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Climate Change Implications for Health-Care Waste Incineration Trends during Emergency Situations

Emilia Mmbando Raila
Walden University

Walden University

College of Health Sciences

This is to certify that the doctoral dissertation by

Emilia Raila

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Review Committee
Dr. Patrick Tschida, Committee Chairperson, Public Health Faculty
Dr. David Anderson, Committee Member, Public Health Faculty
Dr. Raymond Thron, University Reviewer, Public Health Faculty

Chief Academic Officer
Eric Riedel, Ph.D.

Walden University
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Abstract

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Emilia Mmbando Raila

MS, Water Resources Engineering, University of Dar es Salaam, 2004

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Dissertation Submitted in Partial Fulfillment
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Abstract

Healthcare waste (HCW) incineration practices in the global South countries are among the major sources of black carbon (BC) emissions or smoke. This study analyzes HCW incineration trends during emergency situations and smoke from HCW incineration processes in Haiti. The study was prompted by the current arguments about the climate change and the growing health effects associated with BC emissions. The conceptual framework was based on both adverse health effects from BC emissions exposure and climate change potential of BC emissions. Therefore, the goal was to determine whether cardboard HCW sharps containers emit lower BC emissions to the atmosphere during the incineration process, relative to the plastic sharps containers, and the pattern of emergency HCW incineration before and after the 2010 earthquake and cholera emergencies in Haiti. This was an observational study conducted with secondary data on HCW incinerated weights from January 2009 to December 2013 and primary data on average smoke densities. Linear regression analysis of the pattern of HCW incinerated weights revealed a relatively linear pattern ($R^2 = 0.164$) with fluctuating scenarios (peak sharp rise in 2012). Independent samples *t-tests* demonstrated significantly lower smoke emission during the incineration processes of cardboard sharps HCW containers as compared to plastic containers (95 % CI, $p = 0.003$). Implications for positive social change include provision of quantitative evidence of the benefits of cardboard sharps HCW containers in reducing smoke during incineration activities, potential data for policy formulation, suggestions for review of existing HCW guidelines, and additional research on potential health impacts of emergency HCW disposal and BC emissions.

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Dedication

This dissertation is lovingly dedicated to my late father, Augustine Barnabas Mmbando, my endless source of inspiration who died on respect and passion for education.

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Chapter 1: Introduction to the Study

Currently, researchers around the world are studying climate change challenges and its remedies with significant results. So far, the National Academy of Science [NAS] team has identified some of the fundamental issues to understand climate change. These include research, tools, and approaches for addressing human impacts to the climate challenge (National Research Council [NRC], 2010). Likewise, scientists are studying practical mitigation techniques and focusing on curbing carbon dioxide (CO_2) emissions. However, focusing climate change remediation measures on curbing CO_2 emissions as the major cause of climate change, and neglecting the climate change potential of black carbon (BC) emissions, has not been effective for many years (Bond et al., 2013; Santisi, 2012; Spotts, 2013; United Nations Environmental Programme & World Metrological Organization [UNEP/WMO], 2011). Recently, researchers identified BC emissions as the second strongest cause of climate change after CO_2 (Bond et al., 2013; Deangelis, 2011; Mahajan, Evans, Hack, & Truesdale, 2013). It has been estimated that 1 gram of BC emissions contributes to 100 to 200 times more warming than same amounts of CO_2 over a period of 100 years (UNEP/WMO, 2011).

Interestingly enough, BC emissions are reported to have shorter residence times in the atmosphere than CO_2, hence, their remediation will result in immediate health and climatic effects (Bond et al., 2013; Jacobson, 2004; Ramanathan & Carmichael, 2008: Santisi, 2012; Spotts, 2013; WHO, 2014b). BC emissions refer to the incomplete combusted fossil fuels, waste, wood and other biomass soot particles in the atmosphere (Deangelis, 2011; Kuo, 2009; World Health Organization [WHO], 2012). Healthcare waste (HCW) incineration practices in the global South countries are among the major sources of BC emissions in the atmosphere, although they are unrecognized (Batterman, 2004; Ferraz, Cardoso & Pontes, 2000; Ko, 1992; Mangaa, Fortonb, Moforc, & Woodardd, 2011; Zakaria & Labib, 2003; Zakaria, Labib, Mohamed, El-Shall, & Hussein, 2005). Reducing BC incineration emissions will contribute to positive health and climatic conditions (Biello, 2012; Bond et al., 2013; Jacobson, 2004; Ramanathan & Carmichael, 2008: Santisi, 2012; Spotts, 2013; WHO, 2012, 2014b).

Therefore, in this study I examined how BC emissions from emergency HCW incineration practices could be reduced in the global South countries where incineration remains the best available technology (Basel Convention Technical Guidelines on Incineration on Land, 2002; Global Environmental Facility [GEF], 2009; UNEP 1996, 2005). This study chapter is comprised of 12 sections including: the background of the problem, problem statement, purpose of the study, research questions and hypotheses, the conceptual framework in which the study literature and methodology rely, nature of the study, definition of terms, study assumptions, scope and delimitations, limitations, significance of the study and the chapter summary.

Background of the Problem

Numerous episodes of climate change have occurred since the 1950s, resulting in rampant fluctuations in temperature and precipitation, forest fires, drought, sea level rise, floods, melting of glaciers, heat waves, and disruption of habitats to plant and animal species to extinction (American Meteorological Society, 2008; Bond et al., 2013; Jacobson, 2004; Ramanathan & Carmichael, 2008: Santisi, 2012; Spotts, 2013). Yet, the world has only been focused in curbing CO_2, which is a leading cause of climate change. Scientists are formulating newer perspectives on BC emissions for potential impacts on climate change.

According to the United States Environmental Protection Agency [USEPA], climate change occurs when greenhouse gases (GHGs) trap the incoming solar radiation released by the sun and reflect back the infrared radiation which then causes an increase in earth's temperature (USEPA, 2014). Also, the climate of the earth changes because of variation in the reflectivity of earth's surface and atmosphere (Jansen et al., 2007; USEPA, 2014). GHGs, primarily CO_2, have longer residence times in the atmosphere of approximately 400 years and, therefore, recognized as long-lived climate change pollutants (Hegerl et al., 2007; Jansen et al., 2007; Santisi, 2012; Solomon et al., 2007).

Scientific evidence keeps mounting on the increasing significance of BC emissions influencing climate change. BC emissions, or simple *smoke* refers to the particles originating from soot and exist in the atmosphere mostly from anthropogenic activities including the incomplete burning of fossil fuels, wood, waste, and other open biomass burning such as forest fires (Ban-Weiss, Cao, Bala & Caldeira, 2012; Biello, 2012; Bond et al., 2013; Rypdal et al., 2009; Santisi, 2012). Since BC emissions absorb the sunlight's energy, rather than reflecting it back, soot is thought to cause global warming (Bond et al., 2013; Deangelis, 2011; Santisi, 2012). BC emissions, though not GHGs, are climate change pollutants of greater concern because of their ability to absorb solar energy, and, alter the reflectivity of earth's atmosphere and ice surfaces.

In studying global warming due to BC, Ramanathan and Carmichael (2008) concluded that soot accounts for roughly half of the global warming potential of CO_2, suggesting that BC emissions are linked with flooding and drought in southern and northern China respectively. According to Bond et al. (2013) and Ramanathan and Carmichael (2008), BC emission’s contribution to the global warming is ranked second after the CO_2 with a combined warming potential of 1.0 to 1.2 watts per square meter (Wm^{-2}).

Another scholar indicated that BC emissions or smoke emitted from the incomplete burning of biomass, waste and fossil fuels heat the earth twice as much than originally thought by scientists (Deangelis, 2011). BC particles are the principle light-absorbing emissions that absorb radiation from the sun and decrease the reflectivity of the earth’s surface and, therefore, contribute to global warming (Anonymous, 2013; Ban-Weiss et al., 2012; Bond et al., 2013; Kirkevåg, Iversen, Kirstjánsson, Seland, & Debernard, 2008; Kuo, 2009; NRC, 2002). Furthermore, cloud droplets entangle BC emissions, therefore, increasing the level and degree of cloud formation that disturbs thermal gradient. Also, clouds are less able to reflect sunlight when they become darker, thus, make the earth surface warmer (Deangelis, 2011; Forster et al., 2007; Mahajan et al., 2013; Santisi, 2012).

The Intergovernmental Panel on Climate Change [IPCC] is providing additional evidence from their assessment that BC as a short-lived climate change pollutant is contributing to global warming nearly twice as much than originally estimated (Deangelis, 2011). The author stated that BC emissions have approximately 60% of the global warming effects of CO_2 with world-wide warming effects of 0.9 Wm^{-2} (Deangelis, 2011). BC deposits have caused 0.5 to 1 .4 degree Celsius (^0C) of warming over last 100 years (Bond et al., 2013; Deangelis, 2011). Also, they contributed to the rapid warming in the Arctic region over the past 30 years (Bond et al., 2013; Deangelis, 2011; Santisi, 2012). BC deposits in the Arctic and the Himalayas promoted melting of ice by lowering reflectivity of ice which threatens the water supply of more than 10% of the world population (Deangelis, 2011). India and China, as larger emitters of BC emissions, are reported to have caused the melting of Himalaya glaciers because of the proximity to the Himalayan range (Bond et al., 2013; Deangelis, 2011).

BC emissions cause acute lower respiration infections, lung cancer, pneumonia, premature death, and chronic obstructive pulmonary disease (Deangelis, 2011; Hoek et al., 2011; Jansen et al., 2005; Shi et al., 2007; USEPA 2013; WHO, 2012, 2014b). As a result of its small particle size of 2.5 or smaller micrometer diameter, BC is said to penetrate deeply into the lungs, thus, people absorb fatal compounds like polycyclic aromatic hydrocarbons into their bloodstreams which lead to cancer-causing cell mutations and cardiovascular disease risks (Kuo, 2009; WHO, 2012). In addition to contributing to chronic disease risks, Grasso, Manera, Chiabai and Markandya (2012) and Haines and Patz (2004) reported climate change to be among the important factors prompting the occurrence of infectious diseases as well.

In analyzing the potential effects of climate change in relation to heat exposure illness, Casimiro, Calheiros, Filipe, and Kovats (2006) projected an increase in vector-borne diseases mainly schistosomiasis and malaria in Portugal between the year 1980 and

2050. Furthermore, extreme weather, food and water scarcity associated with climate change, tend to modify human behavior and lifestyle, which in turn, contribute to negative health as reported by DeBono, Vincenti and Calleja (2012).

Management of HCW is ineffective in most global South countries in Asia, Africa and Caribbean (Andrea, 2010; Manyele & Kagonji, 2012; Mochungong, Gulius, & Sodemann, 2012; Njagi, Oloo, J. Kithinji, & M. Kithinji, 2012; Taghipour & Mosaferi, 2009). Approximately 85% of HCW generated in healthcare settings is comparable to household waste (WHO, 2014), thus normally disposed of through municipalities. The remaining 15% is infectious sharps, non-sharps, and, hazardous waste that requires treatment, incineration or complex hazardous waste disposal actions (WHO, 2011, 2014c). More specifically, infectious waste comprises of approximately 5% whereas hazardous waste account for 10% of HCW.

Sharps HCW, though represent about 1% of HCW, are major sources of transmitting infections mainly hepatitis B, C, and acquired immunodeficiency syndrome (AIDS), if they are not properly disposed of (Andrea, 2010; Ciplak & Barton, 2012; Ministry of Health and Social Welfare Tanzania, 2006a, 2006b, 2006c; WHO, 2011, 2014c). Ineffective management of HCW in global South countries causes air pollution and exposes healthcare workers, patients and the general community to risks of infections (Andrea, 2010; International Monetary Fund [IMF], 2008; Ko, 1992; WHO, 2011, 2014c).

