

A laboratory simulation of the potential groundwater contamination associated with burial materials

by

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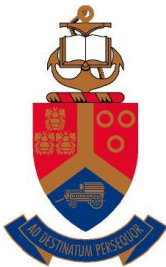
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ABSTRACT

Metals, coatings and embalming fluid used in burial practices may corrode and seep into the soils, which could end up in nearby water sources. However, this basic assumption has not yet been proven. To avoid other anthropogenic factors, this thesis comprised of a laboratory study of the leaching potentials of metals and formaldehyde through different soils under various environmental conditions. After collecting and analysing the coffin samples, twenty-seven containers with taps were filled with either sand, silt or clay soils. Samples of burial materials, cloth saturated with formalin and bacteria were buried within each soil column. These were exposed to high or lower temperatures and conditions simulating heavy or prolonged rainfall using either acidic or slightly acid water. Interment continued for six months.

In addition to testing the effects of these variables, cement was buried in the three soil types with pre-weighed coiled wires of common metals, namely aluminium, iron, copper and zinc. After 24 weeks of testing, the corrosion rates of the various metals were determined, which allowed us to conclude that concrete tombs could be a possible solution to reduce the corrosion rates of coffin materials. It may also retard soil and groundwater contamination.

After analysing the water leachates of each sample, it became evident that coffin materials do indeed corrode and become mobile. It also verifies that the aforementioned variables do in fact affect the corrosion rate and leaching of the various coffin materials and that concrete tombs truly are a solution to reduce corrosion and contamination rates of cemeteries. The results also showed that most formaldehyde percolated through the soil between weeks six to week 14 of interment. Neither temperature nor pH affected the amount of formaldehyde leachate, however, conditions simulating heavy rainfall facilitated leaching. Although a total of only 3% of the initial amount of formaldehyde became mobile, concentrations of up to

15.0 mg/L formaldehyde were recorded on two occasions – considerably higher than the Tolerable Concentration recommended by the World Health Organization.

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“A living body becomes a medium on which many morbid factors can easily produce after death; therefore, corpses and living people must be kept at separate places” (Uslu, et al., 2009)

CHAPTER 1: INTRODUCTION

“Everyone has the right to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that—

- prevent pollution and ecological degradation;
- promote conservation; and
- secure ecologically sustainable development and use of natural resources, while promoting justifiable economic and social development” (NEMA, 1998).

Humanity has the responsibility to protect and conserve surface water and groundwater from potential contaminants since it could result in health problems, reduce the quality of agricultural products, make the water unsuitable for industrial use and pose a threat to ecosystems (Northern Ireland Environment Agency, 2015). Studies have shown that cemeteries are potential health and environmental hazards since contaminants may seep into the groundwater and end up in nearby water reserves. It is, therefore, important to consider the possible risks associated with old and new cemetery sites to enable the making of informed decisions related to site monitoring and future site selections.

1.1 Background

The main sources of pollution from cemeteries are (a) human bodies; (b) embalming fluids, which primarily contain the suspected carcinogen, formaldehyde (Guttman, et al., 2012); and (c) the fabrication materials of coffins, which may contain harmful and toxic metals that could seep into the soil (Jonker & Olivier, 2012). The composition of a 70 kg adult male body include: 43 000g oxygen (O₂); 16000g carbon (C) 7000g hydrogen (H); 1800g nitrogen (N); 1100g calcium (Ca); 500g phosphorus (P); 140g sulphur (S); 140g potassium (K); 100g sodium (Na); 95g chlorine (Cl);

19g magnesium (Mg); 4.2g iron (Fe); 0.07g copper (Cu); 0.12g lead (Pb); 0.05g cadmium (Cd); 0.01g nickel (Ni); and 0.00009g uranium (U) (Dent & Knight, 1998). The elemental composition of females is approximately 68% of that of males (Dent & Knight, 1998) (Fineza, et al., 2014).

When a person is buried, these chemical components and the metal body parts of the deceased, which may include tooth implants and/or orthopaedic materials fabricated from stainless steel, cobalt (Co), chrome (Cr), and titanium (Ti), remain in the grave, from where the chemicals may leach into the surrounding soil or into groundwater. The pollutants leaching from a human corpse are dissolved and other gaseous organic compounds such as indol, skatol, hydrogen sulphate and various carbon compounds are produced (UK Environment Agency, 2004) (Uslu, et al., 2009)(DWAF, 2010).

It takes a human body approximately 10 to 12 years to decompose completely (Dent & Knight, 1998). It is also estimated that half of the pollutant load leaches within the first year of decay and thereafter, halves year-on-year (UK Environment Agency, 2004).

Although not required by law, embalming is performed for the benefit of loved ones to ensure that family members are not left with an undesirable last memory (Frater, 2007). During the 19th and early 20th Centuries, embalming fluids consisted of arsenic or mercury (Spongberg & Becks, 1999). Nowadays, however, embalming fluids contain formaldehyde, distilled water, phenol and glycerol (Anat, 1993), of which 10 litres of the mixture (containing 1.5 litres of formaldehyde) (Karmakar, 2010) is required for a 70-kg body. Formaldehyde is released during decomposition and has been shown to be carcinogenic to living organisms (Guttman, et al, 2012).

Coffins are primarily constructed of wood that is treated with preservatives to minimise decay and rapid leaching of organic contents that may otherwise be seen as a major source of soil contamination (Spongberg & Becks, 1999). Previously,

potentially harmful minerals such as lead, arsenic, mercury, manganese, nickel, copper, vanadium, cadmium, zinc and chromium had been used in paints for coffins (Janin, et al., 2011)(Gondal, et al., 2011). Although some changes have been made to the formulations of paint during the past 20 years, many still contain dangerous heavy metals, such as lead, mercury, and chromium (Gondal, et al., 2011) that are known to exhibit poisonous effects on humans, animals and the environment.

The metals used on coffins for handles, screws, hinges and ornaments include, zinc (Zn) and its alloys, as well as silver (Ag) and bronze (Jonker & Olivier, 2012) may also constitute a hazard. Although the ingestion of small amounts of some of these metals (e.g. copper, selenium and zinc) are essential to maintaining the metabolism of the human body, heavy metals tend to bioaccumulate when they are ingested and stored faster than they are excreted (Lenntech, 2016). Bioaccumulation of heavy metals could lead to severe health effects such as fever, nausea, vomiting, stomach cramps, diarrhoea, coeliac, sickle cell anaemia, haemorrhage, cancer, Alzheimer's and even death (World Health Organization, 1996).

It is evident from the above that compounds originating from burials may decompose or corrode, seep into the soil, and eventually contaminate surface and subsurface water resources. Once contaminants such as heavy metals have been introduced into an environment, they accumulate and may also become mobile. Consequently, higher concentrations of heavy metals may be anticipated in water bodies downslope (Okoronkwo, et al., 2005) from a cemetery. This may constitute a health hazard if such water is used for domestic purposes.

1.2 Research on the pollution potential of cemeteries

Until the mid-1800s, health risks associated with cemeteries were merely speculative in nature, based on the bad odour arising from decomposing bodies. It was not until Dr. George Walker (1839) published a book entitled *“Gatherings from graveyards: particularly those of London: with a concise history of the modes of interment among different nations, from the earliest periods and a detail of dangerous and fatal results produced by the unwise and revolting custom of inhuming the dead in the midst of the living”* that proof was provided of the potentially hazardous nature of cemeteries. This work was followed by a spate of research on biotic contamination associated with burials. It was almost a century later, that the research focus moved from the pollution potential of bodies and their associated bacteria to possible contamination due to the accumulation of minerals in cemeteries. One of the first paper focusing on this aspect was by Van Haaren (1951) who found that there were above normal concentrations of salts in the vicinity of graves in the Netherlands and Australia. The origin of these salts was assumed to be from decomposing bodies.

The pollution potential of decomposing and corroding coffins started much later. However, since 2003, high levels of metals and trace minerals have been recorded in cemeteries in many countries, ranging from Brazil, Iran, Rwanda, Australia, China and South Africa (Dent & Knight, 1998) (Spongberg & Becks, 1999) (Dent, et al., 2003) (Fiedler & Graw, 2003) (Barros, et al., 2008) (Pour & Khezri, 2010) (Zychowski, 2012) (Jonker & Olivier, 2012) (Amuno, 2013) (Fineza, et al., 2014) (Aruomero & Afolabi, 2014) (Dippenaar, 2014) (Paiqa & Delerue-Matos, 2016)

In comparison to research on decomposing bodies and burial materials, possible contamination from embalming agents has received relatively little attention.

1.3 The South African Context

Traditionally, South African cemeteries were located outside of town and city boundaries. The sole criteria for selection of sites were accessibility and soils soft enough to dig. However, urbanisation has slowly encroached upon cemeteries and as a result, many cemeteries are nowadays found within city limits. It is important to note that many of the older (urban municipality) cemeteries in SA were originally considered to be large enough to accommodate future burials. This has been shown to be an overestimation of the situation and the country is presently running out of burial space (Dambudzo, 2012), due to a rapidly growing population and high incidence of HIV/AIDS death rate.

A good example of a potential “time bomb” is that of the city of Durban in KwaZulu-Natal, South Africa, which currently has approximately 500,000 grave sites. Due to the increase in death rate, more than one body is sometimes placed in a single grave. Consequently, the cemeteries presently hold 1.2 million bodies (Moreosele, et al., 2011). In 2010, only seven out of the 22 cemeteries in the city remained open (Louw, 2010), and in October 2013, it was announced that the cemeteries in Durban were officially full (Mbonambi, 2013). Currently, most municipalities in South Africa have less than 50% of cemeteries with capacity for more burials (Dambudzo, 2012).

The siting of cemeteries in South Africa is also a problem. Prior to the implementation of relevant environmental legislation, cemeteries were often constructed on unsuitable land, near domestic water sources, on steep slopes, in wetlands or on the banks of rivers (Dambudzo, 2012). One area of concern is the City of Tshwane (also known as Pretoria), which is the capital of South Africa and its largest municipality (measured by land mass) in Gauteng (Statistics South Africa, 2011). In the year 2011, it was estimated that the City of Tshwane had a population of 2,921,488 (Statistics South Africa, 2011). This accounted for 5.6% of South Africa’s total population. In 2011, there

were 505,803 deaths in South Africa, of which 28,543 deaths occurred in the City of Tshwane (Statistics South Africa, 2011). This amounts to approximately 78 deaths per day in the city. Considering that there are 42 cemeteries in the city, with eight cemeteries that have reached their full capacity, it is reasonable to assume that there may be some cemeteries where more than two burials take place per day. As a consequence of the growing number of deaths, as well as keeping in mind the population growth rate of the city, it is fair to conclude that more burial sites would be required in the near future.

Although there is mounting scientific evidence showing the pollution potential of cemeteries, the (South African) Department of Water Affairs and Forestry (DWAF, 2010) considers “the risk of pollution posed by cemeteries” as “an issue that is of low priority”. In a public statement made by the Department of Water Affairs and Forestry (DWAF, 2010) the water quality management and control over cemeteries as a source of pollution were addressed as follows:

“There appears to be a perception among certain members of the public that cemeteries are a source of pollution which is neglected by the Department of Water Affairs and Forestry (DWAF), and that water supplies are being polluted because of being in the vicinity of cemeteries. This perception is incorrect, and the following policy, which has been formulated by the Minister (see attached letter), should be brought to the attention to those approaching your officials in this regard.”

This may be one of the reasons why little research has been done in South Africa on this topic. Tumagole (2009), one of the few studies done on cemeteries in South Africa, conducted a study in a rural village close to the City of Tshwane in order to establish to what extent poorly cited cemeteries pollute groundwater. The community mainly uses boreholes for domestic purposes. Groundwater samples were collected from boreholes in the village and analysed. The results showed that the water was of poor

quality and that even a once-off consumption of the water would cause serious health concerns as a result of microbiological pollution.

Moreover, Jonker & Olivier (2012) compared the mineral concentrations of soils within the cemetery to off-site samples and those within zones with multiple burials to areas with fewer burials at the Zandfontein Cemetery located in Tshwane. It was found that the mineral concentrations within the cemetery were considerably higher than off-site and that the mineral concentrations within multiple burial blocks were also elevated.

Although these studies provided some insight regarding the effects of the two cemeteries on surrounding soils, it is not known whether other cemeteries pose a human and environmental health risk in terms of mineral contamination.

Consequently, the current pollution levels of cemeteries in South Africa is a topic of concern and should receive attention in order to enable relevant parties to make informed decisions on the selection of future sites, remediation processes and measures to reduce cemetery pollution. This has prompted the Water Research Commission to fund a research project entitled Project K5/2449 “State-of-the-Art Cemetery Guidelines: Impacts of Interments on Water Resources” of which the current research forms part of. The outcome of this dissertation will not only address many of the concerns but could be used to inform the local communities on whether or not their water supply is safe for consumption.

1.4 Rationale, aim and objectives

Due to the anthropogenic action of interment, the biosphere, hydrosphere and lithosphere are possibly being affected by burial materials and practices. Although there are many predictions that can be made regarding the different metals and their corrosion rates in various environmental conditions (Garverick, 1994; Corrosion Institute of South Africa, 2004) (Revie & Uhlig, 2008) (Wood, et al., 2013), it is much

harder to predict what will happen to coffin/burial materials after interment, since the environmental conditions do not only include soil and water, but also increased amounts of microorganisms that accelerate corrosion. Nevertheless, increases in mineral concentrations in cemetery soils and proximate groundwater is generally being assumed to be due to the decomposition of coffin materials, but this basic assumption is yet to be proven. It is clear that our understanding of how coffin materials break down, mobilise and influence proximate receptors is limited.

It should also be noted that there have been efforts to prevent possible pollution from cemeteries by making use of concrete burial vaults in the subsurface. Some speculate that a burial vault would prevent the contents of leaching into the surrounding soil and groundwater. Whether a concrete vault would prevent soil and water contamination of coffins is, however, unknown.

Due to the intrinsic difficulty in determining the relationship of degraded coffin materials, embalming fluid, the corrosivity of soils, the influence of concrete tombs, and subsequent water contamination in situ, a laboratory study under controlled environments was required. It was also essential to conduct long-term experiments of contamination in a variety of different geochemical environments (Fiedler et al. 2003). Only then would it be possible to determine the true risks posed by cemeteries.

The aim of this study was to determine whether coffin materials and embalming fluid contaminate cemetery soils and leach into groundwater under controlled laboratory conditions and if so, whether burial vaults would be a possible solution. This was achieved by means of the following objectives:

- (a) Determining whether coffin/burial materials degrade, become mobile and leach into groundwater and, if so, estimating the rate of corrosion and leaching;

- (b) Assessing whether pH, soil type, rainfall intensity and temperature in cemetery soils play a role in rate of corrosion and leaching; and
- (c) Determining whether concrete tombs would be a possible solution by reducing the corrosion rates of the different metals, while not leaching themselves.

The variables tested in this study included a variety of different metals, cement and embalming fluid used in interments, soil type, soil corrosion rate, pH, rainfall, temperature, corrosion rate and the transport of coffin/burial materials. This research made it possible to exclude other anthropogenic pollutant sources due to urbanisation and agriculture, rendering the results relevant to the specific materials tested and the conditions in which they were evaluated. The study also contributed to the international understanding of corrosion of metals and cement and the implications on cemeteries.

1.5 Layout of dissertation

Chapter 1 has introduced the aim and objectives of this study by highlighting the fact that groundwater systems close to cemeteries may be contaminated with coffin materials and embalming fluid. Chapter 2 contains a literature review focusing on the traditional materials used in burial practices, the factors that may affect the corrosion and leaching rates of coffin materials and their associated pollution potentials. In Chapter 3, the methodology and simulated conditions of the laboratory setup are described. The results are presented and discussed in Chapter 4. The final chapter, chapter 5, contains a summary of the research, which concludes on the type of burial materials currently being used in South Africa, the leaching trends of burial materials, and the potential of burial vaults decreasing the contamination rate of coffin materials.

CHAPTER 2: LITERATURE REVIEW

2.1 Traditional materials used in burial practices

Burials are as old as humanity itself. Every culture and civilisation has attended to the proper care of their dead, however, the methods used in burial practices have changed throughout the years. In order to determine which contaminants may exist from burial practices, the history of funeral practices, burial materials used and reasons for making use of the materials throughout the years need to be considered.

2.1.1 Earliest burial grounds

Recent archaeological evidence suggests that one of the earliest burial grounds may have been that of *Homo naledi* in South Africa (Bothma, 2015). *Homo naledi* is a new species of the human relative that was recently found by Professor Lee Berger and his team of the University of the Witwatersrand (Rawood, 2015). Researchers are not yet sure of *Homo naledi*'s age but estimate it to be approximately 1 - 2 million years old (Phillips, 2015). The unique discovery suggests that *Homo naledi* had intentionally buried its dead in the isolated Dinaledi chamber of the Rising Star Cave system, which is located in Sterkfontein, Gauteng (Rawood, 2015). It was previously thought that this ritualistic behaviour was limited to modern humans, but infants, children, adults and elderly fossils were found within the Dinaledi chamber, which suggests that the dead was intentionally placed within the remote isolated cave. This finding was further supported by the fact that the chamber lacked fossil animals (Bothma, 2015). Figure 2.1 gives a schematic representation of *Homo naledi*'s possible burial site.

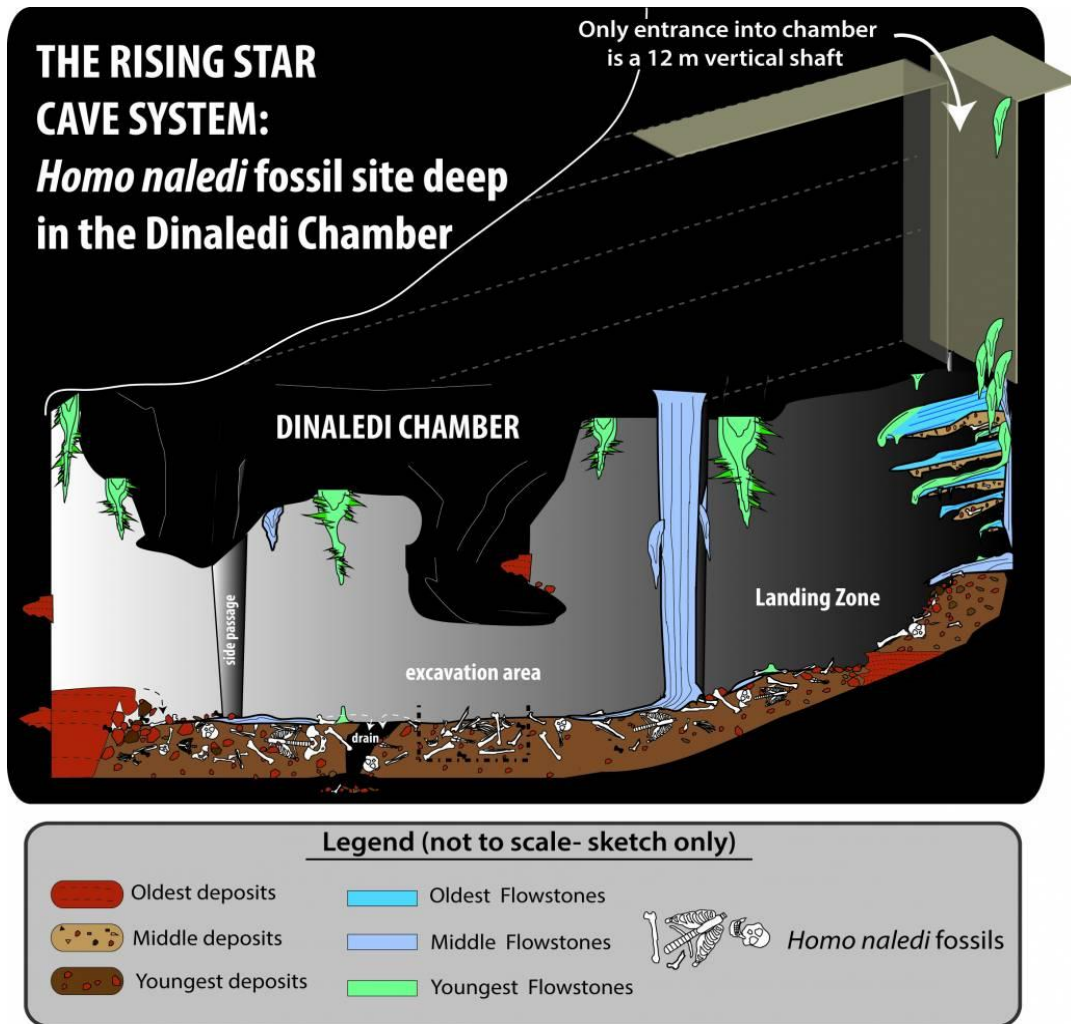


Figure 2.1 Burial site of *Homo naledi* (University of the Witwatersrand, 2015).

The most ancient and universal graves were natural and simple, consisting mostly of a mound of earth, or a heap of stones raised over the body or ashes of the deceased (Moore & Lundell, 2012). More primitive people left corpses in the open, on platforms or in trees (Pearson, 1999). Specimens that have been accidentally or naturally preserved have been found to exist even before Egyptian times (Trochu, 2015). This is where the art of embalming originated before deliberate embalming took place (Trochu, 2015).

2.1.2 Ancient Egypt

As man advanced, so did burial methods and techniques. Mummification is a certain type of embalming or treating method of a dead body, which the ancient Egyptians

used (Smithsonian Institution, 2012). The Egyptians removed all moisture from the body by covering it with natron, a type of salt, and leaving it in a dried form, which would not easily decompose (Smithsonian Institution, 2012). This was practised throughout most of the early Egyptian history (Smithsonian Institution, 2012).

It was previously thought that mummification in Egypt originated from around 2200 BC and that the bodies before then were buried in Cairo's hot, dry sand, which caused natural desiccation (Perkins, 2014). However, Buckley's findings of more than 80 years ago suggested that nature had a little help (Perkins, 2014).

It was found that even long before the Egyptians mummified their pharaohs, their ancestors were using an embalming recipe (Perkins, 2014). This pushes back the time of deliberate embalming techniques with 2000 years (Jones, et al., 2014). It was also found that the resin for the embalming fluid came from areas at least 1000 kilometres away from the grave sites, suggesting that an extensive trade network had already been established by then (Jones, et al, 2014).

In the 1920s, samples from funerary wrappings that came from four graves at a site near the Nile River, called Mostagedda, were analysed to determine the age and composition of the embalming fluid (Phillips, 2015).

Carbon dating suggested that the oldest embalmment samples covered a body around 4200 BC and the youngest samples around 3150 BC. Jones et al. (2014) indicated that the bulk of the embalming material consisted of a mixture of animal fats and plant sterols. Between 5 to 20% of the mixture contained pine resin, aromatic plant extracts, plant-derived sugars and natural petroleum (Phillips, 2015). A lot of these ingredients were antibacterial and assisted the preservation of a body (Jones, et al., 2014). Also, three measurable amounts of substances, typically found when plant resins are heated, were found, which indicated that the balm was intentionally cooked (Phillips,

2015). Since then, no fundamental change was made to the Egyptian recipe for embalmment (Phillips, 2015). The practice of embalming continued and advanced for well over 2,000 years (Smithsonian Institution, 2012).

The third pharaoh of the 19th dynasty (1187 - 1292 BC), Pharaoh Rameses II, ruled Egypt from 1279-1213 BC and is often regarded as the most powerful and greatest pharaoh of the Egyptian Empire (Smithsonian Institution, 2012; Landman, 2014). His embalmed/ mummified body (Figure 2.2) is one of the most preserved specimens in Cairo, Egypt (Landman, 2014).



Figure 2.2 Pharaoh Rameses II (1301-1235 BC) preserved at the museum of Egyptian antiquities in Cairo (Landman, 2014).

Moreover, around 3150 BC, ancient Egyptians were not only making use of embalming fluids but also sarcophagi (Ikram & Dodson, 1998). One of the most famous Egyptian tombs found to date was that of King Tutankhamun in 1922 by the English archaeologist, Howard Carter, in the Valley of the Kings (Jones, 2008). King

Tut's coffin consisted of a series of three anthropoid (human-shaped) coffins, which were encased in a large quartzite sarcophagus (Falck & Wettengel, 2008). The coffins were nested within each other like Russian dolls (Jones, 2008).

The first two coffins were made of cedar and oak wood and were decorated with a greenish blue tin-glazed pottery (Falck & Wettengel, 2008). The pottery consisted of crushed quartz, lime and alkali (Falck & Wettengel, 2008). The wooden coffins were also covered with a thin layer of gold (Carter, 2014). The third coffin was made from solid gold (Carter, 2014). Each coffin was fastened by silver strips and nails (Falck & Wettengel, 2008). See Figure 2.3 for illustration of Tutankhamun's sarcophagi.



Figure 2.3 King Tutankhamun's sarcophagi at the Tutankhamun exhibition in South Africa (van Allemann, 2015).

For the Egyptians, material preparation of the dead not only secured a socio-economic place after death but also provided them with material existence and physical link between the dead and the living (Cooney, 2013). The sarcophagus was also believed to be a vessel for magical-religious safety and a medium for communication (Ikram &

Dodson, 1998). The Egyptians ideally required that their corpse be mummified and buried in an extravagantly decorated coffin. However, only a few could afford to do so (Cooney, 2013). The poor, though, still hoped that by including material objects and burying the deceased close to wealthier individuals would allow them a “reserved seat” in the afterlife (Ikram & Dodson, 1998).

