially available UAV that is used in this research to capture the multispectral images, along with the analysis conducted on the images to extract the required features using the commercially available software, does not necessarily require a specialist nor sophisticated equipment and can be operated by an individual with minimal training on how to use the UAV and the processing software.

This study explored the effectiveness of using multispectral imagery captured from a UAV to track changes in vegetation and detect soil disturbance over time, intending to identify hidden graves in an arid environment. The findings presented in Chapter 4 section 4.2.3, have successfully demonstrated the potential that multispectral imagery has to aid the detection process of soil disturbances created from grave digging and backfilling using the anomaly detection techniques and exploring the differences in the NDVI values between the graves and their adjacent area. Initially, the photogrammetry software Pix4Dmapper was used to process the captured multispectral images. Then, the analysis of the captured multispectral images produced NDVI maps and created four orthomosaics which were subsequently used for detecting soil disturbance using the image processing and analysis software ENVI. When the present research is compared to existing published literature regarding the use of the NDVI to measure vegetation health to help in locating clandestine graves, it is essential to note that it is not directly comparable. The main reason is that the research environment and the vegetation coverage do not resemble what has been previously studied, such as tropical forests (Kalacska et al., 2009), mountainous terrain (Fernández-Álvarez et al., 2016), and in woodland (Pollard and Barton, 2013). Several studies, including Kalacska and Bell (2006), Kalacska

et al. (2009), and Leblanc et al. (2014), have demonstrated that the presence of a mass grave can have an impact on vegetation, as evidenced by changes in vegetation health over varying periods. However, for the current study, since the research is conducted in an arid environment, NDVI was used to estimate soil moisture and identifying the surface anomalies in addition to measuring the vegetation health (Casamitjana et al., 2020; Barone et al., 2022). Following the NDVI classification mentioned in Chapter 2 section 2.1.4, the obtained results categorised the vegetation coverage of the research area as being open soil, shrubs and pastures, and sparse vegetation. However, compared to their surroundings, there was a slight variation between the NDVI values. This variation is explainable since the research environment is considered one of the hottest in the world, and vegetation growth is not very common in such an arid environment due to the dryness of the ground and lack of rain and nearby natural water resources. In addition, the burial is classified as a deep grave (carcasses were buried at 1.5 m), and at such depth, the decomposition process and the release of nutrients might take up to years (Mann, Bass and Meadows, 1990). Hence, only a minor difference in NDVI between the graves and the adjacent surroundings was noticed. Earlier studies questioned the spatial resolution of orbital multispectral imagery, which is too coarse, justifying the use of airborne hyperspectral imagery (Kalacska et al., 2009). However, in recently published literature, multispectral imaging proved its success as a practical geophysical assessment of burials using the NDVI for analysis when used in three case studies (Rocke and Ruffell, 2022). That is because nowadays, UAVs equipped with multispectral sensors combine portability and excellent image quality compared to the orbital multispectral images. In addition, a UAV can be flown at a low altitude, decreasing the ground sampling distance (GSD) obtained from the captured images and avoiding any cloud obstruction.

In relation to the use of multispectral imaging to detect surface anomalies manually and automatically, the results were successful until the last set of data collected in the experiment (15 months). The eighteenth month data was not collected due to an error with the UAV connection with the Pix4Dcapture software. Multispectral sensors typically gather energy across multiple wavelength ranges, often four or more, at varying spectral resolutions, which are typically coarse. Here, the Parrot Sequoia sensor captured wavelengths at green (530-570 nm), red (640-680 nm), red-edge (730-740 nm), and NIR (770-810 nm). When manually viewing those images captured at those wavelengths and trying to identify any surface anomalies in the images, NIR and red-edge represented the critical spectral regions for anomaly detection. The detectability of NIR wavelength is consistent with the reported results from previously published literature where hyperspectral or multispectral imaging

techniques were used to detect anomalies caused by potential burial sites (Pringle et al., 2012b; Sona et al., 2016; Silván-Cárdenas et al., 2017; Dozal et al., 2018; Evers, 2018; Parrott et al., 2019). Moreover, the findings of other studies revealed that the hyperspectral imaging technique readily distinguished the graves from soil disturbances for 16 months using the reflectance spectra (Kalacska et al., 2009; Blau et al., 2018). Similarly, the present results also demonstrated the capability of the multispectral imaging technique to distinguish such disturbance for a similar period.

On the other hand, when analysing the images automatically using the RX Anomaly Detection Tool in ENVI, the most suitable detection method varied from one dataset collection to another, with RXD-UTD being the most suitable method of detection. RXD-UTD suppresses the background and enhances anomalies and is most suitable when the anomalies have an energy level equal to or less than the background (Chang and Chiang, 2002). Therefore, when applying the different methods of detection on the captured images of the arid research area and the anomalies are not easily distinguished, the findings were similar to the literature, and RXD-UTD had the highest rate of anomaly detection. When analysed, the results of the first two months showed high precision in the detectability levels of all graves, which is expected since the disturbance level is high between the surfaces of the graves. This high level of disturbance creates numerous bad pixels in the captured images, which was discussed in depth in Chapter 3 section 3.3.2.1. Hence, the detectability rate of those bad pixels in the early months is relatively high compared to the subsequent datasets. However, the anomaly detection rate lessened toward the third month post-burial, and only three of the six graves were detectable. This low level of detectability can be explained since in November 2020, when the third month post-burial was collected, the precipitation level was at its highest for the year in Kuwait, recording a 19.6 mm (World Weather Online). Hence, the disturbance on the topsoil of the graves got soaked with rain and resulted in the unidentified surface anomaly detection of some of the graves in the third-month data analysis. Henceforward, the detectability level increased, showing better accuracy in anomaly detection. This increment of detectability levels referred back to the fact that once the soil got dry again, the disturbance on the topsoil of the graves became more defined and shaped. However, the exception of the tenth month post-burial, which failed to capture any anomaly on all graves, remains unjustifiable since the disturbance was visible upon examining the images manually.

5.3 RGB imaging

The 4K RGB is the most affordable, accessible, and user-friendly imaging technique among the three

sensors being explored in this research. It is mainly used to capture images in true colour and is available to purchase in-store and online. Moreover, if the UAV is below 249 g in weight, it can be flown without any permits or licenses. As explained in Chapter 2, section 2.3.1.1, an unmodified digital camera deployed on a UAV has proved its effectiveness in detecting clandestine burials on numerous occasions (Urbanová et al., 2017; Blau et al., 2018; Evers, 2018; Murray et al., 2018; Parrott et al., 2019). It might be argued that capturing those images in such narrow spectral bands limits the use of this sensor in grave detection methods. However, when using the appropriate software and applying the proper tools to the captured images, the results might become substantial in aiding the detection process. Areas that are non-vegetated and have open landscapes with no ground obstacles, similar to the presented research area, are preferable when looking for clandestine graves. For the present study, the captured 4K RGB images were processed with multiple software, mentioned in Chapter 4 section 4.2, to analyse the findings and investigate its effectiveness in identifying any surface elevation in the enclosed area that can resemble an outlier in the enclosed area using the DEM technique. Furthermore, 4K RGB images were analysed to explore their usefulness in detecting surface anomalies caused by digging and refilling the graves. Additionally, the visual inspection of the vegetation ground cover was also conducted. These landscape results were then compared to the on-ground observations to test the validity of the aerial method.

Akin to the previously published literature where digital terrain model (DTM) and digital surface model (DSM) were used and successfully demonstrated the effectiveness of such features in detecting clandestine graves (Somma et al., 2018; Rocke, Ruffell and Donnelly, 2021; Rocke and Ruffell, 2022), the present research findings collectively support the use of such features to detect clandestine graves. The calculated DEM values listed in Table 11 illustrate that this feature could be used to detect surface elevation in an arid environment for 18 months. Another study conducted by Corcoran et al. (2018) explored the effectiveness of using terrestrial Light Detection and Ranging (LiDAR), which is far more complex and precise, in identifying changes in elevation associated with unmarked graves. Corcoran et al. (2018) found that a decrease in elevation was detected immediately after the creation of the burial and persisted for up to 108 days. This pattern held true for all simulated graves, including single graves, graves with three individuals, and graves with six individuals. Moreover, Corcoran et al. (2018) found that the same result was obtained for a control grave that only contained backfilled soil. Thus, the research findings using such an affordable technology showed promising results which can be used in the detection method. The aerial results were then compared to the on-ground measurement of grave elevation, and it was found that both the on-ground

and the calculated DEM of grave heights correlate. Hence, this makes the aerial survey a valuable method for identifying areas with uneven surfaces which could be an indication of a burial mound. From the results of measuring the height of the graves both on- ground and using the DEM technique, all graves have shown a steady elevation loss throughout the experiment, except for the experimental graves, where a sharp loss of elevation was noticed. That is due to the intrusion of the scavengers and their digging of the graves to reach for the buried carcass. However, it is worth mentioning that the DEM could not reveal this elevation loss when the graves were dug and their lowest point became below ground level with respect to the underlying ground surface. According to the measured DEM, when the on-ground measurements were below ground level, the calculated DEM revealed that the height of the graves was somewhere between 0.2 and 3 cm above ground level. Thus, the DEM technique is considered beneficial when exploring an area for any burial mounds, while the mounds still exist.

Meanwhile, the results were promising when exploring the efficacy of anomaly detection using 4K RGB images. Like multispectral imaging, the anomaly detection for the 4K RGB images was investigated manually and automatically. For the manual method, the orthomosaic maps of the research area, created using the photogrammetry software Pix4Dmapper, were examined throughout the experiment period, looking for any soil disturbance which might be an indication of a clandestine grave. Upon checking, the orthomosaic maps of the research area had a clear image of soil disturbance for all graves for the first three months. This clarity was expected since the area is isolated from human and mechanical intrusions and only exposed to nature and its wildlife. In addition, the first three months remained out of the rainy season of the country. Hence, this manual detection of soil disturbance was more likely to be possible for the first three months. As far as the sixth- and seventh-month data, where only G5 and G6 were detectable, the vegetation growth of the area played a major factor in diminishing the soil disturbance that appeared on the other graves. Toward the tenth month data, graves G1, G2 and G3 became visible again; this can be related to the fact that the vegetation cover of the research area dried out, and the topsoil of the graves got more defined and shaped from the rainwater absorption. This detection was possible until the fifteenth month and not for the last set of data collected in the eighteenth month. A reason why grave G4 was not identifiable among the other graves beyond the third-month images might be due to the fact that it was a machine-dug experimental single grave, and the carcass inside of it was not fully exposed by scavengers. That means its surface was more flattened than the other graves when backfilled. Additionally, when the scavengers tried reaching down for the buried carcass, they could not create too many surface

disturbances since the carcass stayed inside the grave. Thus, when it rained and the area went under weathering and erosion toward the tenth month, the grave was not as visible as the other graves.

On the other hand, the obtained results mentioned in Chapter 4 section 4.2.1, from the automated soil disturbance detection method on the 4K RGB images demonstrated encouraging technology usage in such arid conditions. Unlike multispectral imaging, which is obtained at a small number of discrete wavebands with a lower image resolution, RGB colour images only process three image bands on the red, green and blue wavelengths using the RGB Bayer filter (RGGB pattern) while maintaining high image resolution. Hence, the RXD-UTD, which is most suitable when the anomalies have an energy level comparable to or less than the background found in the multispectral imaging, was not applicable to the captured 4K RGB images. The 4K RGB images have higher resolution and more distinct image details than the multispectral ones, resulting in more distinguishing features. Therefore, instead of the RXD-UTD detector being the most applicable detector, the RXD and UTD detectors were the most useful method of anomaly detection for the 4K RGB captured images. Until the second month post-burial, RXD was the best detector to distinguish soil disturbance automatically. Whilst RXD extracts targets that are spectrally distinct from the image background, UTD extracts background signatures as anomalies and provides a reasonable estimate of the image background. Hence, referring to Table 13, RXD was a more suitable detector than UTD for the first two months since the area did not undergo any environmental and climate change except for the disturbance caused by the digging and backfilling of the graves. However, the situation was different when capturing the data from the third month and toward the twelfth month. There was a seasonal weather change, and the area experienced rainy days and vegetation growth. Hence, the topsoil and grave edges became more detailed after absorbing the rainwater. Ultimately, the background signatures were extracted as anomalies and a good estimate of the image background is provided. Therefore, the UTD detector was more applicable in this period. Afterwards, with the twelfth- and fifteenth-month post-burial data, and after the area got completely dried out, the RXD detector was once again a more effective detector to be used with the obtained images. Out of the 18 sets of images collected and examined, the detectors could not identify all graves on four occasions. In the first, third and sixth months of post-burial data, the detectors could identify five out of the six graves. Moreover, the detectors could identify three out of six graves in the ninth- and fifteenth-months post-burial. However, none of the non-detected graves was a mass grave on all those undetectable occasions. Consequently, it can be inferred that the technique works better with larger graves than smaller ones since more disturbance can be detected.

