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A laboratory study of the pollution of formaldehyde in cemeteries (South Africa)

Sunette van Allemann[1], Jana Olivier[1], Matthys A. Dippenaar[2a]

[1] Department of Geography, Geoinformatics and Meteorology, University of Pretoria, South Africa

[2] Engineering Geology and Hydrogeology, Department of Geology, University of Pretoria, South Africa

[a] Corresponding author (matthys.dippenaar@up.ac.za / madippenaar@gmail.com)

Abstract

Cemeteries are known to be associated with soil and groundwater pollution from contaminants in coffin materials. However, possible contamination from embalming fluids such as formaldehyde has not been investigated. Formaldehyde is a recognised carcinogen, which is primarily toxic after inhalation, skin contact or ingestion. Although it is maintained that formaldehyde breaks down into innocuous compounds, this has not been established at sites such as cemeteries where there is a continuous addition of formaldehyde-preserved bodies, sometimes on a daily basis. It is also not confirmed whether different soil types and environmental conditions affect the leaching of formaldehyde into groundwater resources. This study comprises a laboratory study of the leaching potential of formaldehyde through different soils and environmental conditions. Twenty-seven containers with taps were filled with either sandy, silty or clayey soils. Samples of burial materials and a cloth saturated with formalin were buried within each column. These were exposed to conditions simulating that of the environment i.e. (i) different temperatures, (ii) heavy or prolonged rainfall, and (iii) using either acidic or slightly acid water. Leachate samples were collected every two weeks for a period of 24 weeks and analysed for formaldehyde using acid titration. The results showed that most formaldehyde percolated through the soil between week six and week 14 of interment, with a greater amount being leached from sand. Neither temperature nor pH affected the amount of formaldehyde leached; however, conditions simulating heavy rainfall facilitated leaching. Although a total of only 3% of the initial amount of formaldehyde mobilised, concentrations of up to 15mg/L formaldehyde were recorded on two occasions, exceeding the Tolerable Concentration recommended by the World Health Organization.

Keywords: Cemeteries; Interment; Formaldehyde; Burial Materials; Embalming; Formalin.

1. Introduction

The main sources of pollution from cemeteries are (a) human bodies; (b) embalming fluids, which primarily contain 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 and Olivier 2012).

The pollution potential of cemeteries has received increasing attention over the past few years. This research has dealt with the environmental and health hazards associated with metals used in coffin materials and microorganisms from decomposing corpses, which may potentially become mobile, seep into the soils and end up in nearby water reserves. However, the potential pollution due to embalming fluids, such as formaldehyde (Guttman et al. 2012), has gone unnoticed.

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). Formaldehyde is currently the main embalming fluid used in South Africa, athough it is not known whether formaldehyde actually leaches into the soil and groundwater. Different soil types, pH, rainfall intensities and temperature may also influence the leaching and decomposition rates of formaldehyde and, since it is difficult to determine these relationships directly in the field, a laboratory study under controlled conditions was conducted.

The aim of this laboratory study is to determine whether formaldehyde from burial materials has the potential to contaminate groundwater. The objectives are to (a) determine whether the formaldehyde becomes mobile and leaches into groundwater and, if so, to (b) estimate the rate of leaching and (c) assess whether the amount of rainfall and its pH, the type of soil and temperature play a role in the rate of leaching.

2. Literature

Despite the widely held belief that the decomposition of bodies and the stench of decomposing corpses were potential health hazards to living individuals, it was only in the mid-1800s when Dr George Walker (a British surgeon) described how the soil around graves became saturated with potentially deadly decomposing matter (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 result in environmental and health hazards (e.g. Dent 2000; Dippenaar 2014; Engelbrecht 1998; Eyler 2001; Fogli 2016; Tumagole 2009; Zychowski 2012).

Although the first studies focused on the contaminants associated with bodies and associated bacteria, recent studies have been conducted to inclide contamination from minerals and metals contained in burial materials such as coffins and caskets. Van Haaren (1951) and Dent (1998) found above normal concentrations of salts in the vicinity of graves in the Netherlands and Australia respectively. High levels of metals and trace minerals were also recorded in cemeteries in many countries ranging from Brazil, Iran, Rwanda, Australia, China and South Africa (Amuno 2013; Amuno and Oluwajana 2014; Barros et al. 2008; Dent and Knight 1995; Jonker and Olivier 2012; Pour and Khezri 2010; Spongberg & Becks 2000)

In comparison to research on decomposing bodies and burial materials, possible contamination from embalming agents has received relatively little attention. According to Ezugworie et al. (2008), Ancient Egypt is principally associated with the beginnings of the art and techniques of embalming. These embalming agents comprised mainly of mixtures of resins, herbs, spices, honey and minerals and may have been innocuous (Mdladenov 2016). It is believed, for instance, that the body of Alexander of Macedonia was transported from Babylon to Macedonia in a coffin filled with honey.

Since the advent of the American Civil War (1861) until about 1910, the main ingredient for embalming fluids was essentially arsenic (Konefes and McGee 2001). Even though arsenic is very effective, it is not only toxic, but also persistent and will never be able to degrade into harmless by-products (Singh et al. 2011). The use of arsenic was a significant improvement from refrigeration or dry ice (carbon dioxide) when preserving the deceased for burial or transport, but embalming practitioners did not take into consideration the long-term effects of these substances (Konefes and McGee 2001). As a result, large concentrations of arsenic were placed within burial grounds and ultimately local water supplies.