Some corpses were fully embalmed and others simply washed and wrapped in reed matting or simple textiles (Jones, 2004). Coffins were also not freely available and the competition to acquire a coffin was fierce (Ikram & Dodson, 1998). This led to coffins being reused, which was quite common during the Third Intermediate Period of Egypt (1070 - 664 BC) (Ikram & Dodson, 1998). Sarcophagi of the Nineteenth Dynasty would be excavated after about 150 years, since seven generations would have passed, meaning that no family members were left to communicate and perform offering rituals (Cooney, 2013). The excavated sarcophagi of the Nineteenth Dynasty were therefore re-decorated with Twentieth Dynasty (1187-1064 BC) paint for another individual (Cooney, 2013). The poor, having no coffin, would use miniature or imitation versions of the sarcophagi, hoping that it would have the same effect (Ikram & Dodson, 1998).

The sarcophagi were either made of granite or wood, depending on their socio-economic class (Cooney, 2013). The environmental impact of Egyptian burial practices was insignificant since they mostly made use of natural materials.

2.1.3 Ancient Greece

Prior to the second century, the Romans mainly practised cremation (Deviese, et al., 2011). The Romans eventually adopted inhumation (burying the dead) as the primary funeral practice, which created a large demand for sarcophagi in the second and third century (Papageorgopoulou, et al., 2009).

In ancient Greece and Roman periods, the corpses were washed with water, wine and essential oils before they were wrapped and buried (Kampassakali, et al., 2003). The most luxurious sarcophagi were made of marble, whereas the least expensive sarcophagi were made of wood, limestone and lead (Deviese, et al., 2011). Wealthier individuals were buried within lead sarcophagi, which was buried within marble sarcophagi (Papageorgopoulou, et al., 2009). These corpses were exceptionally well preserved (Deviese, et al., 2011).

There are not as many studies on Roman mummies as on Egyptian mummies, however, a partially mummified body dating back to 1700 BC was found in Northern Greece. The mummy had soft tissues and long hair, which was uncommon for this period in Greece (Papageorgopoulou, et al., 2009). The mummy was found inside a Roman marble sarcophagus containing a lead coffin in 1972. The body was positioned on a wooden pallet within the lead coffin and was covered with a gold-embroidered, purple silk cloth (Kampassakali, et al., 2003).

Wrapping of a body was common practice 2900 BC in ancient Greece (Deviese, et al., 2011). The presence of terpenes (diverse organic compounds from plants and insects) in the bone and soft tissue was a sign of direct treatment of the body (Papageorgopoulou, et al., 2009). These compounds were antibacterial and antifungal which, combined with dehydration substances of the body, preserved the mummy (Papageorgopoulou, et al., 2009). Apart from lead coffins, the Romans mainly used natural materials for funerary practices.

2.1.4 The American Civil War transforms funeral practices

The start of the American Civil War in 1861 transformed the way in which people in North America handled the deceased (Gagnon, 2015). Since so many Union soldiers died far from home, issues related to burying the dead aroused and the unprecedented

scale of human loss had a profound impact on their way of life (Niven, 1965). Frequent funerals became a reminder of the war's toll and to make things even worse was the fact that they couldn't have proper burials since the troops were so far from home (Gagnon, 2015). The families were often not able to identify or locate their loved ones (Fraust, 2008). Families that could afford to bring the deceased back home made use of ships and trains (Gagnon, 2015). Until 1864, civilians were allowed to enter the battlefields in order to retrieve the dead, as long as they did not hinder troop movement (Niven, 1965).

In the Victorian Age (1837–1901), a funeral was usually held in their family homes, where they mourned for long periods (Fraust, 2008). The war-related deaths, however, made such practices unpleasant since the deceased started to decompose before they even got back home (Gagnon, 2015). It was at this time that families made use of various embalming methods to ensure preservation of the bodies (Fraust, 2008). Then again, the new methods proved unreliable and were rarely effective (Fraust, 2008). The deceased would often return home severely decomposed or worse – not even being the family member (Niven, 1965). It was also at this time where casket companies started to construct various coffins to assist with transport and identification of the deceased (Gagnon, 2015). The caskets had, for example, viewing windows to identify the dead (Gagnon, 2015).

However, there was still no federal provisions for clearing the battlefield of bodies and burying the dead (Fraust, 2008). Civilians or volunteering organisations had to do that themselves (Fraust, 2008). At the end of the Civil War, trained embalmers returned to their hometowns, where they practised embalming (Konefes & McGee, 2001). Honouring the dead through burial and monuments also gave rise to cemeteries (Niven, 1965). However, it was only two years after the Civil War passed in 1867, that formal legislation and national cemeteries became promulgated (Niven, 1965).

From 1830 to 1920, funerals and burials were handled by family members and neighbours (Bern-Klug, et al, 1999). The women were usually responsible for washing, dressing and preparing the body, whereas the men were responsible for making a plain wooden coffin or obtaining it from the local carpenter (Bern-Klug, et al, 1999). The men were also responsible for digging the graves.

Cemeteries were sited outside of cities boundaries, however as industrialisation flourished, the cities became crowded and living spaces became smaller. Not only were homes becoming too small for funeral services, but they were built closer to cemeteries. Funeral practitioners became even more popular for reasons such as embalming practices, arranging spaces big enough for funerals and ensuring that all formalities were being followed (Bern-Klug, et al., 1999).

Religious beliefs also influenced how people handle the deceased. Hinduism and Buddhism require cremation, while Lutherans have no formal position for or against it (Bern-Klug, et al., 1999). The Roman Catholics were opposed to cremation until the 20th Century (Order of Christian Funerals, 1990). The church also opposed cremation until the latter part of the 20th Century, at which time cremation became permitted, but not encouraged (Order of Christian Funerals, 1990). For both cultural and religious reasons, Jewish people are still buried instead of being cremated today, since many Jews believe in the resurrection, “the return of the soul to the resurrected body” (Kastenbaum, 1994).

From the Civil War Era until about 1910, the main ingredient for embalming fluids was essentially arsenic (Konefes & McGee, 2001). Arsenic was a significant improvement from ice when preserving the deceased for burial or transport, however, embalming practitioners did not take into consideration the long-term effects (Konefes & McGee, 2001). Even though arsenic is very effective, it is not only highly toxic but

persistent and will never be able to degrade into harmless by-products (Singh, et al., 2011). As result, large concentrations of arsenic were placed within burial grounds.

Arsenic also poses a significant environmental threat and health hazard to cemetery workers, Archaeologists and surrounding communities (Singh, et al., 2011). Konefes & McGee (2001) suggested that the water seeping through the graves will cause some of the arsenic in an embalmed body to leach out and end up in nearby groundwater, which may supply communities. As an example, Konefes & McGee (2001) proposed a hypothetical scenario to illustrate the possible extent of pollution. They assumed that in a modestly sized town, it was reasonable to assume that 2,000 people died between 1880 to 1910. If only half of the deceased were embalmed with arsenic, using 30 ml of pure arsenic, the cemetery would contain 172 kg of arsenic. If the embalmers used more arsenic, such as 1.5 litres per person (depending on the formula used), the cemetery would contain over one tonne of arsenic. Both of these scenarios would be a significant amount of toxic material in one location.

Although arsenic was the main ingredient to embalming fluids, other embalming compositions were used less frequently but consisted of similar toxins, such as mercury and creosote (Johnson, 1995).

2.1.5 Early 19th to 21st Century

Nowadays embalming fluids contain formaldehyde, distilled water, phenol and glycerol (Anat, 1993), of which 10 litres of the mixture (containing 1.5 litres of formaldehyde) (Karmakar, 2010) is required for a 70-kg body. Formaldehyde is released during decomposition and has been shown to be carcinogenic to living organisms (Guttman, et al, 2012). According to a 2002 World Health Organization report (2002), when formaldehyde comes into contact with water it breaks down into

methanol, amino acids and several other chemicals and therefore, does not persist in the environment.

Traditional coffins are primarily constructed of wood that is treated with preservatives to minimise decay and rapid leaching of organic contents that may otherwise be seen as a major source of soil contamination (Spongberg & Becks, 1999). Chromated copper arsenate (CCA)-treated wood was widely used for coffins until 2004 (Janin, et al., 2011). However, the chromium (VI), arsenic and copper components in CCA could leach into the soil and groundwater (Chou, et al., 2007). Due to serious health concerns, CCA had been replaced by other preservatives such as alkaline copper quaternary (ACQ), copper azole (CA) and micronized copper quaternary (MCQ) (Janin, et al., 2011). Nevertheless, older coffins currently present in cemeteries would still have been treated with CCA.

Previously, potentially harmful minerals such as lead, arsenic, mercury, manganese, nickel, copper, vanadium, cadmium, zinc and chromium were used in paints for coffins (Gondal, et al., 2011). Although some changes have been made to the formulations of paint during the past 20 years or so, many still contain dangerous heavy metals, such as lead, mercury, and chromium (Gondal, et al., 2011) that are known to exhibit poisonous effects on humans, animals and the environment.

Furthermore, the heavy metals that are frequently used for the decoration, construction and corrosion protection of coffins include, zinc and its alloys; as well as silver and bronze (Jonker & Olivier, 2012). Once heavy metals have been introduced into an environment, they accumulate and may also become mobile. Consequently, higher concentrations of heavy metals may be anticipated downslope (Okoronkwo, et al., 2005) from a cemetery.

In the United States, it is estimated that more than 60,000 tonnes of steel caskets; 2,700 tonnes of copper and bronze; 70,000 m³ of hardwood caskets and 18 million litres of embalming fluid are buried each year (Johnson, 2013) (Langtree, 2015). According to Johnson (2013) the steel alone “is enough to build eight Eiffel Towers and fill eight Olympic size swimming pools”.

While metals are still being used for large portions of the coffins or caskets, after a visit to one of the largest coffin suppliers in South Africa, it became apparent that there has been a significant movement towards the use of plastic handles and ornaments. These hard, durable plastics are significantly cheaper than metals and are also lighter in weight. Nevertheless, there is still uncertainty about the long-term environmental effects of these materials.

The average coffin that is made up of plastic handles and other ornaments consists of approximately 880 g of polypropylene i.e. plastic. Considering a small cemetery of 8,000 graves, where half of the cemetery’s coffins contain plastic, it is estimated that there will be an average of 3.5 tonnes of polypropylene in the soil. This equates to about 600,000 plastic shopping bags. In addition to the large amounts of plastic being buried in the soil, it is important to remember that plastic has a very long lifespan.

There has also been a significant movement towards using concrete burial vaults in the United States, which apparently prevents the grave from sinking and contents from leaching out into the soil and groundwater (Johnson, 2013). It is estimated that a total of 1,636,000 tonnes of reinforced concrete vaults have been used in the United States to date (Johnson, 2013).

2.1.6 Movement towards greener burials

While more than 50,000,000 people worldwide die each year, most people still make use of traditional burial practices that have a significant impact on the environment (Grover, 2014). Though, to keep tonnes of steel and harmful materials out of the ground and groundwater, more-and-more individuals are considering cremation and natural burials after death (Grover, 2014). Not only is the impact on the environment significantly lower, but money is also saved in the process (Johnson, 2013).

Greener burials tend to be less expensive than conventional funerals since money is saved on expenses; such as embalming processes and metal/ wooden caskets (Grover, 2014). Greener burials are, however, still more expensive than cremation, which is an option that is also gaining ground (Grover, 2014). Although cremation doesn't require cemetery space, the crematoriums used contribute to air pollution, releasing toxins such as formaldehyde, hydrogen chloride, dioxins, mercury, and greenhouse gas emissions in the open atmosphere (Rose-Innes, 2012). The energy costs associated with cremation is also an issue.

Options in America that are currently available for green caskets or often called 'ecoffins' are bamboo, pine, woven willow, recycled cardboard, or even cord from dried banana plants (Johnson, 2013). People who choose green burials don't use concrete vaults, traditional coffins with metalwork, or any embalming fluids (Rose-Innes, 2013). Instead, the body is wrapped in biodegradable cloth or placed in a pine coffin and laid to rest where it can decompose and become part of the earth (Johnson, 2013).

The biggest obstacle is creating awareness of the choices individuals have to bury the dead, which makes the movement toward 'ecoffins' very slow. In August 2011, South Africa opened the country's first green cemetery (Sibongakonesi, 2011). Wiesenhof

Legacy Park, located in Stellenbosch (South Africa), was created within the oldest privately-owned nature reserve in the country (Sibongakonesi, 2011). Although it will still remain a nature reserve, the park set aside a portion of its space for burials (Sibongakonesi, 2011). This indicates that South Africa and the rest of the globe is moving towards sustainable burials.

Nevertheless, the fact remains that in most cases, conventional burials are still the norm and the impact of this has yet to be assessed.

2.2 Cemeteries and the environment

In ancient times, Romans believed that cemeteries were unsanitary and hazardous, and therefore, sited them outside the cities (Guttman, et al., 2012). In more modern times, though, cemeteries were moved closer to settlements for cultural and accessibility reasons. As a result, many cemeteries were established without the awareness that there might be a potential risk to the local community and/or the environment (WHO, 2000).

Despite the widely-held belief that the decomposition of bodies and the stench of decomposing corpses were potential health hazards to living individuals, this was not proven until the mid-1800, when Dr George Walker (A British surgeon) described how the soil around graves became saturated with decomposing matter which could possibly be deadly (Tarlow, 2000). In 1845, Snow established a clear link between water and cholera within close proximity of graveyards (Eyler, 2001). Subsequent to this research, numerous researchers have shown that water bodies and wells near cemeteries could become contaminated with bacteria from decaying bodies and therefore, could become an environmental and health hazard) (Engelbrecht, 1998) (Dent, 2000) (Eyler, 2001) (Tumagole, 2009) (Zychowski, 2012) (Fogli, 2016).

Although the first studies conducted on the pollution potential of cemeteries focused on the contaminants associated with bodies and associated bacteria, recent studies have been carried out on contamination from minerals and corroded metals contained in burial material such as coffins and caskets.

2.3 The corrosion of burial materials

Corrosion is the undesirable deterioration of a material due to its interaction with the environment (Shaw & Kelly, 2006). According to this definition, materials other than metals, such as plastic, ceramic and cement may also corrode (Corrosion Institute of Southern Africa, 1994). Corrosion is a natural and inevitable process with the purpose of deteriorating a material back to its original natural state. The primary environmental factors that influence the corrosion rate of a material includes the medium (gas, liquid or solid) it finds itself in, the chemical composition of the material and medium, and the temperature (ASM International, 2000).

The corrosivity of soils depend on their resistivity (related to the electrical conductivity), water content, pH, dissolved oxygen levels, chlorides, sulphates, dissolved salts, calcium, magnesium (Corrosion Institute of Southern Africa, 2004), composition and infiltration rates (Tibbett, 2010). The corrosivity of a system depends largely on the solubility of a corrosion product (usually the oxide or hydroxide) formed on the metal surface (Corrosion Institute of Southern Africa, 2004) as an increase in the solubility of a corrosion product will increase its mobility within the soil. Figure 2.4 illustrates the effects of pH on the solubility and mobility of metals. An increase in temperature may also increase the corrosion rate of metals in soil (Pourbaix, 1974).

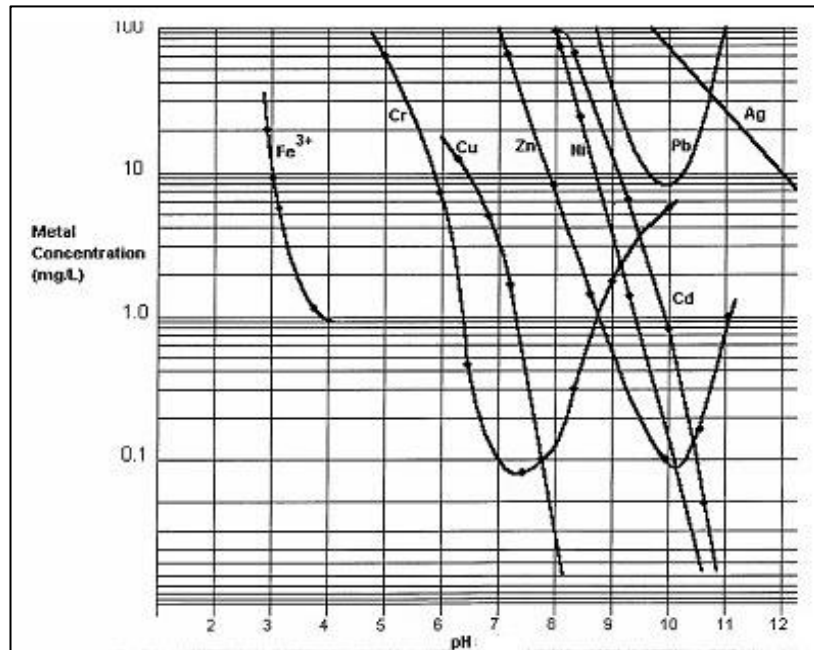


Figure 2.4 Relationship between the solubility of metals and pH (Neutralac, 2015)

As mentioned above, the infiltration rate of a soil plays a large role in the transportation of burial materials. Potential contaminants from a burial site could migrate into (a) the soil surrounding the grave; (b) the unsaturated zone of the underlying aquifer; or (c) the saturated zone of the aquifer (UK Environment Agency, 2004). The “bucket effect” explained by Dent (2000) is the retention of water in a grave, which creates a local water table. This leads to altered distribution of and infiltration rates of soil. Ultimately, cemeteries alter underground interflow pathways (Dippenaar, 2014).

Metals exist in the soil solution as either free metal ions (uncomplex), organic or inorganic complexes or associate with mobile colloidal material (Mclean & Bledsoe, 1992). Biochemical complexes form water soluble complexes with metals, which increases metal mobility (Mclean & Bledsoe, 1992).

Korte et al. (1976) added 11 metals to 10 soils to simulate movement of metals under an anaerobic landfill situation, in order to qualitatively rank their relative mobilities.

At pH 5, it was found that lead (Pb) and copper (Cu) were the least mobile, whereas Arsenic (As) and chromium (VI) were the most mobile. The heavier textured soils and/or soils with a high pH were found to retain the metals effectively, while the sandy soils and/or soils with a low pH did not retain metals effectively. As for clayey soils, containing oxides with a low pH, metals were also contained effectively. Figure 2.5 below shows the relative mobility of the 11 metals in different soil types. The soil types include; Molokai (clayey silty clay), Nicholson (silty clay), Mohave_{ca} (clayey loam), Fanino (clay), Mohave (sandy loam), Davidson (clay), Ava (silty clayey loam), Kalkaska (sand), Anthony (sandy loam) and Wagram (loamy sand) (Korte, et al., 1976). Note that attenuation capacity refers to the filtering ability of the soil.

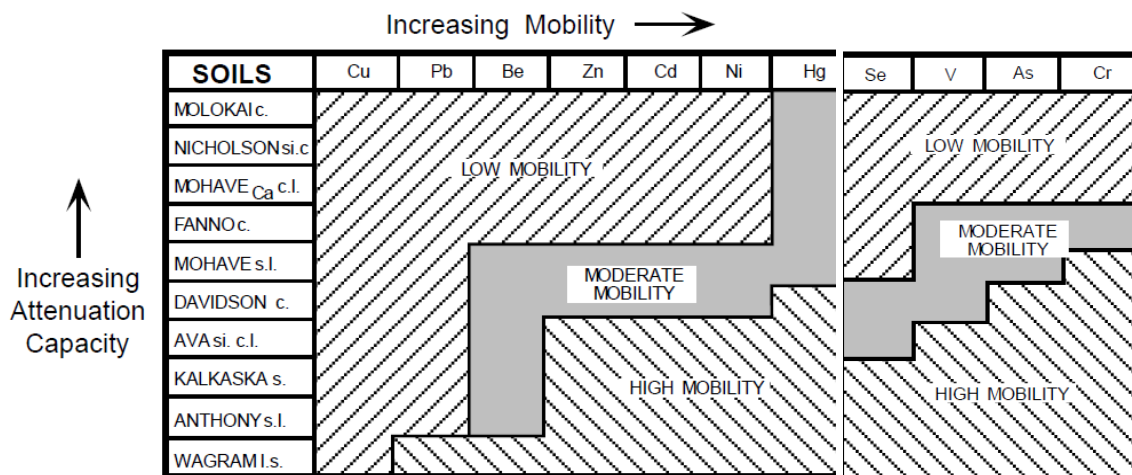


Figure 2.5 Relative mobility of cations through US soils (Korte, et al., 1976)

Different types of corrosion, elaboration being well beyond the scope of this study, include general corrosion, crevice corrosion, pitting corrosion, galvanic corrosion, microbiologically induced corrosion (MIC), all depending on the type of material and its surrounding environment (Corrosion Institute of Southern Africa, 1994).

Corrosion of metals costs the United States economy almost \$300 billion per year (ASM International, 2000), while, in South Africa, it is estimated to cost 5.2% of the

annual national gross product (GNP) (Corrosion Institute of Southern Africa, 1994), which is roughly equivalent to R15.5 billion (\$1 billion) at current exchange rates. It is estimated that one-third of these costs could be reduced by improving corrosion-resistant material applications and related technical practices (ASM International, 2000).

The corrosion of materials in cemeteries has, however, been disregarded as cemeteries are commonly considered a fairly low risk compared to other anthropogenic sources of contamination. Following burial, the body's chemical components, as well as metal body parts of the deceased may leach into the surrounding soil or into groundwater. Coffins and other grave contents have also been proven to play a vital role in contamination of soil in cemeteries (Aruomero & Afolabi, 2014) as the construction of coffins include metals, which are often spray-painted, vacuum metalized or electroplated.

Although there are many other forms of corrosion that could play a role in corrosion in cemetery soils, Microbiologically Induced Corrosion (MIC) is probably the predominant agent (Javaherdashti, 2008). MIC refers to microbiological organisms that produce acid on metal and non-metal surfaces, consequently deteriorating it (Javaherdashti, 2008). Javaherdashti (Pers. Comm. 2016) stated that MIC could play a vital role in the corrosion of materials in cemeteries since there are over 15 types of microorganisms that could deteriorate non-metals and metals, except for titanium oxide, of which the reason is still unknown. Of these microorganisms, *E.coli* (*Escherichia coli*), which lives in the digestive tracts of humans and animals, is one of the main culprits (Javaherdashti, 2016). It is therefore suggested that cemeteries could be even more prone to MIC corrosion than other types of environments.

Apart from MIC, microbial decay is also the primary process regulating the production, release, and migration potential of pollutants from buried corpses. The microbial growth and activity are, however, influenced by (a) the availability of

nutrients; (b) pH; (c) climate; (d) soil lithology; and (e) the depth and materials of the coffin (UK Environment Agency, 2004).

2.4 The pollution potential of corroded coffin materials in cemeteries

One of the first studies done on the mineral contamination of cemeteries was that of Dent & Knight (1998) at the Botany Bari Cemeteries in Australia. During their study, high concentrations of Mg, K, Na, Fe, PO₄ (phosphate), NH₄, NO₄ (peroxynitrate) and Cl were found in the groundwater next to graves. Research by Rodriques & Pacheco (2003) showed inorganic contamination and the presence of harmful pathogens in groundwater adjacent to a cemetery in Brazil. Likewise, Pour & Khezri (2010) conducted a study in Iran of which the findings were very similar to those of the previously mentioned projects.

These studies mainly evaluated groundwater contamination adjacent to cemeteries. However, soil investigations were also done, which showed proof of soil contamination. In Brazil, Barros, et. al. (2008) conducted a study in the Santa Candida Municipal Cemetery. This study revealed significant metal contamination of the soil in the cemetery. Similar studies were conducted by Spongberg & Becks (1999), Jonker & Olivier (2012), Amuno (2013), Aruomero & Afolabi (2014) – all indicating high mineral loads in cemetery soils.

CHAPTER 3: METHODS AND MATERIALS

3.1 Introduction

The methodology comprised of filling columns with either sand, silt or clay. These columns were fitted with taps at their lower ends. Burial materials and a cloth dipped in formalin were buried in the columns and placed in conditions simulating that of the natural environment. Water was poured into each of the columns and the concentration of leachate measured. This was used to estimate the pollution potential of cemetery soils and groundwater. Details of each of the steps in the experimental procedure are provided in this chapter.

3.2 Collection of soil samples

Samples of three major soil types, namely; sand, silt and clay were collected from Klerksdorp, a town located in the North-West Province of South Africa. The soils types were determined (on-site) by means of a particle size assessment technique, involving the following criteria:

- sand - particles of 0.5 – 2.0 mm;
- silt – particles of 0.002 – 0.05 mm; and
- clay - particles less than 0.002 mm (Brady & Weil, 2008).

Approximately 40 kg of each soil type was collected, placed in bags, sealed and taken back to the research test facility for further laboratory testing and analysis.

3.3 Baseline chemical composition and corrosive properties of the soil samples

The baseline chemical compositions of the different soil types were assessed as a first step in the research process. This was achieved by means of X-Ray Fluorescent (XRF)

analysis. A Thermo Fisher ARL Perform'X at the Stoneman X-Ray Analytical Facility located at the University of Pretoria was used to perform the analysis. The instrument is an apparatus with a Rh target 50 μm window, a 4.2kW power supply system and a goniometer, which contains four collimators (0.15°, 0.4°, 1° and 2.5° angular admittance) (Dippenaar, 2017). The apparatus has two detectors (flow proportional and scintillation) and six analysing crystals (Ge111, LiF200, AX-06, AX-16C, AX03 and LiF220). Principal beam filters include Al20, Al200, Al500, Al750 and Cu250 (Dippenaar, 2017). Major and trace elements were analysed by making use of quantitative (OXAS) and semi-quantitative programs (UniQuant and Quantas) (Dippenaar, 2017). Pressed powder samples were used to analyse trace elements and fused beads for both major and trace element analyses.

The corrosive chemical species, i.e. main soil elements contributing to the corrosivity of each soil type, were determined. Research findings by the Corrosion Institute of Southern Africa, the leading corrosion research body in Africa, was used as a basis for analyses. This was to enable the prediction of the most corrosive soil type and whether certain corrosive species would have an impact on the corrosion rates of metals. Properties considered included: moisture content; drainage capacity; amount of sulphur and chlorides; conductivity; pH; soil type and soil colour.