Lastly, there were minor differences in the vegetation and topsoil formation of the research area when comparing the on-ground and aerial images and visually inspecting them. Successfully detecting clandestine burials using their effects on vegetation when carcasses are used has been found in multiple studies (Leblanc, Kalacska and Soffer, 2014; Silván-Cárdenas et al., 2017; Corcoran et al., 2018; Silván-Cárdenas et al., 2021). A noticeable difference in vegetation growth was also recorded between the single and mass graves in the presented arid environment. The single graves were in-line with natural vegetation cover. However, the mass graves had greener and more dense vegetation. Moreover, the experimental mass grave had taller and more dense vegetation than the control. The vegetation cover of the area lasted throughout the first seven months of the experiment, and then the graves gradually started showing loss and dryness of vegetation. By the ninth month, the single graves had no vegetation cover, while the mass graves had a dried vegetation cover. Similarly, to the aforementioned literature, it was expected that the experimental mass grave would show more vegetation growth when compared to the control mass grave due to the decomposition process of the buried carcasses and its enrichment of the soil of the graves with nutrients needed for such growth of vegetation. Hence, the dryness and loss of vegetation can be related to the end of the decomposition process that supplies the soil with the required nutrients. Also, seasonal weather changes played a major factor in these changes in vegetation. On the other hand, the only grave that had a different topsoil formation than the entire research area was the experimental mass grave. Although there is no direct evidence between the number of buried animals and soil crust formation, other factors might have affected the redistribution of moisture within the topsoil of the experimental grave. Those factors might be the arid environment the research was conducted in, the soil type and the soil disturbance.

Both the aerial and on-ground techniques concluded the existence of the vegetation changes in the research area and proved the effectiveness of applying both methods to explore vegetation changes in the area. Alternatively, the soil crust formation on the experimental mass grave was only identifiable when conducting the on-ground survey. Additionally, when conducting the on-ground survey, the grave-edge cracks were evident for the mass graves seven days post-burial and lasted until the fifteenth and eighteenth months for the control and experimental mass graves, respectively. However, those grave-edge cracks were not detectable when examining the aerial images. In those two regards where the aerial images could not detect the soil crust formation and grave-edge cracks, the lack of information in the aerial images is related to the GSD obtained from those images, which had a 1.7 cm/pixel range based on the 30 m height used. Furthermore, since the widest grave-edge crack was

1.5 cm found in the sixth month post-burial, it was impossible to detect those cracks. In comparison, a recently published study conducted in an Australian woodland had grave-edge cracks apparent just 13 days after the experiment commenced on large graves (graves size were (3 m x 2 m x 1 m) and (5 m x 2 m x 1.4 m)) and 68 days for the smaller graves (graves size were (2 m x 0.3 m x 0.3 m) and (3 m x 2 m x 1.4 m)) (Watson et al., 2021). Watson et al. (2021) also suggested that depending on the type of soils and the size of the graves, the cracks form differently. Hence, depending on the environment where the graves are dug, the grave- edge cracks vary in how fast they start to appear. Meanwhile, the vegetation growth was noticed both aerially and on-ground starting from the sixth month of post-burial observations onwards. In a recent study conducted in Australia, the results showed signs of revegetation of grass species that commenced 10 days after the experiment began and remained readily identifiable after 30 months (Watson et al., 2021). Hence, the fertility, organic matter and available water-holding capacity of the soil are a few soil properties that notably impact the appearance of surface irregularities (Knapen et al., 2007). Furthermore, the prevailing soil and climatic conditions appear to hinder vegetation regrowth in disturbed areas (such as the ones caused by grave digging), which extends the period during which potential grave sites may be detectable.

Since there were visual observations of landscape changes and grave-edge cracks, which lasted until the last set of data collected, and a noticeable difference in vegetation growth when comparing the graves and their surroundings. Therefore, the obtained results from the analysis of the acquired data confirm the effectiveness of the presented technology in detecting burial sites in such research conditions.

Whether the results of the missed data on the fourth, fifth- and eighth-months post-burial, which were due to government restrictions related to the COVID-19 pandemic, would have affected the research findings, the following can be concluded. First, the soil moisture results were not affected as changes were detected for up to 10 months. When it comes to the temperature variation between the graves and their surroundings, differences were detectable up to 7 months but not at 9 months. It is, therefore, unknown whether the temperature variation would have been detected at 8 months. Lastly, the anomaly detection results would not have been affected since the anomalies were detectable at later stages.

All the results prove the effectiveness of using commercially available UAVs equipped with 4K RGB, thermal and multispectral sensors in narrowing down the search area of possible recent and fairly old gravesites in an arid environment.

5.4 Summary of discussion

This research aims to evaluate the utility of using thermal, multispectral and 4K RGB imagery obtained by UAVs to monitor temporal changes in topsoil temperature, soil moisture, vegetation health, surface elevation and anomaly detection as a means to detect simulated clandestine graves in an arid environment. In addition, those aerial results are compared to their relevant on-ground measurements and observations to test the validity of the proposed grave detection methods. The research findings were discussed in three separate sections based on the type of sensor used.

The first one explored the effectiveness of using the thermal imaging technique in identifying graves when factoring the heat and soil moisture effect on the graves in comparison to their immediate surroundings. Additionally, how discerned these features are to this thermal sensor deployed on a UAV. The recorded on-ground and aerial temperatures differed in their detectability levels and periods depending on the grave type and method of detection. Based on the investigation conducted, it was found that the results of the hand-dug single graves (G1 and G2) were affected by the intrusion of the scavengers and showed inconsistency and lack of variation when it comes to topsoil temperature and soil moisture analysis in comparison to the results obtained from the mass graves. On the other hand, the interpretation of the machine-dug single graves (G3 and G4) results were better than G1 and G2, regardless of the intrusion of the scavengers on the graves that did not result in pulling the carcass out of the grave, which was the case with G2. Akin to what has been previously published, the result showed that the highest difference in temperature between the experimental grave and its surrounding, including the control grave, was on the second week post-burial, which is related to when the decomposition process had the highest insect activity. Regarding the soil moisture, the method used was adequate for a month post-burial. Lastly, the findings of the mass graves showed a longer period of temperature variation, and the highest difference between them was in the seventh month post-burial. On the other hand, the soil moisture difference was detectable until the tenth month post-burial, rather than for just one month, which was found in the single graves. This longer detection period is because the mass graves were much deeper than the single graves, and the number of carcasses buried in them exceeds the number of carcasses buried in the single graves. To summarise, it was concluded that the size of the grave, the depth of the graves and the buried carcasses did influence the obtained results from the thermal images. That is, the bigger and deeper the grave with more carcasses buried in it, the more extended period of time it will be detectable.

The second section discussed the findings of multispectral imagery. This research evaluated

multispectral imagery and the derived vegetation index (NDVI) to detect disturbance indicative of the presence of clandestine graves. Considering that the research area is one of the hottest in the world, it directly impacted the NDVI findings and the minimal variation in the index map, which was found between the graves and their surroundings. Although those differences were considered minor, the difference could be spotted and interpreted in a manner that could aid the clandestine graves detection missions. Moreover, the portability of the multispectral UAVs and their high image quality present this method in a competitive manner of the much more complex and sophisticated techniques such as hyperspectral imaging. This research, in principle, has demonstrated that a multispectral sensor deployed on a UAV could be used to identify disturbance indicative of a grave in an arid environment for a period that could last for more than 15 months, using both a manual and automated method of detection. For the manual method, the use of multispectral sensors seems to be a promising imaging technique that helps to detect soil disturbance in an arid environment which can be an indication of possible burial sites, with NIR and red-edge being the most suitable wavelengths for such detection, which was similar to previously published literature mentioned earlier (Pringle et al., 2012b; Sona et al., 2016; Silván-Cárdenas et al., 2017; Evers, 2018). On the other hand, the automated detection method showed that the RXD-UTD was the most useful when multispectral imagery is tested for identifying surface anomalies. This can be related to the similarity between the energy level between the anomalies and the background. In addition, the detectability level varied month by month since the area went through erosion, weathering and rainfall.

The last section of this chapter discussed the results obtained from the analysis of the 4K RGB imagery and its usefulness in detecting clandestine graves. This sensor was used to measure the surface elevation using the DEM technique, detect surface anomalies and explore landscape changes. Upon the comparison between the on-ground measurements and the DEM of the research area, the DEM showed its effectiveness when surface elevation was examined for any outlier in the area. The analysis showed that the graves had a steady elevation loss except for graves 2 and 4, which have gone through a sharp loss of elevation explained by the scavenger intrusion. When the graves were dug and their lowest point became below ground level with respect to the underlying ground surface, the DEM technique could not detect the actual height measurement. Therefore, the DEM technique is only appropriate for detecting grave mounds and elevated grounds.

Meanwhile, anomaly detection using the 4K RGB imagery seems to be a promising detection method. The manual method was unable to detect the single graves on some occasions due to

weathering and erosion effects on the graves. Meanwhile, the mass graves were detectable for 15 months post-burial using the manual method. On the other hand, the automated method of detection split evenly between the RXD and UTD in the number of times being the best detector used. This contradicts the findings of multispectral imagery where RXD-UTD was the most suitable detector since the 4K RGB imagery is accompanied by higher image resolution, resulting in a distinct image detail than the multispectral images. Out of the 18 times, only in three occasions the automated method did not detect all graves. The missing graves were always single graves, making the detection more prone to detecting large burial grounds, which causes more extensive soil disturbances. Furthermore, the observations of landscape changes showed that the mass graves had healthier, greener, taller and denser vegetation than the single graves, which were in line with the vegetation of the surrounding nature. The buried carcasses positively affected the density of the vegetation, resulting in the experimental mass grave being more vegetated than the control one, which was expected since the buried carcasses would supply the soil with nutrients throughout the decomposition process. Both the aerial and on-ground techniques helped detect the change in vegetation. However, the soil crust, which was observed on-ground, was not visual using the UAV. Moreover, the grave-edge cracks were also visual only on-ground. That is because the GSD for the obtained images at the height of 30 m was lower than the size of the crack, which was 1.5 cm, and the GSD was 1.7 cm/pixel.

5.5 Thesis limitations

All UAVs are designed and operate in a manner that makes each of them a unique machine, in the sense of whether or not it can be flown in the rain, its resistivity to the wind, battery life and many more features. Regarding the limitation of the Parrot ANAFI thermal used in this experiment, the maximum temperature it can be flown at is 40 °C and a maximum humidity rate of 93%. Additionally, it can only handle a wind resistance of 50 km/h, wind gust resistance of 80 km/h, fly for 26 minutes per battery and other durability and performance limitations (Parrot, 2020a). Whilst the flight condition restrictions that limits the operation of the Parrot Bluegrass are flying the UAV at temperature below 40 °C, 30 km/h wind resistance, battery life of 25 minutes and being unable to operate the UAV in adverse weather conditions such as rain, snow or when visibility is poor at night or in fog (Parrot, 2020b).

When conducting the initial weather condition check before commencing the first UAV flight on the day of data collection, the observations raised some potential limitations concerning the temperature variance between the graves and their surroundings and the inability to test this feature. Since

conducting the first few months of this experiment in the summer, it was not possible to test the effect of the ground temperature variance in the desert. The optimum time for conducting thermal imaging is when the temperature variance between the burial site and its surroundings is detectable, during sunrise and sunset. This is true because the temperature of the surrounding environment would be lower than the grave containing the decomposed body, which produces heat that is easily captured at that time (Pringle et al., 2012b). However, the temperatures recorded for the first two weeks, around sunrise and sunset, were just below 40 °C, the maximum temperature to operate a UAV. Hence, the temperature was only captured at sunrise, which limited the possibility of testing any temperature variance that may have been present.