Today it is known that arsenic poses a significant environmental threat and health hazard since some of the arsenic in an embalmed body can leach out and eventually contaminate nearby groundwater (Konefes and McGee 2001). In a hypothetical case study, Konefes and McGee (2001) estimated that, in a modest-sized town recording 2,000 deaths between 1880 and 1910, and if only half of the deceased were embalmed with 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 ton of arsenic. Both of these scenarios would cause a significant amount of contamination at one location.

Although arsenic was the main ingredient of embalming fluids, other embalming compositions used less frequently also consisted of similar toxins such as mercury and creosote (Johnson 1995). 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) (Karmaka 2010) is required for a 70 kg body. Formaldehyde (CH_2O) is released during decomposition and has been shown to be carcinogenic (especially leukaemia) to living organisms (Guttman et al. 2012). According to a 2002 report, the World Health Organization (2002) indicated that 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. However, its persistence in a cemetery environment has not been assessed, especially given the role of the vadose (unsaturated) zone and the time for it to break down into harmless byproducts.

3. Materials and Methods

Given the difficulty in determining the rate of formaldehyde leaching in situ, a laboratory simulation under controlled conditions was designed. This simulation of formaldehyde at different environmental conditions including variation in (i) the type of soil, (ii) rainfall intensity, (iii) pH and (iv) temperature was carried out over a period of 24 weeks. These experiments were conducted at Orytech (Pty) Ltd, an independent paint/coating, corrosion, environmental and materials testing facility located in Johannesburg, Gauteng (as elaborated by Van Allemann 2017).

Sand, silt and clay were collected from Klerksdorp, located in North-West Province (South Africa). The soil types were determined by means of particle size distribution where sand particles are 0.5-2.0 mm, silt 0.002-0.05 mm and clay less than 0.002 mm (Brady and Weil 2008). The possible presence of some organic materials in the samples are duly noted.

The soil samples were placed into plastic columns with a diameter of 170 mm and a height of 190 mm. The soil samples were slightly compacted to minimize pore spaces between the soil particles. The plastic containers were fitted with a small tap at the bottom of each container to allow water leachate to move out of the column, and a material sieve to prevent blockage.

Embalming fluid and coffin materials were collected from one of South Africa's oldest and largest funeral suppliers. Until recently, coffin materials, such as handles and ornaments, were made of metals such as aluminium, copper, mild steel, zinc and its alloys, as well as silver and bronze. This has now been replaced with plastic handles and ornaments. The material safety data sheets of these indicated that the plastic comprise of polypropylene and contain traces of formaldehyde (Motlatsi

2007). The varnish also contain traces of formaldehyde (Chemical Specialists (Pty) Ltd 2009) and the collected embalming fluid, formalin, consists of 10% formaldehyde.

Information obtained from the South African Weather Service (SAWS 2016) was used to identify general climatic conditions occurring over South Africa. From this it became evident that the average daily temperature ranges between 20°C and 30°C and rainfall, especially in the summer rainfall regions of the country, frequently occur in the form of heavy thunderstorms. Conversely, rainfall is less intense and often prolonged in the winter rainfall region. In rural, pollution-free areas, the rainwater usually has a pH of 5.6, but when combined with emissions containing sulphur dioxide or nitrogen oxide, the rain becomes more acidic than usual with typical acid rain having a pH of 4 (Hairston 2003).

This information was used to simulate natural environmental conditions in the laboratory study.

A sample of each coffin material, as well as a pure cotton cloth of 50 x 50 mm which had been dipped in 15.6 ml formalin, a 4% formaldehyde solution, was 'buried' at a depth of 95 mm of the soil column (Figure 1). The soil columns were given a unique sample identification and labelled accordingly. Half of the containers were then placed within a 30°C chamber and the other half in a temperature controlled room, which was set at 20°C.