The moisture content of the soil was determined by means of a protimeter. Afterwards, a 1:1 mix of soil and water was prepared for the different types of soils prior to testing. The type and colour of the soil was determined by means of visual assessment, the pH with a Horiba Laquatwin pH meter, conductivity with a Hanna 9033 multi-range conductivity meter, sulphur with a Hanna HI 38001 sulphate low and high range test kit and chloride with a Hanna HI 3815 chloride test kit (n.d).

Sulphate levels were determined via a barium chloride titration method, which involves a colour change from violet to blue, which is indicative of the amount of

sulphates in the sample (Hanna Instruments, n.d.). The determination of chloride levels involved adding 2 drops of Diphenylcarbazone indicator, lowering the pH to approximately 3 by adding nitric acid until the solution turns yellow and titrating mercuric nitrate until the solution turns purple (Hanna Instruments, Instruction manual for HI 3815 chloride test kit). The amount of mercury nitrate titrated was proportional to the concentration of chloride in the solution.

3.4 Preparation of soil test columns

Following analysis of the different soil types, test columns of soil (170 mm x 190 mm) were prepared - using clean standard 5-litre polyethylene buckets. Each column was also fitted with a small tap at the lower end for routine sampling of water leachate, as well as with a material sieve, to prevent blockage of the tap. The containers were thereafter similarly filled and compacted with the different soil types. These columns simulated graves in different soils. A total of 33 columns were prepared for burial of the coffin materials.

All experiments were conducted at Orytech (Pty) Ltd, an independent paint or coating, corrosion, environmental and materials testing facility located in Roodepoort, Gauteng (Orytech, 2017).

3.5 Burial sample material acquisition and analysis

Coffin materials and embalming fluid were collected from one of South Africa's largest coffin manufacturers (Figure 3.1). This company is also one of the oldest coffin manufacturers and suppliers in South Africa and has been operating for almost a century. Noteworthy is that until recently, coffin materials, such as handles and ornaments, have been mainly been manufactured from metals, e.g. aluminium, copper, mild steel, zinc and its alloys, as well as silver and bronze. The use of these materials has now been replaced by plastic handles and ornaments.

The material safety data sheets (MSDSs) of the coffin material were reviewed, which indicated that the polymer handles and ornaments comprised of polypropylene - containing acrolein and formaldehyde (Motlatsi, 2007). Moreover, it was indicated that the coffin varnish contained traces of formaldehyde (Chemical Specialists (Pty) Ltd, 2009).

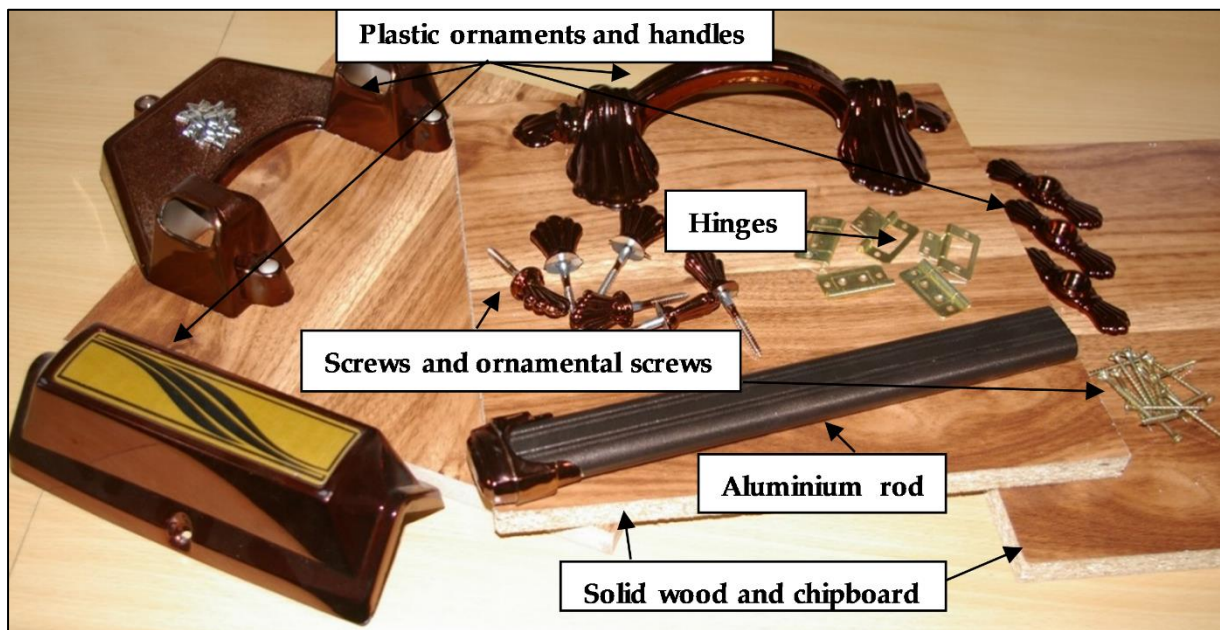


Figure 3.1 Coffin samples collected from one of SA's largest coffin and casket suppliers

A portion of each coffin sample was cut with a small angle grinder, which were then analysed at SGS South Africa's facilities in Midrand, by means of Scanning Electron Microscope (SEM) analysis, using an Energy Dispersive Spectrometer (EDS). SEM-EDS is a chemical analysis method, which identifies and characterizes materials and mineral oxides (Mintek, 2017).

3.6 Burial material quantities and interment

According to the supplier of the coffin material samples, typical coffin material quantities (comprising of the materials indicated above), are given as follows:

- 65 kg chipboard or 85 kg solid wood;

- four hinges;
- six standard handles; or
- six handles with two aluminium rods of 1.2 meter;
- four plastic ornaments for the corners of the coffin; and
- screws.

By using this information, the sample ratio of each material was calculated, per weight of an average coffin. Thereafter, the coffin materials were cut up into smaller pieces by means of a small angle grinder according to the calculated weight ratios.

A sample of each coffin material, as well as pure cotton cloth (of size, 50 x 50 mm), which had been soaked in 15.6 ml formalin, was 'buried' in each of the soil columns. All samples were buried at a depth of 95 mm.

E. coli bacteria, together with a nutrition medium, were also added to each column to simulate the decomposition of a body that may influence the corrosion rate of the materials. The bacterial tests, though, were controlled and analysed by the Council for Scientific and Industrial Research (CSIR). Consequently, the results related to bacterial growth and their persistence or lifespan within the soil, or water, is not included in this dissertation.

The soaked cloth and bacteria were placed on opposite sides of the buried materials to allow the bacteria to flourish without being affected by the formalin. Each of the soil columns were given a unique sample identification and labelled accordingly.

Information pertaining to the general climatic conditions of South Africa (SAWS, 2016) was used as guidance in setting-up of the laboratory test conditions.

3.7 Environmental conditions in South Africa

3.7.1 Rainfall

South Africa is a relatively dry country with an average rainfall of approximately 464 mm per annum (South African Government, 2015), however, certain parts of the country may receive rainfall of up to 2000 mm per annum (Figures 3.2 and 3.3). The Western Cape receives less intense and often prolonged rainfall during winter, whereas the rest of the country is largely a summer-rainfall region area, where rain frequently occurs in the form of heavy thunderstorms

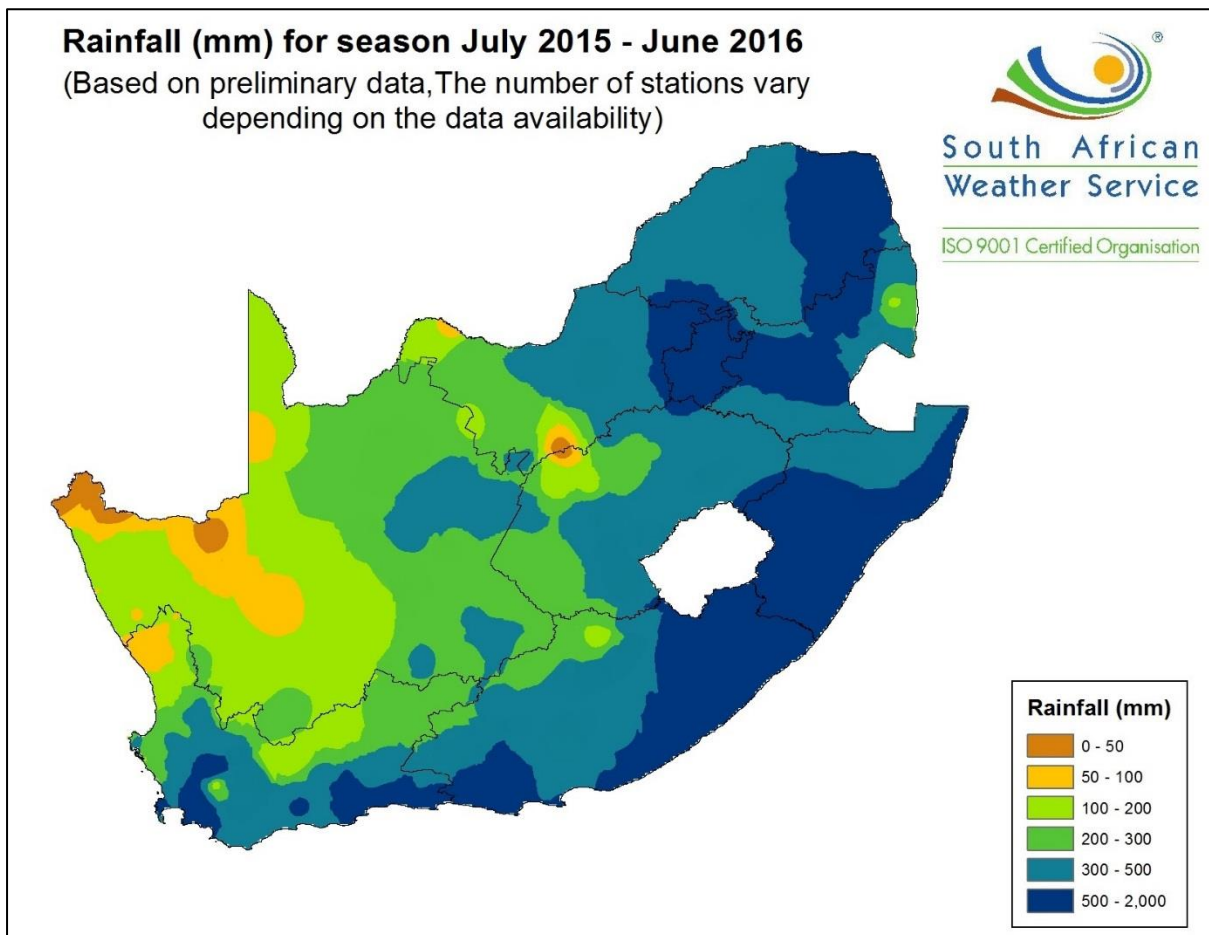


Figure 3.2 Recorded annual rainfall in South Africa for the period of July 2015 - June 2016 (South African Weather Service, 2016).

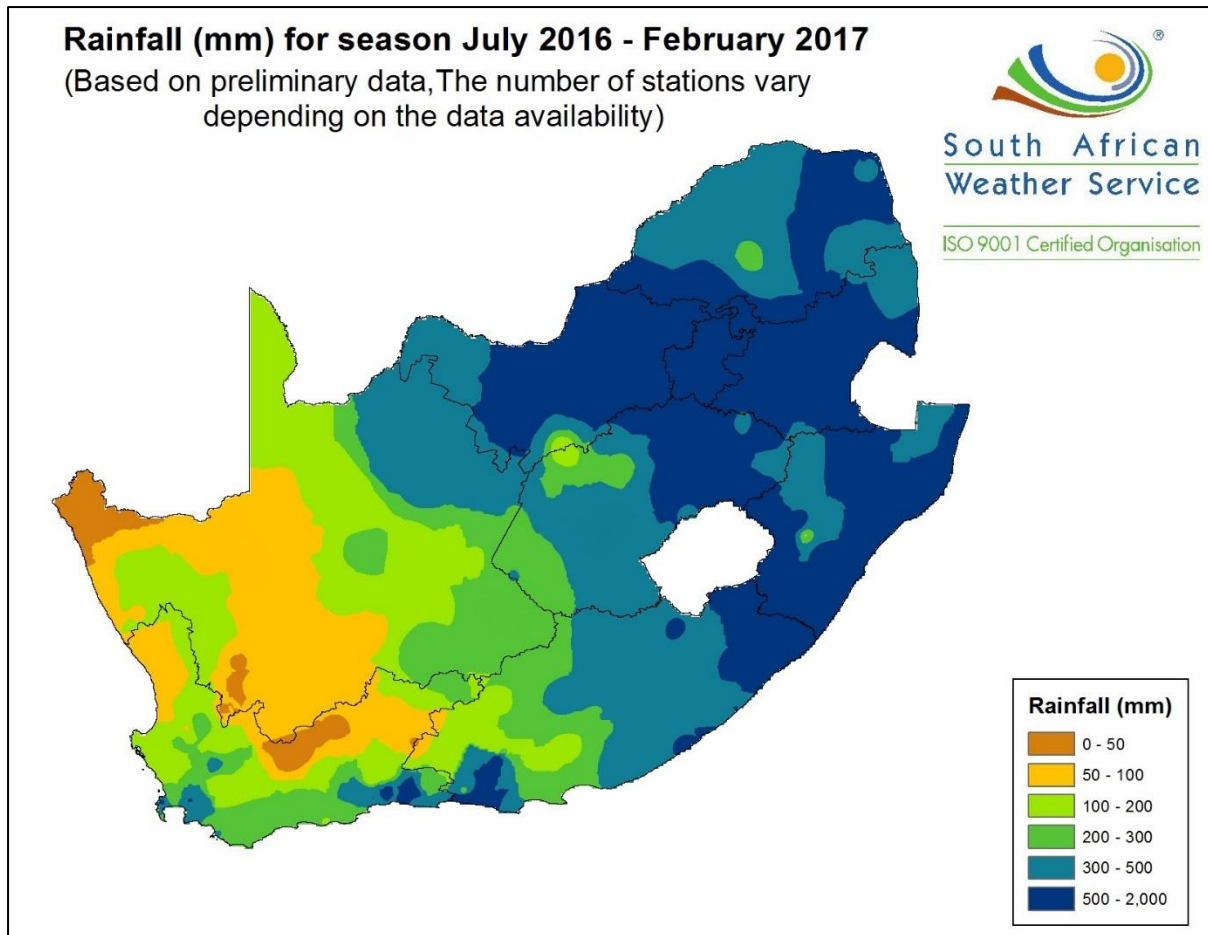


Figure 3.3 Recorded rainfall in South Africa for the period of July 2016 – February 2017
(South African Weather Service, 2016)

Generally, the pH of rainwater is given as 5.6 (Environment News South Africa, 2015) i.e. in rural, pollution-free areas. However, when combined with emissions containing sulphur dioxide or nitrogen oxide, it is reported that rainwater may become more acidic than usual (Hairston, 2003), resulting in the formation of acid rain. Typical acid rain has a pH of 3 to 4 (Hairston, 2003).

3.7.2 Temperature

South Africa's summers are characterised by hot and sunny weather conditions. Temperatures usually range between 25°C to 36°C throughout summer (South African Weather Service, 2016). In winter, temperatures of 14°C to 24°C can be expected with night-time temperatures that can drop to freezing or below freezing

point (South African Weather Service, 2016). Figure 3.4 shows the average temperatures during winter and summer for various parts of South Africa.

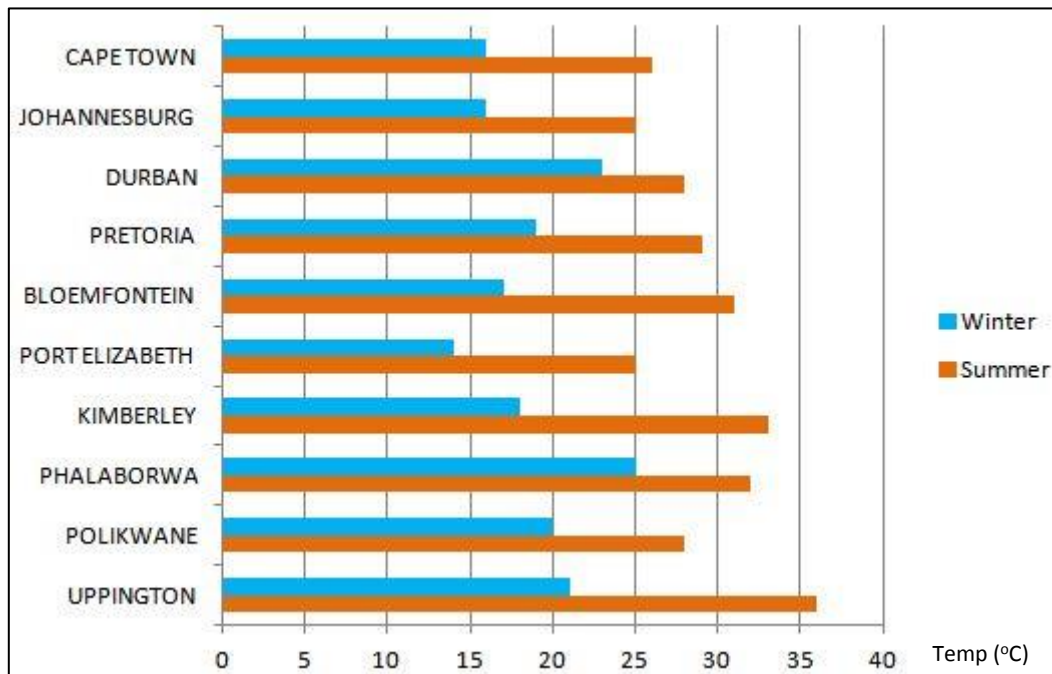


Figure 3.4 Winter and summer temperatures for various parts of South Africa (South Africa Tours and Travel, 2016).

In view of the above information, the test conditions were set-up as indicated in Section 3.8 below.

3.8 Simulated test conditions

Following preparation of the soil test columns and buried coffin materials, 18 of the burial test containers were placed in a dry, 30°C- controlled test chamber, while the other 12 were placed in a dry 20°C temperature controlled chamber.

In addition to the simulation of moderate and warm climatic conditions, the interment samples were watered with 1000 ml of demineralised water every two weeks. To simulate different rainfall intensities, the samples exposed to 'prolonged rainfall' periods, received 1000 ml of water over a period of four days - every second week,

whereas the entire 1000 ml of water was poured into the containers every second week, to simulate heavy rainfall (referred to as 'flash floods').

Since the pH of rainwater may vary, depending on local atmospheric pollution levels, the water added to the samples to simulate the different rainfall intensities, also consisted of different pH values. Half of the samples were given water with a pH of 6 (hereon referred to as 'slightly acidic') and the other half, water with a pH of 4 (henceforth referred to as 'acidic'). The pH adjustment of the water was done by means of the addition of hydrochloric acid. Figure 3.5 presents the various conditions under which the samples were tested.

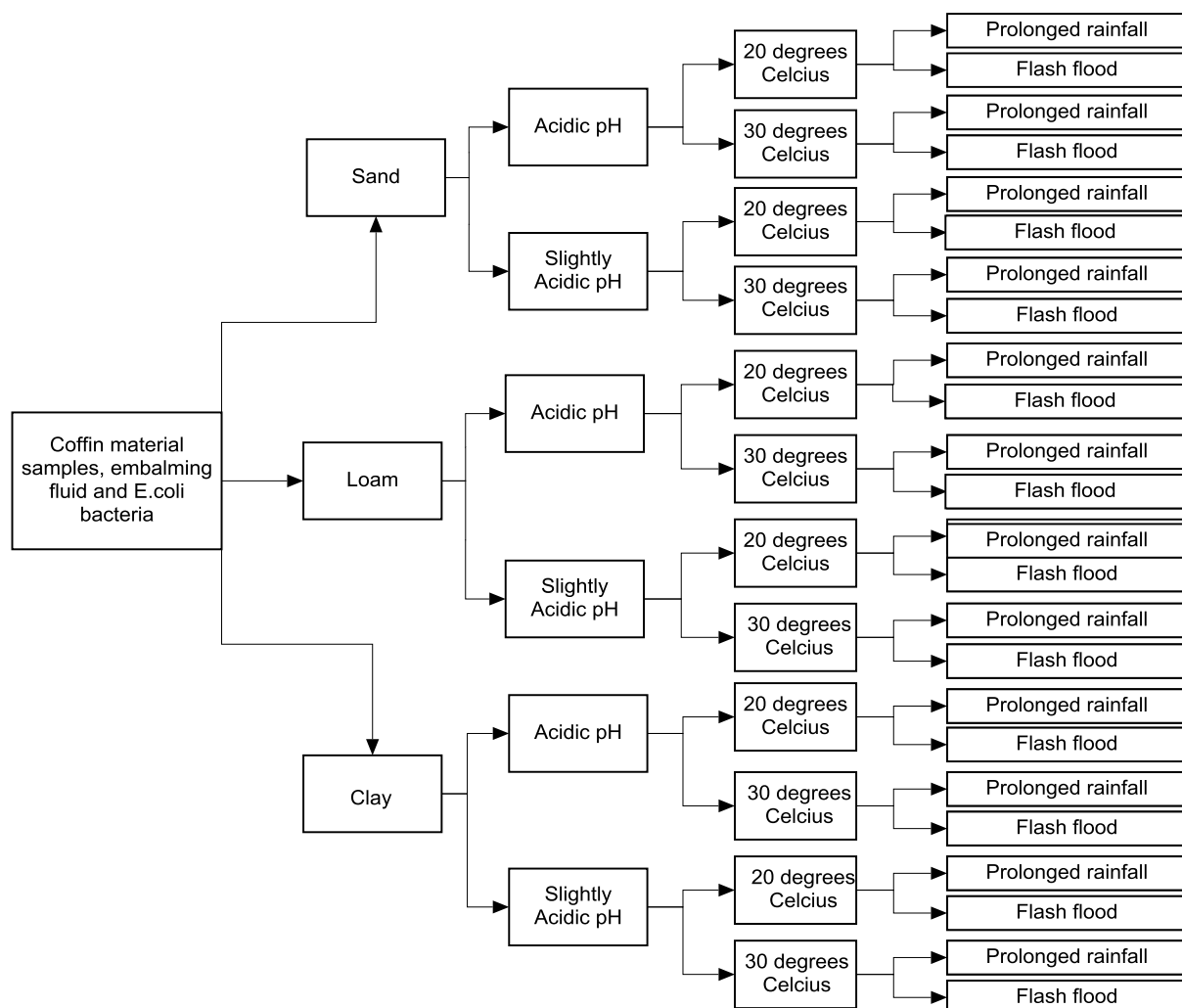


Figure 3.5 An illustration of the variable test conditions.

3.9 Simulation of a concrete tomb

In addition to the wooden and plastic samples, 250g cement (simulating concrete tombs), and *E.coli* bacteria were buried in different soil type columns with one-meter-long coils of aluminium (Al), copper (Cu), zinc (Zn) and iron (Fe). The coils were weighed beforehand. These metals are assumed to be the most common metals used for coffins. The columns containing cement and/or wires were used to determine whether the presence of cement would reduce the corrosion rate of the wires. These samples were also exposed to the expected ‘most severe’ conditions, such as acidic pH, 30°C and heavy rainfall (referred to as ‘flash floods’) in the different types of soil (Figure 3.6).

The cement used was a sample of the commercial brand called “SureBuild”, which comprised of limestone, fly ash and blast-furnace slag. “Surebuild” conforms to the 42.5N strength class of SANS 50197-1 for common cements (PPC, 2016).

Three additional columns with wires, excluding the cement, were also set-up to determine the corrosion rate of each type of wire.

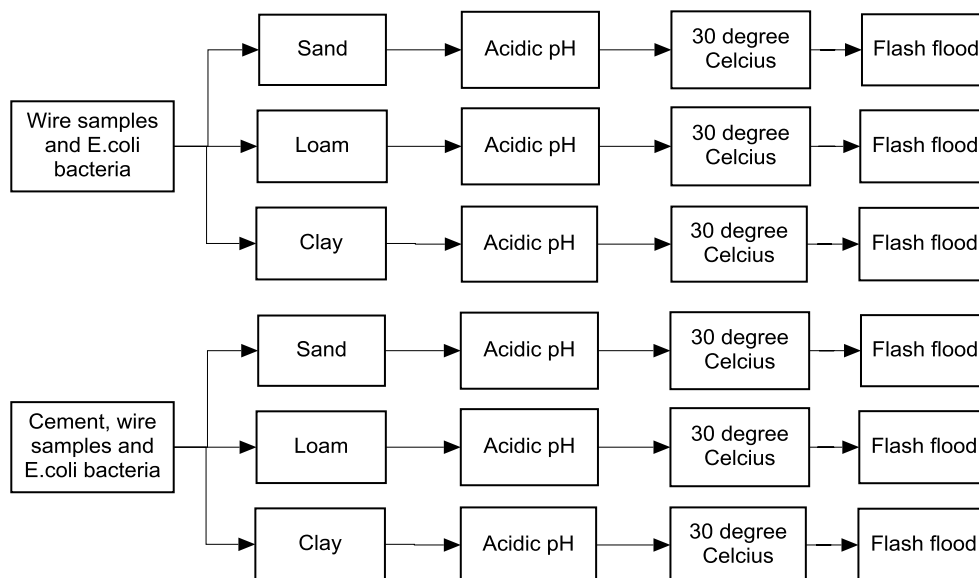


Figure 3.6 Schematic representation of the layout of cement and wire samples tested under the expected ‘most severe’ circumstances.