In studying combustion and emissions from 6 HCW incinerators in Egypt, Zakaria et al. (2005) reported the average smoke emissions to have been exceeded the allowable limits established by the Egyptian environmental law for all incinerators. Incineration of HCW in Haiti "…as practiced by some health facilities is carried out without any filtering system thus raising the problem of air pollution and exposure to risks of disease on the part of the people living near such a pollution source" (IMF, 2008 p. 46). Smoke emission from HCW incineration activities in Haiti is a growing threat to both public health and climate change.

Similarly, Ko (1992) analyzed air particulate samples from two hospitals incinerators in Toronto, Canada, through proton-induced X-ray emission analysis (PIXE) and neutral activation analysis (INAA). The purpose was to identify various sources of emission and their contributions to the ambient atmosphere. The results indicated HCW incineration processes to have been the major source of anthropogenic BC emissions at the two study sites which contributed to 22% and 36% ambient emissions found (Ko, 1992). In addition, higher levels of toxic chemicals such as Ag, Cd, Sb, Cr, Zn and Pb were found in the ambient air owing to the higher plastic content in the HCW (Ko, 1992). Poor HCW segregation, wrongful anticipation of demands and poor inventory, as explained by Hicks (2013) and WHO (2014c), caused higher HCW volumes, and that the cost of wastage is one of the biggest expenditure in the healthcare system. Hicks (2013) thus, recommended the use of inventory technologies in demand forecasting, ordering appropriate amount of required supplies and equipment at the right time, and proper monitoring of inventories in order to reduce HCW volumes that reduce medical cost in general.

Andrea (2010) conducted a study on challenges affecting healthcare waste management (HCWM) in the Caribbean countries including Jamaica, St. Vincent and Grenadines, and the Republic of Trinidad and Tobago public hospitals in October 2009. In his results, Andrea, reported poor HCWM in public hospitals with the widespread lack of sharps waste containers, lack of HCW records and measurements for tracking HCW for disposal (Andrea, 2010). At the roots of his findings were a case of insufficient funds for HCWM, lack of standard operating procedures, inadequate environmental health and safety, absence of occupation health and safety, and lack of regulations in Jamaica (Andrea, 2010). According to Andrea (2010), HCWM costs in Caribbean were neither tracked nor included in hospital operations nor maintenance costs.

Two groups of researchers from Cameroon analyzed HCWM processes from which they noticed ineffective conditions such as poor incineration process, higher HCW generation rates and poor segregation practices (Mangaa et al., 2011; Mochungong et al., 2012). These findings were similarly shared by Bangladesh counterparts, Akter and Tränkler (2003), who finally recommended a chain of steps needed to improve HCW disposal in Bangladesh medical facilities with stricter emission regulations. Similarly, Coker et al. (2009) recommended requirements for monitoring and evaluation of HCWM activities in Ibadan, Nigeria.

On another extreme, Manowan (2009) reporting on the management of HCW in Thailand, suggested the need to acquire an effective incineration process to mitigate climate change effects, while Alhumoud and Alhumoud (2007) pointed to the need for a detailed study to address rules and standards on HCWM in Kuwait. Likewise, Emenike

(2010) studied the efficiency of HCWM interventions in the global South countries through a systematic review of HCWM interventions between 2000 and 2010. The author reported efforts done in China, which, reduced stack emissions and increased efficiency of HCW incineration process (Emenike, 2010). Effectiveness of incineration as the best available HCW disposal technology in the global South countries is necessary in order to reduce BC emissions.

The WHO team argued that treaties to reduce BC emissions would slow global and regional warming and would improve public health, especially in the global South countries where BC emissions originate primarily (WHO, 2012). More precisely, reducing short lived-climate pollutants could prevent 2 to 2.5 million annual deaths in the world (WHO, 2014b). Therefore, additional research on BC emissions reduction and strong policy guidelines towards climate change mitigation measures are crucial (Bond et al., 2013; NRC, 2010; Spotts, 2013; Stott, 2006; Tollefson, 2012), including an analysis of emergency HCW incineration trends and related BC emissions.

Problem statement

Although BC emissions reduction efforts had been traditionally left under the WHO which aims at reducing health risks associated with PM, the evidence of higher atmospheric warming potential of BC emissions requires joint efforts to reduce global BC emissions from different sources (Biello, 2012; Bond et al., 2013; Jacobson, 2004; Ramanathan & Carmichael, 2008; Rypdal et al., 2009; Santisi, 2012; Spotts, 2013). Jacobson (2004) and Rypdal et al. (2009) reported that the framework of Kyoto Protocol described under the United Nations Framework Convention on Climate Change

[UNFCCC] does not focus on BC emissions reduction. Notably, Santisi (2012) indicated that a nearly 3 degree Fahrenheit warming could be reduced above the arctic circles by controlling soot within five years, which are comparable to reversing all the warming that happened in the last 100 years in the Arctic region.

Likewise, smoke or BC emissions are confirmed to be the major source of respiratory health risks affecting worldwide population health mainly in the global South countries (WHO, 2014a). Researchers provided scientific evidence that over ¾ of BC emissions come from the global South countries in the world followed by China (25%) and India (35%) (Deangelis, 2011; Santisi, 2012). HCW incineration activities in the global South countries including Haiti lack air pollution control systems, thus, release smoke into the atmosphere (Andrea, 2010; Batterman, 2004; Ferraz et al., 2000; IMF, 2008; Ko, 1992; Zakaria et al., 2005). Reducing BC particles may cause immediate health and climatic effects because of its shorter atmospheric lifetime as compared to CO_2 (American Meteorological Society, 2008; Bond et al., 2013; Jacobson, 2004; Ramanathan & Carmichael, 2008: Rypdal et al., 2009; Santisi, 2012; Spotts, 2013).

Based on the three identified needs of joint efforts in curbing BC emissions, higher BC emissions in the global South countries, and the observed lack of control systems in HCW incineration activities in the global South countries including Haiti, the study identified a gap related to BC mitigation measures by healthcare facilities. This includes the ways in which HCW generation rates and smoke emissions can be reduced in hospitals. Thus, a call for a study to analyze HCW incineration trends during an emergency situation and smoke measurement for different sharps container’s incineration processes.

Purpose of the Study

The purpose of this study was:

1. To determine whether HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti follow a linear pattern.
2. To measure the average smoke densities coming from incineration of plastic and cardboard sharps HCW containers.
3. To determine if cardboard HCW sharps containers emit lower BC emissions to the atmosphere during the incineration process, relative to the plastic sharps containers.

In order to address the first study purpose, I quantitatively analyzed HCW incineration trend of the United Nations Mission for Stabilization in Haiti (MINUSTAH) within a span of 5 years of data starting from January, 2009 to December, 2013. This entailed going back one year before the most fatal 2010 earthquake and cholera disasters, and 4 years thereafter. The independent variable was the period including 12 months (January to December) in which HCW was incinerated from January, 2009 to December, 2013, while the dependent variable was the weights in kilogram (kg) of incinerated HCW. The second and third purposes were addressed by observing and recording the estimated smoke levels or Ringelmann smoke numbers that are also quantitative by nature. Average smoke densities were computed based on the Ringelmann smoke numbers for BC emissions or smoke from incineration of plastic and cardboard sharps containers. The independent and dependent variables were the types of sharps HCW containers (Cardboard and plastic) and the average smoke densities in percentage respectively.

Research Questions

In this study, I addressed two research questions:

1. Do HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti follow a linear pattern?
2. Do the cardboard HCW sharps containers emit lower BC emissions to the atmosphere during the incineration process, relative to the plastic sharps containers?

The hypotheses for the first research question were:

- Null hypothesis (H_o): the pattern of HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti is linear.
- Alternate hypothesis (H_a): the pattern of HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti is non-linear.

The hypotheses for the second research question were:

- Null hypothesis (H_o): The average densities of BC emissions (smoke) during the incineration process of plastic sharps HCW containers and cardboard boxes are similar.

- Alternate hypothesis (H_a): The average density of BC emissions (smoke) is significantly lower during the incineration process of cardboard box sharps HCW containers.

The independent and dependent variables for the first hypothesis were the time (months) in which HCW was incinerated from January 2009 to December 2013, and the weights in kg of HCW incinerated respectively. For the second hypothesis, the independent variables were the types of sharps containers (cardboard and plastic), while the dependent variables were smoke densities or Ringelmann smoke numbers. In this study, I used the independent samples *t-test* to analyze the differences between smokes means obtained from incineration of cardboard and plastic sharps HCW containers. Likewise, I performed linear regression analysis to analyse the pattern of HCW incinerated weights, and predicted relationships in the resulting emergency HCW incineration model.

Conceptual Framework

The study's conceptual framework focused on the potential health and climate change effects of BC emissions, and, therefore, the need for reducing smoke emissions from HCW incineration activities. Unabated BC emissions are a growing threat, scientifically proven to be causing a variety of human health effects and climate change with extreme impacts in the global South countries (Deangelis, 2011; Pan American Health Organization [PAHO], 2012; WHO, 2012, 2014b).

In previous discussions, it is reported that over three quarters of BC emissions in the world originates primarily in the global South countries (Deangelis, 2011; WHO, 2012, 2014a). Correspondingly, researchers have shown that climate change impacts global population health in many ways including community migration, thus, regional and tribal conflicts towards squeezed resources (PAHO, 2012). Change in intensity, frequency and duration of weather events is the major cause of community relocation (PAHO, 2012).

Grasso et al. (2012) and Haines and Patz (2004) reported climate change to be prompting the occurrence of infectious diseases. In studying climate change effects, Casimiro et al. (2006) projected an increase in vector-borne illnesses mainly schistosomiasis and malaria in Portugal between the year 1980 and 2050. Furthermore, climate change leads to food and water scarcity that tends to modify human behavior and lifestyle, thus, negative health (DeBono et al., 2012). Deangelis (2011) cited the resultant melting of the Himalayan glacier following BC deposits, while Ramanathan and Carmichael (2008) suggested that BC emissions are linked to the flooding and drought in southern and northern China respectively.

Experimental researchers show that exposure to BC emission causes airway inflammation, increase levels of serum amyloid, higher blood coagulation tendency and temporary lipid peroxidation’s increase (Barregard et al., 2006, 2008; Sehlstedt et al., 2010; Solomon, Balmes, Jenkins, & Kleinman, 2003). Grounding in the experimental study results above, epidemiologists reported an association between death rates and BC emissions (Jiang, Kazuhiko, Lall, Lippmann, & Thurston, 2011), and that, the rates vary based on season, location and source of BC emissions as supported by Grigg (2011), Maciejczyk, Zhong, Lippmann, and Chen (2010), and Park et al. (2007). Likewise, the USEPA (2013) and WHO (2012, 2014b) scientists reported long-term exposure effects of BC emissions to be reproductive effects, reduced lung functions, development of chronic bronchitis, low birth weights, cancer, and premature deaths. Short-term effects cause asthma attack, acute bronchitis, and increase susceptibility to respiratory infections (USEPA, 2013; WHO, 2012).

Based on the health and climate change effects of BC emissions, higher BC emissions in the global South countries, and regional variation in climate change impacts, additional studies to evaluate climate change mitigation measures are needed, including BC emissions reduction measures. One of the major methods to controlling BC emissions is by reducing smoke emissions from various sources including emergency HCW incineration activities, a focal point to which this study is directed.

Nature of the Study

This study was an observational undertaking that relied on both primary and secondary data in analyzing smoke emissions from incineration of cardboard and plastic contained sharps waste, and emergency HCW incineration trends respectively. Observational study approach was considered appropriate as it stood to provide useful results for this study that directly relate to physical sciences as emphasized by Frankfort-Nachmias and Nachmias (2008) and Javaherian (2012). I analyzed HCW incineration trend of the United Nations Haiti within a span of 5 year data starting from January 2009 to December 2013 based on the approval note appeared under Appendix B. Equally, primary data on smoke density emitted from incineration of sharps HCW containers were collected and analyzed. As such, I applied a quantitative research design to the effect.