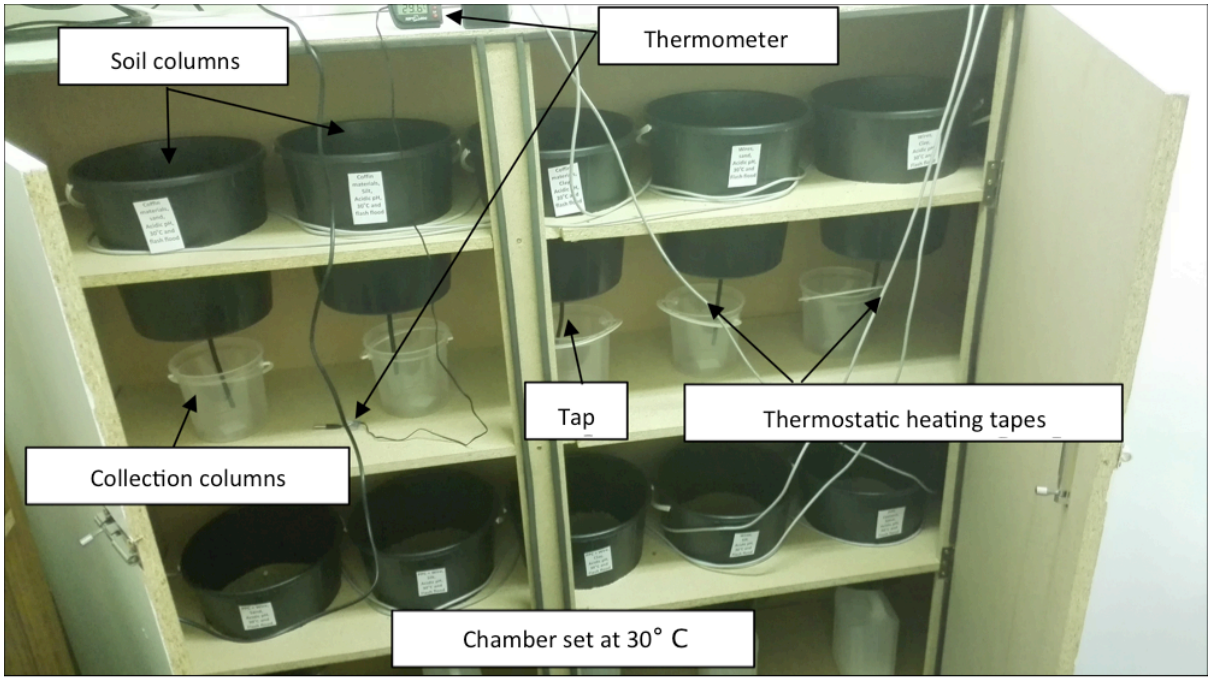

Figure 1. Setup of the laboratory experiment.

In addition to simulating moderate and hot temperatures, the samples were watered with 1L of water every two weeks to simulate different rainfall intensities. The samples exposed to 'prolonged rainfall' periods received 1L of water over a period of 4 days every second week whereas the entire 1 L of water was added to the containers every second week to simulate heavy rainfall (referred to as 'flash floods).

The water added to the samples, which simulated the different rainfall intensities, also had different pH values. Half of the samples were given water with a pH of 6 (slightly acidic) and the other half water with a pH of 4 (acidic). In order to achieve these pH values, hydrochloric acid (HCl) was added to distilled water in order to increase the acidity. Figure 2 illustrates the various conditions under which the samples were tested. Interment continued for a period of 6 months (24 weeks).

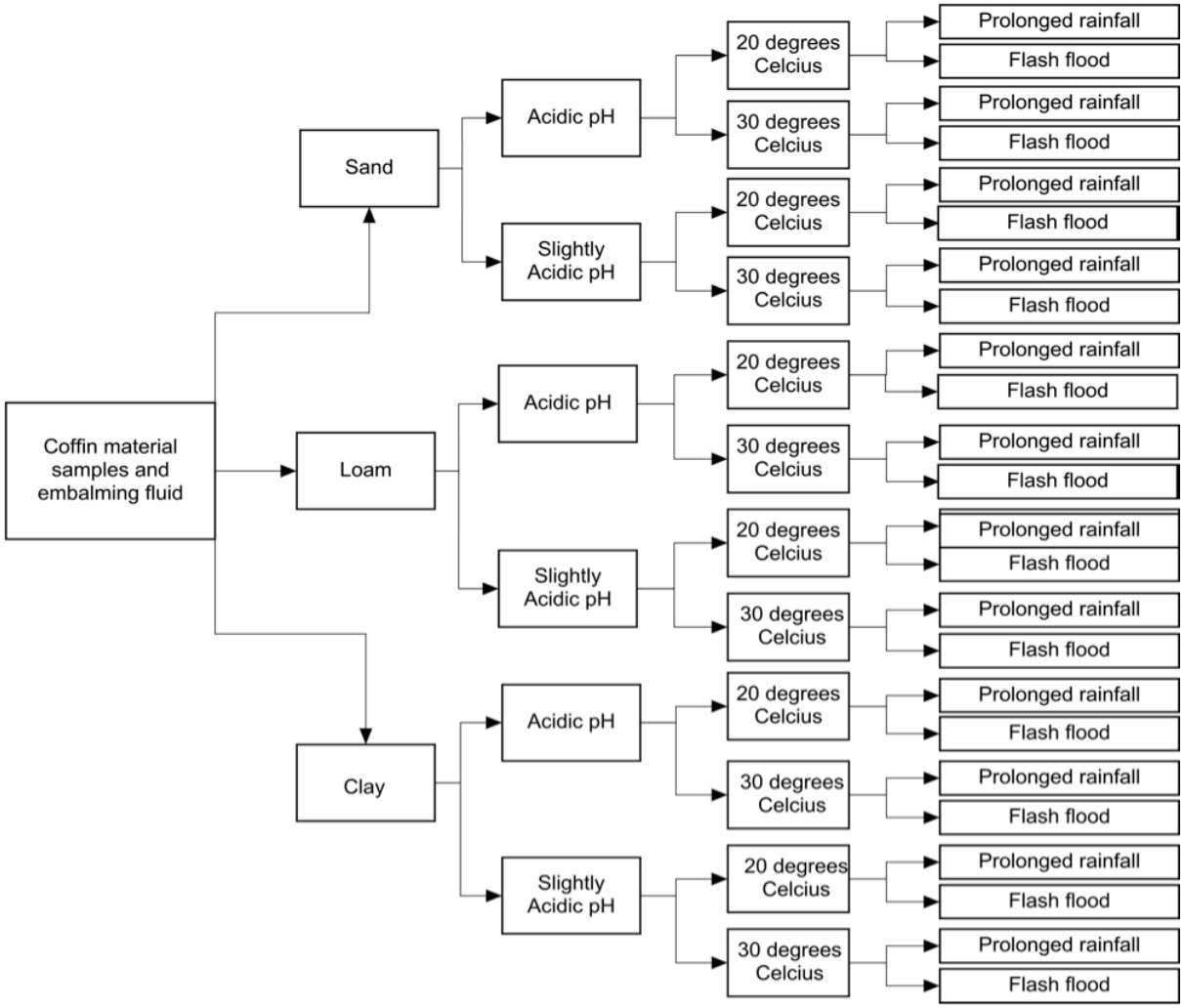

Figure 2. Variables tested during the experimental study.