Another limitation that heavily affected the findings of this research, specifically with the single graves results, is the scavenger intrusion. Scavengers were able to dig their way inside the single graves, and in one case, devour some parts of the buried carcass and the other, devour the whole carcass. Therefore, the findings lack the evaluation of the full decomposition process effect on single graves in a desert environment in terms of topsoil temperature and soil moisture. Hence, despite the promising findings of the mass graves, it would also be interesting to see the results on single graves without the scavenger intrusion. The findings would have then positively aided the local authorities with using this method in the process of searching for clandestine graves that are part of local criminal cases.

Also, it is acknowledged that one limitation of the current research is the restrictions of airspace regulations due to the proximity of the research area location to an airbase. In addition, the flying permission obtained from the Ministry of Interior in Kuwait to operate the UAV, which forbids the capturing of any images outside the research area (Appendix D). This limits the thesis from testing the technology used for false positives and negatives, which would have provided us with more information on the utility of commercially available UAVs in aiding the clandestine graves detection methods.

Lastly, examining a vast area for surface anomalies requires an enormous amount of time and would be much more complex than the examination done within the presented research conditions. If examining the area using the manual method was the only mean of detection available, then dividing the area into smaller zones with multiple people examining it would be the best solution for such limitation.

5.6 Avenues for future research

The current research sought to explore if there is any temperature variance effect on the topsoil temperature of the graves when capturing the thermal images at two different times of the day. The initial plan was to capture two sets of thermal images daily during sunrise and sunset for the first two weeks. Based on previous research, this was expected to show during the first two weeks of the experiment (Bodnar et. al, 2019). It was expected to have a noticeable temperature difference between the graves and their surroundings during those hours. However, due to the high environmental temperature in the first two weeks, this research did not have such variation in temperatures. A future study could investigate these differential cooling patterns, usually shown during fall or winter seasons, in arid environments when temperatures are measured and compared during the first hours of sunrise and sunset (Davenport, 2001).

Moreover, alterations in different soil and vegetation patterns were not heavily studied nor observed in much detail. It only focused on the vegetation cover of the graves in comparison to their surroundings and the length of the vegetation. A future study could focus on detecting any plant species that are unique to burial sites, determine the length of time that soil and vegetation changes persist. Moreover, the study should seek to recognise any factors that may influence the visibility of graves in arid environments such as larger disturbances areas, fine-textured soils, different subsoil and distance from intact vegetation, which has been studied and explored recently but in a different environment (Watson et al., 2021). While the complexity of surface anomalies can vary, utilising the expertise of archaeologists and botanists can aid in developing search techniques for the location of potential burial sites.

It is known that in most search missions for mass graves, the work requires thoroughly covering a large land area. Nonetheless, here the research area was relatively small, and images were only captured in the assigned plot of land, following the permission obtained. Hence the commercially available UAV used in this research is suitable only for the presented experimental research conditions. Therefore, to implement it in real-life scenarios, the UAV would require flying at a higher height for longer time periods and still being able to capture high-resolution images. This would require a longer battery lifetime, a feature currently found on affordable commercially available fixed-wing UAVs that can fly longer and cover large areas. Additionally, capturing images broader than the enclosed limited research area would allow us to further test the validity of these methods of grave detection since it will explore any false positive or false negative results.

Additional steps to be considered in any future work to increase the credibility of the obtained results

include blind testing, whereby the examiner does not have any prior knowledge about the location of the graves when analysing the index maps or the captured images. This step can be repeated with another observer, neither by revealing the decisions and conclusions of the first examiner nor by knowing what is being verified. Such techniques have been previously used in many other fields in the forensic science community, such as in fingerprint and DNA analyses, to avoid any bias in decision making (Dror, Charlton and Péron, 2006).

The thermal image findings are considered adequate under the given conditions for about seven months when analysing the temperature of the graves and ten months when analysing their soil moisture. However, one thing to note is that the results might differ based on the total body mass of the buried carcasses, the nature of the environment where carcasses are buried, the depth of the grave and how many days or months post-burial the data was collected. Hence, such technology is entirely dependent on the given circumstances of the crime committed and is mainly considered an exploratory search method which aims to reduce the area of the suspected burial site.

Lastly, upon completion of this research, the mass graves in the burial site are intended to be used for training the relevant staff of the General Department of Criminal Evidence in Kuwait. The training will include the procedures and approaches of digging mass graves, exhuming buried bodies and collecting buried evidence. This training is hoped to be undertaken in collaboration with Liverpool John Moores University.

Chapter 6 Conclusion

Throughout the years, detecting clandestine graves has posed a great challenge to forensic investigators. As highlighted in Chapter 1, the present thesis aimed to evaluate the use of commercially available UAVs coupled with remote sensing technology to detect clandestine graves in an arid environment. More specifically, the thesis sought to understand the effectiveness of using 4K RGB, thermal and multispectral imagery in identifying soil disturbances, landscape changes, differences in surface elevation, vegetation index, topsoil temperature and soil moisture difference. Ultimately, introducing cost- and time-effective techniques can be used to identify clandestine graves in an arid environment. The research conducted was concerned with addressing the knowledge gap in forensic anthropology with regard to detecting clandestine graves in an arid environment using remote sensing techniques, focusing on three main research questions:

- Do graves in an arid environment have distinguishable temperatures and soil moisture on their surface compared to their surroundings? How long can these features be discerned using the thermal sensor deployed on the UAV?
- Can a multispectral sensor detect soil disturbance produced by a grave in an arid environment? For how long would the sensor give effective results?
- Can a 4K RGB sensor deployed on a UAV detect changes in surface height and surface anomalies produced by a grave in an arid environment?

A holistic examination of the stages and methodological procedures was undertaken to establish how and to what extent commercially available UAVs can be used in an arid environment to aid forensic investigations. Images were captured on 18 different occasions in order to test the usefulness of 4K RGB, thermal and multispectral imagery by empirically investigating whether remote sensing technology deployed on UAVs aids in detecting simulated graves in an arid environment.

First, this study evaluated temperature and soil moisture variations between the control and experimental graves compared to their surroundings. Also, it explored how long such variations were discerned. This was investigated through two approaches, the first by monitoring and analysing the captured thermal images using a thermal sensor mounted on a UAV and the second by conducting an on-ground survey to confirm the validity of the aerial method by measuring the on-ground temperature of the graves and their surroundings and collecting soil samples to measure the soil moisture of the graves. The analysis was conducted based on the type of graves. It was divided into different categories: hand-dug single graves, machine-dug single graves and machine-dug mass

graves. It was found that the captured aerial thermal images of the graves and their surroundings had varied in terms of temperature depending on the number of buried carcasses. Another factor which affected the captured aerial thermal images was whether the graves had been disturbed by scavengers.

The number of buried carcasses had a significant effect on the temperatures of the machine-dug mass grave (G5 and G6); therefore, the more carcasses buried in the grave, the higher the temperature variation between that grave and its surroundings. The results revealed that the temperature of the graves was always lower than the surroundings, except for the period between the third- and seventh-month post-burial. During that time, the temperature of the experimental grave was higher than the control grave and the surrounding area. Yet the single graves (G1, G2, G3 and G4) had an insignificant result when statistically analysed. However, the insignificance of the single graves results was related to the fact that those graves had been affected by scavenger intrusion, which managed to dig the graves and reach for the buried sheep few days post-burial. The highest temperature difference between the single graves was captured on the second week post-burial. Meanwhile, the greater depth of the mass grave delayed capturing the highest temperature difference between the control and experimental mass graves to the seventh month post-burial. Hence, the grave depth factor heavily influenced the decomposition process and, ultimately, when the highest temperature was recorded. Alternatively, the effect of the height at which the UAV was flown to capture the images, had insignificant influence for all graves within the range of height tested on the enclosed area.

Meanwhile, the height at which the UAV flew to capture those images showed an insignificant effect on the obtained results of the topsoil temperature analysis. However, the ground sampling distance (GSD) of the images was all within the recommended GSD for thermal analysis. Therefore, it did not affect the accuracy and effectiveness of mapping and detecting key features of interest. An additional aspect that was investigated using thermal imagery was the soil moisture through the calculation of the TVDI. Again, and due to scavenger intrusion, the single graves could be visually distinguished from their surroundings using the TVDI map for the first month only. Nonetheless, the soil moisture difference of the mass graves compared to their surrounding on the TVDI maps was observed until the tenth month post-burial. Furthermore, similarly to the topsoil temperature findings, the number of carcasses buried in the grave did have a significant effect on the soil moisture of the graves whilst the height at which the UAV was flying at when capturing the image was insignificant. The fact that it

was possible to detect a temperature difference between the graves and their surroundings using commercially available UAVs under extreme weather conditions of this study is considered a great addition to international forensic committees involved in detecting clandestine graves in countries with such a harsh environment.

Second, this study provided insight into whether disturbance from the creation of single and mass graves is detectable using multispectral and 4K RGB imagery. This was achieved by analysing the captured multispectral and 4K RGB images using both manual and automated methods. The ability to detect a grave using remote sensing imagery, whether from multispectral or 4K RGB platforms, depends on several factors, including the spatial resolution of the imagery and the size of the grave. Therefore, the success of mass grave detection through remote sensing hinges on the careful consideration of these various factors. In this research, multispectral imagery was a more suitable approach for manually detecting anomalies than the 4K RGB method. Specifically, NIR and red-edge wavelengths were found to be the most appropriate for this type of detection. However, in some instances, the 4K RGB images were more practical to use in the detection process, especially when there was a vegetation cover on the graves in comparison to their immediate surroundings. Regardless of the type of sensor used, the manual detection method was sustainable for 15 months for both sensors. The eighteenth month was not captured with the multispectral sensor due to an error with the UAV connection with the Pix4Dcapture software. Similarly, the 4K RGB produced unsatisfactory results for the images captured at 18 months. Also, the automated detection method for both sensors showed promising results when using the RX Anomaly Detection tool. It aimed to detect any pixels different from the rest of the recorded image sequence (bad pixels), reflecting the soil disturbances on the graves in the images. Depending on the time of the year and the type of image captured, the detection method which was most informative between the three available options varied. The mass graves were more apparent than the single graves when the automated method was introduced due to the greater amount of disturbance caused when compared to the single graves. Some graves were not apparent when analysing the captured images due to some weathering and erosion effects on the area of interest. Hence, in principle, this research has demonstrated that both the 4K RGB and multispectral imagery can be used to identify a disturbance indicative of the creation of a grave, whether empty or full, for a period that is as long as 18 months and possibly more. Here, the findings presented contradict statements by Kalacska and Bell (2006), Kalacska et al. (2009) and Leblanc et al. (2014) who assert the necessity of having sophisticated hyperspectral sensors in order to locate areas of disturbances. Instead, the results proved that the acquisition of images in

some wavelengths can indeed help in the identification of soil disturbances, which can be related to the location of the graves when conducting a field search for possible burial sites.

Multispectral images were also examined to monitor the normalised difference vegetation index (NDVI) from the surface of the graves. In general, the index map of NDVI showed a minor difference between the graves and their surroundings. Furthermore, relating it to the highest temperature difference of the experimental mass grave, NDVI also had its highest value in the seventh month. In conclusion, it can be said that the use of NDVI and its index map can be considered a good addition to any existing detection methods used on the area of interest in an arid environment that lacks dense vegetation but might not be as valuable when used by itself.

Using a 4K RGB sensor deployed on a UAV proved its applicability and appropriateness in detecting burial sites in arid environments throughout the research period of 18 months. This conclusion was reached from the results of the anomaly detection method mentioned above. Moreover, the analysis of 4K RGB images using the digital elevation model (DEM) accurately identified burial mounds with a 1 cm difference from ground level with respect to the underlying ground surface.

Optical remote sensing, using the inexpensive and time-effective passive sensors mounted on a multicopter UAV, performed well in detecting anomalies that may represent graves in an arid environment with the given circumstances. Evaluating temperature and soil moisture variations, detecting surface anomalies and exploring the landscape changes provided satisfactory results in distinguishing between the graves and their surroundings. Therefore, implementing this technology in such environmental conditions is considered a promising approach that is hoped to serve as a cost- and time-effective search method. The obtained results from the analysed data captured using the different sensors deployed on the UAVs supports the aims and objectives. It showed that remote sensing effectively detects clandestine graves in an arid environment. It is hoped that this research will have an impact in the humanitarian efforts to locate clandestine graves and help the families of those who are missing and presumed dead in several countries that share a similar environment to Kuwait.