I conducted quantitative analysis of HCW incineration trend by using secondary data on HCW incinerated weights by MINUSTAH from January 2009 to December 2013. The independent and dependent variables were monthly periods in which HCW was incinerated, and HCW weights (kg) respectively. Quantitative data allowed statistical tests, including linear regression analysis that determined the pattern of HCW incinerated weights, and predicted relationships in the resulting emergency HCW incineration model as emphasized by Frankfort-Nachmias and Nachmias, (2008). Use of secondary data in this analysis reduced the study costs and time as well as providing answers to the testable hypotheses (Frankfort-Nachmias & Nachmias, 2008).

Conversely, I employed quantitative approach to determine the BC emissions or smoke densities through observation at incinerator initial startup, the charging phase, and the actual burning phase for plastic and cardboard sharps HCW containers. The Ringelmann smoke charts were used to measure the intensity of smoke or Ringelmann smoke numbers which were then be used to compute the average smoke densities. The independent and dependent variables were the types of sharps HCW containers (Cardboard and plastic) and the average smoke densities in percentage respectively. Likewise, the independent samples *t-test* was used to test the differences between smokes means obtained from two separate incineration processes for cardboard boxes and plastic sharps HCW containers. I have discussed in details the data collection procedure in Chapter 3.

Definition of Terms

Soot: Refers to the BC particles formed at higher temperatures through gas-phase processes, such as diesel engines and incinerators (WHO, 2012).

Char: Refers to the carbonaceous materials formed when organic substances are heated up, from the pyrolysis process, or from partial burning of carbonaceous material with limited air or graphitic carbon (WHO, 2012).

Black carbon (BC): Refers to the dark component of particulate matter (PM) which absorbs light and contains two forms of elemental carbon (Bond et al., 2013; WHO, 2012). BC is the generic term introduced by Novakov in 1982 and modified later in 1988 by Goldberg.

Elemental carbon (EC): Refers to the PM in the atmosphere derived from combustion sources containing “Char-EC” and “Soot-EC” (Bond et al., 2013; Borrell, 2008; WHO, 2012).

Particulate matter (PM): Refers to the mixture of liquid droplets and solid particles found in air. PM includes soot, dust, char, smoke, dirt and other invisible particles made up of hundreds of diverse chemicals (USEPA, 2013). Inhalable PM includes fine particles of 2.5 or smaller micrometer diameter size and coarse particles ranging from 2.5-10 micrometer diameter size. Sources of PM into the atmosphere can be primary (from smokestacks/incineration exhausts) or secondary (from complicated reactions of industrial chemicals in the air or industrial operations).

Health-care waste (HCW): Refers to the liquid, gaseous and solid materials generated from healthcare facilities, laboratories, medical research institutions, homes and other minor sources that include infectious sharps and non-sharps waste, pharmaceuticals, general waste, chemicals and radioactive materials (Ministry of Health and Social Welfare Tanzania, 2006a, 2006b, 2006c; WHO, 2014c).

Health-care waste management (HCWM): Refers to a chain of activities that ensure safer HCW generation rates, handling, collection, storage, transport, treatment or destruction and final disposal (Ministry of Health and Social Welfare Tanzania, 2006a, 2006b, 2006c).

Health-care waste incineration: Refers to the HCW organic material's thermal destruction by combusting at higher temperatures of above 800 ^{0}C in order to reduce waste volume and weight to over 80 % (WHO, 2014c). Over 90% of infectious HCW generated in the United States is incinerated (Patki, 2012). HCW incineration by-products are flue gas, heat, particulates and ash (Ahmad, Baharun and Arshad, 2010; WHO, 2014c). Air pollution control system is required in order to clean particles and compounds prior to release into the atmosphere (Basel Convention Technical Guidelines on Incineration on Land, 2002; GEF, 2009; UNEP 1996, 2005; USEPA, 2010; WHO, 2014c).

HCW incinerated weights: Refers to the amount of HCW in kg that was disposed of through thermal destruction by burning in the incinerator.

Thermoplastics: Refers to plastic materials that melt while burning (Boedeker Plastics, Inc., 2014).

Thermoset plastics: Refers to plastic materials that do not melt while burning (Boedeker Plastics, Inc., 2014).

Assumptions

The key study assumptions are highlighted below:

- I assumed that smoke emissions measurements from incinerators, using Ringelmann smoke charts, were unbiased. As such, the study recorded readings from three different smoke readers during the initial startup, the charging phase, and the actual burning phase before using the average phase-based readings as the final unbiased readings; assumed proper eyesight among three smoke readers trained in the use of the Ringelmann smoke charts.
- I assumed that the nature of sharps waste generated before and after the 2010 earthquake and cholera disasters in Haiti is similar.
- I assumed that HCW incineration weight differences are associated with the 2010 earthquake and cholera disasters in Haiti. Other HCW sources during that time are unnoticed.
- I assumed that HCW incinerated weights and patterns by MINUSTAH represent the HCW patterns and weights incinerated by other healthcare disposal facilities in Haiti.

Scope and Delimitations

The study boundaries and aspects were:

- To determine the incineration patterns I used only the MINUSTAH’s HCW incinerated weights in the analysis. This was due to lack of reliable data on HCW incinerated weights from other healthcare facilities in Haiti.

- To measure black smoke emissions at three different healthcare incineration facilities including (a) MINUSTAH, (b) Public hospital, and (c) Private hospital.
- This study's conceptual framework was based on the significant health effects of exposure to BC emissions and climate change potential of the BC emissions. However, other aspects of the BC emissions including its cooling effects are excluded in the study.
- To generalize HCW incinerated weights by MINUSTAH and the smoke measurement from three different healthcare facilities as a representation of the actual HCW incinerated weights and BC emissions in Haiti.

Limitations

The main study limitations were:

- Lack of HCW incineration facilities nor records at Haiti State's Hospital University, the location at which the Ministry of Public Health and Population (MSPP) in Haiti permitted me to conduct my research. I intended to collect primary data from this public hospital as indicated in the second study objective to measure the average smoke densities from incineration of plastic and cardboard sharps HCW containers from three hospitals in Haiti. Similarly, I was unable to get permission from any of the private hospitals visited. Thus, I had to rely only on the MINUSTAH HCW incinerated weights and incineration facilities for the available secondary data and primary data collection.

- Lack of acceptable BC or EC standard measurement methods in the world as reported by the WHO, (2012). As a result, in this study I had to opt for the use of Ringelmann smoke chart, regarded as a valid smoke measurement tool.
- Insecurity impediments in Haiti that prevented me from visiting hospital in Cite Soleil. It is possible that hospitals in this area could, perhaps, have provided different insights in regard to HCW incineration in the country.
- Weather challenges during smoke emission reading had forced me to postpone smoke reading test on a number of days that were either cloudy or highly windy.
- It is possible that the MINUSTAH HCW incinerated weights and patterns might not represent the real patterns in Haiti as the materials came from different sources during the emergency. This infers that other hospitals could well have had different patterns due to the logistical problems including accessibility to transport during emergency.

Significance of the Study

This is the first study where a researcher analyzes HCW weights incinerated by MINUSTAH around the most fatally catastrophic 2010 earthquake, and the resultant cholera disasters that would provide an evidence-based account of what may have transpired. Second, it is optimistic that the results of the HCW incineration patterns analysis have provided information useful to most humanitarian agencies on effective planning of emergency medical responses in the future in order to avoid expired pharmaceuticals, leading to lowered BC emissions and fuel consumption.

Third, reduced HCW incineration emissions could result in positive social change for healthier communities following a drop in BC emission exposure and associated health risks. Fourth, the study findings on the challenges of emergency HCW incineration process in relation to BC emissions in Haiti may provide an informed basis for robust policy formulation and safe management of HCW disposal in Haiti and other countries where emergency and humanitarian efforts could similarly be taking place. Fifth, the findings could possibly provide informed guidelines for the purchase and use of greener sharps HCW containers verifiable for lower smoke emission as among climate change mitigation measures. Finally, the study outcome confirmed that there is a widespread lack of filtering system in incineration facilities in Haiti (IMF, 2008) observation.

Chapter 1 Summary

Enhanced research and tools, faster learning, flexibility and robust policy frameworks are critical measures for effective climate change remedies. According to the recent studies, BC emissions are reported to be the second cause of climate change after CO_2 with approximately 60 % of global warming effects of CO_2. Consequently, this study evaluated BC emissions from sharps HCW incineration, and patterns of emergency HCW incinerated weights for informed measures in the future emergency planning and climate change mitigation measures.

As such, Chapter 1 included background information necessary to grasp the study problem, its purpose and significance to make a difference in the academic world. In

Chapter 2, I provide details on the empirical evidence and conceptual frameworks in analyzing the research problem. This covered health effects of BC emissions, ambient air quality standards for PM, occupational BC exposure limits, as well as climate change effects. Likewise, HCW incineration practices as performed by MINUSTAH, Guidelines on HCW incineration process and smoke emissions are captured in Chapter 3 under tools, design, procedures, and methodology for success of this study. In Chapter 4, I used statistical tests to analyze the research questions, hypotheses and documented the results. Chapter 5 is the final part of this study. In this area I interpreted my findings, discussed study limitations, and drew conclusion and recommendations.

Chapter 2: Literature Review

Introduction

In Chapter 2, I summarize the outcomes of the literature review that supports the conceptual framework, research design and methodology for this study. Most importantly, this is the first study of its kind to analyze the emergency HCW incineration trends and its climate change effects which is exceptional to the available research. In this chapter, my aim was to identify a knowledge gap that has not been documented by previous studies.

BC emissions, also released during HCW incineration process, are identified to be the second strongest cause of climate change after $CO_{2.}$ Scientists reported that reducing BC emissions will result into immediate health and climate change effects due to their shorter residence time in the atmosphere as compared to CO_2. However, BC emissions reduction remained untapped potential that requires action in order to attain healthier environments. Both the literature review and online search processes supported that there is a research gap on the BC emissions from the incineration of HCW and the associated mitigation measures. Similarly, the purpose of the study was to examine the climate change implications of HCW incineration in emergencies based on the conceptual framework of health and climate effects caused by its exhaust emissions.

The literature review for this research based on online search that I conducted through Academic Search Complete, CINAHL Plus with Full Text, Dissertations and Theses, Medline with Full Text, Science Direct and ProQuest Central databases using the Walden University Library. Key search terms that I used included healthcare or hospital or medical waste incineration, black carbon emissions, global warming, climate change, incineration emissions, incineration smoke, health effects of BC emissions exposure, effects of climate change and waste disposal. Apart from online references from search engines, other sources were included such as International Panel on Climate Change [IPCC] meeting proceedings, the USEPA, WHO, United Nations treaties, WMO, and HCWM reports. In the literature search, I prioritized articles and reports that were peer reviewed and published within the last 5 years.

Conceptual Framework

The conceptual framework focused on the potential effects of BC emissions exposure to human health and its associated climate change potential. BC emissions are a growing threat to human health and climate change with extreme impacts in the global South countries where over three quarters of BC emissions are produced (Deangelis, 2011; PAHO, 2012; WHO, 2012, 2014b). Subsequently, this called for the analysis of HCW incineration trends in Haiti after reported lack of control system (IMF, 2008) in order to provide knowledge, insights and scientific evidence towards BC mitigation measures. Some key references underlining the effects of BC emissions included research on climate change potential of BC emissions (Ban-Weiss et al., 2012; Bond et al., 2013; Kuo, 2009; Mahajan et al., 2013; Rypdal et al., 2009; Santisi, 2012; UNEP/WMO, 2011) and regional distribution of climate change effects (PAHO, 2012; WHO, 2012, 2014b).

Likewise, BC emissions are reported to be associated with morbidity, and the global South communities remained at higher risks because of higher generation of BC emissions (Barregard et al., 2006, 2008; Danielsen et al., 2008; Grigg, 2011; Hoek et al., 2011; Jansen et al., 2005; Maciejczyk et al., 2010; Park et al., 2007; Sehlstedt et al., 2010; Solomon et al., 2003; USEPA, 2013; WHO, 2012, 2014b). Also, researchers indicated the evidence on deaths associated with both climate change and BC emissions exposure (Bond et al., 2013; Haines & Patz, 2004; Jian et al., 2011; USEPA, 2013; United States Global Change Research Program [USGCRP], 2009; WHO, 2012, 2014b).