3.10 Control samples

It is important to keep in mind that metals as well as formaldehyde may arise from the oxidation of natural organic materials (World Health Organization, 2005), which suggests that formaldehyde is a natural occurring substance in small concentrations. For this reason, soil columns compacted with the different soil types without any burial materials were kept as controls, which were exposed to neutral flash floods at room temperature.

3.11 Overview of samples and variables

In total, 33 soil columns were prepared, which allowed for differentiation between the different types of soil (sand, loam and clay), at different pH levels (slightly acidic and acidic), varying rainfall (prolonged rainfall and flash floods), different temperatures (ranging from 20°C to 30°C) and the addition of cement. Interment continued for a period of six months (24 weeks).

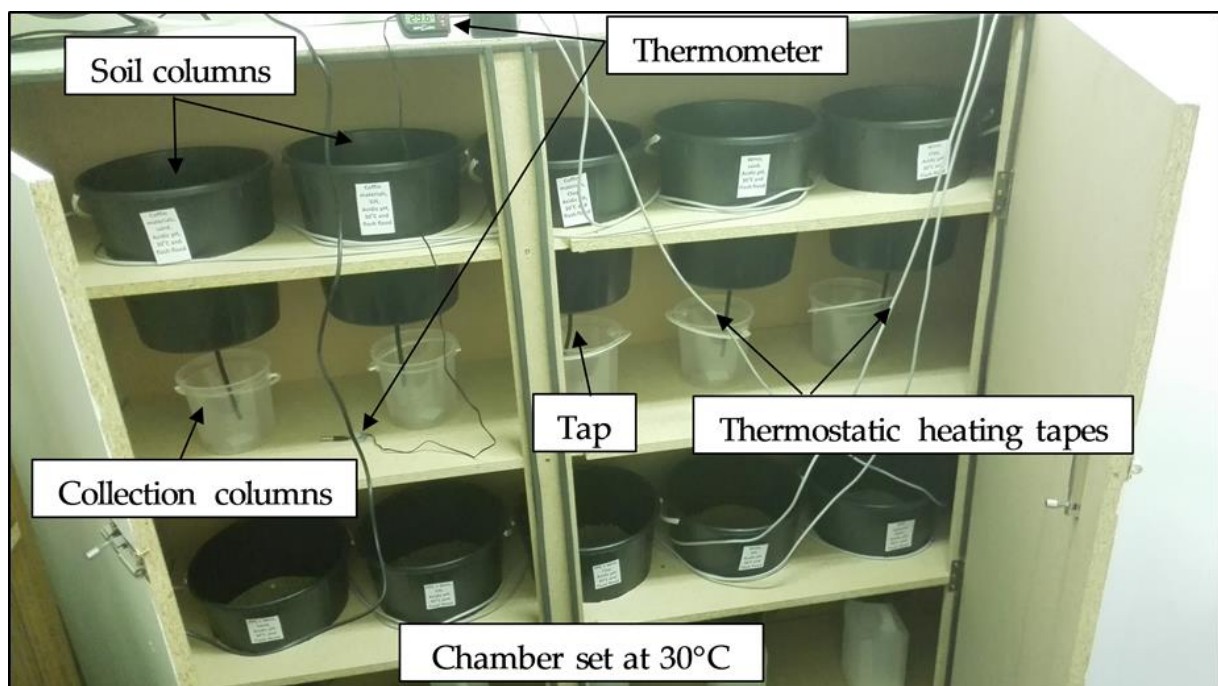
Table 3.2 summarises the simulated materials and conditions to which the samples were exposed.

Table 3.2 A summary of the controlled variables of the laboratory simulation of formaldehyde over a period of 24 weeks.

Variables	Description of each controlled variable	Number of soil columns
Soil Type		
Sand	Added and compacted into 170 mm x 190 mm soil columns	11
Silt	Added and compacted into 170 mm x 190 mm soil columns	11
Clay	Added and compacted into 170 mm x 190 mm soil columns	11
Materials		
Formaldehyde	Pure cotton cloth of 50 x 50 mm, which had been dipped in 15.6 ml formalin and 'buried' within soil columns	24
Coffin Samples	Sample of each coffin material, 'buried' into soil columns	24
Wires	One-meter-long coils of Al, Cu, Zn and Fe, 'buried' into soil columns	6

Variables	Description of each controlled variable	Number of soil columns
Cement	500g 'buried' into soil columns	3
<i>E. coli</i> Bacteria	<i>E. coli</i> bacteria with a nutrition media 'buried' within soil columns	30
'Rainfall' Intensity		
Flash Flooding	1000 ml of distilled water - once-off every second week	18
Prolonged	1000 ml of distilled water - over a period of four days, every second week	12
Temperature		
Moderate	20°C continuously	12
Warm	30°C continuously	18
'Rainfall' pH		
Acidic	pH 4 continuously	12
Slightly Acidic	pH 6 continuously	18
Control Samples	Different soil types with no formaldehyde, coffin materials or <i>E. coli</i> bacteria, which were exposed to neutral flash floods at room temperature	3

Figure 3.7 illustrates the arrangement of the soil test columns and environmental test chambers.



Figures 3.7 Setup of the laboratory experiment

3.12 Collection of leachate and chemical analysis

Following the addition of water, as indicated above, leachate was collected at the bottom of each soil column, via a tap, every two weeks. The water leachate was bottled and given a unique sample identification number. Samples of weeks 8, 16 and 24 were thereafter analysed for Al, Cu, Zn, Fe and every two weeks for formaldehyde.

Aluminium was analysed using a Hanna aluminium portable photometer. The process used in the functioning of the photometer involved the reaction between aluminium and reagents, causing a reddish tint of the sample (Hanna Instruments, n.d.). Iron was analysed by a Hanna iron low-range test kit with a checker disc, which also caused reddish discoloration of the samples when the iron reacted with the reagent. The functioning of the kit comprised the reduction to ferrous ions by means of sodium sulphite followed by the addition of Phenanthroline, which complexed with ferrous ions to form an orange coloured solution. This was proportional to iron's concentration (Hanna Instruments, n.d.).

A Hanna handheld colorimeter was used to determine the concentration of copper in a solution. This involved the reaction of copper with a bicinchoninate reagent, which caused a purple tint in the solutions (Hanna Instruments, n.d.).

The amount of zinc in the leachate was measured by means of a Hanna zinc test kit, with a checker disc. The method used in this kit involved the reaction of zinc with the zincon reagent (a chromogenic substrate for N, Cu and Hg), which formed a brownish solution. Cyanide was also added to the solution, since other metals could likewise form coloured complexes in zircon. Once the zinc and other heavy metals started to complex, cyclohexane was added to selectively free zinc from its complex and form a final brown-violet solution, which was proportional to the concentration of zinc. (Hanna Instruments, n.d.).

The concentration of formaldehyde in each sample was determined by means of a Hanna formaldehyde test kit. This test involved a simple acid titration procedure by which means the formaldehyde reacted with sodium sulphite (Na_2SO_3) to form an alkaline solution, which was then titrated with HCl to form a yellow solution (Hanna Instruments, n.d.). The amount of HCl titrated was proportional to the concentration of formaldehyde in the solution.

After analysis, the results were tabulated and the concentrations divided into equal pentade values, which were indicative of the relative concentration of Al, Cu, Zn, Fe and formaldehyde for a given sample. Excel (Microsoft 2010) was used for calculations and drafting figures.

3.13 Corrosion and metal loss of wire samples

After interment, the wires were removed and cleaned in accordance with ISO 8407 (International Organization for Standardization, 2009), to remove the corrosion products formed. The corroded products were removed as follows:

- a) the aluminium wires were cleaned by means of immersion in phosphoric acid (H_2SO_4) at 90°C for 5 to 10 minutes;
- b) the copper by immersion in HCl at 25°C for 3 minutes;
- c) the iron by immersion in HCl at 25°C for 15 minutes; and
- d) the zinc by immersion in ammonium acetate (CHOONH_4) at 70°C for 5 minutes.

The wires were thereafter re-weighed, and the extent of metal loss by weight was determined.

3.14 Solubility of cement

The solubility of the cement was determined by means of a Hanna hardness test kit, which determined the calcium carbonate (CaCO_3) concentration of the water leachate by titration with Ethylenediaminetetraacetic acid, EDTA (Hanna Instruments, n.d.). The results were used to determine whether concrete tombs would remain intact for long periods without decomposing.

CHAPTER 4: RESULTS AND DISCUSSION

This chapter reports the results of this study - shedding light on whether burial materials do in fact become mobile and leach into groundwater. This includes the role that environmental conditions play in the rate of leaching and whether concrete tombs may be a possible solution to the problem.

4.1 Baseline inorganic chemical compositions of the different soil types

Prior to experimental testing, the inorganic chemical baseline compositions and corrosive species (moisture content, drainage capacity, amount of sulphur and chlorides, conductivity, pH, soil type and soil colour) of the different types of soils, i.e. clay, sand and silt, were determined. The results are presented in Tables 4.1 and 4.2.

Table 4.1 Baseline inorganic chemical compositions of the different soil types.

Mineral	Sand (mg/kg)	Silt (mg/kg)	Clay (mg/kg)
Silicone (Si)	397209	366029	387532
Titanium (Ti)	1019	3597	2458
Aluminium (Al)	23928	31509	30205
Iron (Fe)	8809	49729	17385
Manganese (Mn)	266	1027	386
Magnesium (Mg)	2471	1350	3421
Calcium (Ca)	18129	1339	7881
Sodium (Na)	3962	148	1952
Potassium (K)	14546	7774	9668
Phosphorus (P)	305	532	283
Chromium (Cr)	44	278	73
Nickel (Ni)	17	55	28
Vanadium (V)	29	30	53
Zirconium (Zr)	74	370	222
Copper (Cu)	8	8	8
Arsenic (As)	0	0	0
Molybdenum (Mo)	5	24	13

Mineral	Sand (mg/kg)	Silt (mg/kg)	Clay (mg/kg)
Niobium (Nb)	4	10	7
Lead (Pb)	0	0	0
Rubicon (Rb)	1	6	6
Strontium (Sr)	13	52	24
Thorium (Th)	0	4	0
Uranium (U)	57	47	51
Tungsten (W)	112	38	75
Yttrium (Y)	0	0	0
Zink (Zn)	0	0	0
Zircon (Zr)	238	139	183

Table 4.1 indicates that the main inorganic constituents of the collected soil samples included, silicon, aluminium, iron, magnesium, calcium, sodium, potassium and titanium. Table 4.2 shows that, purely from an inorganic chemistry perspective, the clay sample appeared somewhat more corrosive than the sand and silt samples, due to the higher levels of sulphates and conductivity. Even though silt had higher levels of phosphorous (Table 4.1), which is also a primary corrosive species, sulphates are generally considered more corrosive than phosphorous (Corrosion Institute of Southern Africa, 2004).

Table 4.2 Corrosive species of the different soil types.

Soil Type	% Moisture	Drainage Capability/ Infiltration	Soil Colour (visual)	pH	Conductivity ($\mu\text{S}/\text{cm}$)	Chlorides (ppm)	Sulphates (ppm)
Sand	15	Mostly Dry	Brown	8.0	980	<25	50
Silt	19	Often Wet	Red	7.4	1040	<25	40
Clay	55	Often Wet	Dark Grey	8.3	1090	<25	250

4.2 Chemical composition of burial samples

Scanning Electron Microscopy with X-ray microanalysis of plastic coffin handles, varnish and metal screws were carried out. (Refer to Annexure 1 for the detailed chemical compositions of each coffin material.) The results indicated that the coffin handles contained traces of aluminium, silicon, chlorine, calcium, chromium and titanium. The rest of the composition was mostly made up of organic materials. The varnish contained traces of silicon and sulphur, while the metal screws were found to be mainly ferrous-based, with the surfaces being protected with a chromium-zinc metallic coating.

The collected embalming fluid, formalin, consisted of a 4% formaldehyde solution.

4.3 Leaching of metals contained in burial materials

4.3.1 Leaching trends of aluminium (Al)

Table 4.3 provides the results of detailed analyses for aluminium corrosion in the three types of soils.

Table 4.3 Aluminium ($\mu\text{g/L}$) concentrations of tested water samples over a period of 24 weeks

Sample Identification	Concentrations every eight weeks ($\mu\text{g/L}$)			Sum (Σ)
	Week 8	Week 16	Week 24	
A coffin sand slightly acidic 20 prolong	370	560	100	1030
B coffin sand slightly acidic 30 prolong	450	730	210	1390
C coffin sand acidic 20 prolong	250	630	450	1330
D coffin sand acidic 30 prolong	500	1580	680	2760
E coffin sand slightly acidic 20 flash	50	100	300	450
F coffin sand slightly acidic 30 flash	90	200	420	710
G coffin sand acidic 20 flash	20	180	100	300
H coffin sand acidic 30 flash	10	100	500	610
I sand control	0	0	0	0
Total Sand (Σ)	1740	4080	2760	8580
J coffin silt slightly acidic 20 prolong	0	50	320	370
K coffin silt slightly acidic 30 prolong	20	380	1700	2100
L coffin silt acidic 20 prolong	100	370	950	1420

Sample Identification	Concentrations every eight weeks (µg/L)			Sum (Σ)
	Week 8	Week 16	Week 24	
M coffin silt acidic 30 prolong	100	280	2400	2780
N coffin silt slightly acidic 20 flash	40	50	500	590
O coffin silt slightly acidic 30 flash	200	10	600	810
P coffin silt acidic 20 flash	100	50	320	470
Q coffin silt acidic 30 flash	100	50	480	630
R silt control	10	0	0	10
Total Silt (Σ)	670	1240	7270	9180
S coffin clay slightly acidic 20 prolong	50	500	430	980
T coffin clay slightly acidic 30 prolong	20	450	670	1140
U coffin clay acidic 20 prolong	20	90	400	510
V coffin clay acidic 30 prolong	10	560	2650	3220
W coffin clay slightly acidic 20 flash	10	50	400	460
X coffin clay slightly acidic 30 flash	20	100	700	820
Y coffin clay acidic 20 flash	10	200	560	770
Z coffin clay acidic 30 flash	30	800	1500	2330
ZA clay control	20	0	0	20
Total Clay (Σ)	190	2750	7310	10250
I PPC + Al wire sand acidic 30 flash	20	100	60	180
II PPC + Al wire silt acidic 30 flash	40	70	90	200
IV PPC + Al wire clay acidic 30 flash	10	60	80	150
V Al wire sand acidic 30 flash	30	100	300	430
VI Al wire silt acidic 30 flash	10	200	670	880
VII Al wire clay acidic 30 flash	40	30	530	600

Legend (µg/L)	0 to 530	531 to 1060	1061 to 1590	1591 to 2120	2121 to 2650
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The corrosion rate of aluminium in clay (10 250 µg) was higher than in silt (9180 µg) and sand (8 580 µg), and consequently, flushed out more aluminium in total after six months. The results in Table 4.3 and Figure 4.1 indicate that sand flushed out more aluminium than silt and clay within the first 16 weeks of testing, where after a significant reduction in Al leaching was recorded for sand, in comparison with that of silt and clay. This was indicative of the percolation effect of sand, allowing aluminium to freely move through the sand, whereas in the case of clay and silt, the aluminium tended to remain trapped in the soil for longer periods, prior to being released at a more even rate.

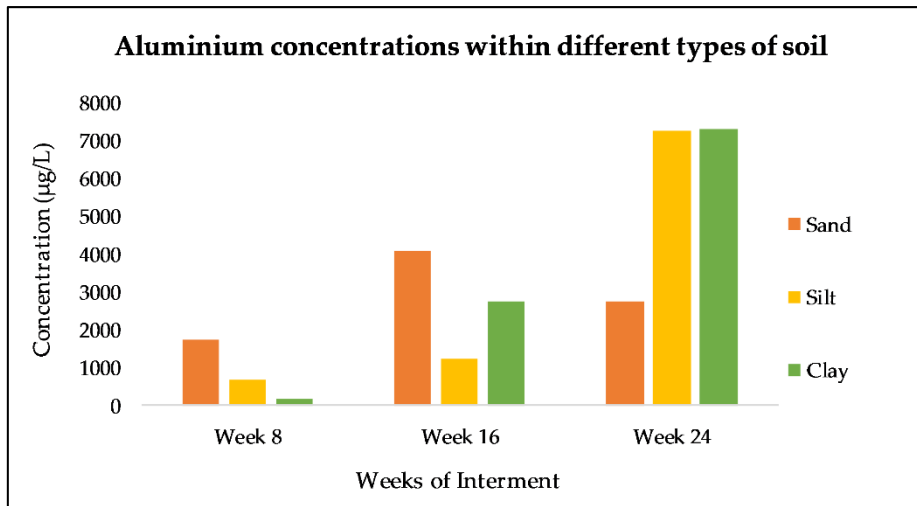


Figure 4.1 Total aluminium concentrations leached out over the 24-week period.

It was observed that most of the sand samples, in particular, those exposed to higher temperatures, were dry before the start of each new watering cycle. This increased the drainage and percolation effects of sand and explained why silt and clay flushed out more aluminium than sandy soils at high temperatures. Evidently, the clay and silt exhibited increased periods of wetness due to their higher water storage capacity, especially during prolonged rainfalls. This result was directly related to the particle size distribution of these soils, which in turn impacted on their corrosivity.

Figure 4.2 (a) indicates that higher temperatures enhanced corrosion. More than twice the amount of Al was leached out through the clay and silt samples at a temperature of 30°C than at 20 °C. The amount of Al leachate through sand was also significantly higher at high temperatures than at the lower temperature. The Student's t-test illustrated and confirmed that the effect of temperature on the leaching rate of aluminium was significant with a p-value of 0.008 where $p > 0.05$.

Further scrutiny of the effects of rainfall in Figure 4.2 (b) showed that the sand, silt and clay samples flushed out more aluminium during prolonged rainfall periods than flash floods. This was due to the increased periods of wetness, which are known to have the most significant impact on the corrosion of metals (Corrosion Institute of

Southern Africa, 2004). According to Roberge (2012), saturated water flow is governed by the pore size and particles size distribution, consistency, structure and organic material in the soil. Ultimately, the longer metallic surfaces remain wet, the faster they will corrode, resulting in their rapid oxidisation and leaching into the ground. According to the t-test with a p-value of 0.012, where $p < 0.05$, the effect of rainfall intensity on the leaching rate of aluminium was significant.

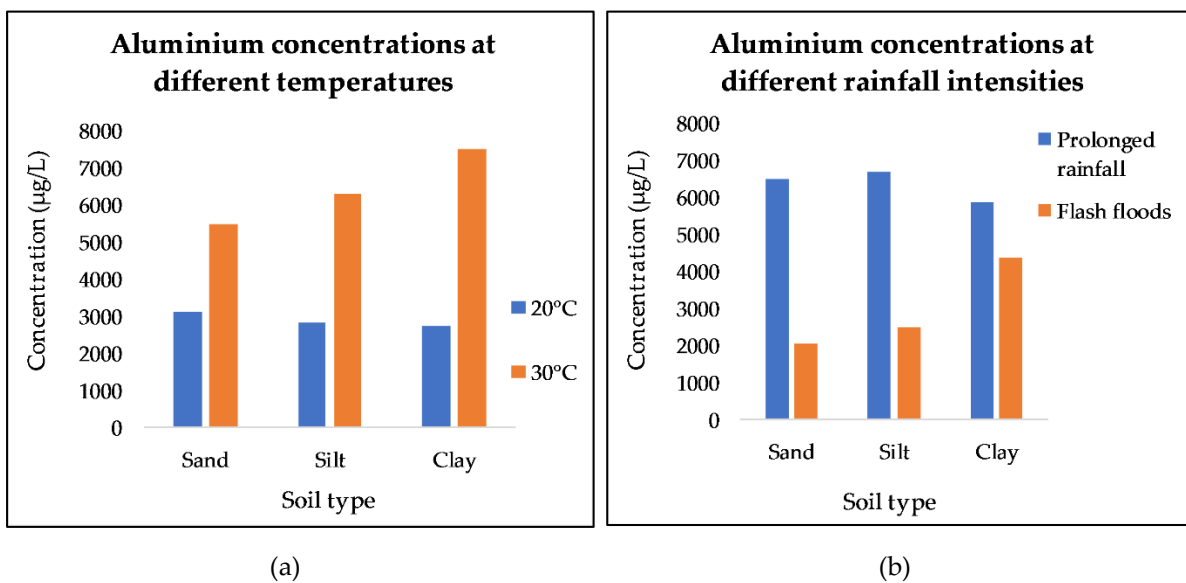


Figure 4.2 (a) Total amount of aluminium leached at different temperatures (b) Total amount of aluminium leached at different rainfall intensities.

The acidity of rainfall also played an important role in the corrosion rate of aluminium (Figure 4.3(a)). In this regard, it is important to bear in mind that the corrosion of aluminium mainly depends on the formation of tenacious protective oxide films, which are said to be stable in water-containing media in the pH range of 4.0 to 8.5 (Roberge, 2012). It is not surprising that more Al was leached from the soils under acidic conditions. However, the t-test showed that the pH was not a significant factor in the leaching of Al in sand and silt (p-value of 0.135 at $p > 0.05$).

Figure 4.3 shows that clay and sand flushed out large amounts of aluminium during rainfall periods with acidic pH. Though it was considered that the effect could be

masked by the water storage capacities of the different soil types, individual t-tests of each soil type's acidity results confirmed that the result was indeed insignificant.

Overall prolonged rainfall periods with an acidic pH at 30°C allowed for optimal conditions for the corrosion of aluminium. This applied to all three types of soils (Table 4.3, rows D, M and V). This conclusion is justified, considering that aluminium exhibits amphoteric behaviour (Corrosion Institute of Southern Africa, 2004), meaning that it is affected by low and high pH, as well as that the corrosion rate of aluminium is potentially speeded-up two-fold with every 10°C rise in temperature (Corrosion Institute of Southern Africa, 2004).

Conversely, where cement was added to the soil, which is known to exhibit a pH of about 12.6 (Corrosion Institute of Southern Africa, 2004), the acidity pH of the rain was neutralised to some extent, resulting in significant reductions in the corrosion rate of aluminium in all three soil types as shown in Figure 4.3 (b). The t-test confirmed this significance with a p-value of 0.025 ($p < 0.05$)

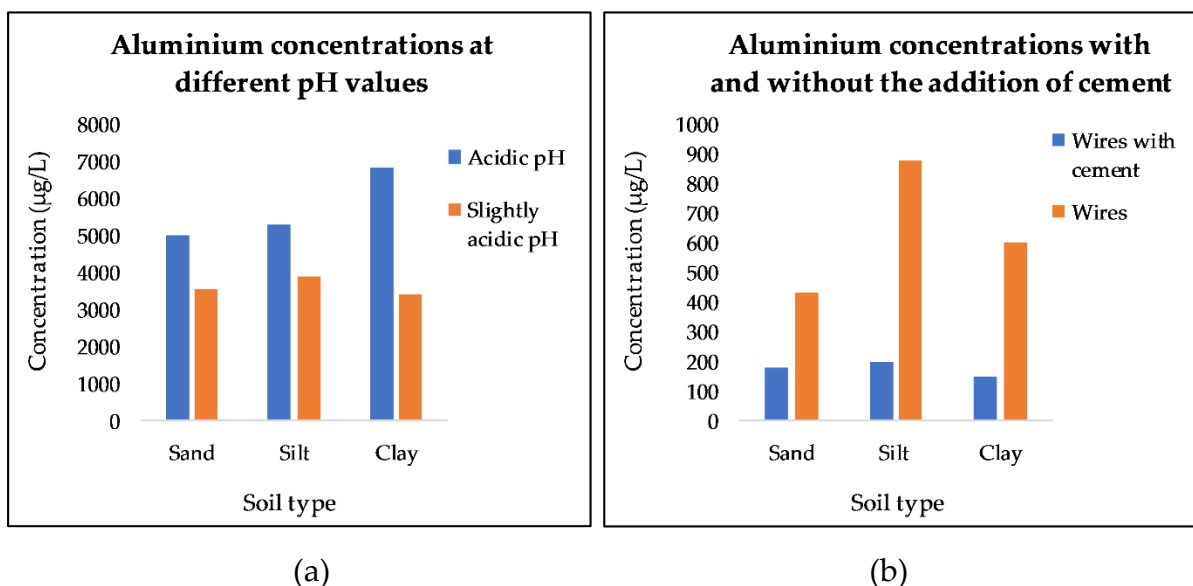


Figure 4.3 (a) Total amount of aluminium leached at pH values (b) Aluminium concentrations leached with and without the addition of cement.

4.3.2 Leaching trends of iron (Fe)

Table 4.4 provides the results of analyses for iron corrosion in the three types of soils.

Table 4.4 Iron ($\mu\text{g/L}$) concentrations of tested water samples over a period of 24 weeks.