In summary, there is no simple answer or single technique for the best method used in clandestine grave detection. It is all constrained by the environment, the size of the grave, the depth of the grave, the number of the bodies buried in the grave, the time of the year when conducting the search, the budget dedicated and the human resources available.

References

Abate, D., Sturdy Colls, C., Moyssi, N., Karsili, D., Faka, M., Anilir, A. and Manolis, S. (2019) Optimizing search strategies in mass grave location through the combination of digital technologies. *Forensic Science International*, 1, 95-107.

Aber, J.S., Marzolff, I. and Ries, J.B. (2010) Chapter 3 - Photogrammetry. In: Aber, J. S., Marzolff, I. and Ries, J. B. (ed.) *Small-Format Aerial Photography*. Amsterdam: Elsevier. pp. 23-39.

Agüera-Vega, F., Carvajal-Ramírez, F. and Martínez-Carricondo, P. (2017) Accuracy of Digital Surface Models and Orthophotos Derived from Unmanned Aerial Vehicle Photogrammetry. *Journal of surveying engineering*, 143 (2), 4016025.

Al-Dossari, F. (2018) *Almohima Alkubra: Masirat Albahth Aljinaee [The Grand Mission: The Criminal Investigation]*. 2nd ed. Al.Alfain.

Amendt, J., Rodner, S., Schuch, C.-P., Sprenger, H., Weidlich, L. and Reckel, F. (2017) Helicopter thermal imaging for detecting insect infested cadavers. *Science & Justice*, 57 (5), 366-372.

Animals (Scientific Procedures) Act 1986. (2014) *Guidance on the Operation of the Animals (Scientific Procedures) Act 1986* [online]

Available at: <https://www.gov.uk/guidance/guidance-on-the-operation-of-the-animals-scientific-procedures-act-1986#guidance-on-the-operation-of-aspa>

[Accessed: 23 April 2022]

Assmann, J.J., Kerby, J.T., Cunliffe, A.M. and Myers-Smith, I.H. (2018) Vegetation monitoring using multispectral sensors — best practices and lessons learned from high latitudes. *Journal of Unmanned Vehicle Systems*, 7 (1), 54-75.

Awadhwai, N.K. and Thierstein, G.E. (1985) Soil crust and its impact on crop establishment: A review. *Soil and Tillage Research*, 5 (3), 289-302.

Baluja, J., Diago, M.P., Balda, P., Zorer, R., Meggio, F., Morales, F. and Tardaguila, J. (2012) Assessment of vineyard water status variability by thermal and multispectral imagery using an unmanned aerial vehicle (UAV). *Irrigation Science*, 30 (6), 511-522.

Barone, P.M. and Di Maggio, R.M. (2019) Forensic geophysics: ground penetrating radar (GPR) techniques and missing persons investigations. *Forensic Sciences Research*, 4 (4), 337-340.

Barone, P.M., Matsentidi, D., Mollard, A., Kulengowska, N. and Mistry, M. (2022) Mapping Decomposition: A Preliminary Study of Non-Destructive Detection of Simulated body Fluids in the Shallow Subsurface. *Forensic Sciences*, 2 (4), 620-634.

Blau, S., Sterenberg, J., Weeden, P., Urzedo, F., Wright, R. and Watson, C. (2018) Exploring non-invasive approaches to assist in the detection of clandestine human burials: developing a way forward. *Forensic Sciences Research*, 3 (4), 304-326.

Bodnar, S., Ciotti, J., Soroka, J., Larsen, R., and Sprague, E. (2019) Drone-Assisted Thermal Imaging to Determine the Location of Unmarked Graves. *Journal of Forensic Identification*, 69 (3), 378-393.

Booyesen, R., Gloaguen, R., Lorenz, S., Zimmermann, R. and Nex, P.A.M. (2021) Geological Remote Sensing. In: Alderton, D. and Elias, S. A. (ed.) *Encyclopedia of Geology (Second Edition)*. Oxford: Academic Press. pp. 301-314.

Brilis, G.M. (2000) Remote Sensing Tools Assist in Environmental Forensics. Part I: Traditional Methods. *Environmental Forensics*, 1 (2), 63-68.

Buck, S.C. (2003) Searching for graves using geophysical technology: field tests with ground penetrating radar, magnetometry, and electrical resistivity. *J Forensic Sci*, 48 (1), 5-11.

Bugnion, F. (2012) Birth of an idea: the founding of the International Committee of the Red Cross and of the International Red Cross and Red Crescent Movement: from Solferino to the original Geneva Convention (1859–1864). *International Review of the Red Cross*, 94 (888), 1299-1338.

Butters, O., Krosch, M.N., Roberts, M. and MacGregor, D. (2021) Application of forward-looking infrared (FLIR) imaging from an unmanned aerial platform in the search for decomposing remains. *Journal of Forensic Sciences*, 66 (1), 347-355.

Callamard, A. (2019) *Extrajudicial, summary or arbitrary executions :note*. [New York] :: UN.

Campbell, J.B. and Wynne, R.H. (2011) *Introduction to remote sensing*. 5th ed. ed. New York :: Guilford.

Casamitjana, M., Torres-Madroño, M.C., Bernal-Riobo, J. and Varga, D. (2020) Soil Moisture Analysis by Means of Multispectral Images According to Land Use and Spatial Resolution on Andosols in the Colombian Andes. *Applied Sciences*, 10 (16), 5540.

Casana, J., Kantner, J., Wiewel, A. and Cothren, J. (2014) Archaeological aerial thermography: a case study at the Chaco-era Blue J community, New Mexico. *Journal of Archaeological Science*, 45, 207-219.

Catts, E.P. and Goff, M.L. (1992) Forensic entomology in criminal investigations. *Annual Review of Entomology*, 37, 253-272.

Chang, C.-I. and Chiang, S.-S. (2002) Anomaly detection and classification for hyperspectral imagery. *Geoscience and Remote Sensing, IEEE Transactions on*, 40, 1314-1325.

Chein, I.C. and Shao-Shan, C. (2002) Anomaly detection and classification for hyperspectral imagery. *IEEE Transactions on Geoscience and Remote Sensing*, 40 (6), 1314-1325.

Chen, S., Wen, Z., Jiang, H., Zhao, Q., Zhang, X. and Chen, Y. (2015) Temperature Vegetation Dryness Index Estimation of Soil Moisture under Different Tree Species. *Sustainability*, 7, 11401-11417.

Cohen, Y., Alchanatis, V., Prigojin, A., Levi, A., Soroker, V. and Cohen, Y. (2011) Use of aerial thermal imaging to estimate water status of palm trees. *Precision Agriculture*, 13 (1), 123-140.

Corcoran, K.A., Mundorff, A.Z., White, D.A. and Emch, W.L. (2018) A novel application of terrestrial LIDAR to characterize elevation change at human grave surfaces in support of narrowing down possible unmarked grave locations. *Forensic Science International*, 289, 320-328.

Davenport, G.C. (2001) Remote sensing applications in forensic investigations. *Historical Archaeology*, 35 (1), 87-101.

DesMarais, A.M. (2014) Detection of Cadaveric Remains by Thermal Imaging Cameras. *Journal of Forensic Identification*, 64 (5), 489-511.

Dorriety, J.K. (2007) Cadaver Dogs as a Forensic Tool: An Analysis of Prior Studies. *Journal of Forensic Identification*, 57 (5), 717-725.

Dozal, L., Silván-Cárdenas, J., Moctezuma, D., S. Siordia, O. and Naredo, E. (2018) Evolutionary Approach for Detection of Buried Remains Using Hyperspectral Images. *Photogrammetric Engineering & Remote Sensing*, 84, 435-450.

Dror, I.E., Charlton, D. and Péron, A.E. (2006) Contextual information renders experts vulnerable to making erroneous identifications. *Forensic Science International*, 156 (1), 74-78.

Dupras, T.L., Schultz, J.J., Wheeler, S.M. and Williams, L.J. (2011) *Forensic Recovery of Human Remains : Archaeological Approaches, Second Edition*. Baton Rouge, UNITED STATES: Taylor & Francis Group.

E P Catts, a. and Goff, M.L. (1992) Forensic Entomology in Criminal Investigations. *Annual Review of Entomology*, 37 (1), 253-272.

ESRI (2002) ArcGIS Desktop (10.8.1.14362) [software]

Available at: <https://www.esri.com/en-us/arcgis/products/arcgis-desktop/resources>

[Accessed 20 July 2020]

Evers, R. (2018) The application of low-altitude near-infrared aerial photography for detecting clandestine burials using a UAV and low-cost unmodified digital camera. *Forensic Science International*, 289, 408.

Exelis Visual Information Solutions (2020) ENVI (5.6) [software]

Available at: <https://www.l3harrisgeospatial.com/docs/whatsnewenvi56.html>

[Accessed 10 July 2020]

Fernández-Álvarez, J.-P., Rubio-Melendi, D., Martínez-Velasco, A., Pringle, J.K. and Aguilera, H.-D. (2016) Discovery of a mass grave from the Spanish Civil War using Ground Penetrating Radar and forensic archaeology. *Forensic Science International*, 267, e10-e17.

FLIR Systems Inc (2015) FLIR Thermal Studio Suite (6.4.18039.1003) [software]

Available at: <https://www.flir.co.uk/products/flir-thermal-studio-suite/>

[Accessed 10 July 2020]

Franzini, M., Ronchetti, G., Sona, G. and Casella, V. (2019) Geometric and Radiometric Consistency of Parrot Sequoia Multispectral Imagery for Precision Agriculture Applications. *Applied Sciences*, 9, 5314.

Freeman, L. (2018) Digital evidence and war crimes prosecutions: The impact of digital technologies on international criminal investigations and trials. *Fordham international law journal*, 41 (2), 283.

Fuentes-Peailillo, F., Ortega-Farías, S., Rivera, M., Bardeen, M. and Moreno, M. (2018) Comparison of vegetation indices acquired from RGB and Multispectral sensors placed on UAV. *IEEE International Conference on Automation/XXIII Congress of the Chilean Association of Automatic Control (ICA-ACCA)*, 17-19 Oct. 2018 of Conference.

Gaggioli, G. (2018) International Humanitarian Law: The legal framework for humanitarian forensic action. *Forensic Science International*, 282, 184-194.

Gasser, H.-P. (1998) *International humanitarian law and the protection of war victims* [online]

Available at: <https://www.icrc.org/en/doc/resources/documents/misc/57jm93.htm#1>

[Accessed: 17 January 2021]

Gowravaram, S., Tian, P., Flanagan, H., Goyer, J. and Chao, H. (2018) *UAS-based Multispectral Remote Sensing and NDVI Calculation for Post Disaster Assessment*. Dallas, TX, USA: 2018 International Conference on Unmanned Aircraft Systems (ICUAS).

Gu, H., Lin, Z., Guo, W. and Deb, S. (2021) Retrieving Surface Soil Water Content Using a Soil Texture Adjusted Vegetation Index and Unmanned Aerial System Images. *Remote Sensing*, 13, 145.

Haglund, W., Connor, M. and Scott, D. (2001) The Archaeology of Contemporary Mass Graves. *Historical Archaeology*, 35, 57-69.

Haglund, W.D. and Sorg, M.H. (2002) *Advances in forensic taphonomy : method, theory, and archaeological perspectives*. CRC Press.

Hsu, W.-L. and Chang, K.-T. (2019) Cross-estimation of Soil Moisture Using Thermal Infrared Images with Different Resolutions. *Sensors and Materials*, 31 (2).