Table 1 summarises the simulated conditions to which the sources of formaldehyde were exposed.

Table 1. A summary of the controlled variables of the laboratory simulation of formaldehyde over a period of 24 weeks.

Variables	Description of each controlled variable
Soil Type	
Sand	Added and compacted into 170 mm x 190 mm soil columns
Silt	Added and compacted into 170 mm x 190 mm soil columns
Clay	Added and compacted into 170 mm x 190 mm soil columns
'Rainfall' Intensity	
Flash Flooding	1L of distilled water once-off every second week
Prolonged	1L of distilled water over a period of 4 days every second week
Temperature	
Moderate	20°C continuously
Warm	30°C continuously
'Rainfall' pH	
Acidic	pH 4 continuously
Slightly Acidic	pH 6 continuously
Control Samples	**Different soil types with no formaldehyde, which were exposed to neutral flash floods at room temperature**

It is important to note that formaldehyde also arises from the oxidation of natural organic material (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 formaldehyde were kept as controls, which are also exposed to neutral flash floods at room temperature. Thus, there were 27 samples in total, which allowed for differentiation between the three different soil types, simulated rainfall intensities (flash floods or prolonged rainfall periods), temperature (20°C or 30°C) and slightly acidic or acidic 'rain'.

The water leached out of each sample was collected fortnightly and given a unique sample identification number. The concentration of formaldehyde in each sample was determined (in triplicate) by means of a Hanna formaldehyde test kit. The test involved simple acid titration where formaldehyde reacts with sodium sulphite (Na_2SO_3) to form an alkaline solution, which is then titrated with HCl to form a yellow solution (Hanna Instruments n.d.). The amount of HCl titrated is proportional to the concentration of formaldehyde in the solution. After analysis, the results were tabulated and the formaldehyde concentrations were divided into equal pentad values, which are indicative of the relative concentration of formaldehyde for a given sample. Excel (Microsoft 2010) was used for calculations and rafting figures.

Experimental studies such as this have certain limitations. Natural environments may be more prone to bioaccumulate metals or digest formaldehyde than the biologically inert soils used in the study. Furthermore, this experimental study do not account for all possible influences of other parameters such as ultraviolet radiation or light, variable temperatures, variable redox conditions and so forth.

4. Results and Discussion

The amount of formaldehyde collected from each of the containers is given in Table 2.

Table 2. Formaldehyde (mg/l) concentrations of tested water samples over a period of 24 weeks (W2 – week 2; etc.).