Sample Identification	Concentrations every eight weeks ($\mu\text{g/L}$)			Sum (Σ)
	Week 8	Week 16	Week 24	
A coffin sand slightly acidic 20 prolong	200	0	100	300
B coffin sand slightly acidic 30 prolong	100	400	500	1000
C coffin sand acidic 20 prolong	30	500	450	980
D coffin sand acidic 30 prolong	0	100	650	750
E coffin sand slightly acidic 20 flash	50	50	100	200
F coffin sand slightly acidic 30 flash	50	300	400	750
G coffin sand acidic 20 flash	100	100	200	400
H coffin sand acidic 30 flash	850	800	950	2600
I sand control	400	350	0	750
Total Sand (Σ)	1780	2600	3350	7730
J coffin silt slightly acidic 20 prolong	150	500	650	1300
K coffin silt slightly acidic 30 prolong	100	200	750	1050
L coffin silt acidic 20 prolong	100	100	50	250
M coffin silt acidic 30 prolong	50	100	50	200
N coffin silt slightly acidic 20 flash	50	200	50	300
O coffin silt slightly acidic 30 flash	50	100	1500	1650
P coffin silt acidic 20 flash	0	150	50	200
Q coffin silt acidic 30 flash	750	700	1400	2850
R silt control	300	300	0	600
Total Silt (Σ)	1550	2350	4500	8400
S coffin clay slightly acidic 20 prolong	50	100	650	800
T coffin clay slightly acidic 30 prolong	20	100	800	920
U coffin clay acidic 20 prolong	50	100	450	600
V coffin clay acidic 30 prolong	400	50	2450	2900
W coffin clay slightly acidic 20 flash	50	500	300	850
X coffin clay slightly acidic 30 flash	100	100	600	800
Y coffin clay acidic 20 flash	50	200	300	550
Z coffin clay acidic 30 flash	100	200	50	350
ZA clay control	0	200	0	200
Total Clay (Σ)	820	1550	5600	7970
I PPC + Fe wire sand acidic 30 flash	1000	500	100	1600
II PPC + Fe wire silt acidic 30 flash	50	150	400	600
IV PPC + Fe wire clay acidic 30 flash	10	200	300	510
V Fe wire sand acidic 30 flash	950	1500	200	2650
VI Fe wire silt acidic 30 flash	50	500	1250	1800
VII Fe wire clay acidic 30 flash	150	500	800	1450

Legend ($\mu\text{g/L}$)	0 to 490	491 to 980	981 to 1470	1471 to 1960	1961 to 2450
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Similar to the aluminium results, sand flushed out more iron than silt and clay as shown in Figure 4.4 until week 16. This was due to the increased water drainage capacity and resulting percolating effect of sand. Contrary, silt and clay only showed a marked increase in the leaching of iron at week 24, which could be attributed to these soils types' increased water holding capacities and water residence times.

At week 24, the average iron concentrations of the clay and silt leachates exceeded that of sand (Figure 4.4). This was owing to the increased corrosion rate of iron in these soil types. The Corrosion Institute of Southern Africa (2004) states that the corrosivity of soils towards buried materials may be rated as follows:

Peats/clays > Clays > Loams > Sandy soil types.

Notable was the fact that Sample V in Table 4.3, a clay sample exposed to acidic, elevated temperature and prolonged wetting conditions, leached out a significantly large amount of iron during week 24 - potentially indicating to the optimal conditions for the corrosion of iron. Nonetheless, the total concentrations of iron of each soil type after six months revealed that silt (8 400 µg) flushed out more iron than sand (7 730 µg) and clay (7 970 µg) (Table 4.3).

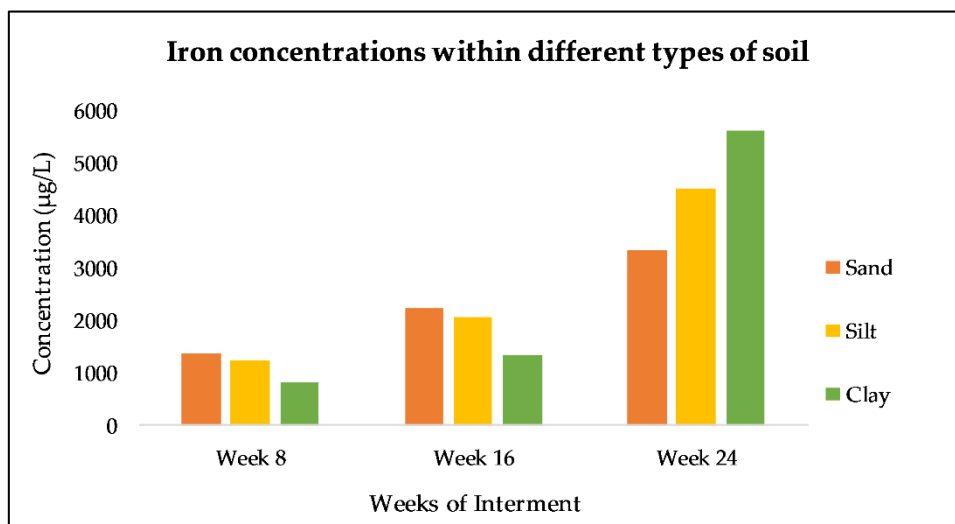


Figure 4.4 Total iron concentrations leached out over the 24-week period.

Although, Figure 4.5 (a) illustrates that flash floods allowed for oxidation to occur in sand and silt, whereas prolonged rainfalls in clay led to long-term residence of moisture, resulting in even higher concentrations of iron ultimately filtering out of the system. A p-value of 0.912 at $p > 0.05$ showed that the effect of rainfall on the leaching rate of iron was insignificant. However, by further analysis, it became apparent that the different soil types masked the effect of rainfall intensity in sandy soils. When calculating the p-value for each soil type, sand had a p-value of 0.031, which shows the effect of rainfall on sand was significant. The opposite was true for silt and clay.

Clay and sand flushed out more iron at acidic rainfalls in Figure 4.5 (b). Controversially, silt with a slightly acidic pH leached out more iron than silt with increased acidity. This was a plausible result, particularly when considering that iron and steel tend to develop corrosion products that are insoluble in the pH range of 4 to 14 (Integrated Publishing, 2017) (Corrosion Institute of Southern Africa, 2004) even though, the t-test calculated that the effect of pH on the leaching rate of iron was insignificant at $p = 0.504$ ($p > 0.05$). Figure 4.6 illustrates the effect of pH on the corrosion rate of iron as given by Integrated Publishing (2017).

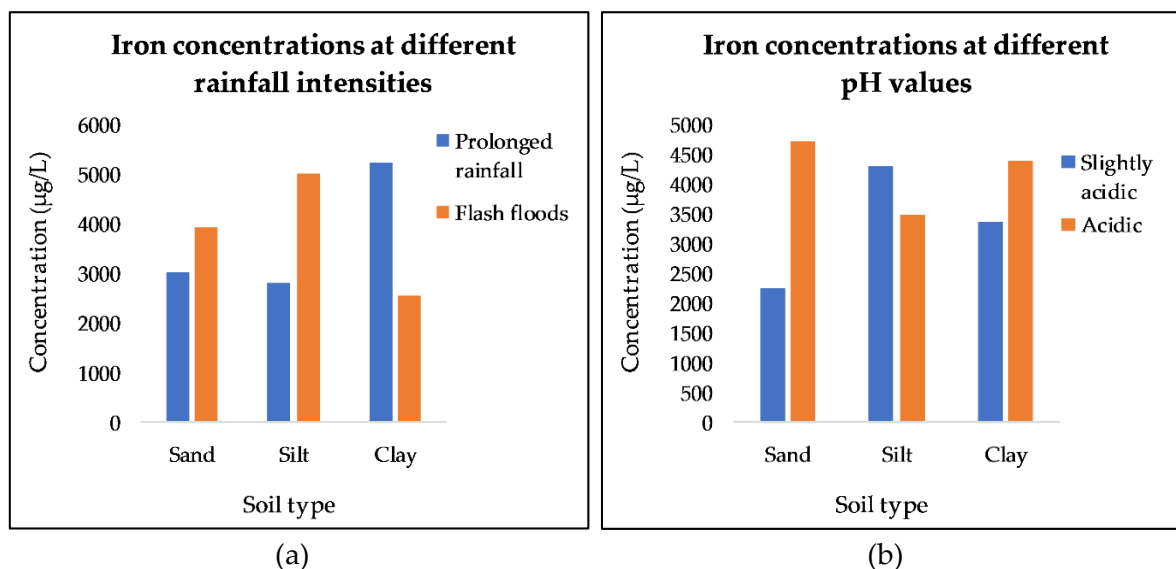


Figure 4.5 (a) Total iron concentrations leached at different rainfall intensities (b) Total amount of iron leached at pH values.

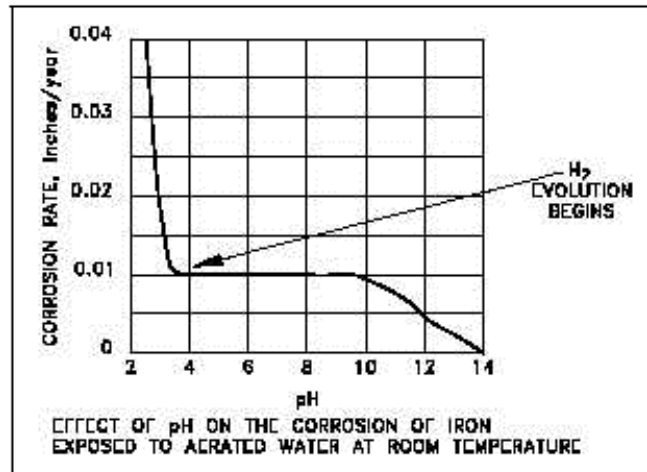


Figure 4.6 Effect of pH on the corrosion rate of iron.

Increased temperature significantly affected the corrosion rate of iron, leading to increased leaching rates at 30°C as shown in Figure 4.7 (a). The Student's t-test confirmed this statement with a calculated p-value of 0.016, which is significant at $p > 0.05$.

In total, increased soil temperatures and acidity during heavy rainfall (flash floods) accelerated the corrosion of iron, i.e. by nearly two-fold as shown in Table 4.4 and Figure 4.4.

As in the case of the aluminium results, Figure 4.7 (b) illustrates that the addition of cement to the soil columns reduced the corrosion rate of iron, even though the t-test at $p = 0.100$ ($p > 0.05$) calculated the result as insignificant. The reduced rate was not only due to the neutralising effect of cement, but also owing to the formation of a protective ferric oxide film, i.e. magnetite (Fe_3O_4), on the steel surfaces, which is known to form on steel when surrounded by cement containing media (Corrosion Institute of Southern Africa, 2004).

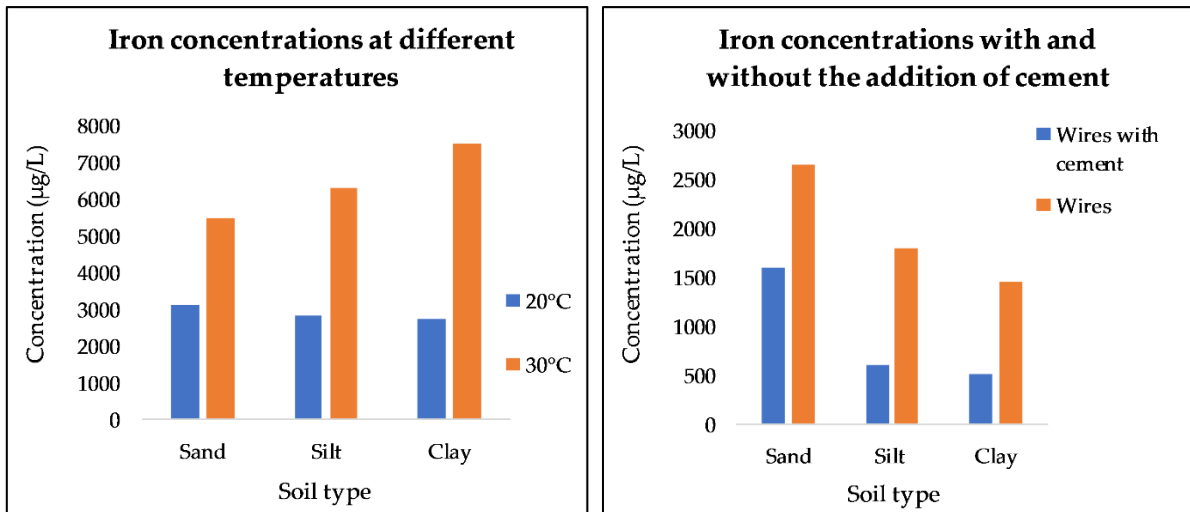


Figure 4.7 (a) Total iron concentrations leached at different temperatures (b) Iron concentrations leached with and without the addition of cement.

4.3.3 Leaching trends of zinc (Zn)

Table 4.5 provides the results of detailed analyses for zinc corrosion in the three types of soils.

Table 4.5 Zinc (µg/L) concentrations of tested water samples over a period of 24 weeks

Sample Identification	Concentrations every eight weeks (µg/L)			Sum (Σ)
	Week 8	Week 16	Week 24	
A coffin sand slightly acidic 20 prolong	1000	1000	1300	3300
B coffin sand slightly acidic 30 prolong	1500	2000	0	3500
C coffin sand acidic 20 prolong	1000	0	500	1500
D coffin sand acidic 30 prolong	1500	1500	1200	4200
E coffin sand slightly acidic 20 flash	500	1000	0	1500
F coffin sand slightly acidic 30 flash	1500	2500	1000	5000
G coffin sand acidic 20 flash	1500	300	500	2300
H coffin sand acidic 30 flash	3000	2000	500	5500
I sand control	0	0	0	0
Total Sand (Σ)	11500	10300	5000	26800
J coffin silt slightly acidic 20 prolong	1500	1500	0	3000
K coffin silt slightly acidic 30 prolong	0	1500	500	2000
L coffin silt acidic 20 prolong	500	1000	0	1500
M coffin silt acidic 30 prolong	0	1500	0	1500
N coffin silt slightly acidic 20 flash	0	500	0	500
O coffin silt slightly acidic 30 flash	0	1000	500	1500
P coffin silt acidic 20 flash	1000	500	0	1500
Q coffin silt acidic 30 flash	0	500	1000	1500
R silt control	0	0	0	0

Sample Identification	Concentrations every eight weeks (µg/L)			Sum (Σ)
	Week 8	Week 16	Week 24	
Total Silt (Σ)	3000	8000	2000	13000
S coffin clay slightly acidic 20 prolong	0	500	1000	1500
T coffin clay slightly acidic 30 prolong	500	1500	500	2500
U coffin clay acidic 20 prolong	0	0	500	500
V coffin clay acidic 30 prolong	0	3000	800	3800
W coffin clay slightly acidic 20 flash	0	500	500	1000
X coffin clay slightly acidic 30 flash	500	1800	2500	4800
Y coffin clay acidic 20 flash	0	1000	500	1500
Z coffin clay acidic 30 flash	500	1500	500	2500
ZA clay control	0	0	0	0
Total Clay (Σ)	1500	9800	6800	18100
I PPC + Zn wire sand acidic 30 flash	0	1500	0	1500
II PPC + Zn wire silt acidic 30 flash	0	500	500	1000
IV PPC + Zn wire clay acidic 30 flash	0	500	500	1000
V Zn wire sand acidic 30 flash	2500	2500	0	5000
VI Zn wire silt acidic 30 flash	500	1500	0	2000
VII Zn wire clay acidic 30 flash	0	1000	1000	2000

Legend (µg/L)	0 to 600	601 to 1200	1201 to 1800	1801 to 2400	2401 to 3000
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Notably, zinc wires corroded more readily than the aluminium and iron wires within the first six months of interment (Table 4.5). Although zinc is more corrosion resistant than other metals when exposed to the open atmosphere, without proper oxidation, zinc performs poorly in soils and have increased corrosion rates (Total Materia, 2016).

Figure 4.8 illustrates that sand was the most corrosive soil type in the zinc experiments, which continuously flushed out large amounts of zinc, resulting in higher total concentrations of zinc leachate (26 800 µg) compared to clay (18 100 µg) and silt (13 000 µg) after the test period.

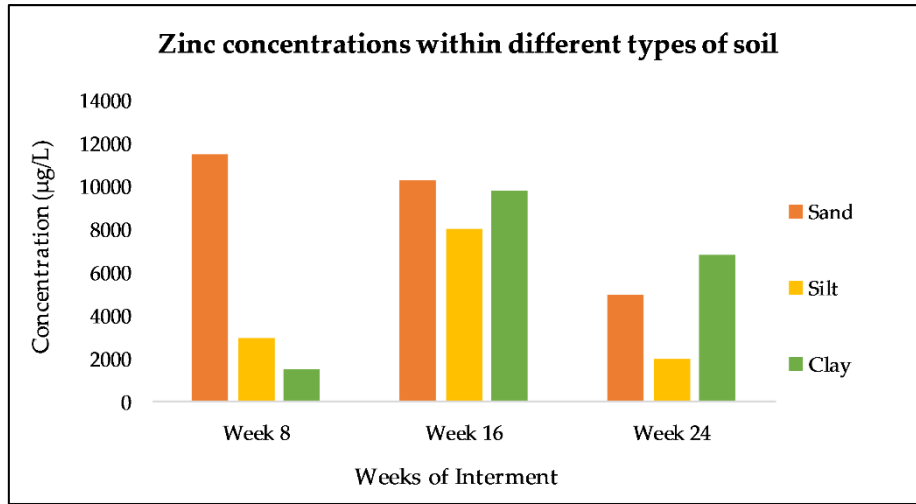


Figure 4.8 Total zinc concentrations leached out over the 24-week period.

Increased temperatures in Figure 4.9 (a) showed that temperature had a significant effect on the leaching rate of zinc, which was confirmed with a t-test p-value of 0.004 ($p < 0.05$). Rainfall, however, represented different effects than expected, with a p-value of 0.966 ($p > 0.05$), which is insignificant. Nevertheless, Figure 4.9 (b) illustrates that flash floods resulted in the accelerated corrosion of zinc in clay, whereas in sand and silt, continued rainfall (increased periods of wetness) allowed for higher corrosion rates.

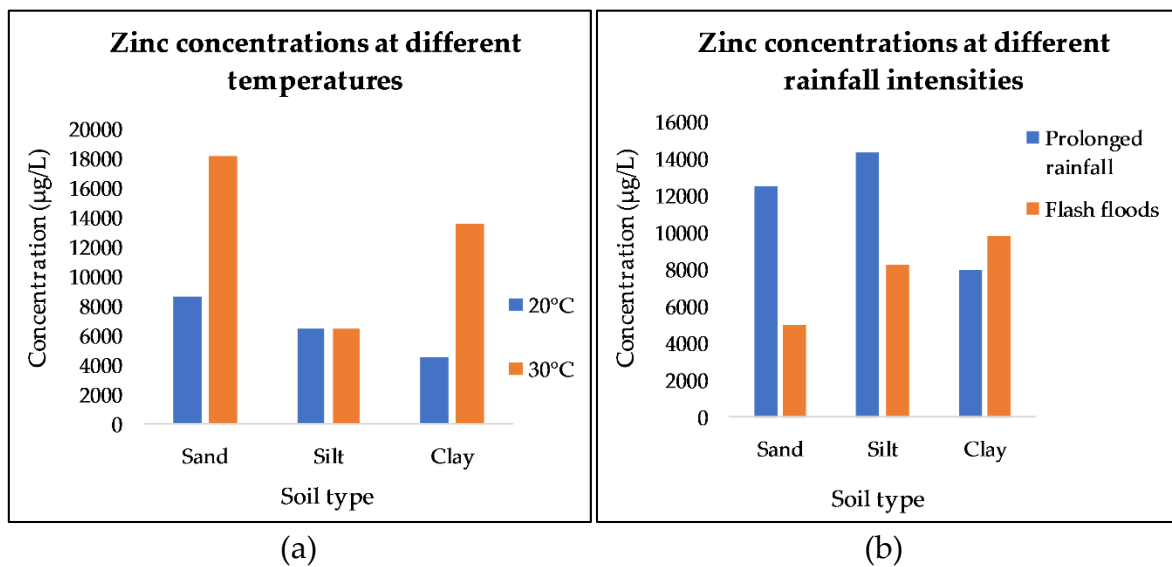


Figure 4.9 (a) Total amount of zinc leached at different temperatures (b) Total amount of zinc leached at different rainfall intensities.

Figure 4.10 (a) revealed that a less acidic pH led to higher corrosion rates of zinc, while the Student's t-test calculated that the effect of pH on the corrosion rate of zinc was insignificant at $p = 0.749$ ($p > 0.05$). However, zinc corrosion studies have shown that zinc is specifically sensitive to pH (Chapman, et al., 2013) and zinc ions are stabilised at higher pH values (Garverick, 1994). Contentiously, therefore, but similar to aluminium, the zinc wires appeared to have corroded more during the slightly acidic rainfall periods than acidic rainfall times in silt and clayey soils. This phenomenon could be explained owing to the fact that the original pH values of the different soils were 9.2, 8.3 and 8.0 for the clay, silt and sand soils respectively, which would have had a neutralising effect on the rain water. Zinc is also an amphoteric metal, i.e. producing soluble oxides at both low and high pH values (Corrosion Institute of Southern Africa, 2004), and tends to be less sensitive to pH variation between 6.0 and 12.5. These factors clarified why zinc reacted less predictable in terms of pH change.

Increased corrosion rates of zinc in all types of soil were observed at week 24. Therefore, even greater amounts could be expected to leach out of silt and clay in the long-term. Again, the t-test calculated a p-value of 0.119 ($p > 0.05$), which showed that the addition of cement had an insignificant effect on the corrosion rate of zinc. Yet, Figure 4.10 (b) shows that the burial of cement in the soil, together with zinc, reduced the corrosion rate of zinc in the different soil types, particularly in sand, which was the least corrosive soil type in the present study.

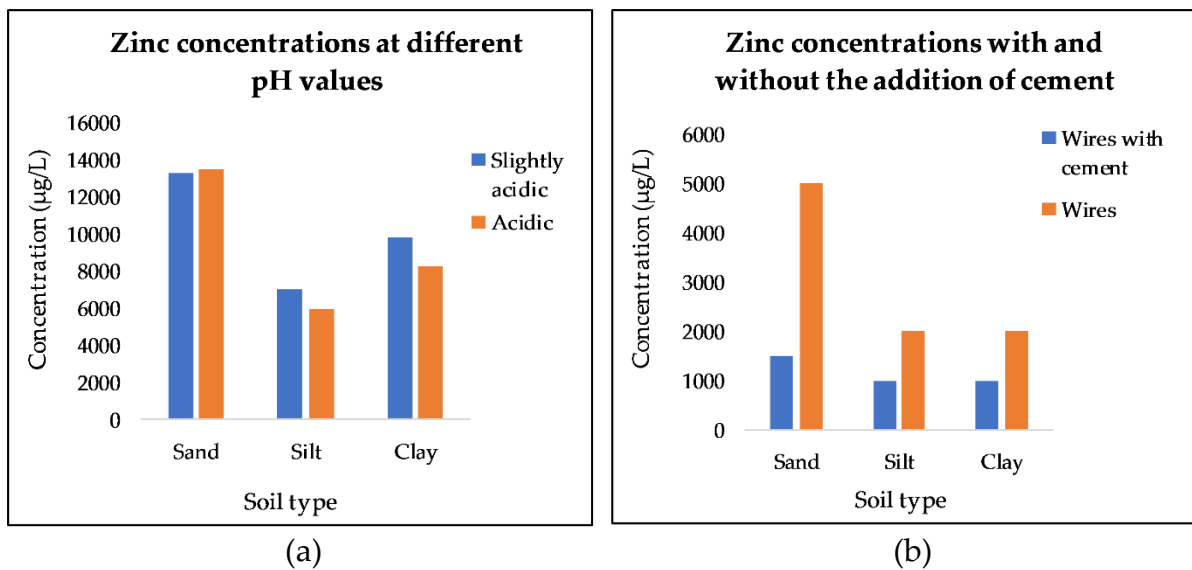


Figure 4.10 (a) Total amount of zinc leached at pH values (b) Zinc concentrations leached with and without the addition of cement.

4.3.4 Leaching Trends of Copper (Cu)

Table 4.6 provides the results of detailed analyses for copper corrosion in the three types of soils.

Table 4.6 Copper (µg/L) concentrations of tested water samples over a period of 24 weeks

Sample Identification	Concentrations every eight weeks (µg/L)			Sum (Σ)
	Week 8	Week 16	Week 24	
A coffin sand slightly acidic 20 prolong	50	18	55	123
B coffin sand slightly acidic 30 prolong	47	144	86	277
C coffin sand acidic 20 prolong	303	0	74	377
D coffin sand acidic 30 prolong	50	220	321	591
E coffin sand slightly acidic 20 flash	99	5	324	428
F coffin sand slightly acidic 30 flash	116	17	453	586
G coffin sand acidic 20 flash	275	300	264	839
H coffin sand acidic 30 flash	398	554	324	1276
I sand control	0	0	0	0
Total Sand (Σ)	1338	1258	1901	4497
J coffin silt slightly acidic 20 prolong	6	166	327	499
K coffin silt slightly acidic 30 prolong	13	80	876	969
L coffin silt acidic 20 prolong	8	19	43	70
M coffin silt acidic 30 prolong	0	0	1754	1754
N coffin silt slightly acidic 20 flash	78	80	213	371
O coffin silt slightly acidic 30 flash	41	120	235	396
P coffin silt acidic 20 flash	111	20	785	916
Q coffin silt acidic 30 flash	214	1030	756	2000

Sample Identification	Concentrations every eight weeks (µg/L)			Sum (Σ)
	Week 8	Week 16	Week 24	
R silt control	0	0	0	0
Total Silt (Σ)	471	1515	4989	6975
S coffin clay slightly acidic 20 prolong	13	18	54	85
T coffin clay slightly acidic 30 prolong	123	100	826	1049
U coffin clay acidic 20 prolong	10	117	645	772
V coffin clay acidic 30 prolong	187	150	1526	1863
W coffin clay slightly acidic 20 flash	156	100	321	577
X coffin clay slightly acidic 30 flash	15	111	754	880
Y coffin clay acidic 20 flash	84	0	670	754
Z coffin clay acidic 30 flash	15	185	111	311
ZA clay control	0	0	0	0
Total Clay (Σ)	603	781	4907	6291
I PPC + Cu wire sand acidic 30 flash	85	2	51	138
II PPC + Cu wire silt acidic 30 flash	81	12	60	153
IV PPC + Cu wire clay acidic 30 flash	51	123	112	286
V Cu wire sand acidic 30 flash	275	339	412	1026
VI Cu wire silt acidic 30 flash	280	290	760	1330
VII Cu wire clay acidic 30 flash	92	106	2750	2948

Legend (µg/L)	0 to 550	551 to 1100	1101 to 1650	1651 to 2200	2201 to 2750
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Table 4.6 shows that copper barely corroded during the first 16 weeks of interment. However, at week 24, larger amounts of copper finally started to leach out of the different soil columns. In the case of the sand columns, though, the copper concentrations were significantly lower than in the case of the clay and silt columns. This delay in leaching, compared to aluminium, iron and zinc, can be attributed to the fact that copper is generally more corrosion resistant, as well as develops an oxide film, which thickens with time, providing a more superior tightly adherent protective patina layer (Roberge, 2012).