IBM (2021) SPSS Statistics Product (28.0.0.0 (190)) [software]

Available at: <https://www.ibm.com/support/pages/ibm-spss-statistics-product-release-version-2801>

[Accessed 18 May 2023]

- ICRC. (1949) Accounting for missing persons [online]
Available at:
https://ihl-databases.icrc.org/customary-ihl/eng/docs/v1_rul_rule117#refFn_7218634_00028
[Accessed: 23 November 2020]
- Johnson, A.P., Mikac, K.M. and Wallman, J.F. (2013) Thermogenesis in decomposing carcasses. *Forensic Science International*, 231 (1-3), 271-277.
- Johnson, A.P. and Wallman, J.F. (2014) Infrared imaging as a non-invasive tool for documenting maggot mass temperatures. *Australian Journal of Forensic Sciences*, 46 (1), 73-79.
- Kalacska, M. and Bell, L.S. (2006) Remote Sensing as a Tool for the Detection of Clandestine Mass Graves. *Canadian Society of Forensic Science Journal*, 39 (1), 1-13.
- Kalacska, M., Bell, L., Sanchez-Azofeifa, A., and Caelli, T.. (2009) The Application of Remote Sensing for Detecting Mass Graves: An Experimental Animal Case Study from Costa Rica. *Journal of Forensic Sciences*, 54 (1), 159-167.
- Kislov, M.A., Chauhan, M., Stepanov, S.A., Zolotenkova, G.V., Pigolkin, Y. and Brazhnikov, Y. (2022) Forensic diagnostics of the range of rifled firearm calculated by back spatter over clothing. *Legal Medicine*, 57, 102051.
- Klinkner, M. (2017) Towards mass-grave protection guidelines. *Human Remains and Violence*, 3 (1), 52-70.
- Knapen, A., Poesen, J., Galindo-Morales, P., Baets, S.D. and Pals, A. (2007) Effects of microbiotic crusts under cropland in temperate environments on soil erodibility during concentrated flow. *Earth Surface Processes and Landforms*, 32 (12), 1884-1901.
- Korchagina, I., Goleva, O., Savchenko, Y. and Bozhikov, T. (2020) The use of geographic information systems for forest monitoring. *Journal of Physics: Conference Series*, 1515, 032077.
- Larson, D.O., Vass, A.A. and Wise, M. (2011) Advanced Scientific Methods and Procedures in the Forensic Investigation of Clandestine Graves. *Journal of Contemporary Criminal Justice*, 27 (2), 149-182.
- Lattimer, M. (2018) Two concepts of human rights. *Hum. Rts. Q.*, 40, 406.
- Leblanc, G., Kalacska, M. and Soffer, R. (2014) Detection of single graves by airborne hyperspectral imaging. *Forensic Science International*, 245, 17-23.

Lee, M.J., Voss, S.C., Franklin, D. and Dadour, I.R. (2018) Preliminary investigation of aircraft mounted thermal imaging to locate decomposing remains via the heat produced by larval aggregations. *Forensic Science International*, 289, 175-185.

Liu, J.-G. (2016) *Image processing and GIS for remote sensing : techniques and applications*. Second edition. ed. Chichester, England : Wiley Blackwell.

Liu, J.G. and Mason, P.J. (2016) *Image Processing and GIS for Remote Sensing : Techniques and Applications*. Chichester, UNITED KINGDOM: John Wiley & Sons, Incorporated.

Loke, M.H., Rucker, D.F., Chambers, J.E., Wilkinson, P.B. and Kuras, O. (2020) Electrical Resistivity Surveys and Data Interpretation. In: Gupta, H. K. (ed.) *Encyclopedia of Solid Earth Geophysics*. Cham: Springer International Publishing. pp. 1-6.

Mann, R.W., Bass, W.M. and Meadows, L. (1990) Time since death and decomposition of the human body: variables and observations in case and experimental field studies. *J Forensic Sci*, 35 (1), 103-111.

Mant, A.K. (1987) Knowledge acquired from post-war exhumations. *Death, decay and reconstruction: approaches to archaeology and forensic science*, 65-78.

Martin, C., Diederich, C. and Verheggen, F. (2020) Cadaver Dogs and the Deathly Hallows—A Survey and Literature Review on Selection and Training Procedure. *Animals*, 10 (7), 1219.

Matheson, M.J. (2017) The United States position on the relation of customary international law to the 1977 protocols additional to the 1949 Geneva Conventions. In: (ed.) *The Development and Principles of International Humanitarian Law*. Routledge. pp. 233-245.

Matuszewski, S., Hall, M.J.R., Moreau, G., Schoenly, K.G., Tarone, A.M. and Villet, M.H. (2020) Pigs vs people: the use of pigs as analogues for humans in forensic entomology and taphonomy research. *International Journal of Legal Medicine*, 134 (2), 793-810.

Meng, X.-l., Zhang, W., Cong, M.-y., Cao, Y.-m. and Bao, W.-z. (2010) *Bad pixel replacement based on spatial statistics for IR sensor*. SPIE.

Murray, B., Anderson, D., Wescott, D., Moorhead, R. and Anderson, M. (2018) Survey and Insights into Unmanned Aerial-Vehicle-Based Detection and Documentation of Clandestine Graves and Human Remains. *Human Biology*, 90 (1), 1-17.

Office of the United Nations High Commissioner for Human Rights (2017) The Minnesota protocol on the investigation of potentially unlawful death *United Nations*.

Okin, G. and Roberts, D.A. (2004) Remote sensing in arid regions: Challenges and opportunities. *Manual of Remote Sensing*, 4, 111-146.

Pádua, L., Marques, P., Hruška, J., Adão, T., Peres, E., Morais, R. and Sousa, J.J. (2018) Multi-Temporal Vineyard Monitoring through UAV-Based RGB Imagery. *Remote Sensing*, 10 (12), 1907.

Parrot (2020a) Parrot ANAFI Thermal [hardware]

Available at: <https://www.parrot.com/en/drones/anafi-thermal>

[Accessed 6 February 2022]

Parrot (2020b) Parrot Bluegrass [hardware]

Available at: <https://www.parrot.com/en/support/documentation/bluegrass-and-bluegrass-fields>

[Accessed 6 February 2022]

Parrott, E., Panter, H.A., Morrissey, J. and Bezombes, F. (2019) A Low Cost Approach to Disturbed Soil Detection Using Low Altitude Digital Imagery from an Unmanned Aerial Vehicle. *Drones*, 3 (2).

Pix4D (2022a) Pix4Dcapture (4.13.1) [software]

Available at: <https://www.pix4d.com/product/pix4dcapture/>

[Accessed 9 July 2020]

Pix4D (2022b) Pix4Dmapper educational license (4.6.4) [software]

Available at: <https://www.pix4d.com/product/pix4dmapper-photogrammetry-software/>

[Accessed 9 July 2020]

Pollard, T. and Barton, P. (2013) The Use of First World War Aerial Photographs by Archaeologists: A Case Study from Fromelles, Northern France. In: Hanson, W. S. and Oltean, I. A. (ed.) *Archaeology from Historical Aerial and Satellite Archives*. New York, NY: Springer New York. pp. 87-103.

Pringle, J.K., Jervis, J.R., Hansen, J.D., Jones, G.M., Cassidy, N.J. and Cassella, J.P. (2012a) Geophysical Monitoring of Simulated Clandestine Graves Using Electrical and Ground-Penetrating Radar Methods: 0–3 Years After Burial*,†. *Journal of Forensic Sciences*, 57 (6),

1467-1486.

Pringle, J.K., Ruffell, A., Jervis, J.R., Donnelly, L., McKinley, J., Hansen, J., Morgan, R., Pirrie, D. and Harrison, M. (2012b) The use of geoscience methods for terrestrial forensic searches. *Earth-Science Reviews*, 114 (1-2), 108-123.

Pringle, J.K., Stimpson, I.G., Wisniewski, K.D., Heaton, V., Davenward, B., Mirosch, N., Spencer, F. and Jervis, J.R. (2020) Geophysical monitoring of simulated homicide burials for forensic investigations. *Scientific Reports*, 10 (1), 7544.

Pulla, V.R. and Kalinganire, C. (2021) The 1994 Genocide against the Tutsi in Rwanda. *Space and Culture, India*, 9 (3), 17-31.

Reed, I.S. and Yu, X. (1990) Adaptive multiple-band CFAR detection of an optical pattern with unknown spectral distribution. *IEEE Transactions on Acoustics, Speech, and Signal Processing*, 38 (10), 1760-1770.

Rocke, B. and Ruffell, A. (2022) Detection of Single Burials Using Multispectral Drone Data: Three Case Studies. *Forensic Sciences*, 2 (1), 72-87.

Rocke, B., Ruffell, A. and Donnelly, L. (2021) Drone aerial imagery for the simulation of a neonate burial based on the geoforensic search strategy (GSS). *Journal of Forensic Sciences*, 66 (4), 1506-1519.

Rodriguez, W.C., 3rd and Bass, W.M. (1985) Decomposition of buried bodies and methods that may aid in their location. *J Forensic Sci*, 30 (3), 836-852.

Ruffell, A. and McKinley, J. (2005) Forensic geoscience: applications of geology, geomorphology and geophysics to criminal investigations. *Earth-Science Reviews*, 69 (3-4), 235-247.

Ruffell, A. and McKinley, J. (2014) Forensic geomorphology. *Geomorphology*, 206, 14-22.

Ruotsala, A.-H. (2016) *Digital Close-Range Photogrammetry – A Modern Method to Document Forensic Mass Graves*. Master of Science in Technology thesis, Aalto University.

Saifizi, M., Azani Mustafa, W., Syahirah Mohammad Radzi, N., Aminudin Jamlos, M. and Zulkarnain Syed Idrus, S. (2020) UAV Based Image Acquisition Data for 3D Model Application. *IOP conference series. Materials Science and Engineering*, 917 (1), 12074.

Schabas, W.A. (2006) *The UN International Criminal Tribunals: The Former Yugoslavia, Rwanda and Sierra Leone*. Cambridge: Cambridge University Press.

Schowengerdt, R.A. (1997) CHAPTER 2 - Optical Radiation Models. In: Schowengerdt, R. A. (ed.) *Remote Sensing (Second Edition)*. Boston: Academic Press. pp. 35-66.

Schowengerdt, R.A. (2007) *Remote sensing, models, and methods for image processing*. 3rd ed. Burlington, MA: Burlington, MA : Academic Press.

Schuldenrein, J., Trimble, M.K., Malin-Boyce, S. and Smith, M. (2017) Geoarchaeology, Forensics, and the Prosecution of Saddam Hussein: A Case Study from the Iraq War (2003–2011. *Geoarchaeology*, 32 (1), 130-156.

Schultz, J.J. (2007) Using Ground-Penetrating Radar to Locate Clandestine Graves of Homicide Victims: Forming Forensic Archaeology Partnerships With Law Enforcement. *Homicide Studies*, 11 (1), 15-29.

Servello, J. (2010) *Thermal identification of clandestine burials: A signature analysis and image classification approach*. Gill-King, H.: ProQuest Dissertations Publishing.

Shi, S., Yao, F., Zhang, J. and Yang, S. (2020) Evaluation of temperature vegetation dryness index on drought monitoring over Eurasia. *IEEE Access*, 8, 30050-30059.

Silván-Cárdenas, J.L., Caccavari-Garza, A., Quinto-Sánchez, M.E., Madrigal-Gómez, J.M., Coronado-Juárez, E. and Quiroz-Suarez, D. (2021) Assessing optical remote sensing for grave detection. *Forensic Science International*, 329, 111064.

Silván-Cárdenas, J.L., Corona-Romero, N., Madrigal-Gómez, J.M., Saavedra-Guerrero, A., Cortés-Villafranco, T. and Coronado-Juárez, E. (2017) On the Detectability of Buried Remains with Hyperspectral Measurements. In: (ed.) *Pattern Recognition*. pp. 201-212.

Skinner, M. (1987) Planning the archaeological recovery of evidence from recent mass graves. *Forensic Sci Int*, 34 (4), 267-287.

Skinner, M., Alempijevic, D. and Djuric-Srejic, M. (2003) Guidelines for International Forensic Bio-archaeology Monitors of Mass Grave Exhumations. *Forensic Science International*, 134 (2-3), 81-92.

Sobotkova, A. and Ross, S.A. (2010) High-resolution, multi-spectral satellite imagery and extensive archaeological prospection: case studies from Apulia, Italy and Kazanluk, Bulgaria. *Third international conference on remote sensing in archaeology*, 50, 23-30.

Somma, R., Cascio, M., Silvestro, M. and Torre, E. (2018) A GIS-based Quantitative Approach for the Search of Clandestine Graves, Italy. *Journal of Forensic Sciences*, 63 (3), 882-898.

Sona, G., Passoni, D., Pinto, L., Pagliari, D., Masseroni, D., Ortuani, B. and Facchi, A. (2016) UAV multispectral survey to map soil and crop for precision farming applications. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives)*, XLI-B1, 1023-1029.

Steadman, D. and Haglund, W. (2005) The Scope of Anthropological Contributions to Human Rights Investigations. *Journal of Forensic Sciences*, 50, 23-30.