Sample Identification	Fortnightly Concentrations in mg/l												
	W 2	W 4	W 6	W 8	W 10	W 12	W 14	W 16	W 18	W 20	W 22	W 24	Sum (mg)
A coffin sand slightly acidic 20 prolong	1.50	0.50	5.00	4.00	3.00	2.00	0.50	0.20	0.10	0.10	0.10	0.10	17.10
B coffin sand slightly acidic 30 prolong	0.50	0.40	5.00	4.00	4.00	1.00	0.40	0.40	0.20	0.20	0.10	0.15	16.35
C coffin sand acidic 20 prolong	2.00	0.40	2.50	15.00	0.40	0.10	0.20	0.10	0.10	0.10	0.15	0.20	**21.25**
D coffin sand acidic 30 prolong	1.00	0.50	1.00	4.00	9.00	0.20	0.10	0.10	0.10	0.10	0.15	0.10	16.35
E coffin sand slightly acidic 20 flash	1.50	0.40	7.00	5.00	2.00	0.40	0.10	0.20	0.20	0.20	0.10	0.15	17.25
F coffin sand slightly acidic 30 flash	1.50	0.60	8.00	7.00	0.40	0.20	0.00	0.20	0.10	0.15	0.20	0.10	18.45
G coffin sand acidic 20 flash	1.50	0.50	10.00	2.00	0.40	0.40	0.20	0.40	0.20	0.10	0.15	0.10	15.95
H coffin sand acidic 30 flash	0.50	0.80	5.00	6.00	4.00	0.25	0.10	0.30	0.10	0.10	0.15	0.20	17.50
I sand control	0.10	0.10	0.20	0.10	0.10	0.10	0.20	0.10	0.10	0.10	0.10	0.10	1.40
Total Sand (Σ) excluding control	10.00	4.10	43.50	47.00	23.20	4.55	1.60	1.90	1.10	1.05	1.10	1.10	140.20
J coffin silt slightly acidic 20 prolong	1.50	0.40	5.00	2.50	4.00	1.00	3.00	0.20	0.10	0.20	0.10	0.15	18.15
K coffin silt slightly acidic 30 prolong	1.00	0.40	5.00	2.00	3.00	2.00	0.20	0.10	0.20	0.10	0.10	0.10	14.20
L coffin silt acidic 20 prolong	0.50	0.40	0.20	4.00	5.00	3.00	0.40	0.10	0.20	0.15	0.10	0.15	14.20
M coffin silt acidic 30 prolong	2.00	0.40	4.00	3.00	4.00	1.00	0.30	0.20	0.40	0.20	0.10	0.10	15.70
N coffin silt slightly acidic 20 flash	1.00	0.40	4.00	4.00	5.00	0.40	0.20	0.20	0.20	0.20	0.10	0.15	15.85
O coffin silt slightly acidic 30 flash	1.50	0.40	2.50	3.00	5.00	3.00	0.50	0.30	0.40	0.15	0.15	0.10	17.00
P coffin silt acidic 20 flash	1.00	1.00	8.00	2.00	0.40	1.00	1.00	0.40	0.10	0.10	0.10	0.10	15.20
Q coffin silt acidic 30 flash	1.50	0.40	12.00	3.00	0.40	0.20	0.10	0.10	0.20	0.10	0.15	0.20	18.35
R silt control	0.20	0.10	0.20	0.10	0.20	0.20	0.20	0.20	0.10	0.10	0.20	0.20	2.00
Total Silt (Σ) excluding control	10.00	3.80	40.70	23.50	26.80	11.60	5.70	1.60	1.80	1.20	0.90	1.05	128.65
S coffin clay slightly acidic 20 prolong	1.50	0.40	8.00	1.00	1.00	0.20	0.40	0.20	0.30	0.10	0.20	0.15	13.45
T coffin clay slightly acidic 30 prolong	1.50	0.40	8.00	2.00	0.50	0.40	0.20	0.10	0.50	0.10	0.20	0.10	14.00
U coffin clay acidic 20 prolong	1.00	0.40	0.20	1.00	5.00	3.00	4.00	0.50	0.20	0.10	0.10	0.20	15.70
V coffin clay acidic 30 prolong	0.50	0.60	5.00	3.00	2.00	1.00	3.00	0.80	0.10	0.20	0.10	0.15	16.45
W coffin clay slightly acidic 20 flash	1.00	0.40	1.00	14.00	0.10	0.40	0.10	0.10	0.20	0.10	0.20	0.15	17.75
X coffin clay slightly acidic 30 flash	1.00	0.50	2.00	15.00	0.10	0.10	0.20	0.20	0.10	0.20	0.10	0.10	19.60
Y coffin clay acidic 20 flash	1.00	0.60	4.00	1.00	5.00	0.50	3.00	0.20	0.20	0.10	0.20	0.10	15.90
Z coffin clay acidic 30 flash	1.00	0.40	0.50	1.00	10.00	2.00	0.20	0.40	0.20	0.15	0.20	0.20	16.25
AZ clay control	0.10	0.20	0.10	0.10	0.00	0.10	0.10	0.20	0.00	0.10	0.10	0.10	1.20
Total Clay (Σ) excluding control	8.50	3.70	28.70	38.00	23.70	7.60	11.10	2.50	1.80	1.05	1.30	1.15	129.10
Legend (mg/l)	0.00 to 3.00		3.10 to 6.00		6.10 to 9.00			9.10 to 12.00			12.10 to 15.00		

4.1. General trends in formaldehyde leaching

Comparison of the total amount of formaldehyde leached over the 24-week period from sand, silt and clay (Table 2) indicated that a total of 140.2 mg/l was leached from sand, 128.65 mg/l from the silt columns and 129.1 mg/l from the clay. This suggests that some of the formaldehyde were attached to soil particles and could possibly flush out of silt and clay at a later stage. However, the soils themselves were sources of formaldehyde (as shown by the controls). If this portion of the formaldehyde is excluded from each of the samples, a total of 138.8 (i.e. 140.20-1.40), 126.65 and 127.9 mg/l were leached from sand, silt and clay, respectively. Sand appears to leach formaldehyde at a greater rate. However, use of Student's t-test revealed that there is no significant difference in the amounts leached from the different soils, since the p-value is 0.316 between sand and silt. This is not significant at $p > 0.05$.

Table 2 also indicates that most of the soils only started to percolate formaldehyde out of the system at week six, and most of the formaldehyde appeared to have leached out of the soil by week 16. Further scrutiny (Figure 3) shows that sand flushed formaldehyde out faster than silt and clay. By weeks 12 and 14, the amount of formaldehyde leached from the burial materials in sandy soils had decreased markedly whereas such low amounts were only reached in week 16 in silty and clayey soils. This may, in part, be ascribed to the high permeability well-drained nature of sand compared to silt and clay, implying that formaldehyde may be retained longer in finer-grained soils.