Overall, more copper leachate in total was collected after six months of interment in silt (6 975 µg) than in the clay (6 291 µg) and sand (4 497 µg) as shown in Figure 4.11.

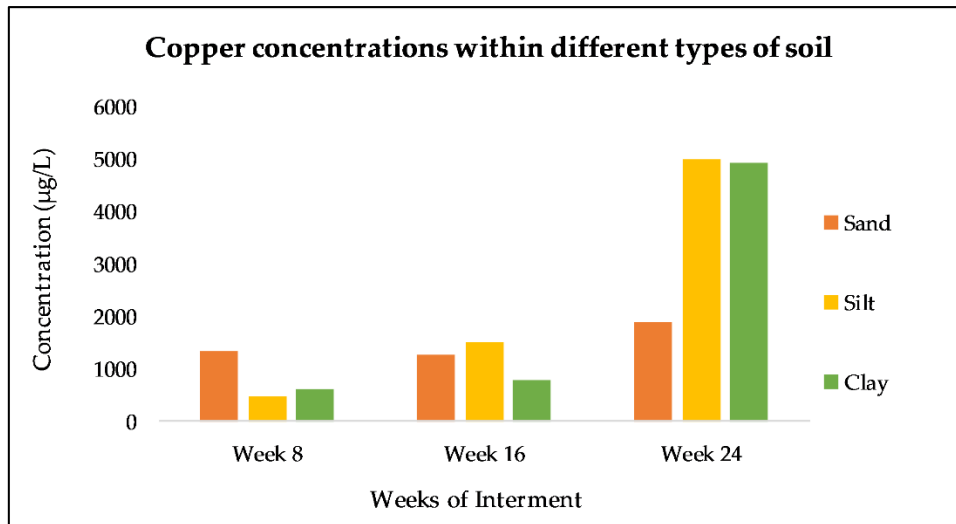


Figure 4.11 Total copper concentrations leached out over the 24-week period.

Higher temperatures also led to the increased leaching rates of copper in Figure 4.12 (a). The t-test confirmed the significance of this result with a p-value of 0.016 ($p < 0.05$).

In addition, Figure 4.12 (a) revealed that copper corrosion products were flushed out of sand and silt during the flash floods, while the flushing process was enhanced during prolonged wet conditions in clay. The t-test calculated the rainfall results as insignificant at $p = 0.739$ ($p > 0.05$). Nevertheless, since a considerable amount of copper was still leaching out of the columns in week 24, further leaching of copper was to be expected in the long-term.

Acidic pH also led to even greater amounts of copper being leached from the soil columns (Figure 4.13 (a)). This was due to the fact that copper oxides become more soluble with lowering pH values. This significance was confirmed with a t-test p-value of 0.042 ($p < 0.05$).

Figure 4.13 (b) illustrates that the addition of cement in the soil neutralised the acidic conditions, particularly in the case of the clayey columns.

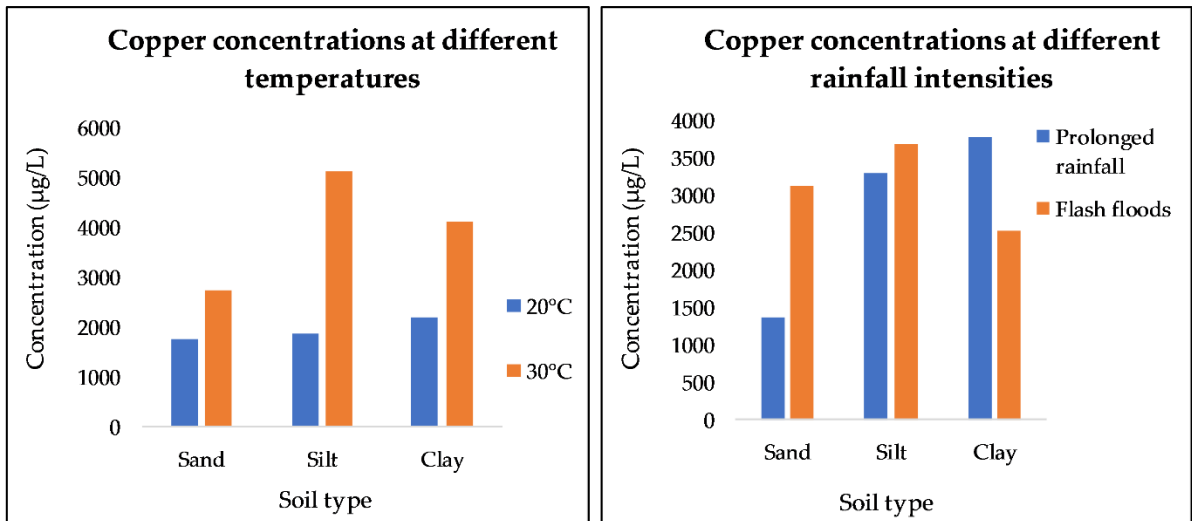


Figure 4.12 (a) Total amount of copper leached at different temperatures intensities (b) Total amount of copper leached at different rainfall intensities

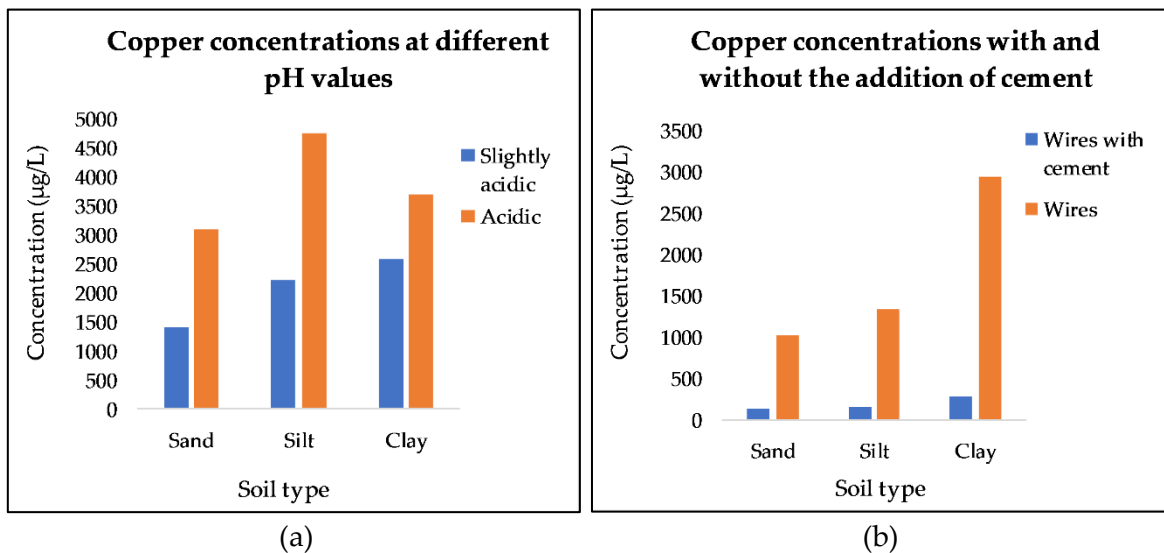


Figure 4.13 (a) Total amount of copper leached at pH values (b) Copper concentrations leached with and without the addition of cement.

4.4 Summary of Leached Concentrations of the Tested Metals

Table 4.7 summarises the effect of environmental factors on the corrosion and leaching rates of aluminium, iron, zinc and copper.

Table 4.7 Summary of the effect of environmental factors on the corrosion and leaching of the various tested metals

	20°C	30°C	Flash	Prolonged	pH 6	pH 4	Total
Sand	3110	5470	2070	6510	3580	5000	8580
Silt	2850	6320	2500	6670	3870	5300	9170
Clay	2720	7510	4380	5850	3400	6830	10230
Total Al	8680	19300	8950	19030	10850	17130	27980
Sand	1880	5100	3950	3030	2250	4730	6980
Silt	2050	5750	5000	2800	4300	3500	7800
Clay	2800	4970	2550	5220	3370	4400	7770
Total Fe	6730	15820	11500	11050	9920	16980	22550
Sand	8600	18200	14300	12500	13300	13500	26800
Silt	6500	6500	5000	8000	7000	6000	13000
Clay	4500	13600	9800	8300	9800	8300	18100
Total Zn	19600	38300	29100	28800	30100	27800	57900
Sand	1767	2730	3129	1368	1414	3083	4497
Silt	1856	5119	3683	3292	2235	4740	6975
Clay	2188	4103	2522	3769	2591	3700	6291
Total Cu	5811	11952	9334	8429	6240	11523	17763

4.5 Solubility of Cement

The hardness or concentration of calcium carbonate (CaCO_3) of the water revealed that the concentrations of the control samples, as well as of those of the other samples with added PPC cement, were similar, except in the case of sample C, which was likely caused by the leaching out of loose cement particles from the clayey soil column.

According to the results presented in Table 4.8 below, it appeared as if the solubility of cement exposed to the acidic and neutral waters was low. This finding seemed valid, even in the case of the control samples at 30 °C. In this regard, it is important to highlight that calcium carbonate becomes less soluble at higher temperatures, at which stage it tends to form scale, rather than solubility products (Corrosion Institute of Southern Africa, 2004). It also has a neutralising effect on acidic soils and rainwater. Consequently, it is reasonable to conclude that concrete tombs themselves would not leach significantly after a short period of interment.

Table 4.8 Hardness (mg/L) concentrations of tested water samples over a period of 24 weeks

Sample Identification	Concentrations every eight weeks (µg/L)		
	W 8	W 18	W 24
A PPC sand acidic 30 flash	90	123	99
B PPC silt acidic 30 flash	120	101	91
C PPC clay acidic 30 flash	189	93	107
D Sand control	114	141	132
E Silt control	90	111	112
F Clay control	84	102	97

4.6 The corrosion rates of zinc, aluminium, copper and iron

The corrosion rates of the zinc, aluminium, copper and iron wires in the different soil columns were determined by means of weight-loss measurements. According to the results obtained, the weight-loss of the metals significantly decreased with the addition of cement, implying that their corrosion rates reduced with an increase in pH. This finding is supported by the Corrosion Institute of Southern Africa (2004), stating that a decrease in pH generally accelerates the corrosivity of soils, owing to hydrogen depolarization. The metal exhibiting the highest corrosion rate was iron, followed by zinc, aluminium and copper.

According to Table 4.9, clay was found to be the most corrosive soil (followed by silt), i.e. in terms of aluminium, iron and copper. This finding appeared to be valid, apart from zinc, which apparently corroded more in silt than in clay. This occurrence could be explained by the difference in the pH values of the original soil samples, as well as the amphoteric behaviour of zinc.

Table 4.9 summarises the corrosion rates of the different metals in the different soils.

Table 4.9 Corrosion rates for copper, zinc, aluminium and iron

Sample Identification	Corrosion Rate of the Various Metals							
	Aluminium		Copper		Zinc		Iron	
	(µg)	%	(µg)	%	(µg)	%	(µg)	%
A. PPC + wire sand acidic 30 flash flood	12800	0.15	4200	0.02	149400	0.68	563600	6.07
B. PPC + wire silt acidic 30 flash flood	24600	0.28	6800	0.04	446400	2.04	563500	6.06
C. PPC + wire clay acidic 30 flash flood	23800	0.28	2000	0.01	182400	0.83	1272200	13.68
D. wire sand acidic 30 flash flood	20000	0.23	48400	0.27	189200	0.86	1227200	13.17
E. wire silt acidic 30 flash flood	25600	0.30	98400	0.55	507000	2.31	3876200	41.78
F. wire clay acidic 30 flash flood	45800	0.53	119800	0.67	226000	1.03	4029600	43.38
Total Weight loss	152600	1.77	279600	1.56	1700400	7.75	11532300	124.14

The sum (Σ) leachate of Samples I to VII in Tables 4.3 to 4.6 was converted to percentage in order to compare the actual corroded product leachates to their weight loss after interment (Table 4.10). The following formula was used to convert the aforementioned results:

$$\left(\frac{\text{Concentration of leachate}}{\text{Initial weight before interment}} \times 100 \right) = \%$$

Table 4.10 Percentages of the actual corrosion product leachates of the various tested metals

Sample Identification	Leachate of the Various Metals							
	Aluminium		Copper		Zinc		Iron	
	(µg)	%	(µg)	%	(µg)	%	(µg)	%
I PPC + wire sand acidic 30 flash	180	0.002	138	0.001	1500	0.007	1600	0.017
II. PPC + wire silt acidic 30 flash	200	0.002	153	0.001	1000	0.005	600	0.006
IV. PPC + wire clay acidic 30 flash	150	0.002	286	0.002	1000	0.005	510	0.005
V. wire sand acidic 30 flash	430	0.005	1026	0.006	5000	0.023	2650	0.028
VI. wire silt acidic 30 flash	880	0.010	1330	0.007	2000	0.009	1800	0.019
VII. wire clay acidic 30 flash	600	0.007	2948	0.016	2000	0.009	1450	0.016
Total Leachate	2440	0.028	138	0.001	12500	0.057	8610	0.093

Based on the results, the leachates of the various metals were found to be much lower than their individual weight-loss measurements. This suggested that either significant amounts of corrosion products still remained in the soil columns, or on the metal surface itself. The latter scenario is likely to be more true since excess corroded products formed on the metal surfaces were removed by means of acid cleaning procedure in order to determine the corrosion rates. If left in the ground, however, without chemical cleaning, it is likely that the wires would have resulted in greater amounts of metal being leached into the ground.

As a whole, it was concluded that coffin metals do indeed corrode, some more significantly than others, and that their corrosion products may leach out of the burial ground systems.

4.7 General trends in the leaching of formaldehyde

Comparison of the total amounts of formaldehyde leached over the 24-week period from sand, silt and clay (Table 4.11), indicated that a total of 140.2 mg/l was leached from sand, 128.7 mg/l from the silt columns and 129.1 mg/l from the clay. This finding and Figure 4.14 suggested that some of the formaldehyde particles were retained in the soil and were likely to be flushed out of silt and clay at a later stage.

It should be noted that the original soil samples were sources of formaldehyde themselves (as shown by the control samples). This was also confirmed by the World Health Organization in 2002. If this portion of the formaldehyde is excluded from each of the samples, a total of 129.0 [i.e. $140.2 - (8 \times 1.4)$], 112.7 and 119.5 mg/l formaldehyde were leached from burial materials and embalming fluid in sand, silt and clay, respectively.

Sand appeared to leach formaldehyde at a greater rate. Though, by applying the Student's t-test, it was shown that there was no significant difference in the amounts of formaldehyde leached from the different soils since the p-value was 0.32 between sand and silt. This was not significant at $p > 0.05$.

Table 4.11 and Figure 4.14 also indicate that most of the soils only started to percolate formaldehyde out of the system at week six until week 16.

Table 4.11 Formaldehyde (mg/l) concentrations of tested water samples over a period of 24 weeks

Sample Identification	Fortnightly Concentrations in mg/l												Sum
	W 2	W 4	W 6	W 8	W 10	W 12	W 14	W 16	W 18	W 20	W 22	W 24	
A coffin sand slightly acidic 20 prolong	1.5	0.5	5.0	4.0	3.0	2.0	0.5	0.2	0.1	0.1	0.1	0.1	17.1
B coffin sand slightly acidic 30 prolong	0.5	0.4	5.0	4.0	4.0	1.0	0.4	0.4	0.2	0.2	0.1	0.2	16.4
C coffin sand acidic 20 prolong	2.0	0.4	2.5	15.0	0.4	0.1	0.2	0.1	0.1	0.1	0.2	0.2	21.3
D coffin sand acidic 30 prolong	1.0	0.5	1.0	4.0	9.0	0.2	0.1	0.1	0.1	0.1	0.2	0.1	16.4
E coffin sand slightly acidic 20 flash	1.5	0.4	7.0	5.0	2.0	0.4	0.1	0.2	0.2	0.2	0.1	0.1	17.3
F coffin sand slightly acidic 30 flash	1.5	0.6	8.0	7.0	0.4	0.2	0.0	0.2	0.1	0.2	0.2	0.1	18.5
G coffin sand acidic 20 flash	1.5	0.5	10.0	2.0	0.4	0.4	0.2	0.4	0.2	0.1	0.2	0.1	16.0
H coffin sand acidic 30 flash	0.5	0.8	5.0	6.0	4.0	0.3	0.1	0.3	0.1	0.1	0.2	0.2	17.5
I sand control	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	1.4
Total Sand (Σ) excluding control	10.0	4.1	43.5	47.0	23.2	4.6	1.6	1.9	1.1	1.1	1.1	1.1	140.2
J coffin silt slightly acidic 20 prolong	1.5	0.4	5.0	2.5	4.0	1.0	3.0	0.2	0.1	0.2	0.1	0.2	18.2
K coffin silt slightly acidic 30 prolong	1.0	0.4	5.0	2.0	3.0	2.0	0.2	0.1	0.2	0.1	0.1	0.1	14.2
L coffin silt acidic 20 prolong	0.5	0.4	0.2	4.0	5.0	3.0	0.4	0.1	0.2	0.2	0.1	0.2	14.2
M coffin silt acidic 30 prolong	2.0	0.4	4.0	3.0	4.0	1.0	0.3	0.2	0.4	0.2	0.1	0.1	15.7
N coffin silt slightly acidic 20 flash	1.0	0.4	4.0	4.0	5.0	0.4	0.2	0.2	0.2	0.2	0.1	0.2	15.9
O coffin silt slightly acidic 30 flash	1.5	0.4	2.5	3.0	5.0	3.0	0.5	0.3	0.4	0.2	0.2	0.1	17.0
P coffin silt acidic 20 flash	1.0	1.0	8.0	2.0	0.4	1.0	1.0	0.4	0.1	0.1	0.1	0.1	15.2
Q coffin silt acidic 30 flash	1.5	0.4	12.0	3.0	0.4	0.2	0.1	0.1	0.2	0.1	0.2	0.2	18.4
R silt control	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	2.0
Total Silt (Σ) excluding control	10.0	3.8	40.7	23.5	26.8	11.6	5.7	1.6	1.8	1.2	0.9	1.1	128.7
S coffin clay slightly acidic 20 prolong	1.5	0.4	8.0	1.0	1.0	0.2	0.4	0.2	0.3	0.1	0.2	0.2	13.5
T coffin clay slightly acidic 30 prolong	1.5	0.4	8.0	2.0	0.5	0.4	0.2	0.1	0.5	0.1	0.2	0.1	14.0
U coffin clay acidic 20 prolong	1.0	0.4	0.2	1.0	5.0	3.0	4.0	0.5	0.2	0.1	0.1	0.2	15.7
V coffin clay acidic 30 prolong	0.5	0.6	5.0	3.0	2.0	1.0	3.0	0.8	0.1	0.2	0.1	0.2	16.5
W coffin clay slightly acidic 20 flash	1.0	0.4	1.0	14.0	0.1	0.4	0.1	0.1	0.2	0.1	0.2	0.2	17.8
X coffin clay slightly acidic 30 flash	1.0	0.5	2.0	15.0	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.1	19.6
Y coffin clay acidic 20 flash	1.0	0.6	4.0	1.0	5.0	0.5	3.0	0.2	0.2	0.1	0.2	0.1	15.9
Z coffin clay acidic 30 flash	1.0	0.4	0.5	1.0	10.0	2.0	0.2	0.4	0.2	0.2	0.2	0.2	16.3
AZ clay control	0.1	0.2	0.1	0.1	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.1	1.2
Total Clay (Σ) excluding control	8.5	3.7	28.7	38.0	23.7	7.6	11.1	2.5	1.8	1.1	1.3	1.2	129.1

Legend (mg/L)	0.0 to 3.0	3.1 to 6.0	6.1 to 9.0	9.1 to 12.0	12.1 to 15.0
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Further scrutiny of the results (Figure 4.14) revealed that sand flushed formaldehyde out faster than silt and clay. This was due to the higher drainage capacity or percolation effect of soil. By weeks 12 and 14, though, the amount of formaldehyde leached from the burial materials in the sandy soil had decreased markedly, whereas such low amounts were only noticed in week 16 in the silty and clayey soils.

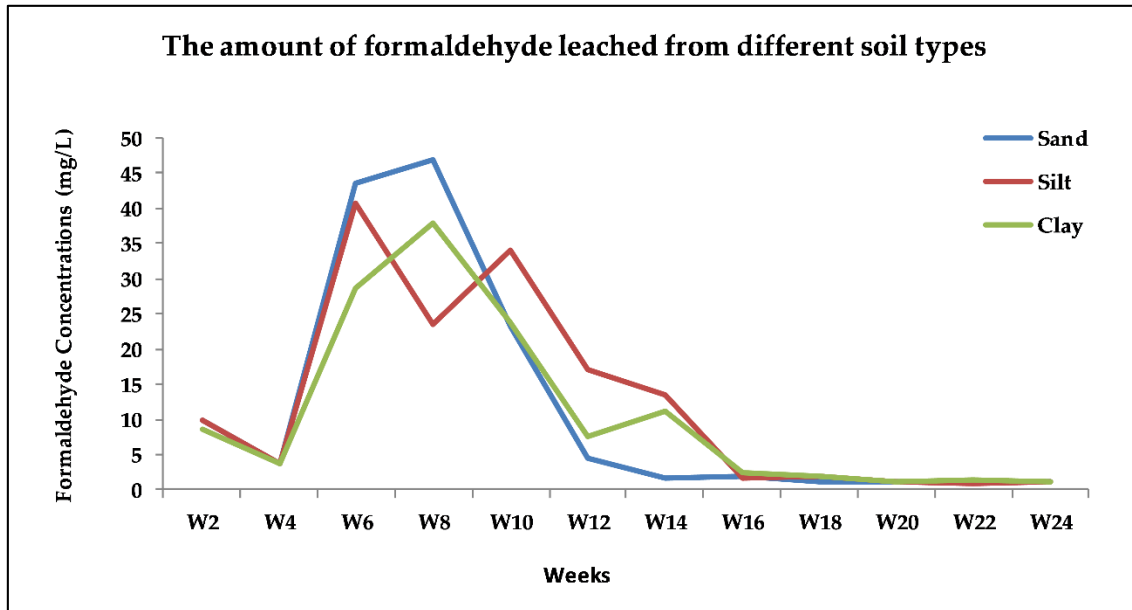


Figure 4.14 Total formaldehyde concentrations leached out over the 24-week period.

4.7.1 The effect of changing environmental conditions

The effects of the differences in the amount of formaldehyde leached from sand, silt and clay with changes in temperature, rainfall intensity and pH, are summarised in Table 4.12. These values were obtained by summing the appropriate values in Table 4.11, for example, formaldehyde leached from sand at 20 °C was $17.1 + 21.3 + 17.3 + 16.0 = 71.6$ mg/l.

Table 4.12 Total amount of formaldehyde leached from soils over a 24-week period (mg/L).

Type of Soil	Temperature (°C)		Rainfall Intensity		Rainfall pH	
	20	30	Prolonged	Flash floods	Slightly Acidic	Acid
Sand	71.6	68.7	71.1	69.2	69.2	71.1
Silt	63.4	65.3	62.3	66.4	65.2	63.5
Clay	62.8	66.3	59.6	69.5	64.8	64.3
Total	197.8	200.2	192.9	205.1	199.2	198.8
Mean (n = 12)	16.5	16.7	16.1	17.1	16.6	16.6

4.7.1.1 Temperature

Table 4.12 and Figure 4.15 clearly show that in sand, higher temperatures appear to delay formaldehyde from percolating out of the system. However, the opposite seemed to be valid for clay and silt, which showed increased amounts of formaldehyde being leached out of the system at increased temperatures. Observation of the soil columns indicated that sand seemed to be much drier than silt and clay at 30°C, which could explain this variation. (The sand simply dried out faster than silt and clay, which stayed moist for longer, allowing them to flush out greater amounts of formaldehyde at higher temperatures).

The Student's t-test indicated that there is no significant difference in the amounts of formaldehyde leached from sand at different temperatures since the p-value was found to be 0.29, which was not significant at $p > 0.05$. Since the effect of temperature difference was less in silt and clay, these could be assumed to be statistically not significant at $p > 0.05$.