Teo, C., Pawita, A., Osman, K., Ghani, A.A. and Hamzah, N.H. (2013) Post mortem changes in relation to different types of clothing. *The Malaysian journal of pathology*, 35, 77-85.

Ubelaker, D.H. (2018) A history of forensic anthropology. *American Journal of Physical Anthropology*, 165 (4), 915-923.

Ubelaker, D.H., Shamlou, A. and Kunkle, A.E. (2019) Forensic anthropology in the global investigation of humanitarian and human rights abuse: Perspective from the published record. *Sci Justice*, 59 (2), 203-209.

United Nations. (1998) *Statute of the International Criminal Court* [online]

Available at: <https://unispal.un.org/UNISPAL.NSF/0/26D5982060C2D2AD85256B3B0074F5F8>

[Accessed: 17 January 2021]

United Nations. (2018) *Human Rights* [online]

Available at: <https://www.un.org/en/global-issues/human-rights>

[Accessed: 18 December 2020]

United Nations Department of Political Affairs (1991) United nations manual of the effective prevention and investigation of extra-legal, arbitrary and summary executions. *United Nations*.

Urbanová, P., Jurda, M., Vojtíšek, T. and Krajsa, J. (2017) Using drone-mounted cameras for on-site body documentation: 3D mapping and active survey. *Forensic Science International*, 281, 52-62.

Veerendra, T., Latha, M. and GP, M.R. (2014) Classification of Remotely Sensed Data using ENVI 4.7 Tool. *International Journal of Research in Advent Technology*, 2.

Wang, B.Y., Raymond, N.A., Gould, G. and Baker, I. (2013) Problems from Hell, Solution in the Heavens?: Identifying Obstacles and Opportunities for Employing Geospatial Technologies to Document and Mitigate Mass Atrocities. *Stability: International Journal of Security and Development*, 2 (3), 53.

Watson, C.J., Ueland, M., Schotsmans, E.M.J., Sterenberg, J., Forbes, S.L. and Blau, S. (2021) Detecting grave sites from surface anomalies: A longitudinal study in an Australian woodland. *J Forensic Sci*, 66 (2), 479-490.

Winterbottom, S.J. and Dawson, T. (2005) Airborne multi-spectral prospection for buried archaeology in mobile sand dominated systems. *Archaeological Prospection*, 12 (4), 205-219.

World Weather Online, *Kuwait historical weather data* [online], <https://www.worldweatheronline.com/> [Accessed 27/02/2023]

APPENDICES

Appendix A

Ethical Review Form for The Use of Live Animals in Unregulated and Non-Licensed Teaching and Research Protocols in accordance with Liverpool John Moores University ethics committee (CE_ASA/2020-4), which obtained on January 5, 2020.



Ethical Review Form for The Use of Live Animals in Unregulated and Non-Licensed Teaching and Research Protocols

Applicant Name	ABDULLAH ALAWADHI	Module Code	
School	BIOLOGICAL AND ENVIRONMENTAL SCIENCE	Email	A.S.ALAWADHI@2020.ljmu.ac.uk
Subject Team		Supervisor's Phone	(0151)231 2038
Date of submission		Supervisor's Name	DR. CONSTANTINE ELIOPOULOS
Level of study (hons, PhD, etc.)	PhD	Programme of Study	
Species - please provide details (species/strain) of the animals that you are using or intend to use: Ten sheep (<i>Ovis aries</i>), all over the age of 6 months and weighing around 30 kg, will be legally purchased from the local abattoir. They will be slaughtered according to the Islamic Sharia Law which is known as the Halal method.			
Sex of animal (if known): Please tick box			
0	Work that involves data analysis from existing data (previously ethically approved) does not require screening		
1	Observational work in the field and zoological settings – with minimal disturbance to animal or habitat can be approved by the Module Leader or Project Supervisor . Special consideration should be given to land entry and necessary permits/permissions and risk assessments.		
2a	Work involving invertebrates off University premises. Screening by a nominated expert within the School who will consider the principles of the 3Rs ¹ . For larger studies, involving significant numbers, applications may be passed onto the Animal Welfare & Ethics Steering Group for a decision. N.b. The nominated individual must not sign off on his or her own work and should instead refer their own applications to Steve Broadfoot.		
2b	Work involving invertebrates on University premises must have prior approval from the relevant Senior Research Officer or Technician Team Leader regarding husbandry requirements before any application is made. Once husbandry arrangements have been approved the screening will be done by a nominated expert within the School, who will consider the principles of the 3Rs ¹ . For larger studies, involving significant numbers, applications may be passed onto the Animal Welfare & Ethics Steering Group for a decision. N.b. The nominated individual must not sign off on his or her own work and should instead refer their own applications to Steve Broadfoot.		
3a	Observations or work involving vertebrates or cephalopods, off University premises , which may cause a disturbance, or is more invasive e.g. disturbing habitat, physical contact, trapping, clipping, tagging, etc.. Applications should be made to Steve Broadfoot who will review and pass onto the Steering Group if necessary. In some circumstances, the Steering Group may pass on applications to the University's Animal Welfare and Ethics Review Board for a final decision.	✓	
3b	Observations or work involving embryos, vertebrates or cephalopods on University premises must have prior approval from the relevant Senior Research Officer or Technician Team Leader regarding husbandry requirements before any application is made. Applications should be made to Steve Broadfoot who will also assess the husbandry arrangements as well as the project proposal. Applications		

Version1 (23/10/2017)

	may be passed onto the Steering Group if necessary, who may in turn pass applications to the University's Animal Welfare and Ethics Review Board for a final decision.	
Nb.	Work involving human subjects must be submitted to the University's Ethics Committee direct. The Animal Welfare and Ethics Steering Group has no remit to discuss studies involving human beings.	
Numbers of animals to be used: Ten		Expiry/End date of Research: December 2021
Details of Usage (use a separate sheet if necessary giving a brief overview of your objectives, define exposure periods and an estimate of the time scale for completion. Please note that ethical approval will only be given for the methods that you specify in this section. If you subsequently change your project, e.g. change the methodology, or the species then you will have to resubmit your application. The aim of the research is to develop a methodology that will allow us to detect clandestine graves in a desert environment. Kuwait government has the responsibility to account for and identify the remains of those killed during the Gulf War (1990-1991). The proposed research is designed to contribute for this effort as the first step in this investigation is to locate where the remains are buried. The research will involve the burial of the sheep in different conditions (depth, single and multiple) and the use of UAV to detect these sites by observing any changes as these are captured by thermal and multispectral cameras. The burial sites will be monitored at specific time intervals for a period of up to eighteen months. It is hoped that the data obtained will allow the development of a methodology that will make a significant contribution to the resolution of this humanitarian issue.		
Where will the animals be kept and/or Address/location where research will be carried out: The animals will be transported from the abattoir directly to the burial location which is a privately owned land approximately 100 km north of Kuwait city		
Who is responsible for care/husbandry (confirm this with the relevant staff member first and sign to confirm that adequate arrangements are in place): N/A		
What are the associated costs (e.g. food, special equipment) and please provide an estimation for these costs. The only cost will be the purchase of the animals at the abattoir and the transportation fee to the burial location		
Who will be paying the costs (e.g. student who is school funded, research grant, School, etc.): Student		
What will you do with the animals after the work is complete? They will be used for training of Kuwait police officers in the excavation of clandestine graves. Once excavated, the skeleton remains can be donated to the local university for the teaching of animal anatomy.		
Can you confirm that you are competent in the skills required for what is proposed? (please provide details of any training). Yes. I have been a police officer for 10 years and I have done several types of investigation of clandestine graves. In addition, I have trained with the use of drones, multispectral cameras and thermal camera at LJMU.		
Can you confirm that you have carefully considered the justification for using animals? (please provide brief justification). Yes. The use of animals to simulate the conditions of human bodies that have been buried in the desert is the only possible way. A number of studies in this area has made use of animals.		
Is your work regulated by any other body e.g. DEFRA? If so, please provide the licence number:		

Version1 (23/10/2017)

(Please contact Dr Alan Simm for information pertaining to DEFRA.)	
No	
If your work is outside the UK could you please confirm: The country: Kuwait	
If the work is regulated by another regulator? And if so, confirmation and the details of what arrangements are in place. No	
It is an offence to carry out investigations on living vertebrates that might cause <u>pain, suffering, distress or lasting harm</u> . Any research that might exceed this threshold will be deemed as <u>regulated</u> and require Home Office permission. Regulated research is not allowed under any conditions by undergraduate or PhD students within LJMU (except under very special circumstances). I confirm this research does not breach the pain threshold outlined above and falls outside the remit of the Home Office licensing system legislated by the ASPA** (1986) Amended.	
Approved by:	
Date:	1.5.20
Approval number (only for applications approved by Steve Broadfoot, or the Review Group for the Use of Non-regulated Animals)	CE_ASA/2020-4 Additional condition: When animals are sourced from the supplying abattoir a receipt or other documentation of proof must accompany this approval form.

Approvers

Level 0	Approval not required
Level 1	Module Leader or Project Supervisor
Level 2a	Subject Head/Nominated School Specialist
Level 2b	i) Technician Team Leader for husbandry requirements ii) Subject Head/Nominated School Specialist
Level 3a	Steve Broadfoot (Senior Research Officer and LSSU Manager)
Level 3b	Steve Broadfoot (Senior Research Officer and LSSU Manager)

NB Work involving human subjects must be referred to the University's Ethics Committee direct. The Animal Welfare and Ethics Steering Group has no remit to discuss studies involving human beings.

Appendix B

UK Civil Aviation Authority drone and model aircraft flyer ID number.



The image shows a flyer ID card from the UK Civil Aviation Authority. The card has a repeating pattern of small aircraft icons in the background. At the top left, it says "UNITED KINGDOM" in blue, followed by "Drone and model aircraft" in large black font, and "Proof of completion of online training" in smaller black font. On the top right is the UK Civil Aviation Authority logo. The "Flyer ID" is prominently displayed in large black font as "GBR-RP-GNPJZ6YRX3TX". Below this, the holder's details are listed: "First name: ABDULLAH", "Last name: ALAWADHI", and "Expiry date: 29 June 2028". In the bottom left corner, a red box indicates the category: "A1 & A3", "OPEN", "SUB", "CATEGORY". In the bottom right, there is a QR code, a "SCAN ME" button with a smartphone icon, and the website "register-drones.caa.co.uk".

UNITED KINGDOM
Drone and model aircraft
Proof of completion of online training

Flyer ID
GBR-RP-GNPJZ6YRX3TX

First name: ABDULLAH
Last name: ALAWADHI
Expiry date: 29 June 2028

A1 & A3
OPEN
SUB
CATEGORY


SCAN ME
register-drones.caa.co.uk

Appendix C

Environment Public Authority permission to use the research area in Al-Jahra Natural Reserve.



مكتب المدير العام
ENVIRONMENT PUBLIC AUTHORITY KUWAIT

12 / 8 / 2020
EPA / DG / 2010



دولة الكويت

To Whom it May Concern

This is to certify that the Biodiversity Conservation Department at the Environment Public Authority has given Mr. Abdullah Alawadhi the permission to conduct his Ph.D. research in the field of Forensic Anthropology at Liverpool John Moores University. This also serves as assurance that the Environment Public Authority has accommodated all researcher's requests to conduct research in Al-Jahra Natural Reserve.

For further information, please do not hesitate to contact Mrs. Leina Alawadhi- Head of Natural Reserve Section on the following email address:

l.alawadhi@epa.org.kw

Abdullah Ahmad Alhamoud AlSabah
Chairman of the Board & Director General



11 / 8



ENVIRONMENT PUBLIC AUTHORITY

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Appendix D

The Ministry of Interior permission to fly the UAVs at Al-Jahra Natural Reserve.