Conversely, I based this study's conceptual framework on potential health effects of BC emissions to humans directly exposed. Furthermore, in the literature review, I focused on the studies about the climate change potential of the BC emissions. The following is a summary of the literature review based on the two key components of the conceptual framework.

Health Effects of Black Carbon Emissions Exposure

The effects of exposure to BC emissions are associated with that of $PM_{2.5}$ or PM_{10} and vice versa (WHO, 2012). Also, World Health Organization (2012), through reviewers, noted that health effects of BC emissions are much greater as compared to $PM_{2.5}$ or PM_{10} when particulates are measured in unit mass concentration of microgram per cubic meters ($\mu g/m^3$). "Studies of short-term health effects show that the associations with BC are more robust than those with $PM_{2.5}$ or PM_{10}, suggesting that BC is a better indicator of harmful particulate substances from combustion sources (especially traffic) than undifferentiated PM mass" (WHO, 2012 p. vii).

Existing studies of BC emissions exposure and associated health effects largely target experimental, long and short-term exposure to different sources of BC emissions including wood smoke, rice-straw smoke (RSS), ultrafine PM and EC. These are particularly relevant to study together with the WHO review research. In a 3-days experimental study to evaluate health effects of RSS exposure to 27 women and 18 men, Solomon et al. (2003) reported airway inflammation among healthy, asthmatic and allergic rhinitis subjects. The impact manifested after single exposure to PM_{10} ~600 μg/m^3 and three uninterrupted exposure patterns to PM_{10} ~200 μg/m^3 each lasting 30-minutes. According to Solomon et al. (2003), asthmatic subjects showed higher inflammation as compared to healthy subjects, and repeated exposure to PM_{10} ~200 μg/m^3 caused a more powerful inflammation than a single PM_{10} ~600 μg/m^3 exposure among all subjects.

Other BC experimental exposure studies were performed by Barregard, et al. (2006, 2008) and Sällsten et al. (2006) from the Swedish University of Gothenburg. The authors generated smoke from logwood burn on a cast iron stove and exposed healthy volunteers (seven women and six men of 20 to 56 years) to wood smoke of $PM_{2.5}$ ~ 279 and 243 μg/m^3 in two different sessions of 4 hours each. Clean air break patterns of 25 minutes period were presented between wood smoke exposure patterns in which light exercises were performed at clean air of 13 and 11μg/m^3 PM respectively. According to the results, wood smoke exposure was associated with elevated levels of serum amyloid (cardiovascular risk factor), higher blood coagulation tendency, impermanent increase in lipid peroxidation and inflammatory response (Barregard et al., 2006, 2008). The exposure session was followed by substantial up-regulation of blood mononuclear cell's repair gene among subjects 20 hours after wood smoke exposure (Danielsen et al., 2008).

Similar wood smoke exposure study was evaluated by Sehlstedt et al. (2010). The study was performed among 9 women and 10 men of 21 to 31 years. After two-3 hours exposure patterns to wood smoke with mean $PM_{2.5}$ of 224 $\mu g/m^3$ from a 15 kilo Watt residential pallet burner and clean air, progressive mild irritation occurred in the nose and throat especially between 90 and 150 minutes of wood burning. Furthermore, Riddervold et al. (2011) reported a significant increase in mucosal irritation among allergic subjects (10 women and 10 men of 19 to55 years) after exposure to wood smoke from logwood burner. Three exposure patterns of 3.5 hours each were presented to subjects and characteristics of smoke for this experiment were $PM_{2.5}$ ~200 $\mu g/m^3$ and $PM_{2.5}$ ~ 400 $\mu g/m^3$ (Riddervold et al., 2011).

Different from experimental studies above is an epidemiological study to assess the association between health effects and PM including BC among 16 older respiratory disease subjects in Seattle by Jansen et al. (2005). Data on the fractional exhaled nitric oxide, blood pressure, spirometry, blood oxygen saturation and pulse rate were sampled for 12 days and analyzed simultaneously with the collected air filters located inside and outside subject's houses. Jansen et al. (2005) showed that increase in 1$\mu g/m^3$ BC emissions were associated with elevations in fractional exhaled nitric oxide among subjects. The author reported that BC particles are useful in assessing the associations between PM from primary combustion and health effects (Jansen et al., 2005). This was supported by meta-analysis and systematic review by Hoek et al. (2011) in which the author suggested that "BCP is a valuable additional air quality indicator to evaluate the health risks of air quality dominated by primary combustion particles" (p. 1691).

Based on the above findings, Jiang et al. (2011) performed a time-series study aimed at assessing the mortality effects of fine PM components in Seattle and Detroit from 2002 to 2004. Jiang et al. (2011) collected 24 hour Teflon filter samples of $PM_{2.5}$ in two sets for 3 years and analyzed them for BC and trace elements using light reflectance and X-ray fluorescence respectively. In order to estimate seasonal variation in cardiovascular and respiratory deaths, 3 sources of data applied in the processes of conducting the poison regression model analysis.

Data sources included those of the mortality data from the National Center for Health Statistics [NCHS], gaseous pollutant data from the Health Effects Institute [HEI], and metrological data from the National Oceanic and Atmospheric Administration. Jiang et al. (2011) in his result indicated that the composition of PM influenced health effects associated with PM and that Seattle's mortality rates were associated with traffic during the cold season and other BC emission sources such as wood burning and residual lubricant (Jiang et al., 2011). Detroit's mortality rates according to Jiang et al. (2011) were associated with traffic makers and secondary emissions during the warm season, explaining seasonal, locale, and source mortality difference as proposed by Grigg (2011), Maciejczyk et al. (2010), and Park et al. (2007).

More specific, WHO (2012) systematically reviewed several studies on health effects of BC emissions and the review team concluded that:

- Epidemiological short-term studies sufficiently evidenced the association between daily BC emission's concentration difference and short-term health changes.

- Cohort studies sufficiently evidenced the relationship between long-term BC average emission exposure and mortality including cardiopulmonary mortality and all-cause mortality.
- Toxicological research recommended that BC could not be a fine PM's main toxic constituent, but rather a common carrier of toxic compounds to the lung, major body defense cells and perhaps the blood's systemic circulation.
- Reducing exposure to BC and combustion-related particulates of $PM_{2.5}$ should reduce health effects related to PM exposure.

Likewise, the USEPA (2013) and WHO (2012, 2013, 2014b) scientists reported short and long-term exposure effects of BC emissions to be: low birth weights and premature deaths, reduced lung functions, reproductive effects, development of chronic bronchitis and cancer, acute bronchitis, asthma attack and increase susceptibility to respiratory infections. Nearly 235 million people in the world suffer from asthma illness with most deaths being in the global South countries (WHO, 2013). Asthma is a persistent chronic ailment in Haiti and the Capital Allergy and Respiratory Disease Center is among organizations that work to improve asthma disease treatment in Haiti (Capital Allergy and Respiratory Disease Center, 2013).

In summarizing the above findings, it is evident that BC emissions exposure is associated with health effects and that mortality differences based on season, location and PM source. In the next sub-sections, I show the gap in relation to the air quality standards for PM, smoke emission limits for HCW incineration activities, and reduction of BC emissions as among pollutants significant to climate fix.

Ambient Air Quality Standards for Particulate Matter

The WHO team reported non-existence of any acceptable BC or EC standard measurement methods in the world over the last 20 years, the exhaustive efforts notwithstanding (WHO, 2012). Scientifically speaking, this is such an expansive void in the face of the escalating climate change threat, thus, the tallying with this study's problem statement and social change implications. Subsequently, the WHO experts called for the need to address inherent biases in thermal optical and filter-based light absorption carbon measurements to find definite and world unifying scientific frameworks soonest (WHO, 2012).

There exist both the annual and daily ambient air quality standards for PM in general set by the WHO and various countries, mostly the developed nations. However, some of the county-specific PM standards are far above the WHO as shown in Table 1, and also its implementation remains big dilemmas. A review of PM air monitoring studies in twelve African countries indicated higher $PM_{2.5}$ level above the WHO limits as reported by Petkova, Jack, Volavka-Close and Kinney (2013).

Table 1

Ambient Air Quality Standards for Particulate Matter

Country / institution	PM size	24 hours mean limits (μg/m^3)	Annual mean limits (μg/m^3)	Reference
WHO	$PM_{2.5}$	25	10	WHO (2014a)
	PM_{10}	50	20	
USA	$PM_{2.5}$	35^{ab}	12^{a}, 15^{b}	USEPA (2012)
	PM_{10}	-	150	
EU	$PM_{2.5}$	-	25	European Commission (2014)
	PM_{10}	50	40	
CANADA	$PM_{2.5}$	1^{0c}	30^{d}, 28^{c}	Environment Canada (2014)
	PM_{10}	-	-	
AUSTRALIA	$PM_{2.5}$	25	8	The Australian Government Department of Environment (2014)
	PM_{10}	50	-	
CHINA	$PM_{2.5}$	50^{e}, 150^{f}, 250^{g}	40^{e}, 100^{f}, 150^{g}	Code of China (2014)
	PM_{10}	50^{e}, 150^{f}, 250^{g}	40^{e}, 100^{f}, 150^{g}	

Note: Ambient air quality standards for smoke or Particulate Matter (PM) as is given by different institutions. a = primary source, b = secondary source, c = new air quality standards to be implemented in 2015, d = existing or old air quality standards, e = residential areas, f = commercial areas, g = industrial areas.

Occupational Black Carbon Exposure Limits

In my literature search for occupational BC emissions exposure limits, I found world-wide information inadequacy in this area. It follows that most of the global South countries lack BC emissions occupational limits which, in fact, is no good news but a wake-up-call for future research. Smoke emissions from HCW incineration processes remain unregulated in most global South countries, hence, expose healthcare workers, the general community, and contribute to climate change (Andrea, 2010; Ferraz et al., 2000; Ko, 1992; Mangaa et al., 2011; Zakaria & Labib, 2003; Zakaria et al., 2005). According to the Mine Safety and Health Administration, the final exposure limit for total carbon exposure for mine workers is 160 micrograms of total carbon (160_{TC} μg/m^3) or 308 micrograms of elemental carbon per cubic meter of air (308_{EC}μg/m^3) as reported under the United States Department of Labor (MSHA, 2001).

Climate Change

Climate change played an important role in formulating this studies' conceptual framework. For years, its remedies have focused on curbing CO_2 emission based on one particular scientific argument that global warming primarily occurs when GHGs trap the incoming solar radiation and reflect back to the earth's surface the infrared radiation (Hansen et al., 2007, 2013; USEPA, 2014). However, very recent, researchers released scientific evidence that BC emissions heat the earth twice as much than originally thought by scientists (Bond et al., 2013; Deangelis, 2011; Santisi, 2012). Furthermore, BC emissions cause approximately 60% of the global warming effects of CO_2 (Bond et al., 2013; Deangelis, 2011; Santisi, 2012), making it the second most important global warming pollutant. Santisi (2012) and Deangelis (2011) argued that global warming reduction efforts could have been quickly achieved by reducing BC emissions as a short-lived climate pollutant.

In principle, BC emissions cause global warming by absorbing heat radiation from the sun and reduce the sunlight's reflecting ability of snow and ice upon its deposition, (Ban-Weiss et al., 2012; Kirkevåg et al., 2008; Kuo, 2009; NRC, 2002). Also, cloud droplets entrap BC emissions hence increase the level and degree of cloud formation. This interrupts thermal gradient because clouds are less able to reflect sunlight when they become darker, thus, warms the earth's surface (Deangelis, 2011; Foster, 2007; Mahajan et al., 2013; Santisi, 2012).