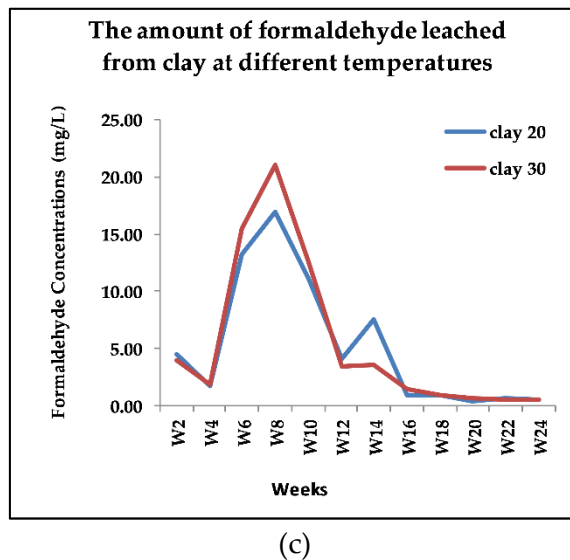
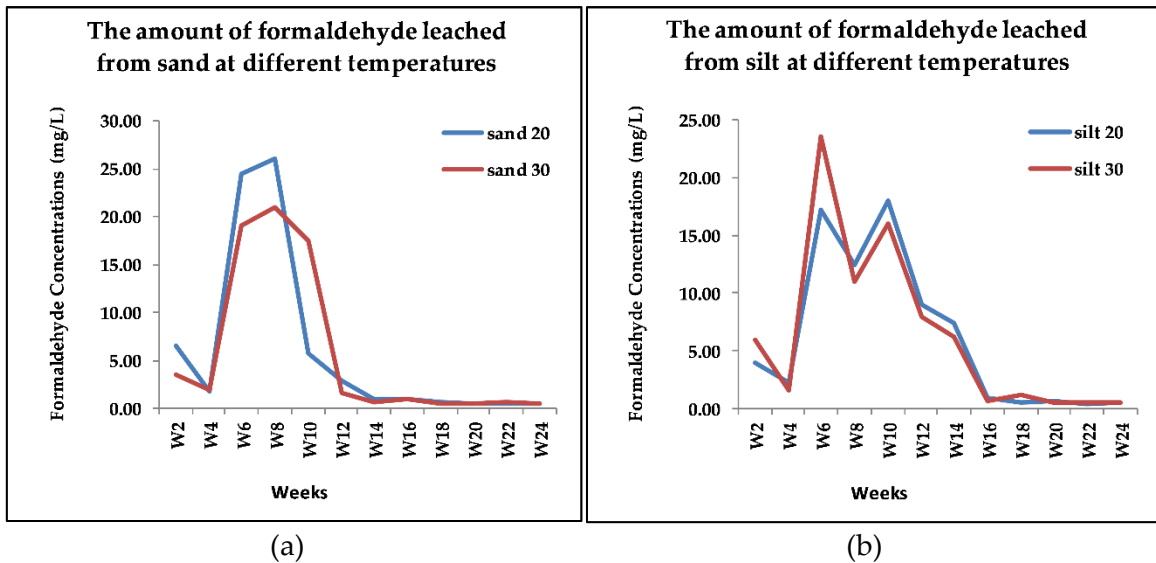


Figure 4.15 (a) The amount of formaldehyde leached from sand at different temperatures. (b) The amount of formaldehyde leached from silt at different temperatures. (c) The amount of formaldehyde leached from clay at different temperatures.

4.7.1.2 Rainfall intensity

More formaldehyde was leached from sandy soils during prolonged rainfall, whereas the opposite was true for silt and clay (Table 4.12). Comparisons of Figures 4.16 (a to c) showed that generally, prolonged rainfall periods appeared to have flushed out formaldehyde faster than flash floods in sandy soils (week 12), while silt and clayey soils only released most of the formaldehyde by week 16. However, silt and clay

showed several instances of high formaldehyde leaching during ‘flash floods’ for the first 10 weeks of testing. The Student’s t-test confirmed that there was a significant difference in the amounts of formaldehyde leached from clay at different rainfall intensities since the p-value was 0.03 ($p < 0.05$). The opposite was found to be true for sand and silt, with p-values of 0.36 and 0.20, respectively.

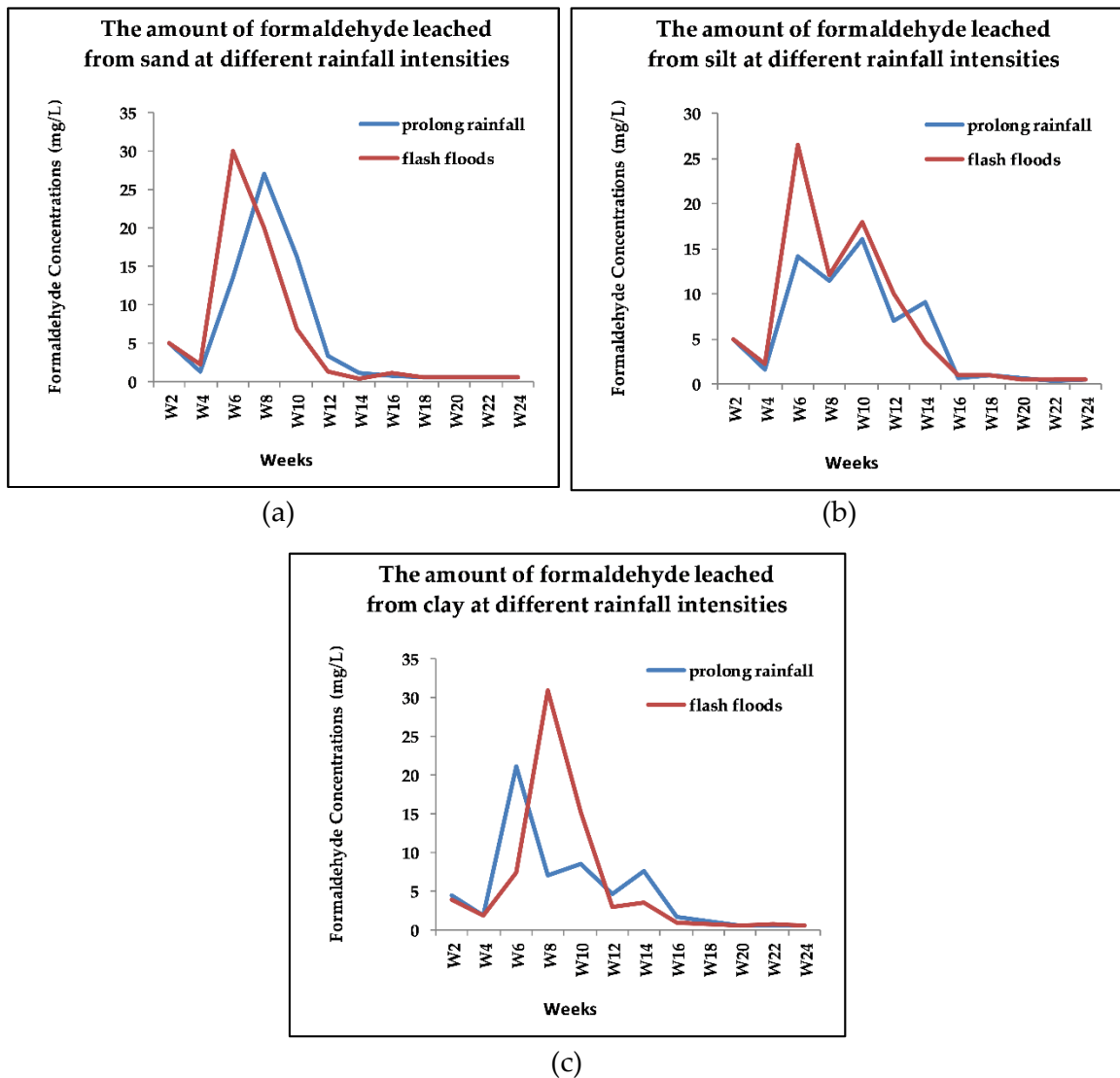


Figure 4.16 (a) The amount of formaldehyde leached from sand at different rainfall intensities. (b) The amount of formaldehyde leached from silt at different rainfall intensities. (c) The amount of formaldehyde leached from clay at different rainfall intensities.

4.7.1.3 Rainfall pH

Perusal of Table 4.12 indicates that the acidity of the water did not seem to have a significant effect on the rate of leaching. Initially, more formaldehyde was flushed out of sandy and clay soils under less acidic rainfall conditions. Thereafter, the more acidic rainwater flushed out the remaining formaldehyde. With the exception of week 6, the same pattern seemed to hold true for silty soils (Figure 4.17). Yet, application of Student's t-test revealed that there was no significant difference in the amounts of formaldehyde leached from clay with rainfalls at different pH values since the p-value was 0.47 ($p > 0.05$).

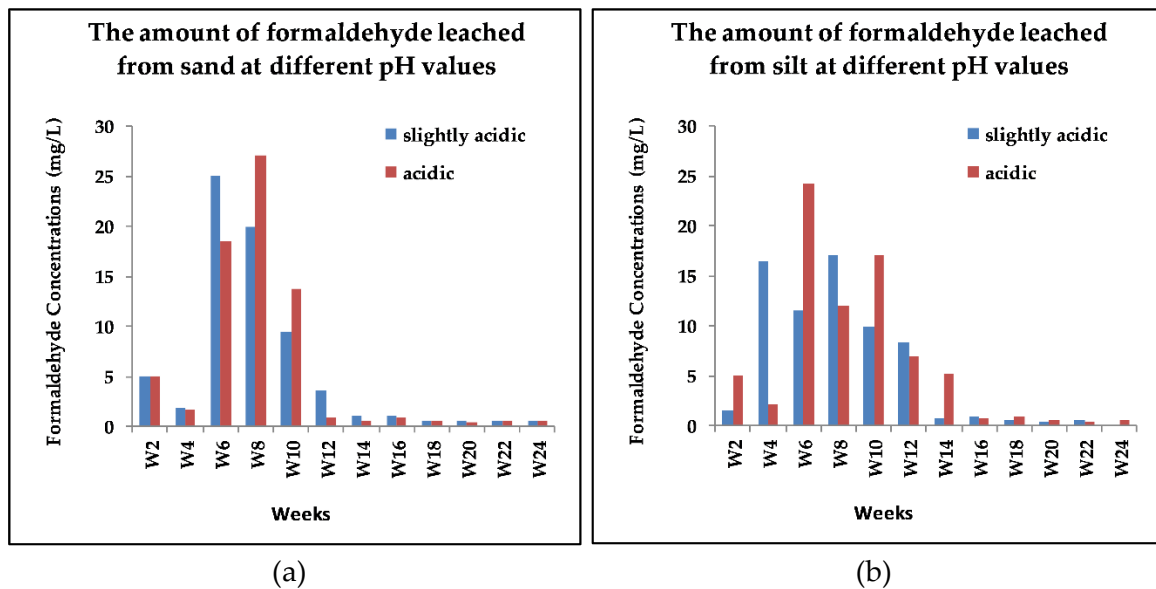
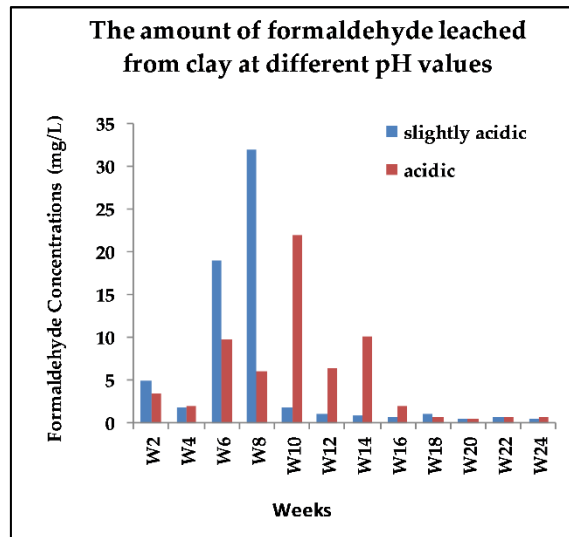


Figure 4.17 (a) The amount of formaldehyde leached from sand at different pH values. (b) The amount of formaldehyde leached from silt at different pH values.



(c)

Figure 4.17 *Cont.* (c) The amount of formaldehyde leached from clay at different pH values.

4.7.2 Total amount of formaldehyde leached from soils

Calculations showed that the 15.6 ml formalin (4% formaldehyde, with density approx. 1.0 g/ml) solution interred in the columns contained approximately 620.0 mg formaldehyde. Of this, an average 16.6 mg and a maximum of 21.3 mg leached from the samples (Table 4.11). As mentioned before, formaldehyde also arises from the oxidation of natural organic material, which explains why small concentrations of formaldehyde persisted for a long period of time in the soil samples, including in the control samples (Table 4.10).

Ostensibly, the embalming fluid does not appear to pose a risk to the environment, since only approximately 3% formalin buried in the soil percolated out over a 6-month period. Nonetheless, it is important to keep in mind that under natural conditions in a cemetery, burials take place at regular intervals - often daily. In the case of the Zandfontein Cemetery in Tshwane (Pretoria, South Africa) for example, 60 000 burials have taken place over a period of 60 years (Jonker & Olivier, 2012). This equates to almost 20 burials per week.

It is thus reasonable to assume that high concentrations of formaldehyde could leach from cemetery soils on a daily basis. Whether these concentrations make their way through water systems and into water sources/estuaries are still unknown and would depend on the environmental and other conditions. Noteworthy is the fact that the formaldehyde leachate in this experiment reached concentrations of up to 15.0 mg/L on two occasions. This is six times higher than the established tolerable concentration of 2.6 mg/L for ingested formaldehyde (WHO, 2005;WHO, 2002).

CHAPTER 5: CONCLUSIONS

5.1 Materials used in burial practices

In reviewing the different entombment materials employed by humans as they evolved, it was evident the modern funeral industry has come a long way since using arsenic and lead as part of its burial ingredients. However, current practices still include the use of known organic and inorganic health and environmental hazards, such as formaldehyde, phthalates, polypropylene, zinc, copper, etc.

Accordingly, further efforts need to be taken by all parties concerned to prevent the pollution of valuable soil and water resources in and around South Africa's existing and future cemeteries. It is not only of vital importance that South Africa's people are properly informed about greener burial options, such as cremation but also of the availability of more eco-friendlier materials that can be used for the manufacturing of coffins, without polluting the environment.

5.2 The pollution potential of coffin materials

Silt flushed out more iron and copper in total after six months of interment. Clay flushed out more aluminium after interment, while sand flushed out the greatest amount of zinc. This phenomenon could be explained by the difference in their pH values and soil corrosivity.

As expected, flash floods caused high concentrations of metals being flushed out of the system, whereas prolonged rainfall periods lead to even higher concentrations of corroded products, since the soils stay moist for longer periods at a time. Acidic pH and higher temperatures also increased the corrosion and leaching rates of the various metals. Yet, zinc seemed to have corroded more in slightly acidic rainfall periods than acidic rainfall periods when buried in silt and clay, which was controversial.

However, the original pH values of the different soils could have had a neutralising effect on the 'rainfall'. Zinc is also an amphoteric metal and tends to be less sensitive to pH variation between 6.0 and 12.5. These factors clarified why zinc reacted less predictable in terms of pH change.

Despite the amount of metals corroded, the percentage of the actual metal wires corroded indicated that more iron was corroded than zinc, copper and aluminium within six months of interment. Zinc wire had the second largest corrosion rate and although zinc is very resistant to atmospheric corrosion when it forms protective insoluble basic carbonate films, environmental conditions that interfere with the formation of carbonate films allows for rapid degradation of zinc. Although the amount of leachate from the various metals were far less than their actual weight loss after cleaning, leaving the wires in the soil without cleaning would have resulted in even higher leaching rates, which would have increased significantly after six months of interment.

Silt and clay exhibited considerably higher corrosion rates and irregular leaching rates, which could result in hazardous metal concentrations in nearby groundwater sources. Also, sand has a very low attenuation capacity, which restricts it from immobilising metals or reducing the severity of groundwater contamination.

Influences of burial conditions on the corrosion of the metals interred are summarised in Table 5.1.

Table 5.1 Parameters with **inducing** (*and limiting*) influence of corrosion of selected metals.

	Al	Cu	Zn	Fe
Soil type	clay (<i>sand</i>)	silt (<i>sand</i>)	sand (<i>silt</i>)	silt (<i>sand</i>)
pH	acidic (<i>alkaline</i>)	acidic (<i>alkaline</i>)	acidic (<i>alkaline</i>)	acidic (<i>alkaline</i>)
Temperature	high (<i>low</i>)	high (<i>low</i>)	high (<i>low</i>)	high (<i>low</i>)
Wetting	Intermittent (<i>waterlogged</i>)	Intermittent (<i>waterlogged</i>)	Intermittent (<i>waterlogged</i>)	Intermittent (<i>waterlogged</i>)
Hardness	(<i>hard water</i>)	(<i>hard water</i>)	(<i>hard water</i>)	(<i>hard water</i>)

The contamination of metals in cemeteries remains a topic of concern since it is evident that burial grounds are sources of pollution, which percolate various contaminants that become mobile under controlled laboratory conditions. Of particular concern is the high metals concentrations that were observed on several occasions. Most of these metal concentrations exceeded the limits of the South African National Standard (SANS 241) for drinking water, which could lead to serious health concerns.

5.3 Leaching trends of formaldehyde

The contamination of soil and groundwater by embalming fluids is a key element that has been overlooked in cemetery studies. In this study, the environmental conditions prevailing in South Africa were emulated in order to determine the amount and rate of leaching of formaldehyde through different types of soils.

Contrary to expectation, formaldehyde persists in soils and slowly percolates through the soil for a period of at least 14 weeks. Different environmental conditions such as soil type, high and low temperatures, rainfall and pH of rainfall do not appear to affect the amount of leachate or the mobility rate through soils, although sand allows more effective leaching.

A total of around 3% of the formalin introduced into the experimental soil columns leached from the soil over a six month period. It is not known whether the remaining 97% breaks down or whether it could leach out of the soil column at a later stage. Despite the small amount of formalin found in the leachates, concentrations exceeding the tolerable concentration of the compound, as given by the World Health Organisation, leached from all the experimental soil columns between weeks 6 to 14.

5.4 Further recommendations/ shortcomings

Considering the fact that burials take place on a weekly basis in operational cemeteries in South Africa, the accumulated amount of metals and formaldehyde reaching the groundwater may be a matter of concern. It is recommended that surface and groundwater sources in the immediate vicinity be monitored on a regular basis. It is also recommended that drinking water standards for formalin be introduced in this country.

Furthermore, the plastic and varnishes used on the coffin materials contain phthalates, which are used to make plastics more flexible and durable. When exposed to high levels of phthalates, the reproductive system may be affected. It is therefore recommended that the potential mobility and leaching rate of phthalates associated with burial practices be investigated. It is also recommended that the testing period be extended to at least one year and that more frequent testing of the water leachates be done.

In addition, advanced hydrological studies need to be done to trace the path of contaminants in groundwater.

The selection of sites for cemeteries must be done with the utmost care to ensure that flooding does not occur within the cemetery or that the groundwater table reaches the graves.

Finally, green burials seem to offer a good solution to the current problem. However, this study has also shown that cement reduced the corrosion rate of all the metals in each soil column and had a very low solubility rate. The question “**Are concrete burial vaults a possible solution?**” can thus be answered. It does indeed seem that this might be a good interim measure until more green burials can be implemented.

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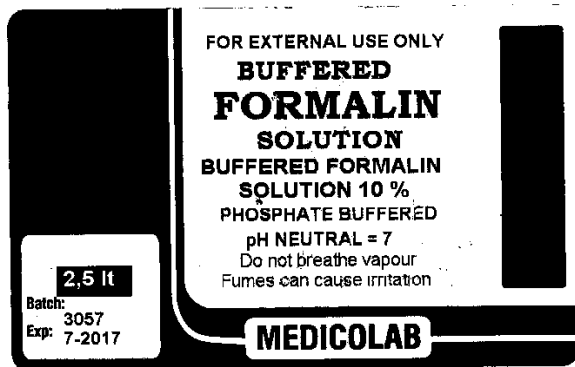
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ANNEXURE 1

a) Material Safety Data Sheets (MSDS)

Identification of the Substance/Mixture and Company

Product Name: 10% Buffered Formalin



Composition

Chemical characterization: Mixtures

Description: Mixture of the substances listed below with nonhazardous additions.

Dangerous components:

50-00-0	formaldehyde	<5%
67-56-1	methanol	<3%

Handling and Storage

Handling:

Precautions for safe handling:

Ensure good ventilation/exhaustion at the workplace.

Open and handle receptacle with care.

Prevent formation of aerosols.

Information about protection against explosions and fires: Keep respiratory protective device available.

Conditions for safe storage, including any incompatibilities

Storage:

Requirements to be met by storerooms and receptacles: No special requirements.

Information about storage in one common storage facility: Not required.

Further information about storage conditions: Keep receptacle tightly sealed.

Specific end use(s): No further relevant information available.

Accidental Release Measures

Personal precautions, protective equipment and emergency procedures: Not required.

Environmental precautions:

Dilute with plenty of water.

Do not allow to enter sewers/ surface or ground water.

Methods and material for containment and cleaning up:

Absorb with liquid-binding material (sand, diatomite, acid binders, universal binders, sawdust).

Dispose contaminated material as waste according to item 13.

Ensure adequate ventilation.



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MATERIAL SAFETY DATA SHEET

Date issued 27/08/2009

8270-203 : WOODLINE CLEAR SEALER



Flammable



Harmful



HARTEPOLLUTANT

SECTION 1. PRODUCT AND COMPANY IDENTIFICATION

Product Code	8270-203	Product Name	WOODLINE CLEAR SEALER	
CAS No.	Not applicable	EC No	Not applicable	UN No 1263
Company Name	<u>SOUTH AFRICA</u>	<u>AUSTRALIA</u>	<u>UNITED STATES OF AMERICA</u>	
Address	Chemical Specialities (Pty) Ltd 2029 Old Mill Road Canelands Verulam 4340	ChemSpec Coatings (Pty) Ltd 52-54 Chard Road Brookvale, NSW	ChemSpec USA, Inc. 9297 Smucker Road Orrville, Ohio	
Telephone	+27 32 541 8600	+61 02 9907 1425	44667	
Facsimile	+27 32 541 8704	+61 02 9907 1465	+1 330 669 8512	
Contact	Group Technical Manager techservice@chemspecpaint.com http://www.chemspecpaint.com	techservice@chemspecpaint.com	techservice@chemspecpaint.com	

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Class	PAINT or PAINT RELATED
Classification	F Xn R Phrases R11,20/22,41,43,67 S Phrases S37/39,02,13,16,24,26,43A,46,51
Comment	OEL Type : Mixture - See tables in Sections 2 and 8

	% m/m	EC Labels	CAS No.	EC No.
HAZARDOUS AND/OR OTHER RELEVANT COMPONENTS				
N-BUTANOL	<12 %	Xn	71-36-3	603-004-00-6
FORMALDEHYDE	<0,5 %	T	50-00-0	605-001-00-5
SBP SOLVENT 2	<22 %	F XN	84742-48-9	
SBP SOLVENT 2 (Benz. <0.1%)	<5 %	F XN	64742-48-9	649-327-00-6

SECTION 3. HAZARDS IDENTIFICATION

SAPMA Health Rating	2-MODERATE - Temporary or minor injury possible even if treatment given
Inhalation	Irritating, narcotic. Formaldehyde may be released during curing.
Skin	HARMFUL BY CONTACT. Potential sensitiser.
Eyes	Highly Irritating and risk of irreversible damage.
Ingestion	Harmful if swallowed.
	No carcinogenic, mutagenic or genetic effects established
	May have short term environmental effects. Contain, monitor & remove
	Skin Sensitiser

SECTION 4. FIRST AID MEASURES

Inhalation	Move to fresh air. In severe cases seek medical attention.
Skin	Use hand cleaner/soap & water. Remove contaminated clothing. If any discomfort get medical attention
Eyes	ACT FAST! Rinse immediately with plenty of water. Refer immediately to Doctor.
Ingestion	Wash mouth with plenty of water. Do NOT induce vomiting. Seek medical advice.

SECTION 5. FIRE FIGHTING MEASURES

Highly flammable with toxic fumes.
Containers liable to burst in a fire.
Foam. Dry powder. Fog to cool and control. Do NOT use water jets.

SECTION 6. ACCIDENTAL RELEASE MEASURES - SEE ALSO SECTIONS 5, 8, 13

Contain. Collect as much as possible and rinse residue to sewer/effluent with plenty of water.

SECTION 7. HANDLING AND STORAGE

Store only in designated places.
No open flames. No smoking. No sparks.
Store containers with due care in case of fire.
Subject to local bylaws

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

HAZARDOUS AND/OR OTHER RELEVANT COMPONENTS	CAS No.	OEL (mg/m ³)	OEL (ppm)	STOEL (mg/m ³)	STOEL (PPM)	OEL Type
N-BUTANOL	71-36-3	150	50	150	50	RL S
FORMALDEHYDE	50-00-0	1.5	1.0	2.5	2.0	CL
SBP SOLVENT 2	64742-48-9	2500	200			S
SBP SOLVENT 2 (Benz.<0.1%)	64742-48-9		100			RL

(CL/RL = Controlled/Recommended level 'S' = Skin annotation)

SAPMA Rating 2-H-E PPE : Respirator and Eye protection
Inhalation Ensure adequate ventilation or use respiratory protection. Ventilate curing areas/ovens properly.
Skin Avoid direct contact. Use barrier cream and impervious gloves.
Eyes Use goggles. Avoid direct contact.
Ingestion Observe the rules of hygiene. Wash before eating, drinking or smoking.
 OEL Type : Mixture - See tables in Sections 2 and 8
 Skin Sensitiser



SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance	Viscous liquid	Odour	Pungent
pH	6-8	Boiling Point	>35°C
Flash Point	<23°C (derived)	Water solubility	-

SECTION 10. STABILITY AND REACTIVITY

Stable under normal conditions
 Could generate static - USE EARTHING
 No reaction with fire-fighting water

SECTION 11. TOXICOLOGICAL INFORMATION

No carcinogenic, mutagenic or genetic effects established
 LD50 Oral: l.b.e. (derived)

SECTION 12. ECOLOGICAL INFORMATION

May have short term environmental effects. Contain, monitor & remove

SECTION 13. DISPOSAL INFORMATION

Use reputable waste disposal contractors. Exercise caution in disposal of used containers.