 وزارة الداخلية قطاع شؤون المرور والعمليات الإدارة العامة المركزية للعمليات إدارة الخطط واوامر الخدمة (تصريح تصوير) 			
الجهة الطالبة	تصوير شخصي	رقم التصريح	(71 / 2020)
نوع التصوير	☐ تصوير مشاهد	☒ تصوير جوي / طائرة لاسلكية عدد (2)	
• يصرح للمذكورين أدناه بالتصوير :			
م	الاسم	الرقم المدني	الصفة / المهنة
1	عبدالله سعد العوضي	287121400175	مصور
• الأماكن المصرح التصوير بها :			
م	المواقع		
1	محمية الجهراء		
نوع الطائرة		(S.N : 2AG61CHIMERA) Bluegrass (S.N : 2AG61ANAF) Anafi	
اقصى ارتفاع		(1000) قدم	
• الفترة :			
الفترة	من	الي	التاريخ
	2020 / 7 / 19	2020 / 10 / 19	
منسق الجهة الطالبة	الاسم	عبد الله سعد العوضي	رقم مدني
	الهاتف	96960066	التوقيع
• مع التعهد بالآتي : - عدم التصوير بالمواقع المحظورة مثل (القصور الاميرية ، المنشآت العسكرية ، المؤسسات والهيئات الحكومية ، المنشآت الحيوية والنقطية ، الهيئات والبعثات الدبلوماسية) . - اتباع تعليمات رجال الامن الخاصة بالتصوير واظهار التصريح عند اللزوم . - التقيد بالفترة المحددة والاماكن المخصصة بالتصريح .			
مدير ادارة الخطط واوامر الخدمة بالانابه عقيد / احمد عبد الله ابالخير 		مدير عام الإدارة العامة المركزية للعمليات عميد / عبد الله احمد العتيقي 	
برقية رقم (1294 / 2020)			



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TECHNICAL NOTE

Anthropology; General



The detection of clandestine graves in an arid environment using thermal imaging deployed from an unmanned aerial vehicle

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Email: c.elopoulos@ljmu.ac.uk**Funding information**

Kuwait Ministry of Interior, Grant/Award Number: Ministerial Decree Number 860/2019

Abstract

The Middle East is one of the world regions that has frequently suffered from armed conflicts that resulted in mass burials. However, the detection of clandestine graves in such an arid environment by deploying remote sensing payload on unmanned aerial vehicles (UAVs) has received little attention. The present study used a UAV equipped with a thermal sensor aimed at narrowing down the search area of possible gravesites in the arid climate of Kuwait. The enclosed research area, which includes both control and experimental mass graves, was imaged for 18 months. The variation in topsoil temperature and soil moisture between the graves and their surroundings was evaluated. The results of the analysis demonstrated the effectiveness of thermal imaging techniques in detecting heat produced from buried sheep carcasses and detecting the change in grave soil moisture for our research environment for 7 and 10 months, respectively. The buried animals significantly influenced the topsoil temperature ($p=0.044$), while the height from which the images were captured had an insignificant effect on the measured temperature within the range tested ($p=0.985$). Furthermore, there was a negative correlation (-0.359) between grave temperature and the calculated soil moisture. The results from these cost- and time-effective search methods presented in this study confirm their potential for the detection of burial sites in an arid environment.

KEYWORDS

burial detection, drone, forensic anthropology, forensic archeology, mass graves, remote sensing, thermal imaging, UAV

Highlights

- The temperature variation between the mass grave and its surroundings is detectable for 7 months.
- Soil moisture can be used to aid the detection of mass graves for 10 months in an arid climate.
- The height of the UAV has an insignificant effect on the detection of grave temperature.
- This is the first research on grave detection in a desert environment to use these methods.
- The results are promising and can lead to further research despite some limitations.

Presented at the 74th Annual Scientific Conference of the American Academy of Forensic Sciences, February 21-26, 2022, in Seattle, WA.

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1 | INTRODUCTION

Current practice in forensic archaeology suggests a phased approach in detecting burials in which the search moves from large-scale remote sensing methods [1] to the application of medium-range geophysical technologies [2] and finally, a ground search for a specific and defined area of interest [3]. On-foot coverage of a large land area and a thorough search for a possible burial site place a significant demand on both human and financial resources. Therefore, successfully implementing drone technology for image capturing in an arid climate would be highly beneficial to all the agencies involved in the detection of burial sites. The advantage of remote sensing deployed using drone technology lies in its non-invasive nature that covers a large area of interest in a short amount of time with minimal human and non-human resources [4]. In forensic science, remote sensing has been used in various cases to aid criminal investigation [4–9]. Past research has demonstrated that optical remote sensing can detect burial sites in tropical forests [1], rural landscapes [10], mountainous terrain [11], and woodland [12]. On the other hand, very little research has been conducted on grave detection in arid environments [9, 13]. The importance of detecting such burials arises from the fact that several countries in the Middle East have suffered from armed conflicts that resulted in many clandestine mass graves [14]. More precisely, there is an area which has received limited attention in the past and that is the detection of the heat produced by the decomposition process of the carcasses and the change of soil moisture in a burial site in an arid climate. The goal of the research presented here was to assess the effectiveness of using a commercially available UAV equipped with a thermal sensor in narrowing down the search area of gravesites by assessing the heat and soil moisture of the gravesites.

2 | MATERIALS AND METHODS

Kuwait is a country located in the north-western corner of the Arabian Gulf in the Middle East. It is known for its arid climate with a

verified recorded temperature of 53.9°C in July 2016, making it the highest recorded temperature in Asia and the third hottest temperature ever recorded in the world [15]. A measured 30 m x 30 m plot of land in Jahra Pools Nature Reserve, an 18 km² nature reserve located at Jahra town in the north of Kuwait, was used for the research. At the time, the site consisted of dry soil with uniform roughness, no vegetation cover and was flat, with no significant slope (Figure 1). This site was chosen because it resembles the landscape of previously excavated mass graves in Kuwait dating to the Gulf War [16]. It also follows the description of Schuldenrein and co-authors on mass grave location and features in Iraq. They state that mass graves are usually located in remote places with minimal susceptibility to degradation, erosion, and exposure [14].

Two graves were simulated, 5 m apart to avoid cross-contamination or interference from the buried animals' decomposition fluids [17]. The graves were dug using a backhoe and had the same dimensions: 5 m by 2 m and 1.5 m in depth. Although it is expected that old mass graves that were dug more than 30 years ago, such as the ones from the 1990 Gulf War, would not be detectable using this technology, the depth of the graves at 1.5 m (Figure 2) was chosen to resemble similar conditions. This would aid in the determination of the useful timeframe to detect changes by using this technology in these specific conditions [16]. One grave served as a control (G1) and had no buried carcasses in it. This serves to simulate soil disturbance caused by other factors such as construction rather than a burial site. The experimental grave (G2) contained eight sheep and had some added content such as clothing and 9 mm handgun shell casings to make them resemble a real-life scenario. It is not the first time that mammals other than pigs have been successfully used when conducting such experiments [1]. The sheep used were purchased from the local abattoir with an average weight of 32 kg, which is within the recommended carcass weight for experimental studies when a human analog is used and within the average weight of an adult human torso of 22–35 kg [1, 18, 19]. The use of animals in this research was conducted in compliance with Liverpool



FIGURE 1 The research area and the two graves captured the day after the burial.



FIGURE 2 The grave's depth was checked using a measuring tape while digging the mass grave by the backhoe loader.

John Moores University's ethical guidelines for the use of animals in research.

A Parrot Anafi Thermal, a quadcopter (four propellers) UAV equipped with a forward-looking infrared (FLIR) Lepton 3.5 microbolometer (radiometric) sensor was used to capture the thermal images within the enclosed research area. In addition to the airspace restriction around the area, image capturing was limited to the enclosed experimental area in accordance with the obtained permission to fly the UAV from the Ministry of Interior of Kuwait. Previous literature suggested that heights of 50 ft (approximately 15 m) and 100 ft (approximately 30 m) are ideal to aid the investigation of a potential gravesite when a thermal UAV is used [20]. Hence, images were captured at different heights to explore the ultimate height for our research environment that covers the most area possible in a single flight while maintaining the on-ground details of the captured images which is known as Ground Sampling Distance (GSD). The lower the GSD, the more details and information can be obtained from the image. The heights used in this research were 10, 30, and 50 m. A total of 18 sets of thermal images were captured throughout the experiment period, which lasted for 18 months. The first images were captured 1 day before the burial, the day of burial, and then 1, 3, and 7 days after burial. Thereafter, images were captured weekly for 3 weeks. Next, a periodic (monthly) set of images were captured until 1 year after burial except for the fourth, fifth, and eighth months due to government restrictions related to the COVID-19 pandemic. Lastly, images were captured in the fifteenth and eighteenth months.

The captured images were then transferred to the photogrammetry software Pix4Dmapper to generate different orthorectified outputs [21]. FLIR and ArcMap were used to explore the temperature and soil moisture variations, respectively. The focus of the examination was the variation between the graves and their surroundings. These specialized software tools aid the process of detecting possible burial sites in an arid environment by highlighting the differences between G1 and G2.

The topsoil surface temperature of the enclosed research area was recorded using the commercially available Parrot Anafi Thermal

UAV which is equipped with a FLIR radiometric thermal-imaging camera. The temperature variation between the graves and the undisturbed research area within the enclosure was analyzed using the FLIR tool software [22].

Soil moisture was calculated for both graves using the temperature vegetation dryness index (TVDI) formula:

$$TVDI = \frac{T_s - T_{s_{min}}}{T_{s_{max}} - T_{s_{min}}}$$

where T_s is the temperature at a specific pixel, $T_{s_{min}}$ is the lowest temperature of the area of interest and $T_{s_{max}}$ is the highest temperature of the area of interest.

TVDI ranges from 0 to 1, where 0 represents the highest water content point and 1 the lowest water content point. For the captured thermal image of the research area, T_s was extracted for each pixel utilizing the *Spatial Analyst Tools – Extract by Mask* feature available in geospatial processing software ArcGIS Desktop v.10.8.1 using its *Esri ArcMap application v.10.8.1.14362* [23]. Thereafter, the TVDI for the extracted points was calculated using the relevant formula mentioned above.

3 | RESULTS

The initial analysis demonstrated that the ultimate height which maintained a clear GSD, was 30 m. Henceforth, all aerial analyses listed will represent the obtained results at 30 m. There was a visible difference between the G1 (control grave) and G2 (experimental grave) when analyzing the captured images. The temperature of G2 was always higher than G1 up until the tenth month after burial when G1 got higher. The highest temperature difference was recorded in the seventh month, when G2 was 3.3°C warmer than G1. The temperatures of G1 and G2 were consistently lower than the temperature of the surrounding area, except for the third month after burial when G2 was higher than both G1 and the surrounding (Table 1).

The effect of UAV height and the buried carcasses on the temperature of the graves was tested using a two-way ANOVA. Within the range of heights tested, it was found that there is an insignificant effect of height ($p=0.985$) when tested against the grave temperature. The captured temperature is not affected by the three different heights at which the UAV was flown in this experiment. On the other hand, buried carcasses showed a significant effect on the measured temperature ($p=0.005$). Hence, having buried animals in the grave does influence the topsoil temperature.

There was a difference in soil moisture between the graves and the surrounding area, which lasted up to the tenth month. A noticeable color difference between the marked graves (blue) and their surrounding (yellow/red) is evident when examining the map. This indicates a difference in soil moisture between the graves and the surrounding areas (Figure 3). Some areas immediately around the graves also appear to have a higher soil moisture and this is the result of the soil disturbance by the backhoe loader during the

TABLE 1 A comparison between the captured temperature of the control mass grave (G1), experimental mass grave (G2) and the surrounding area throughout the experiment.

Measured	G1 aerial temperature (°C)	G2 aerial temperature (°C)	Surrounding temperature (°C)
Same day	36.4	36.2	43.3
1 day PB*	36.8	37.1	38.8
3 day PB	35.9	36.2	38.4
1 week PB	27.6	28.8	29.2
2 weeks PB	29.1	30	31.4
3 weeks PB	29.3	29.9	31.2
1 month PB	22.8	22.9	23.2
2 months PB	21.5	21.9	23.4
3 months PB	23.5	25.4	23.1
6 months PB	5.8	7.9	5.4
7 months PB	9.5	12.8	9.2
9 months PB	23.2	23.6	24.1
10 months PB	29.4	29.1	30.4
11 months PB	32.7	32.5	33.2
12 months PB	30.1	30.3	31.1
15 months PB	9.1	8.8	8.7
18 months PB	2.9	3	2.9

Abbreviation: PB, post-burial.