BC emissions contribute to world-wide warming effects of 0.9 Wm^{-2} (Deangelis, 2011), and their deposits on the Arctic ice have caused 0.5 to 1 .4 ^{0}C warming over the past 100 years, contributing to rapid warming in the Arctic region over the last 30 years. In the Arctic and Himalaya, BC deposits promoted the ice melting by lowering its reflectivity, which threatens the water supply of more than 10% of the world population due to its proximity to larger BC emitters, India and China (Deangelis, 2011).

Climate effects of BC emissions depend on their altitudinal position in the atmosphere (Ban-Weiss et al., 2012; Bond et al., 2013). When BC emissions concentrate in stratosphere and upper troposphere, they decrease the surface temperature and vice-versa. Ban-Weiss et al. (2012) studied the warming effects of BC emissions through simulation models. The author added 1 million tons of BC emissions uniformly at different horizontal layers (0, 3, 6, 1, 3, 20 and 23), corresponding to atmospheric attitudes of 0 km near surface, 1, 4, 12, 20 and 29 kilometers respectively (Ban-Weiss et al., 2012). The author reported that BC emissions added at higher levels produce less surface warming whereas the addition of 1 Mt of BC, at a point closer to the earth's surface increases terrestrial air temperature by 2.22+-0.007 Kelvin (Ban-Weiss et al., 2012).

Building on the same results, Mahajan (2013) modelled an experiment to simulate an increase in tropospheric BC emissions and climate response. The author discovered that the atmospheric radiative forcing of BC warms and increases linearly as the concentration of BC increases (Mahajan, 2013). The climate's BC sensitivity from the experiment was estimated to be 0.42 KW^{-1} m^2 and 0.22 KW^{-1} m^2 with semi-direct and direct effects considered respectively, and was forced with 0, 1X, 2X, 5X, and 10X daily BC emissions while maintaining the current day universal latitudinal and longitudinal distribution.

Based on the study findings above, climate change remains the most challenging world-wide topic that calls for the research to provide up-to-date scientific results; knowledge, insights and experience to the decision makers for adjustment of policy mitigation measures. According to the NRC (2010), research, tools and approaches are cross-cutting issues for improving the understanding of human's contribution to climate change, and that, the effective management of climate change requires flexible and robust actions by the decision makers. Consequently, scientific research is said to play a key role in informing decision makers on mitigation focus (NRC, 2010). As such, decision makers need to be very flexible, open to learn and equip with robust action plans for assured climate change risks management and mitigation measures including reduction of BC emissions (NRC, 2010; Spotts, 2013; Stott, 2006; Tollefson, 2012).

This study, therefore, would inform decision makers on matters pertaining to climate change potential of BC emissions from HCW incineration and their mitigation measures towards policy formulation. BC is the second highest climate change pollutant that originates primarily in the global South countries (Deangelis, 2011; WHO, 2012). Figure 1 summarizes the climate change potential of BC emissions in the climate system.

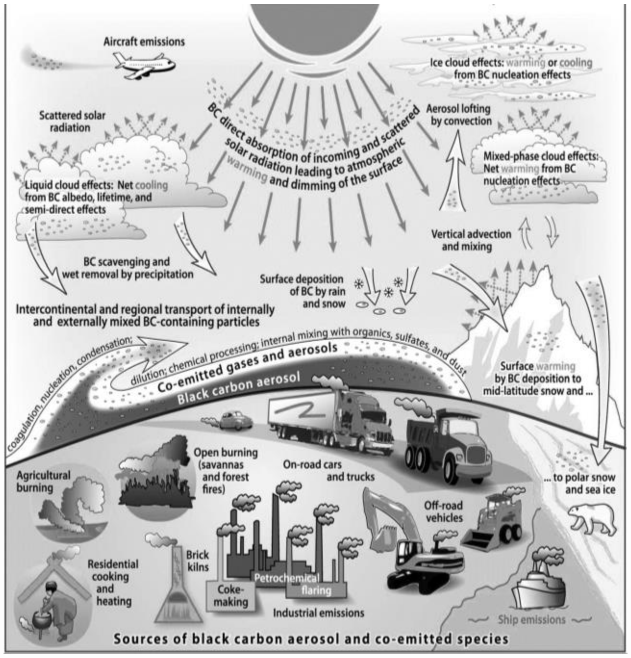

Figure 1. Black Carbon Emission and Processes in The Climate System.
Note. From "Bounding the role of black carbon in the climate system: A scientific assessment", by Bond, et al., 2013. *Journal of Geophysical Research: Atmospheres*, 118, p. 5390, doi:10.1002/jgrd.50171 Reprinted with permission (see Appendix H (ii)).

Guidelines on Healthcare Waste Incineration Process and Smoke Emissions

The WHO (2014c) recommended the use of medium temperature double-chambered incinerators with a minimum temperature of 850 ^{0}C for the emergency HCW disposal. This includes disposal of pharmaceuticals except antineoplastic waste that requires a higher temperature of above 1200 ^{0}C (WHO, 2001, 2014c).

Correspondingly, two types of sharps containers permitted for use are disposable containers made of plasticized plastic or cardboard, and reusable containers made of metal or plastics (WHO, 2014c). According to the WHO (2007), plastic containers are not supposed to be incinerated. In case incineration is the only available option, containers made of materials that emit toxic fumes, ozone depleting substances and gases with higher climate change potential are not permitted (WHO, 2007).

Although over 90% of HCW in the USA is incinerated as reported by Patki (2012), the United States Food and Drug administration [USFDA] (2013) permits the use of plastic sharps containers made of rigid plastic. Also, the USFDA (2013) permits the use of improvised containers such as empty detergent containers for home-based sharps HCW. Global south countries use both plastic and cardboard sharps HCW containers depending on the availability of such containers (see appendix G). Disposal of these containers as recommended by manufacturing companies is through incineration. There is variation on the choice of sharps HCW containers and their final disposal options in the globe.

Hence, the WHO emphasized greener procurement, re-use and recycling strategies to minimize HCW, use of non-polyvinyl chloride (PVC) equipment to avoid its toxicity, and proper HCW segregation (WHO, 2001, 2014c). Consequently, the WHO (2014c) added that the Environmental Procurement Policy (EPP) and re-use strategies are beneficial to both the environment and human health. The EPP is reported to have reduced HCW volumes in a UK hospital by 4.1 %, water and energy consumption by 9.8 % and 3.6 5 % respectively (WHO, 2014c).

Additionally, a formal approach called environmental management system (EMS) is used in developed countries having stringent environmental laws in order to manage the environmental impacts caused by organizations (WHO, 2014c). Hospitals and health centers should derive benefits from introducing and implementing an EMS in order to lower running cost by reducing quantities of waste and energy use, increasing recycling, and improving public image with efficient HCW management and environmental protection (WHO, 2014c). According to the WHO (2014c), approximately 41 % of Canadian hospitals re-use non-disposable medical devices. However, Neely, Maley, and Taylor (2003) evaluated over 250 reusable containers and found that over 99 % were contaminated, $p < 0.001$. Reusable plastic sharps HCW containers unlike single use cardboard boxes can cause hospital acquired infections because of ineffective disinfection practices.

The USEPA and European Union established emission guidelines for PM, smoke or dust emissions from HCW incineration process (WHO, 2014c; USEPA, 2010, 2012). However, HCW incineration smoke emissions remain unregulated in many areas of the world mainly the global South countries that lack emission standards and/or fail to comply with the set standards, thus, higher smoke levels from HCW incineration activities (Andrea, 2010; Batterman, 2004; Ferraz et al., 2000; IMF, 2008; Ko, 1992; Manowan, 2009; Zakaria et al.,2005; Zakaria & Labib, 2003).

The Stockholm Convention's primary measures of reducing toxic smoke by introducing HCW into combustion chambers at temperatures greater than 850 ^{0}C (WHO, 2014c), is hardly implementable. This is due to the wide use of low-temperature incinerators in the global South countries (Batterman, 2004) and manual incineration operations including waste loading. Table 2 shows HCW incinerator emissions guidelines for PM or smoke under different operational conditions.

Table 2

Healthcare Waste Incinerators Emission Limits for Particulate Matter

Pollutant (mg/m^3)	Standard conditions	USEPA emission limits	EU emission limits	Air pollution emission factor AP42	Reference
Particulate matter or total dust	20 (%) C, 101.3kPa, 7 (%) O$_{2,}$dry	66[a], 22[b], 18[c]	-	223	USEPA (2010)
	273^{0}k, 101.3kPa, 11 (%) O$_{2,}$dry	-	10[d], (10,30)[e],	15	WHO (2014c)

Note: Smoke, total dust or particulate matter emission limits for healthcare incinerators.
a = small incinerators of capacity up to 200 lbs. /hr., b = medium incinerator of capacity >200 to 500 lbs. /hr., c = a large incinerator of capacity >500 lbs. /hr., d = daily limits, e = Half-hour average limits to be attained by 97% and 100% respectively, AP42 = United States Environmental Protection Agency (USEPA) emission estimates for incinerators lacking filtering system, EU = European Union.

United Nations Stabilization Mission in Haiti Healthcare Waste Management

The Government of Haiti, through the Ministry of Public Health and Population (MSPP), recommends the incineration method of HCW disposal and functional incinerators exist in Haiti (UNEP, 2010). MINUSTAH through Property Disposal Unit (PDU) under the Property Management Section is disposing of infectious HCW (sharps and non-sharps waste), pathological waste and some of the expired solid drugs generated within MINUSTAH medical facilities through incineration in dual chambered incinerators (MINUSTAH, 2009). This follows the WHO recommendations on the emergency disposal options for the HCW through medium temperature incineration (WHO, 1999, 2014c) which is done by MINUSTAH since the year 2009.

The MINUSTAH incinerators called MediBurn operate at medium temperatures with controlled exhaust temperatures ranging from 1000 to 1025 ^{0}C during the burning cycle. The MediBurn portable medical waste incinerators are electronically controlled dual chambered, portable, and medium temperature incinerators manufactured by the Elastec Company in the US (Elastec American Marine Innovative Products, 2013). The MediBurn units are medical waste incinerators capable of burning a load of up to 8 cubic feet of HCW (equivalent to 150 kg in 12 hours or 18 to 20 kg per hour) using 11 liters of diesel and 0.35 kilowatts of electrical energy (Elastec American Marine Innovative Products, 2013).

The USEPA, UNEP and Basel Convention on the Control of Trans-boundary Movements on Hazardous Waste and Their Disposal recognize incineration as among the disposal options if the set air emission standards meet (Basel Convention Technical Guidelines on Incineration on Land, 2002; UNEP 1996, 2005; USEPA, 2010). The World Health Organization identified the best incineration practices to be observed during incineration (WHO, 2001, 2014c). MINUSTAH, through the PDU, takes measures to reduce toxic emissions (dioxins and furans) by complying with the WHO best practices for incineration (MINUSTAH, 2009).

1. Waste reduction to reduce the volume and toxicity through:
    - Proper segregation of HCW in which halogenated plastics, such as polyvinyl chloride (PVC) equipment including IV bags, tubes and other plastic materials (except sharps containers that are disposable), are not incinerated;
    - Waste materials with high mercury content, such as broken thermometers, are excluded from the incineration stream and managed according to the

PDU guidelines distributed to the Military and Formed Police Units (FPUs) medical facilities (MINUSTAH, 2009). Long-term measures to phase out mercury and PVC medical supplies in MINUSTAH facilities are addressed in PDU Field Occupational Safety Risk Assessment (O-SRA) document;

- Sealed ampoules or ampoules containing controlled drugs are encapsulated and excluded from the incineration stream;
- Incineration ash is encapsulated in order to avoid the possibility of leaching dioxins and furans into the environment, and
- X-ray films are excluded from incineration stream.

2. Proper incineration design and operation:

   MINUSTAH opts for the high temperature incineration with double chambers that refine the exhaust gases. In addition, the operational standards are followed according to the incinerator manual and annual training provided by the manufacturing company.

3. Proper Siting:

   Incinerators are located on non-agricultural lands and less populated areas.