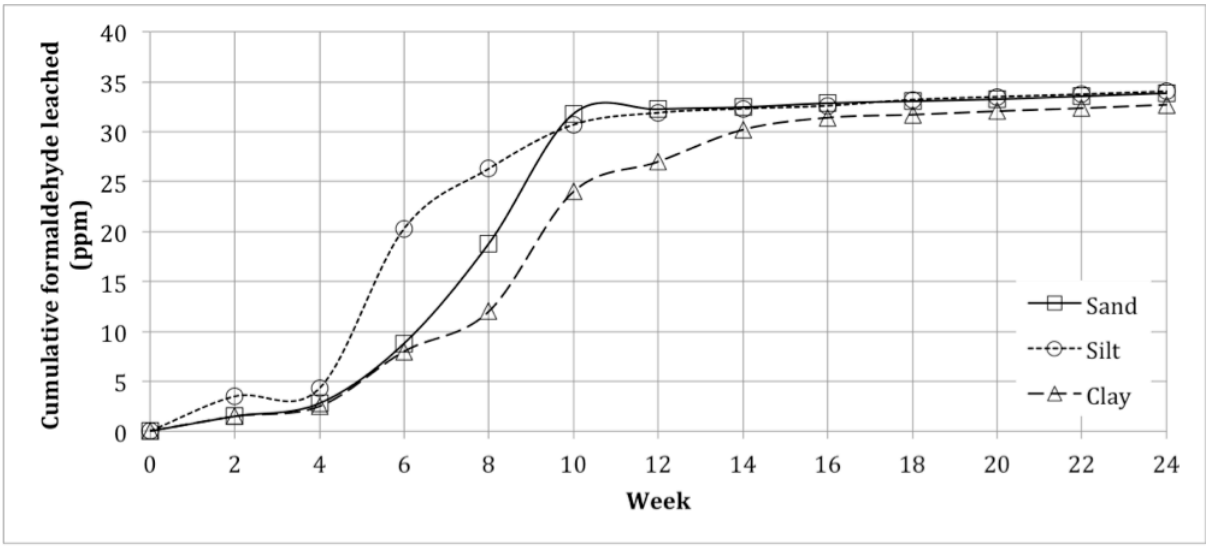

Figure 3. Cumulative plot of formaldehyde leached out of different soil types over the 24-week period.

4.2. The effect of changing environmental conditions

The effects of differences in the amount of formaldehyde leached from sand, silt and clay with changes in temperature, rainfall intensity and pH are summarised in Table 3. These values were

obtained by summing the appropriate values in Table 2 (for example, formaldehyde leached from sand at 20°C was 17.1+21.25+17.25 + 15.95 = 71.55 mg/l).

Table 3. 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	71.55	68.65	71.05	69.15	69.15	71.05
Silt	63.40	65.25	62.25	66.40	65.20	63.45
Clay	62.8	66.25	59.60	69.50	64.80	64.30
Total	197.75	200.15	192.90	205.05	199.15	198.80
Mean (n = 12)	16.48	16.68	16.08	17.08	16.60	16.57

4.2.1. Temperature

Table 3 clearly shows that, in sand, higher temperatures inhibited formaldehyde from percolating out of the system. However, the opposite seems to be true for clay and silt, showing increased amounts of formaldehyde leaching out of the system at increased temperatures. Comparison of Figures 4a-c shows that, during higher temperatures, silt released the formaldehyde more uniformly than sand and clay. In general, the temporal pattern of formaldehyde percolated from the soils were essentially the same at 20°C and 30°C.