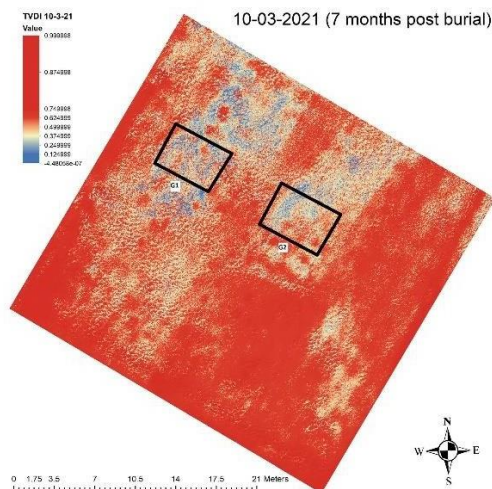


FIGURE 3 Calculated index map of the TVDI for the research area in the seventh month. Soil moisture is evident in both the control (G1) and experimental graves (G2).

construction of the graves. When calculated, soil moisture in both graves was higher than in the surrounding area, having a TVDI closer to 0. Table 2 illustrates the values extracted from the TVDI map for G1, G2 and the surrounding area.

When tested, the topsoil temperature and the calculated soil moisture of the graves showed a statistically significant correlation between them ($p < 0.001$). The correlation between aerial temperature and soil moisture is -0.359 , which means that there is a moderate negative relationship between them. Hence, an increase in temperature would result in a lower soil moisture, and vice versa.

4 | DISCUSSION

In line with previously published literature [5, 8, 20], a distinguishable surface temperature difference between the control and experimental graves was detected when analyzing the findings of the research area. The total weight of the buried carcasses and the grave depth of the present study were almost the same as those in previously reported experiments. Furthermore, it is noticed that the temperature of the experimental grave was higher than both the control grave and the surrounding area in the third month after burial, and this temperature rise can be explained due to the process of decomposition that was taking place at that time. This is similar to previous research in detecting buried remains in a similar environment, where a better detection performance was observed 3 months after burial [13]. However, after the seventh month, this temperature variance between the graves was not detectable. A reason for this could be a result of the completion of the process of putrefaction. On the other hand, the experimental grave was moister than the control grave for 10 months and eventually leveled up.

The missed data on the fourth, fifth, and eighth months post-burial were due to government restrictions related to the COVID-19 pandemic. For the soil moisture, the results have not been affected as we were able to detect changes for up to 10 months. When it comes to the temperature variation between the graves and their surroundings, differences were detectable up to 7 months but not at 9 months. It is therefore unknown whether or not the temperature variation would have been detectable at 8 months.

All the aforementioned results are promising, as they are suggestive of the effectiveness of using a commercially available UAV equipped with a thermal sensor in narrowing down the search area of relatively recent gravesites in an arid climate. This method has shown to be effective under the given conditions for about 7 months when analyzing the temperature and 10 months when analyzing the soil moisture of the graves. It should be noted that the results might differ based on the total body weight of the buried carcasses, the nature of the environment where they were buried, the depth of the grave, and for how many days/months post-burial the data were collected. The present study used a small number of carcasses and it is encouraging that changes were detectable after 10 months. One can assume that if it was a larger grave containing more individuals, the grave would have been even more visible and for a longer period of time. Hence, such technology is largely dependent on the given grave characteristics and is considered an exploratory search method which aims to reduce the area under examination for a suspected burial site.

	Minimum TVDI	Maximum TVDI	Range TVDI	Mean TVDI
Control mass grave (G1)	0.04	0.57	0.53	0.24
Experimental mass grave (G2)	0.02	0.58	0.56	0.25
Surrounding area	0.44	0.99	0.95	0.33

Abbreviation: TVDI, temperature vegetation dryness index.

All UAVs are designed and operate in a manner that makes each a unique machine, in the sense of whether or not it can be flown in the rain, its resistivity to the wind, battery life, and many more features. Regarding the limitations of the Parrot ANAFI thermal used in this experiment, the maximum temperature it can be flown at is 40°C and a maximum humidity of 93%. Additionally, it can only handle a wind resistance of 50 km/h, wind gust resistance of 80 km/h and fly for 26 min per battery [24].

The present study is not free of limitations. For example, conducting the first few months of this experiment in the summer prevented us from being able to test the effect of the ground temperature variance at the desert. This is because the optimum time for conducting thermal imaging is when the temperature variance between the burial site and its surroundings is detectable, which is most likely to happen during sunrise and sunset. During these times of the day, the temperature of the surrounding environment would be lower than the grave containing the decomposed body, which produces heat that is easily captured [7]. However, the temperatures recorded for the first 2 weeks, around sunrise and sunset, were just below 40°C, the maximum temperature to operate a UAV. Hence, the temperature was only captured at sunrise, which limited the possibility of testing any temperature variance that might have been available. A future study could test this temperature variance usually shown during fall/winter seasons in a desert environment when temperatures are measured and compared at sunrise and sunset. Additionally, blind testing of the index maps by different observers who do not have any prior knowledge about the location of the graves would strengthen the validity of these methods when applied in an arid environment. It should be noted that some knowledge of the software used and its output is required by the observer, but this is true for the vast majority of specialized image processing programs.

It is known that in most search missions for mass graves, the work requires thoroughly covering a large land area. Nonetheless, our research area was relatively small, and images were only captured in the assigned plot of land, following the permission obtained. Hence, the commercially available UAV used in this research is suitable only for our experimental research conditions. Therefore, to implement it in real-life scenarios, the UAV would require flying at a greater height for longer time periods and still being able to capture high-resolution images. This would require a longer battery lifetime, a feature currently found on affordable commercially available fixed-wing UAVs that can fly for longer and cover large areas. Additionally, capturing images in larger areas than our limited research plot of land would allow us to further test the validity of these methods of grave detection.

TABLE 2 The minimum, maximum, range and mean TVDI values of the graves and the surrounding area.

5 | CONCLUSION

Optical remote sensing, using the inexpensive and time-effective passive sensors mounted on a multirotor UAV, performed well in narrowing down the search of the graves in an arid environment. Evaluating temperature and soil moisture variation provided satisfactory results to distinguish between the mass grave and its surroundings. The results obtained from analyzing the thermal images aided the assessment of the temperature and soil moisture of the graves and the effect of the buried carcasses on such features. Therefore, implementing this technology in such environmental conditions is considered a new approach that is hoped to serve as a cost- and time-effective search method. Furthermore, it will have a definite humanitarian impact as it can help to locate human remains and give closure to the families of the individuals who are missing and presumed dead in many countries.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

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REFERENCES

- Kalacska ME. The application of remote sensing for detecting mass graves: an experimental animal case study from Costa Rica. *J Forensic Sci.* 2009;54(1):159–67. <https://doi.org/10.1111/j.1556-4029.2008.00938.x>
- Pringle JK, Jervis JR, Hansen JD, Jones GM, Cassidy NJ, Cassella JP. Geophysical monitoring of simulated clandestine graves using electrical and ground-penetrating radar methods: 0–3 years after burial. *J Forensic Sci.* 2012;57(6):1467–86. <https://doi.org/10.1111/j.1556-4029.2012.02151.x>
- Skinner M, Alempijevic D, Djuric-Srejic M. Guidelines for international forensic bio-archaeology monitors of mass grave exhumations. *Forensic Sci Int.* 2003;134(2–3):81–92. [https://doi.org/10.1016/s0379-0738\(03\)00124-5](https://doi.org/10.1016/s0379-0738(03)00124-5)

4. Blau S, Sterenberg J, Weeden P, Urzedo F, Wright R, Watson C. Exploring non-invasive approaches to assist in the detection of clandestine human burials: developing a way forward. *Forensic Sci Res.* 2018;3(4):304–26. <https://doi.org/10.1080/20961790.2018.1493809>
5. Butters O, Krosch MN, Roberts M, MacGregor D. Application of forward-looking infrared (FLIR) imaging from an unmanned aerial platform in the search for decomposing remains. *J Forensic Sci.* 2021;66(1):347–55. <https://doi.org/10.1111/1556-4029.14581>
6. Murray B, Anderson D, Wescott D, Moorhead R, Anderson M. Survey and insights into unmanned aerial-vehicle-based detection and documentation of clandestine graves and human remains. *Hum Biol.* 2018;90(1):1–17. <https://doi.org/10.13110/humanbiolog.90.1.03>
7. Pringle JK, Ruffell A, Jervis JR, Donnelly L, McKinley J, Hansen J, et al. The use of geoscience methods for terrestrial forensic searches. *Earth Sci Rev.* 2012;114(1–2):108–23. <https://doi.org/10.1016/j.earscirev.2012.05.006>
8. Silván-Cárdenas JL, Caccavari-Garza A, Quinto-Sánchez ME, Madrigal-Gómez JM, Coronado-Juárez E, Quiroz-Suarez D. Assessing optical remote sensing for grave detection. *Forensic Sci Int.* 2021;329:111064. <https://doi.org/10.1016/j.forsciint.2021.111064>
9. Silván-Cárdenas JL, Corona-Romero N, Madrigal-Gómez JM, Saavedra-Guerrero A, Cortés-Villafranco T, Coronado-Juárez E. On the detectability of buried remains with hyperspectral measurements. *Pattern Recognit. Lecture Notes in Computer Science.* 2017;201–12. https://doi.org/10.1007/978-3-319-59226-8_20
10. Parrott E, Panter HA, Morrissey J, Bezombes F. A low cost approach to disturbed soil detection using low altitude digital imagery from an unmanned aerial vehicle. *Drones.* 2019;3(2):50. <https://doi.org/10.3390/drones3020050>
11. Fernández-Álvarez J-P, Rubio-Melendí D, Martínez-Velasco A, Pringle JK, Aguilera H-D. Discovery of a mass grave from the Spanish civil war using ground penetrating radar and forensic archaeology. *Forensic Sci Int.* 2016;267:e10–e7. <https://doi.org/10.1016/j.forsciint.2016.05.040>
12. Pollard T, Barton P. The use of first world war aerial photographs by archaeologists: a case study from Fromelles, northern France. In: Hanson WS, Oltean IA, editors. *Archaeology from historical aerial and satellite archives.* New York, NY: Springer New York; 2013. p. 87–103. https://doi.org/10.1007/978-1-4614-4505-0_6
13. Dozal L, Silván-Cárdenas JL, Moctezuma D, Sordía OS, Naredo E. Evolutionary approach for detection of buried remains using hyperspectral images. *Photogramm Eng Remote Sensing.* 2018;84:435–50. <https://doi.org/10.14358/PERS.84.7.435>
14. Schuldenrein J, Trimble MK, Malin-Boyce S, Smith M. Geoarchaeology, forensics, and the prosecution of Saddam Hussein: a case study from the Iraq war (2003–2011). *Geoarchaeology.* 2017;32(1):130–56. <https://doi.org/10.1002/gea.21586>
15. Merlone A, Al-Dashti H, Faisal N, Cerveny RS, AlSarmi S, Bessemoulin P, et al. Temperature extreme records: World Meteorological Organization metrological and meteorological evaluation of the 54.0°C observations in Mitribah, Kuwait and Turbat, Pakistan in 2016/2017. *Int J Climatol.* 2019;39(13):5154–69. <https://doi.org/10.1002/joc.6132>
16. Al-Dossari F. *Almohima alkubra: Masirat albahth aljinaee [the grand mission: the criminal investigation]*. 2nd ed. Kuwait City, Kuwait: Al. Alfain Publishers; 2018. p. 347.
17. Teo C, Pawita A, Osman K, Ghani AA, Hamzah NH. Post mortem changes in relation to different types of clothing. *Malays J Pathol.* 2013;35:77–85.
18. Catts EP, Goff ML. Forensic entomology in criminal investigations. *Annu Rev Entomol.* 1992;37(1):253–72. <https://doi.org/10.1146/annurev.en.37.010192.001345>
19. DesMarais AM. Detection of cadaveric remains by thermal imaging cameras. *J Forensic Identif.* 2014;64(5):489–511.
20. Bodnar SR. Drone-assisted thermal imaging to determine the location of unmarked graves. *J Forensic Identif.* 2019;69(3):378–93.
21. Pix4D. Pix4Dmapper photogrammetry software. Version 4.6.4. Lausanne, Switzerland: Pix4D; 2022.
22. FLIR Systems Inc. FLIR tools software. Version 6.4.18039.1003. Wilsonville, OR: FLIR Systems Inc; 2015.
23. ESRI. ArcGIS Desktop. Version 10.8.1.14362. Redlands, CA: ESRI; 2020.
24. Parrot. ANAFI thermal white paper. Version 1.4. Paris, France: Parrot; 2019.

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