Study Design and Method Rationale

Whereas incineration is still the best technology available for HCW disposal in global South countries, researchers, through their observational studies, indicated the problem of higher BC emissions or smoke (Alvim-Ferraz & Afonso, 2003; Andrea, 2010; Batterman, 2004; Manyele & Kagonji, 2012; Njagi et al., 2012; Zakaria et al., 2005). Additional observational studies have analyzed poor HCWM as conducted by Gupta and Boojh (2006) and by Taghipour and Mosaferi (2009).

In this study, I utilized observational approach in order to analyze emergency HCW incineration trends and smoke emissions from incineration of sharps HCW contained in cardboard boxes and plastic containers. Primary data on smoke emission and secondary data on HCW incinerated weights before and after the 2010 earthquake and cholera disasters were used in this quantitative study. The intent was to determine whether cardboard HCW sharps containers emit lower BC emissions to the atmosphere during the incineration process, relative to the plastic sharps containers. In addition, the study aimed to determine whether HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti follow a linear pattern.

Frankfort-Nachmias and Nachmias (2008) and Javaherian (2012) emphasized that the observational approach is appropriate for the conceptual framework of the study that directly relates to physical sciences. Similarly, Manyele and Kagonji (2012) have demonstrated the significance of the observational approach and mixed-method study design in assessing the performance of HCW incineration process using statistical data analysis. Manyele and Kagonji (2012) utilized HCW incinerated weights for a period of 22 months to assess time series for HCW incineration data, difference in HCW incinerated weights and HCW incinerator performance (probability density functions). The researchers identified poor HCW incinerator performance in terms of fuel consumption and cycle time. Most importantly, the two authors reported that the use of properly collected HCW incineration data together with statistical analysis results was beneficial (Manyele & Kagonji, 2012). The study results formed the basis information for realistic planning, budgeting and designing HCW incineration activities towards effective, efficient and economical HCW disposal systems (Manyele & Kagonji, 2012).

In evaluating HCW incineration and associated public health effects, Njagi et al. (2012), observed HCW incineration process at Kenyatta National Hospital and Moi Referral hospital. The authors analyzed exhaust gases including Oxygen, CO_2, nitrous oxide, sulfur dioxide, nitrogen oxides and nitrogen dioxide when HCW incinerators were entirely operational (Njagi et al., 2012). Through the analyses, Njagi et al. (2012) established combustion efficiency (CE) for HCW incinerators. Kenyatta National Hospital and Moi Referral hospital attained CE of 48.1% and 60.8% respectively under respective stack operational temperature of 764 and 811 ^{0}C (Njagi et al., 2012). The two HCW incinerators were found to operate below the minimum limit of 99% set by the Government of Kenya (Njagi et al., 2012). Based on that fact, thus, the researchers feared much that other emissions too were very much likely to take place (Njagi et al., 2012).

Likewise, Taghipour and Mosaferi (2009) collected hospital HCW data through a checklist, observed HCW disposal at sites through site visits to 10 out of 25 Tabriz, Iran hospitals in 2007, and quantitatively analyzed weights of HCW generated. The purpose of the analysis was to find a scientific base from which to describe HCWM in Tabriz, Iran. As a result, Taghipour and Mosaferi (2009), through physical observation and quantitative analysis, revealed that nearly 50% of health facilities had been provided with HCW incinerators. However, they realized that only 10 % had been operational at the time of visit despite higher HCW generation rates. They further raised concerns over environmental pollution and disease transmission due to illegal HCW recycling and segregation practices at final disposal. Taghipour and Mosaferi (2009) thus, recommended waste minimization strategies be applied to reduce HCW generation rates up to 70.11% and centralized HCW incineration or autoclaving process.

One more observational study with relevance to this research was conducted by Alvim-Ferraz and Afonso (2003), and its aim was to assess the influence of HCW segregation and composition in relationship to emission factors. In this study, the researchers emphasized the need for HCW segregation to reduce toxic emissions, projection of HCW volumes and management model for efficient HCW disposal.

Based on the review of observational studies above, I found the use of observational study design to be appropriate for this study. Quantitative study design using both primary and secondary statistical data enhances greater understanding of research results while increasing its validity (Creswell, 2009).

Chapter 2 Summary

In this chapter, the researcher detailed both the conceptual framework and empirical evidence analysis to support the climate change potential of BC. The literature has further highlighted the practical cases of increased climate change and associated health and environmental effects. These include the ice melting and threats on water shortage in Himalaya, disease vectors, food scarcity, extreme weather events and other effects. On another hand, the chapter pointed the lack of standard BC emission measurement and inadequate efforts on BC emission curb as compared to CO_2.

Similarly, the literature review has drawn parallels in a cross-section studies indicating that HCW incineration processes emit higher smoke levels thus global warming especially in the global South countries. The chapter also captured WHO (2014c) position in providing the PM emission guidelines for HCW incineration and general ambient air quality standards. Requirement for greener HCW equipment purchase and use adherence that extends to sharps containers is questionable based on low priority on HCWM, thus, the need for a study in this area. Based on the literature review, chapter 3 outlined the design, methodology, tools and procedures that are correspondingly requisite in evaluating HCW incineration trends in Haiti and BC emissions resulting from incineration processes.

Chapter 3: Research Method

Introduction

In concert with approval number 09-03-14-0156572 by the Institutional Review Board (IRB), this was an observational study where I relied on both primary and secondary data analyses. The secondary data was generated from MINUSTAH's HCW weights that were incinerated periods before and after the 2010 earthquake and the subsequent cholera disasters outbreak. The aim was to determine whether the pattern of HCW incinerated weights is linear, and to measure the intensity of smoke emissions from incineration of HCW contained in different types of containers including cardboard boxes and plastic containers. The determination processes was performed through physical observation of the current sharps HCW incineration smoke using Ringelmann smoke charts. This based on the assumption that the nature of sharps waste before and after the emergency is similar. Therefore, data analysis in this study considered any inherent trend realized from secondary data used in here and primary data on smoke density. The analysis spread within a span of 5 years, starting from January 2009 to December 2013. This scope of analysis took 1 year before the most fatal 2010 earthquake and cholera disasters, and those in the 4 years that followed.

Research Design and Rationale

In this study, I addressed two research questions as discussed earlier:

1. Do HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti follow a linear pattern?

2. Do the cardboard HCW sharps containers emit lower BC emissions to the atmosphere during the incineration process, relative to the plastic sharps containers?

I used quantitative research design in order to analyze the study data due to its benefits of allowing statistical analysis, enhancing greater understanding of study findings, and increasing the validity of study findings (Creswell, 2009). Quantitative research allow the scientific claim be tested as emphasized by Creswell (2009). The analyzed patterns of HCW incineration included the patter before and after the 2010 earthquake and cholera disasters.

On the other hand, I used Ringelmann smoke charts to evaluate the intensity of BC emissions (smoke) by observing the emissions during the initial startup, the charging phase, and the actual burning phase for plastic and cardboard sharps waste containers. This quantitative analysis supported the use of greener medical waste collection containers by healthcare facilities for climate change mitigation measures.

Linear regression analysis was appropriate analysis for studying the pattern of HCW incinerated weights while at the same time predicting relationships in the resulting model. Likewise, the independent samples *t-test* suited the evaluation of the differences between smoke means obtained from two separate incinerations in which I incinerated cardboard boxes and plastic sharps HCW containers.

Population and Setting

The study was conducted at the United Nations Mission base in Haiti. This research setting is favorable for the study on the account that the researcher has served for a period of 6 years. During the entire period of service as a United Nations Volunteer, the researcher has both actively and consistently been handling technical aspects of a myriad waste disposal work in the field. The significance of this research setting is its being the point at which all United Nations disposal operations in Haiti are headquartered. This study did not need any population as it entirely relied on MINUSTAH secondary data and primary data that were generated from observational process of measuring smoke densities from a practical incineration operation.

Sampling and Data collection

In this study, I used convenient sampling techniques to sample and collected primary data by observing 20 incineration processes of varying quantities and types of sharps HCW containers. The incineration smoke intensity measuring operations were generated from the routine HCW incineration at the MINUSTAH. Likewise, I retrieved secondary data on HCW incinerated weights by MINUSTAH at the 5-year scope beginning from January 2009 to December 2013 (60 months). The said secondary data came from MINUSTAH database volumes that were systematically compiled from the body’s daily incineration time sheet before getting transferred to the computer under the shared drive (MINUSTA/PMS/PDU). This database was copied from MINUSTAH database and used for this study with direct and full authorization of the United Nations as attached in the Appendix B. Daily incineration log sheets are kept by MINUSTAH for quality assurance and can be reviewed. I used Tabachnick and Fidell (2007) formula, and, Equation 5 for calculating sample size required based on the desired power of 80 % and statistical significance level or α (alpha) level of 0.05.

Secondary Data Retrieval from MINUSTAH's HCW incineration Database. The HCW secondary data at MINUSTAH, a database from which this research is to benefit, were systematically collected through a well-established process. The incineration operators ultimately file primary data from their specific field operation into the transfer vouchers for HCW from the PDU yard. The form depicted the type of HCW, its weight, and generation source or healthcare facility. The means that whenever HCW is delivered at the PDU yard, the receiving officer there took the weight in kg and confirmed it by filling the specified space in the form. The HCW is then stored in the PDU yard in readiness for incineration. Prior to incineration, the facility operators are required to take HCW weights. The aim was to establish quantities at hand in relation to the incineration capacity per cycle versus the length that each cycle has to go. Such details were systematically recorded in MINUSTAH incineration logbook. The data were transferred into soft copy before getting to final centralized computer storage at MINUSTAH/PMS/PDU database under the shared drive.

Primary Data Collection for Incineration Smoke Emissions Testing. In this study, I observed 20 incineration process of various types of sharps HCW containers and recorded the smoke emission intensity in each case to determine the density levels of the BC emissions or smoke produced. Smoke levels were recorded at incinerator initial startup, the charging phase, and the actual burning phase for plastic and cardboard sharps HCW containers. In this case, Ringelmann smoke charts were used, in the process of collecting the data, to determine the level of intensity on smoke emission from sharps HCW incineration activities. I purchased the *Right to Use Manual* from the

British Standards Institution [BSI] as shown in the Appendix D and compared the density of smoke with a known greyness scale of the Ringelmann smoke charts. I conducted pilot tests in order to increase the proficiency in using the Ringelmann smoke charts, and performed the practical application of smoke reading protocol.

Primary Data collection Tool. The Ringelmann smoke chart, an invention of Prof Maximilan Ringelmann of La Station d'Essais de Machine in Paris, is a scientific tool used to measure smoke level by comparing its apparent density contrary to the known greyness scale levels representing different smoke densities (BSI British Standards 2009; Solid Fuel Technology Institute [SOLiFTEC], 2010; United States Bureau of Mines, 1967; USEPA, 1993). As such, this tool ranges from '0' to '5', different density levels inferred from a grid of black lines on a white surface under which smoke column reading at Level '0' is complete white or lightest in colour and complete black or darkest at Level '5'(BSI British Standards 2009; SOLiFTEC, 2010; United States Bureau of Mines, 1967; USEPA, 1993).

The appended interpretation goes that the lighter the colour (British Spelling of the smoke), the lower the density or concentration of BC or smoke PM in the effluent, the smaller the size of particulate, the lesser the depth of the smoke column being viewed in relation to the direction of the natural lighting (sun) from the position where the smoke viewer stands, and the vice versa is also true (BSI British Standards 2009; SOLiFTEC, 2010; United States Bureau of Mines, 1967; USEPA, 1993). The smoke column readings between Level 1 to 4 are represented by 10 millimeter square black grids drawn with line thicknesses of 1mm, 2.3mm, 3.7mm and 5.5 mm (see Appendix

C). When viewing the grid from a distance, the smoke levels are supposed to merge into known shades of greyness. The chart Level 1, 2, 3, 4, and 5 represent 20 %, 40 %, 60 %, 80 %, and 100% smoke levels respectively. Also, in that instance, Level 0 would simply be meaning smokeless or white background in which only the sky color is depicted during observation (BSI British Standards 2009; SOLiFTEC, 2010; United States Bureau of Mines, 1967; USEPA, 1993).