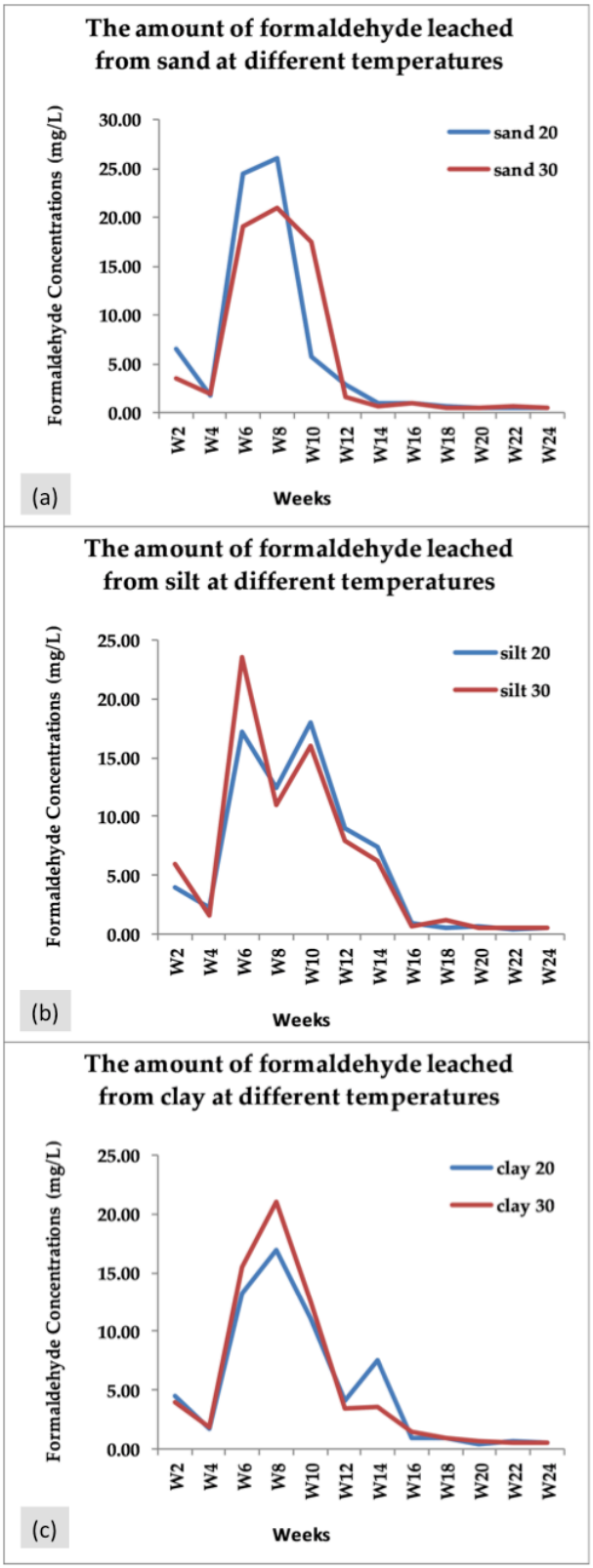

Figure 4. (a) The amount of formaldehyde leached from sand at different temperatures. (b) The amount of formaldehyde leached from silt at different temperatures. (c) The amount of formaldehyde leached from clay at different temperatures.

Observation of the soil columns indicated that sand were much drier than silt and clay at 30^{o}C (as is expected by the low moisture retention and high permeability compared to silt and clay), which could explain this variation. Silt and clay subsequently stayed moist for longer, allowing them to flush out greater amounts of formaldehyde at higher temperatures. Once again, the Student's t-test indicated that there is no significant difference in the amounts leached from sand at different temperatures, since the p-value is 0.294, which is not significant at $p > 0.05$. Since the effect of temperature difference is less in silt and clay, these can also be assumed to be statistically not significant at $p > 0.05$.

4.2.2. Rainfall intensity

More formaldehyde was leached from sandy soils during prolonged rainfall, whereas the opposite is true for silt and clay (Table 3). Comparison of Figures 5a-c show that generally, prolonged rainfall periods appeared to have flushed out formaldehyde faster than flash floods in sandy soils (week 12) while silt and clay soils only released most of the formaldehyde by week 16. However, silt and clay showed several instances of high formaldehyde flushing during 'flash floods' during the first 10 weeks. The Student's t-test confirmed that there is a significant difference in the amounts leached from clay at different rainfall intensities, since the p-value is 0.033 ($p < 0.05$). The opposite is true for sand and silt, with p-values of 0.362 and 0.203, respectively.

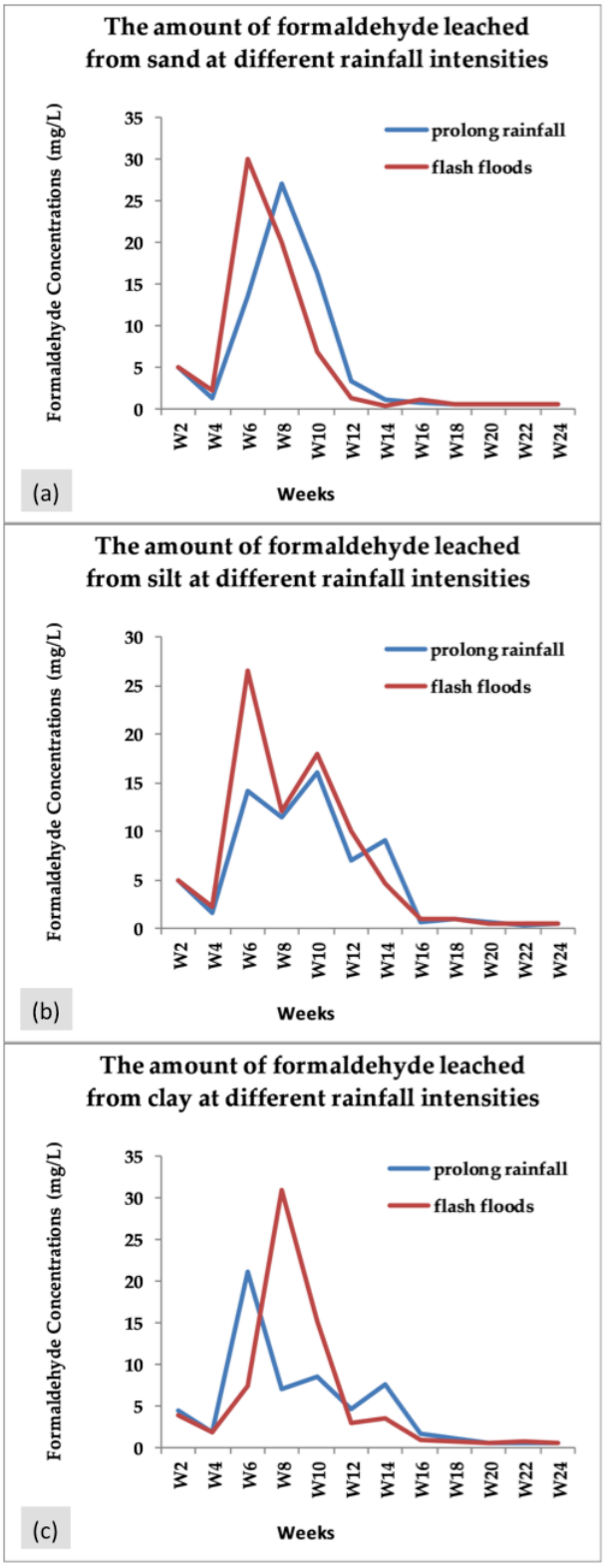

Figure 5. (a) The amount of formaldehyde leached from sand at different rainfall intensities. (b) The amount of formaldehyde leached from silt at different rainfall intensities. (c) The amount of formaldehyde leached from clay at different rainfall intensities.