SECTION 14. TRANSPORT INFORMATION

UN Number	1263		
Shipping Name	PAINT or PAINT RELATED MATERIAL		
IMO Class	3.2	Packing Group	II
Action Code	127		
HazChem	3[Y]E		
Kemler Code	30		



SECTION 15. REGULATORY INFORMATION

EC no. : n/a
 F Xn R Phrases R11,20/22,41,43,67 S Phrases S37/39,02,13,16,24,26,43A,46,51
 R11 - Highly Flammable
 R20/22 - Harmful by inhalation and if swallowed
 R41 - Risk of serious damage to eyes
 R43 - May cause sensitisation by skin contact
 R67 - Vapours may cause drowsiness and dizziness.
 S37/39 - Wear suitable gloves and eye/face protection
 S2 - Keep out of reach of children. (Retail sales items)
 S13 - Keep away from food, drink and animal feeding stuffs
 S16 - Keep away from sources of ignition - No smoking
 S24 - Avoid contact with the skin
 S26 - In case of contact with eyes, rinse immediately with plenty of water and seek medical advice
 S43A - In case of fire, use water fog, foam or powder - Do not use water jets!
 S46 - If swallowed seek medical advice immediately and show this container or label
 S51 - Use only in well ventilated areas



SECTION 16. OTHER INFORMATION

**THIS SUBSTANCE IS A POTENTIAL SENSITISER - ENSURE PRECAUTIONS ARE TAKEN.
 IN CASE OF ANY DISCOMFORT ALWAYS SEEK MEDICAL ADVICE.**

This MSDS conforms with General Administrative Regulations of 8 Sept.1996 (ISO-11014/ANSIZ400.1.1996)
 OELs derived from OHS Act Regulations for Dangerous Chemical Substances of 25 Aug.1995 (EH-42)
 SAPMA Rating - South African Paint Manufacturers Association Guide to Health Hazards (SABS ARP 006:1991)
 All information is given in good faith but without guarantee in respect of accuracy.
 No responsibility is accepted for errors or omissions or the consequences thereof.

(Date of issue : 27/08/2009 Date of analysis : 27/08/2009)



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MATERIAL SAFETY DATA SHEET

Date issued 27/08/2009

8270-212 : WOODLINE CLEAR SATIN



SECTION 1. PRODUCT AND COMPANY IDENTIFICATION

Product Code	8270-212	Product Name	WOODLINE CLEAR SATIN		
CAS No.	Not applicable	EC No	Not applicable	UN No	1263
Company Name	<u>SOUTH AFRICA</u> Chemical Specialities (Pty) Ltd	<u>AUSTRALIA</u> ChemSpec Coatings (Pty) Ltd	<u>UNITED STATES OF AMERICA</u> ChemSpec USA, Inc.		
Address	2029 Old Mill Road Canelands Verulam 4340	52-54 Chard Road Brookvale, NSW	9297 Smucker Road Orrville, Ohio		
Telephone	+27 32 541 8600	+61 02 9907 1425	44667 +1 330 669 8512		
Facsimile	+27 32 541 8704	+61 02 9907 1465	+1 330 669 3965		
Contact	Group Technical Manager techservice@chemspecpaint.com http://www.chemspecpaint.com/	techservice@chemspecpaint.com	techservice@chemspecpaint.com		

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Class PAINT or PAINT RELATED
Classification F Xn R Phrases R11,20/22,41,43,67 S Phrases S37/39,02,13,16,24,26,43A,46,51
Comment OEL Type : Mixture - See tables in Sections 2 and 8

	% m/m	EC Labels	CAS No.	EC No.
HAZARDOUS AND/OR OTHER RELEVANT COMPONENTS				
N-BUTANOL	<12 %	Xn	71-36-3	603-004-00-6
FORMALDEHYDE	<0.5 %	T	50-00-0	605-001-00-5
SBP SOLVENT 2	<22 %	F XN	64742-48-9	
SBP SOLVENT 2 (Benz.<0.1%)	<5 %	F XN	64742-48-9	649-327-00-6

SECTION 3. HAZARDS IDENTIFICATION

SAPMA Health Rating 2-MODERATE - Temporary or minor injury possible even if treatment given
Inhalation Irritating, narcotic. Formaldehyde may be released during curing.
Skin HARMFUL BY CONTACT. Potential sensitiser.
Eyes Highly Irritating and risk of irreversible damage.
Ingestion Harmful if swallowed.
 No carcinogenic, mutagenic or genetic effects established
 May have short term environmental effects. Contain, monitor & remove
 Skin Sensitiser

SECTION 4. FIRST AID MEASURES

Inhalation Move to fresh air. In severe cases seek medical attention.
Skin Use hand cleaner/soap & water. Remove contaminated clothing. If any discomfort get medical attention
Eyes ACT FAST! Rinse immediately with plenty of water. Refer immediately to Doctor.
Ingestion Wash mouth with plenty of water. Do NOT induce vomiting. Seek medical advice.

SECTION 5. FIRE FIGHTING MEASURES

Highly flammable with toxic fumes.
Containers liable to burst in a fire.
Foam. Dry powder. Fog to cool and control. Do NOT use water jets.

SECTION 6. ACCIDENTAL RELEASE MEASURES - SEE ALSO SECTIONS 5, 8, 13

Contain. Collect as much as possible and rinse residue to sewer/effluent with plenty of water.

SECTION 7. HANDLING AND STORAGE

Store only in designated places.
No open flames. No smoking. No sparks.
Store containers with due care in case of fire.
Subject to local bylaws

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

HAZARDOUS AND/OR OTHER RELEVANT COMPONENTS	CAS No.	OEL (mg/m ³)	OEL (ppm)	STOEL (mg/m ³)	STOEL (PPM)	OEL Type
N-BUTANOL	71-36-3	150	50	150	50	RL S
FORMALDEHYDE	50-00-0	1.5	1.0	2.5	2.0	CL
SBP SOLVENT 2	64742-48-9	2500	200			S
SBP SOLVENT 2 (Benz.<0.1%)	64742-48-9		100			RL

(CL/RL = Controlled/Recommended level 'S' = Skin annotation)

SAPMA Rating 2-H-E PPE : Respirator and Eye protection
Inhalation Ensure adequate ventilation or use respiratory protection. Ventilate curing areas/ovens properly.
Skin Avoid direct contact. Use barrier cream and impervious gloves.
Eyes Use goggles. Avoid direct contact.
Ingestion Observe the rules of hygiene. Wash before eating, drinking or smoking.
 OEL Type : Mixture - See tables in Sections 2 and 8
 Skin Sensitiser



SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance	Viscous liquid	Odour	Pungent
pH	6-8	Boiling Point	>35°C
Flash Point	<23°C (derived)	Water solubility	--

SECTION 10. STABILITY AND REACTIVITY

Stable under normal conditions
 Could generate static - USE EARTHING
 No reaction with fire-fighting water

SECTION 11. TOXICOLOGICAL INFORMATION

No carcinogenic, mutagenic or genetic effects established
 LD50 Oral: t.b.e. (derived)

SECTION 12. ECOLOGICAL INFORMATION

May have short term environmental effects. Contain, monitor & remove

SECTION 13. DISPOSAL INFORMATION

Use reputable waste disposal contractors. Exercise caution in disposal of used containers.

SECTION 14. TRANSPORT INFORMATION

UN Number	1263		
Shipping Name	PAINT or PAINT RELATED MATERIAL	Packing Group	II
IMO Class	3.2		
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 R41 - Risk of serious damage to eyes
 R43 - May cause sensitisation by skin contact
 R67 - Vapours may cause drowsiness and dizziness.
 S37/39 - Wear suitable gloves and eye/face protection
 S2 - Keep out of reach of children. (Retail sales items)
 S13 - Keep away from food, drink and animal feeding stuffs
 S16 - Keep away from sources of ignition - No smoking
 S24 - Avoid contact with the skin
 S26 - In case of contact with eyes, rinse immediately with plenty of water and seek medical advice
 S43A - In case of fire, use water fog, foam or powder - Do not use water jets!
 S46 - If swallowed seek medical advice immediately and show this container or label
 S51 - Use only in well ventilated areas



SECTION 16. OTHER INFORMATION

THIS SUBSTANCE IS A POTENTIAL SENSITISER - ENSURE PRECAUTIONS ARE TAKEN.
 IN CASE OF ANY DISCOMFORT ALWAYS SEEK MEDICAL ADVICE.

This MSDS conforms with General Administrative Regulations of 6 Sept.1996 (ISO-11014/ANSIZ400.1.1996)
 OELs derived from OHS Act Regulations for Dangerous Chemical Substances of 25 Aug.1995 (EH-42)
 SAPMA Rating - South African Paint Manufacturers Association Guide to Health Hazards (SABS ARP 006:1991)
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(Date of issue : 27/08/2009 Date of analysis : 27/08/2009)

SASOL
reaching new frontiers



Material Safety Data Sheet

Polypropylene

Version 1.00

Revision Date 12.04.2007

1. Identification of the substance/preparation and of the company/undertaking

Trade name	Polypropylene
Synonyms	Polypropylene, Propylene Polymer, Propene Polymer
Company	Sasol Polymers 56 Grosvenor Road Brayston 2021

Information (Product safety) Telephone: +27 11 458 0701 Fax: +27 11 458 0710

Emergency telephone number	Europe, Israel, Africa, Americas	+44 (0)208 762 8322
	Middle East, Arabic African countries	+961 3 487 287
	Asia Pacific	+65 633 44 177
	China	+86 10 5100 3039
	South Africa	+27 (0)17 610 4444

2. Composition/information on ingredients

Polypropylene

Contents: 100.00 %W/W

CAS-No. 9003-07-0

Symbol(s)

Index-No.

R-phrase(s)

EC-No.

3. Hazards identification

The product does not need to be labelled in accordance with EC directives or respective national laws.

Particular risks to human beings and the environment

Molten polymer can cause severe burns in contact with skin and eyes. Pellets spilled on the floor can cause slipping.

4. First aid measures

Inhalation

Product does not release fumes at ambient temperatures. If exposed to fumes from heated polymer move to fresh air environment.

Print Date 12.04.2007

100000005520

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Material Safety Data Sheet

Polypropylene

Version 1.00

Revision Date 12.04.2007

Skin contact	<i>At room temperature the product is not considered harmful when in contact with skin. In case of skin contact with molten polymer immediately submerge the affected area in cold water to cool down polymer.</i>
Eye contact	<i>At room temperature the product is not considered hazardous in contact with eyes. In case of eye contact with molten polymer, cool under running water for 3-5 minutes. Do not attempt to remove molten polymer. Get medical attention immediately.</i>
Ingestion	<i>At room temperature the product is not considered harmful when swallowed.</i>

5. Fire-fighting measures

Suitable extinguishing media	<i>Dry chemical, Carbon dioxide (CO₂), Water spray</i>
Specific hazards during fire fighting	<i>Substance evolves toxic gases when burned.</i>
Special protective equipment for fire-fighters	<i>Wear self-contained breathing apparatus and protective suit.</i>

6. Accidental release measures

Environmental precautions	<i>No special environmental precautions required.</i>
Methods for cleaning up	<i>Shovel into suitable container for disposal.</i>

7. Handling and storage

Handling	
Safe handling advice	<i>No special handling advice required under normal conditions. Molten polymer: Wear heat-resistant protective equipment.</i>
Storage	
Requirements for storage areas and containers	<i>Keep away from direct sunlight. Keep away from heat.</i>



Material Safety Data Sheet

Polypropylene

Version 1.00

Revision Date 12.04.2007

Advice on common storage

Do not store with solvents and oxidising agents. Store in a cool dry well-ventilated place.

8. Exposure controls / personal protection

Components with workplace control parameters

NATIONAL OCCUPATIONAL EXPOSURE LIMITS

EUROPEAN OCCUPATIONAL EXPOSURE LIMITS

Contains no substances with occupational exposure limit values.

Personal protective equipment

Respiratory protection *No personal respiratory protective equipment normally required. In the case of respirable dust and/or fumes, use self-contained breathing apparatus.*

Hand protection *No hand protection required under normal conditions. Molten polymer: Wear heat-resistant gloves.*

Eye protection *No eye protection is required under normal conditions. Molten polymer: Wear safety glasses with side shields.*

Skin and body protection *No special body protection is required under normal conditions. Molten polymer: Wear heat-resistant protective clothing.*

9. Physical and chemical properties

Form	<i>solid</i>
state of matter	<i>solid</i>
Colour	<i>translucent to white</i>
Odour	<i>none to slightly waxy</i>
Melting point/range	<i>130 - 165 °C</i>
Flash point	<i>> 350 °C; open cup</i>
Autoignition temperature	<i>> 390 °C</i>
Density	<i>0.88 - 0.92 g/cm³</i>
Water solubility	<i>insoluble</i>

10. Stability and reactivity

Materials to avoid	<i>Oxidizing agents</i>
Hazardous decomposition products	<i>Carbon dioxide (CO₂) Carbon monoxide (CO)</i>

Print Date 12.04.2007

100000005520

3/5



Material Safety Data Sheet

Polypropylene

Version 1.00

Revision Date 12.04.2007

Acrolein
Formaldehyde

Thermal decomposition Stable under normal conditions. Continuous heating above 160 °C will lead to thermal oxidation.

Hazardous reactions Strong oxidizing agents

11. Toxicological information

Further information no data available

12. Ecological information

Ecotoxicity effects

General advice no data available

13. Disposal considerations

Product Disposal can be done with normal domestic waste, Can be recycled, Can be incinerated

14. Transport Information

Further information Not classified as dangerous in the meaning of transport regulations.

15. Regulatory information

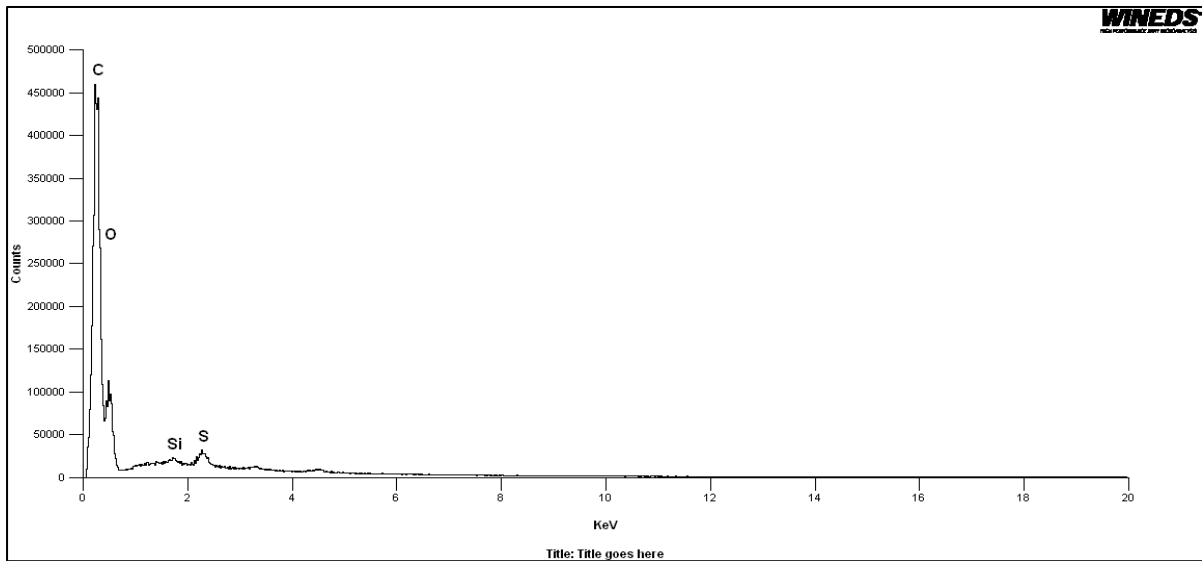
Labelling

Regulatory base 1999/45/EC

Additional advice The product does not need to be labelled in accordance with EC directives or respective national laws.

b) SEM (EDS) Results

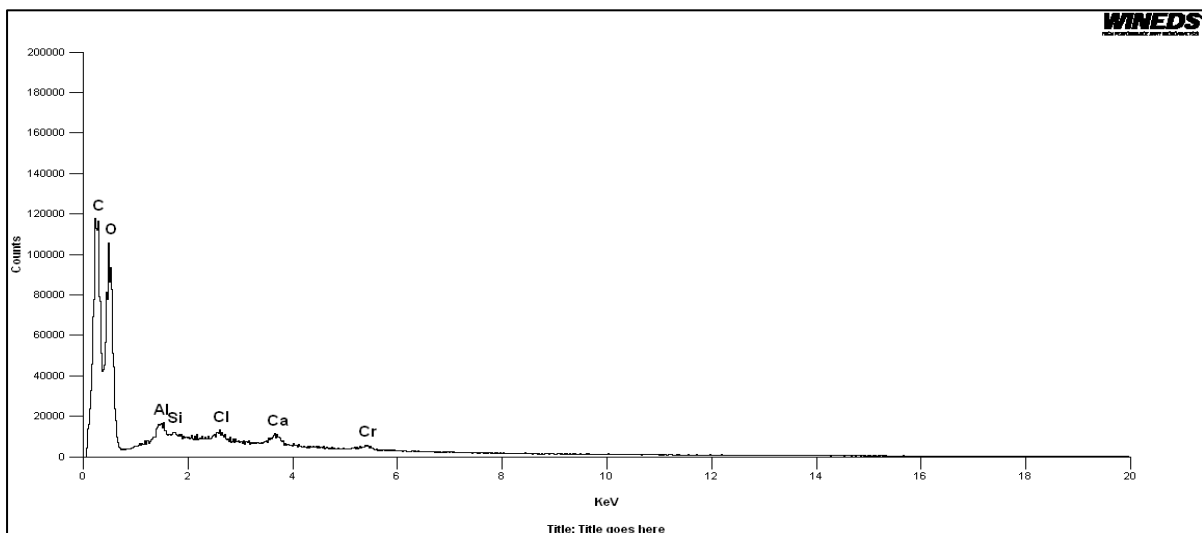
i) Varnish on solid/ chipboard wood



Element	Atom %	Compound	Weight %	Error (±)
Si	11.90	SiO ₂	31.63	1.00
S	32.15	SO	68.37	0.92

EDS Parameters - 25KV, Take-off Angle: 35.0°, Fit Index: 1.73
Correction: ZAF, Cycles: 3

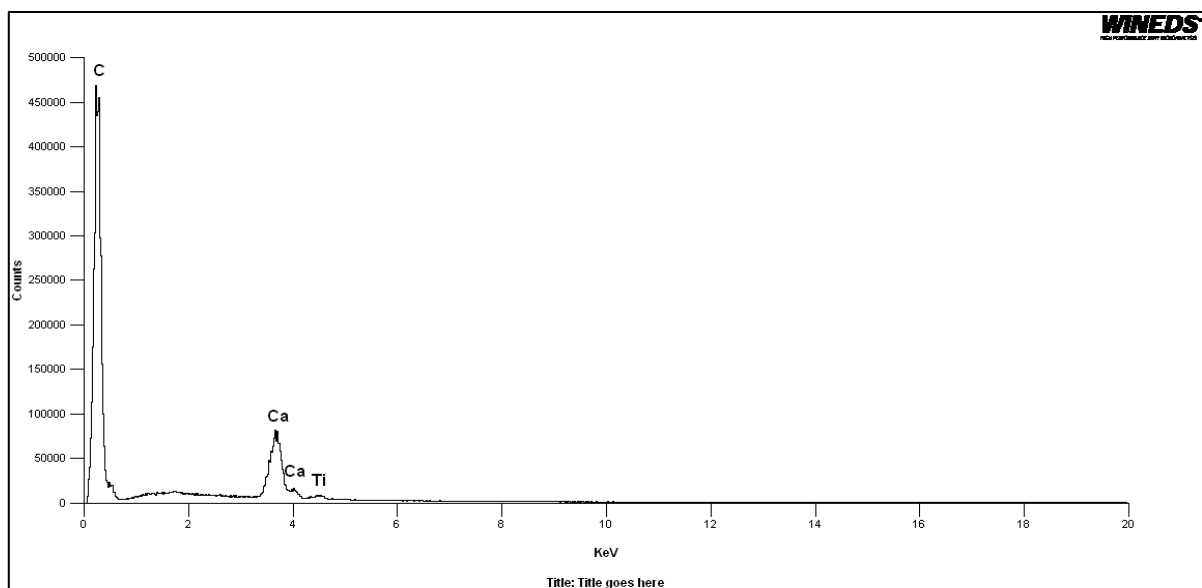
ii) Coating of plastic samples



Element	Atom %	Compound	Weight %	Error (±)
Al	21.38	Al ₂ O ₃	46.61	0.65
Si	3.72	SiO ₂	9.57	0.71
Cl	7.13	Cl ₂ O	13.25	0.51
Ca	7.49	CaO	17.97	0.65
Cr	3.88	Cr ₂ O ₃	12.61	0.71

EDS Parameters - 25KV, Take-off Angle: 35.0°, Fit Index: 183.79
Correction: ZAF, Cycles: 4

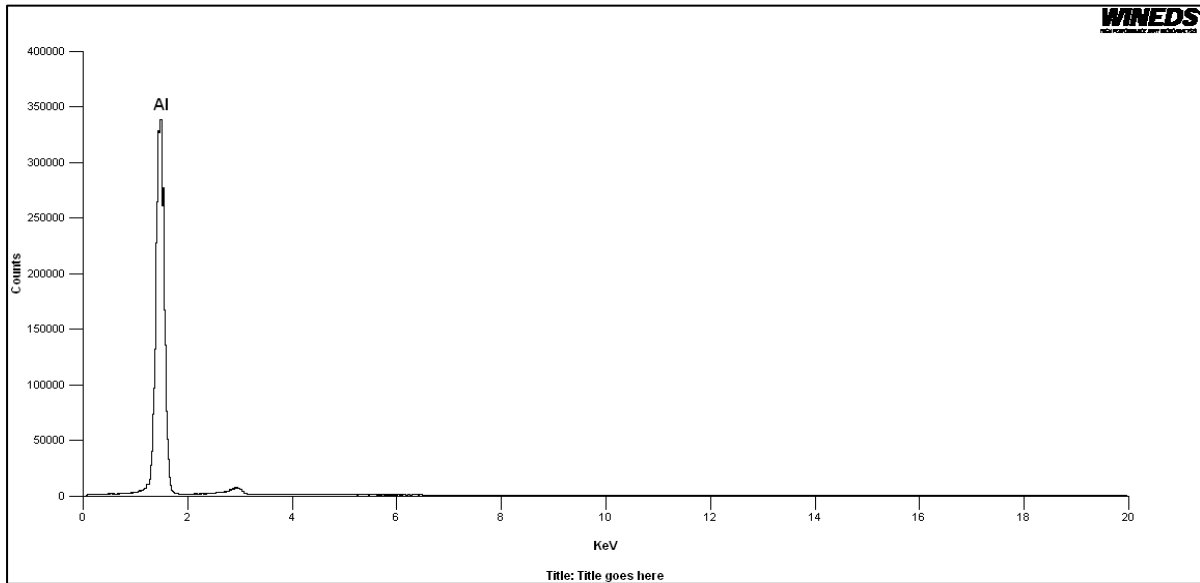
iii) Plastic samples



Element	Atom %	Compound	Weight %	Error (±)
Ca	44.06	CaO	88.65	0.42
Ti	3.96	TiO ₂	11.35	0.21

EDS Parameters - 25KV, Take-off Angle: 35.0°, Fit Index: 161.15
Correction: ZAF, Cycles: 3

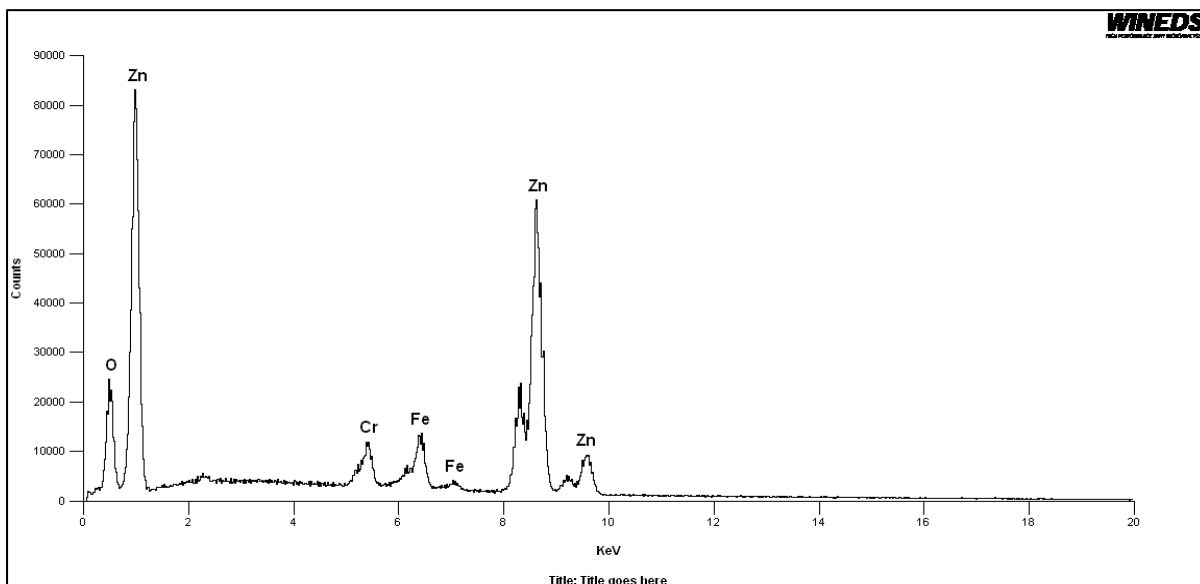
iv) Aluminium bar without coating



Element	Atom %	Compound	Weight %	Error (±)
Al	40.00	Al ₂ O ₃	100.00	0.16

EDS Parameters - 25KV, Take-off Angle: 35.0°, Fit Index: 140.22
Correction: ZAF, Cycles: 1

v) Screws



EDS Parameters - 25KV, Take-off Angle: 35.0°, Fit Index: 76.36
Correction: ZAF, Cycles: 3