Although the modern version of Ringelmann smoke chart was published in 1967 for use by the United States Bureau of Mines in circular 8333, the British Standard Version was used based on its simplicity in terms of data collection form and the overall chart use as emphasized by SOLiFTEC (2010). Quality Ringelmann smoke charts were used and natural lighting facilitated smoke measurement with minimal obstructions. The smoke readers conducted a series of observations at regular intervals as emphasized by the USEPA (1993). According to the smoke law in the United Kingdom, darker smoke of more than shade 2 of the Ringelmann smoke chart is considered illegal (SOLiFTEC, 2010; BSI British Standards 2009).

Miniature smoke charts (bar and circle type) are recognized as handy interpretation of the Ringelmann smoke chart. I used them for additional clarification on how to take smoke readings for everyday incineration processes on a much simplified interpretation (BSI British Standards 2009; SOLiFTEC, 2010). Bar-type miniature smoke charts were printed black and white while the circle types were printed under grey-scale. For the circle type, the smoke readers made a central hole, held the charts at arm’s length, and finally, observed the source of smoke through the hole. For the bar-type, the smoke readers cut along the edge (as shown in the Figure 2), held the charts at arm's length and compared the source of smoke with the cutting edge as recommended by BSI British Standards (2009) and SOLiFTEC (2010). Figure 2 and 3 show the bar type and circle type miniature smoke charts.

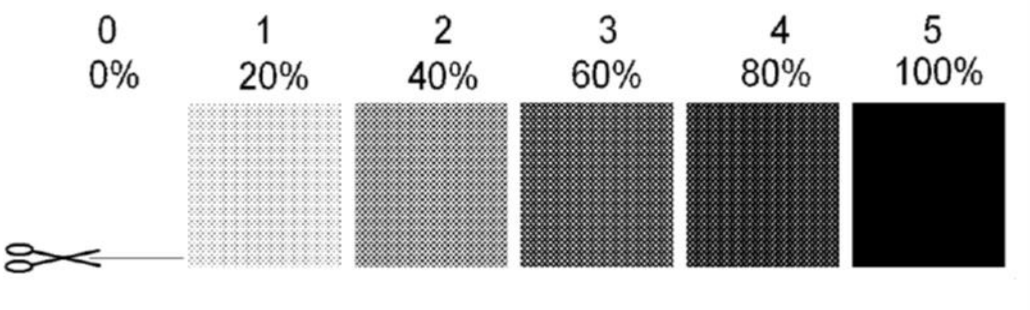

Figure 2: Bar-Type Miniature Smoke Chart.
Note: From "The Ringelmann smoke chart" by SOLiFTEC, 2010. With Purchased Right to Use, British Standards BS 2742:2009 (see Appendix D).

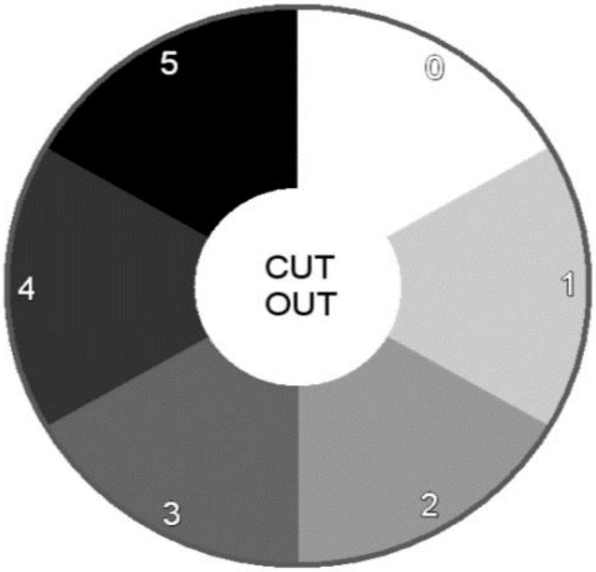

Figure 3: Circle-Type Miniature Smoke Chart.
Note: From "The Ringelmann smoke chart" by SOLiFTEC, 2010. With Purchased Right to Use, British Standards BS 2742:2009 (see Appendix D).

Primary Data Collectors. In this study, three smoke readers were involved in the quantitative measurement of smoke densities. I was a keen reader by participating in practical observation of smoke emission from HCW incineration process of cardboard boxes and plastic sharps containers. In this effect, I was among the three smoke readers. I am certified visible emissions reader by the USEPA and the two smoke readers were trained in the use of both the Ringelmann and miniature smoke charts.

Pilot smoke reading. Pilot smoke readings during HCW incineration process were performed 2 weeks prior to data collection period. Different HCW amounts were incinerated, and I attended the two newly trained smoke readers until they were competent with their readings. Being a USEPA certified visible emissions reader, together with extensive experience in smoke reading, I took measures to ensure quality measurements by simultaneously recording of emissions and comparing the results. This uncovered any problems faced by the two newly trained smoke readers as stated by the USEPA (1993). Additional field trainings and practices were performed for higher discrepancies of greater than 20% Ringelmann smoke results or 10% average smoke densities by different readers. Pilot tests raised skills and tactics among smoke readers, and, ensured quality measurements by not exceeding the allowable discrepancies as emphasized by USEPA (1993).

Estimation of Average Smoke Densities. Based on the user manual and smoke reading levels, I calculated the average smoke density in percentage as the total of the average Ringelmann number multiplied by 20 that is the equivalent of the standard smoke. The average Ringelmann number was obtained by dividing the total Ringelmann numbers recorded for a serial observation divided by the total number of observation. The Equations 1 and 2 summarize the average smoke density estimation.

$$Average\ Ringelmann\ Number = \frac{Total\ of\ Ringelmann\ Numbers}{Total\ number\ of\ observations} \tag{1}$$

$$Average\ Smoke\ Density\ (\%) = (Average\ Ringelmann\ Number) \times 20 \tag{2}$$

Level of Measurement. Frankfort-Nachmias and Nachmias (2008) identified the four principle levels of measurement as nominal, ordinal, interval and ratio. In this study, I utilized all four levels starting with the lowest (nominal) to the highest (ratio). The nominal levels included 12 months (January –December) in which HCW were incinerated, equivalent to 52 weeks, which is also nominal value. The ordinal level included lower and higher smoke levels to be determined by the Ringelmann smoke chart readings, whereas the interval level included both the smoke intervals and five days interval in which HCW was incinerated in a week. The last level of measurement is the ratio with the true zero point, used for measurement of HCW weights incinerated by MINUSTAH.

Validity. The validity of the measurements according to Frankfort-Nachmias and Nachmias (2008) is the ability to measure exactly what the study intends to measure. This study measured smoke levels from incineration of sharps HCW contained in different types of containers (cardboard box and plastic). Also, the study evaluated the pattern of HCW incinerated weights from January 2009 to December 2013.

In assuring content validity (Frankfort-Nachmias and Nachmias, 2008), the researcher used a weighing scale and Ringelmann smoke charts. The Ringelmann smoke charts are widely used tool in measuring smoke column density. However, in adherence to the empirical validity of the measurement standard which questions the appropriateness of the measurement performed and the instrument used (Frankfort-Nachmias & Nachmias, 2008), the study relied on the accuracy of the Ringelmann smoke charts. The empirical validity of the Ringelmann smoke charts was, therefore, attained by using pure white paper and modern black ink as emphasized by the United States Bureau of Mines (1967), USEPA (1993), BSI British Standards (2009), and SOLiFTEC (2010). In view of the meaning of *construct validity* as the ability to match the measuring instrument and the study's conceptual framework (Frankfort-Nachmias & Nachmias, 2008), the collected data and instruments used in this study including the weighing scale and the Ringelmann smoke charts are recognized as the measurement tools for weight and smoke respectively.

Reliability. According to Frankfort-Nachmias and Nachmias (2008), reliability of the measurement instrument is the ability to provide similar results under different-tests. The reliability of the Ringelmann smoke charts relied on the blackness of inks and whiteness of the printing while the apparent smoke darkness relied on smoke column depth, effluent PM concentration, and natural lighting. In this effect, a series of observation were performed by 3 smoke readers and compared results as a measure towards reliability. More specific, inter-rater reliability were performed by constructing 2 similar tests in order to measure consistency of smoke densities. Accuracy relied on the ability of the smoke reader and all of the readings were taken by trained readers. Furthermore, I conducted pilot test in order to test the accuracy of Ringelmann smoke charts and assessed whether the protocol for reading smoke was realistic and practical. Furthermore, pilot testing raised skills and tactics among smoke readers.

Data Analysis

I used Statistical Package for the Social Sciences (SPSS) software to perform univariate and bivariate data analyses for the secondary and primary data. Conversely, Ringelmann smoke charts were used in the process of analysing smoke in order to determine the frequency distribution for each observed Ringelmann number in a 30-minute record. Data cleaning were performed by reorganizing HCW incinerated weights into months rather than days in order to eliminate zero effect for days without incineration activities. Furthermore, decimal points were eliminated by rounding the numbers to the nearest tenths. Study questions and hypotheses as explained in the first chapter include:

1. Do HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti follow a linear pattern?
2. Do the cardboard HCW sharps containers emit lower BC emissions to the atmosphere during the incineration process, relative to the plastic sharps containers?

The hypotheses for the first research question were:

- Null hypothesis (H_o): the pattern of HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti is linear.
- Alternate hypothesis (H_a): the pattern of HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti is non-linear.

The hypotheses for the second research question were:

- Null hypothesis (H_o): The average densities of BC emissions (smoke) during the incineration process of plastic sharps HCW containers and cardboard boxes are similar.
- Alternate hypothesis (H_a): The average density of BC emissions (smoke) is significantly lower during the incineration process of cardboard box sharps HCW containers.

The independent variables for the first hypothesis were months in which HCW was incinerated while the dependent variables were the weights of incinerated HCW in kg. For the second hypothesis, the independent variables were the types of sharps containers (cardboard and plastic) while the dependent variables were smoke levels or Ringelmann smoke numbers.

Box plots, line graphs and independent samples *t-test* were used respectively to present the average smoke density and to evaluate the differences between smoke means obtained from two separate incinerations in which cardboard and plastic sharps HCW containers were incinerated. Likewise, the researcher performed linear regression analysis to determine whether HCW incinerated weights from January 2009 to December 2013 follow a linear pattern (Frankfort-Nachmias & Nachmias, 2008), and predicted relationships in the resulting model.

Ethical Procedures

In concert with approval number 09-03-14-0156572 by the Institutional Review Board (IRB), this study did not cause any harm to human subjects. The approval MEMO attached in the Appendix B allowed the use of secondary data and primary data collection from MINUSTAH incineration facilities. Primary data collection was conducted without causing any harm to smoke readers (2 MINUSTAH staff and the researcher). A minimum of N-95 face masks were used as emphasized by the Occupational Safety and Health Administration (2014). Masks were not required during an upwind of emissions, and all smoke readers were advised to avoid emissions. The study was conducted at researcher’s place of work without any conflict of interest. It is important to point out that the researcher collected data for this study after completing the volunteer contract with MINUSTAH. In this regard, the relationship with data collectors was purely that of the researcher and her assistant in the field. Data collected were non-confidential, and they have been stored in hard discs and metal cabinet with locker, pending destroy in the year 2020.

Dissemination of Study Findings

The study findings will be disseminated to the WHO, United Nations Agencies, National and International HCWM stakeholders in several ways. First, the study results will be presented to the HCWM team of the WHO during the HCWM Meetings and for

Sub-Saharan Africa and during working sessions throughout the year 2015. Second, the researcher will conduct some public presentation at two universities that are yet to be identified in the parts of Haiti and Tanzania. In other instances, hard copies of this study shall be presented to MINUSTAH office, United Nations Headquarters in New York and at some two libraries and universities in Haiti and Tanzania. Third, a synopsis of the study will be presented to the Department of Peace Keeping Operations (DPKO), MINUSTAH, UNEP, and UNDP-GEF during a visit to their specific offices. Fourth, study results will be disseminated through scientific journals.