4.2.3. Rainfall pH

Table 3 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 sand 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 seems to hold for silty soils (Figures 6a-c). Yet, application of Student's t-test revealed that there is no significant difference in the amounts leached from clay with rainfalls at different pH values, since the p-value is 0.468 ($p > 0.05$).

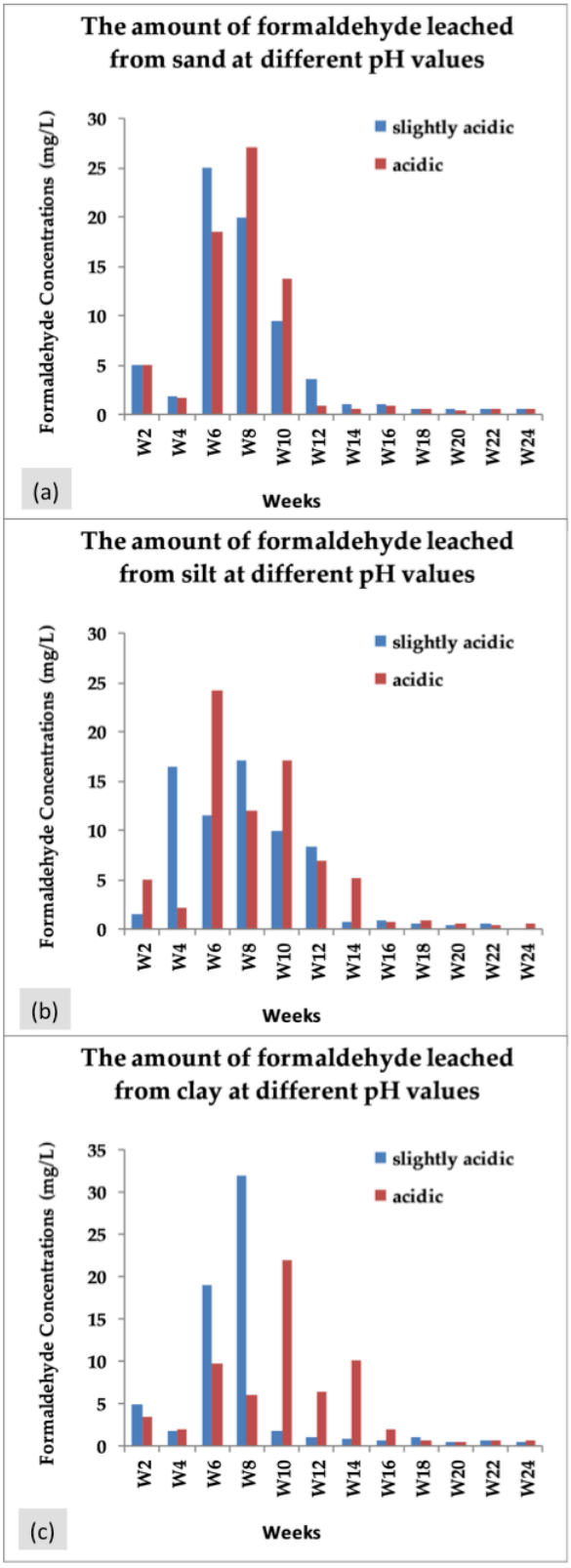

Figure 6. (a) The amount of formaldehyde leached from sand at different pH values. (b) The amount of formaldehyde leached from silt at different pH values. (c) The amount of formaldehyde leached from clay at different pH values.

4.3. Total amount of formaldehyde leached from soils

Calculations showed that the 15.6 ml formalin (containing 4% formaldehyde and with a density approx. 1 g/ml) solution interred in the columns contained approximately 624 mg formaldehyde. Of this an average of 16.38 mg and a maximum of 21.25 mg leached from the samples (Table 2). As mentioned before, formaldehyde also arises from the oxidation of natural organic material, which explains why small concentrations of formaldehyde persist for a long period of time in the soil samples, including the control samples (Table 2). However, this naturally occurring formaldehyde in not included in the calculations.

Ostensibly the embalming fluid does not appear to pose a risk to the environment since only approximately 2.6% formalin buried in the soil percolates out over a 6-month period. However, 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 and Olivier 2012), equating to almost 20 burials per week. Since a 1.5 L formalin solution is used to embalm a 70 Kg body, 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 are still unknown and would depend on the environmental and other conditions. Noteworthy is the fact that, in this laboratory study, the formaldehyde leachate in the experiment reached concentrations of up to 15 mg/L on two occasions, that is six times higher than the established a tolerable concentration of 2.6 mg/L for ingested formaldehyde (World Health Organisation 2002, 2005).

5. Conclusions

The contamination of soil and groundwater by embalming fluids is a key element that has largely been overlooked in research involving cemeteries. This study comprises of a laboratory study in which environmental conditions prevailing in South Africa are emulated 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 periods 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 2.6% of the formalin introduced into the experimental soil columns leached from the soil over a six-month period. The remaining >97% can safely be assumed to either break down, or to only mobilise 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 at some stages between weeks 6 to 14.

Considering the fact that burials take place on a weekly basis in operational cemeteries in South Africa, the accumulated amount of 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, and it is also recommended that drinking water standards for formalin be introduced.

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