Chapter 3 Summary

The researcher conducted an observational study to analyse HCW incineration trends and smoke from HCW incineration activities. The Ringelmann and miniature smoke charts were used to measure the average intensity of smoke emission from HCW incineration. Similarly, 5-year secondary data were used for the analysis of incineration trends at MINUSTAH as from January 2009 to December 2013. The study did not cause harm to human subjects and results of this study will be widely disseminated through meetings, visiting lectures, working sessions, posted on the website and hardcopy distributed to relevant offices and institutions of higher learning. The results of the statistical analysis that answered both the research questions and hypotheses are discussed in chapter 4.

Chapter 4: Results

Introduction

In this chapter, I analyze both secondary data on HCW incinerated weights by MINUSTAH at the 5-year scope beginning from January 2009 to December 2013, and primary data on smoke densities collected from practical incineration processes at MINUSTAH incineration facilities. In so doing, I considered two research questions at the core of my analysis work. These included:

1. Do HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti follow a linear pattern?
2. Do the cardboard HCW sharps containers emit lower BC emissions to the atmosphere during the incineration process, relative to the plastic sharps containers?

This chapter includes the information on the data collection process, the generated results from statistical analysis, as well as a summary to help readers grasp main points in an easy way.

Data Collection

Secondary Data on Healthcare Waste Incinerated Weights from 2009 to 2013

In view of the introduction above, I retrieved secondary data from MINUSTAH on HCW incinerated weights before, during and after the 2010 earthquake and cholera disasters in Haiti. The said data covers the period as from January 2009 to December 2013. The data source was MINUSTAH/PMS/PDU database, a computer facility under the shared drive. I copied the data in my external drive disc ready for the analysis. Table 3 shows the secondary data retrieved from MINUSTAH.

Table 3

Secondary Data on HCW Incinerated Weights

	HCW incinerated weights (kg)				
Months	2009	2010	2011	2012	2013
January	170	590	434	587	777
February	229	627	393	571	461
March	185	343	558	556	419
April	160	254	347	793	497
May	197	382	268	635	406
June	218	298	427	680	159
July	203	114	261	723	473
August	503	140	292	576	292
September	178	704	778	492	292
October	404	795	623	477	421
November	199	437	649	488	718
December	201	527	611	685	223
Total	2847	5211	5641	7263	5138

Note: Healthcare waste incinerated Weights (kg) by MINUSTAH (2009-2013).

Primary Data Collection on Smoke Levels from MINUSTAH Incineration Facility

Pilot test. I collected the primary data on smoke levels by way of performing a series of activities. I began by organizing a number of pilot smoke readings. This took a period of two weeks. The purpose for doing this was to familiarize the two newly trained smoke readers into understanding how the actual smoke readings were to be conducted competently, and to achieve the desired goals from the whole process as required of this study. These two smoke readers were currently serving as full-time incineration assistants at the MINUSTAH facility.

Primary data collection. In the second phase, I embarked on the actual primary data collection on smoke levels at the MINUSTAH incineration facility. I led the team of two newly trained smoke readers in conducting the whole process and the ultimate primary data collection. Smoke levels were recorded at incinerator initial startup, the charging phase, and the actual burning phase for plastic and cardboard sharps HCW containers. The whole process started by taking the weights of sharps HCW in readiness for incineration by MediBurn portable and electronically controlled medical waste incinerators. The two incinerator assistants loaded the incinerators with sharps HCW kept in different containers (plastic containers and cardboard boxes). The weights in those containers lined-up for incineration ranged between 3 and 14.6 kg. While doing all these, the bottom-line here was to measure and take readings of smoke levels resulting from the incineration process for sharps HCW kept in plastic and cardboard containers.

The actual incineration processes were initiated by incinerator operators by selecting the cycle time and pressing the start button once the incinerators had been loaded with sharps HCW. The two incinerator operators were cautious enough to make sure that there were enough fuel in the incinerators prior to starting incineration. A complete incineration cycle started after pressing the start button in which the upper burner started firing for a period of 6 minutes in order to preheat the top burner to a temperature of 640 ^{0}C. Soon after the top burner had attained the required preheat temperature of 640 ^{0}C, the bottom burner ignited and burned the load of sharps HCW.

During the entire burning phase, the MediBurn incinerator maintained an exhaust temperature of up to 1025 ^{0}C by firing the top burner which normally reached *a high-end* *shut-off* at 1140 ^{0}C. Soon after the MediBurn completed the cycle, it automatically began to cool down to 300 ^{0}C before the operator chose to reload a new sharps HCW load in readiness for a new cycle of burning or simply shut of the incinerator.

Some three smoke readers' recorded smoke levels emitted during incineration processes by using Ringelmann smoke charts as described under Chapter 3. Consequently, I used Equations 1 and 2 on estimating average smoke densities under Chapter 3 to compute the average smoke densities in percentage. Table 4 captures the amounts of sharps HCW incinerated in MediBurn incinerators owned by MINUSTAH for a cycle time of thirty minutes each. Likewise, the table shows a list of recorded Ringelmann smoke numbers and smoke densities.

Table 4

Primary Data on Smoke Densities from Incineration Processes of Plastic and Cardboard Sharps HCW Containers

Quantities of sharps HCW incinerated (kg)	Types of sharps containers used	Incinerator barcode number	Initial bottom burner temperature (^{0}C)	Final bottom burner temperature (^{0}C)	Average Ringelmann smoke number	Average smoke density (%)
14.6	Plastic	MSH-Y-01386	389	1095	48.0	32.0
	Cardboard box	MSH-Y-01386	398	950	21.5	14.3
13.7	Plastic	MSH-Y-01386	379	1062	43.5	29.0
	Cardboard box	MSH-Y-01386	389	948	20.0	13.3
11.7	Plastic	MSH-Y-01386	372	1049	38.0	25.3
	Cardboard box	MSH-Y-01386	382	952	17.0	11.3
10.0	Plastic	MSH-Y-01386	378	978	31.3	20.9
	Cardboard box	MSH-Y-01384	401	916	11.3	7.6
8.0	Plastic	MSH-Y-01386	377	951	14.7	9.8
	Cardboard box	MSH-Y-01384	363	896	8.3	5.6
5.0	Plastic	MSH-Y-01386	389	949	18.7	12.4
	Cardboard box	MSH-Y-01384	364	879	10.3	6.9
3.0[*]	Plastic[**]	MSH-Y-01386	388	910	20.3	13.6
	Plastic[***]	MSH-Y-01386	378	881	13.3	8.9
	Cardboard box	MSH-Y-01384	363	851	1.7	1.1
	Cardboard box	MSH-Y-01384	396	859	4.7	3.1
	Plastic[***]	MSH-Y-01386	386	912	19.7	13.1
	Cardboard box	MSH-Y-01384	390	891	4.0	2.7
	Plastic[***]	MSH-Y-01384	398	927	19.0	12.7
	Cardboard box	MSH-Y-01386	387	861	3.3	2.2

Note: Data on smoke densities emitted from practical incineration processes of cardboard and plastic sharps HCW containers, Haiti (2014). * = empty sharps HCW containers; ** = yellow-colored plastic containers with red top lid; *** = yellow-colored plastic containers with colorless top lid.

Primary Data Collection on Smoke Levels from Haiti State's Hospital University (HUEH)

The exercise for collecting primary data from sharps HCW incineration at the Haiti National Hospital (Haiti State's Hospital University) revealed a lack of incineration facility at the Hospital. This is because the January 2010 earthquake in Haiti destroyed the incinerator and the entire incinerator building. The hospital had been, therefore, disposing of its sharps HCW through open burning at the main dump site in Port au Prince called Trutier.

HCWM supervisor of the hospital organized disposal sessions based on the quantities of sharps HCW collected and the availability of truck to transfer sharps HCW for burning. Soon after the sharps HCW had reached the disposal site, HCW disposal assistant off-loaded the consignment at the identified location and sprayed up the heap with up to 4 liters of diesel to facilitate burning of the material. The disposal session ended once the plastic and cardboard materials have completely burnt except for needles and other metallic sharps. The successful burning of sharps HCW under the open-air burning process solely depends on weather conditions.

Equally, the exercise for collecting primary data revealed that the quantities of HCW generated by Haiti State's Hospital University are neither tracked nor recorded by the hospital staff. Lack of incineration facility, therefore, made the entire data collection from this particular hospital being excluded from the analysis since the aim was to measure smoke levels from incineration processes. A disposal session of sharps HCW from Haiti State's Hospital University through open burning was performed in the presence of the researcher during data collection period.

Descriptive and Statistical Results

Descriptive Statistics

Descriptive statistics of secondary data on HCW incinerated weights. The descriptive statistics of HCW incinerated weights by MINUSTAH from January 2009 to December 2013 are summarized in Table 5.

Table 5

Descriptive Statistics for HCW Incinerated Weights

Year	*n*	Minimum	Maximum	Mean	Std. deviation
2009	12	160	503	237.25	104.95
2010	12	114	795	434.25	218.26
2011	12	261	778	470.08	170.11
2012	12	477	793	605.25	99.89
2013	12	159	777	428.17	182.35
Total (*N*)	60	114	795	435	196.22

Note: Healthcare waste (HCW) incinerated weights (kg) by MINUSTAH (January, 2009 - December, 2013).
Std. Deviation =Standard Deviation, *n* = Proportion of the sample, *N* = Total sample.

As indicated in Table 5, the HCW incinerated weights in 60 month's period ranged from 114 kg to 795 kg, with a mean value of 435 kg and a standard deviation of 196.22. The lowest and the highest mean HCW incinerated weights were 237.25 kg and 605.25 kg in year 2009 and 2012 respectively as indicated in Figure 4.

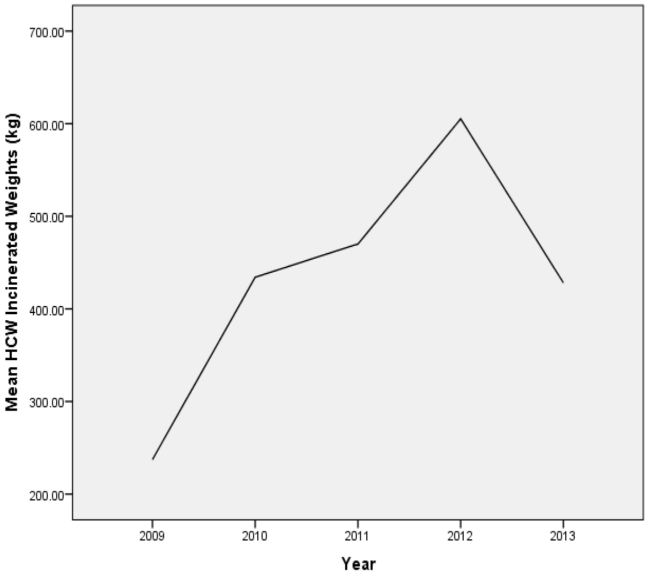

Figure 4: Line Graph of Mean HCW Incinerated Weights (2009 – 2013).

Group statistics of primary data on smoke densities. The group statistics of primary data on smoke densities are summarized in Table 6.

Table 6

Group Statistics for Smoke from Incineration of Plastic and Cardboard HCW Containers

Smoke Density	*n*	Minimum	Maximum	Mean	Std. deviation
Smoke density (%) for Plastic containers	10	8.9	32.0	17.77	8.38
Smoke density (%) for Cardboard boxes	10	1.1	14.3	6.81	4.79
Total (*N*)	20	1.1	32.0	12.29	8.70

Note: Smoke densities emitted during practical incineration processes of sharps HCW containers and their mean values.
Std. Deviation =Standard Deviation, *n* = Proportion of the sample, *N* = Total sample,
(%) = Percentage.

As indicated in Table 6, the smoke densities emitted from practical incineration process of sharps HCW containers ranged from 1.1 % to 32 %, with a mean value of 12.29 %, and a standard deviation of 8.7. The smoke densities emitted from practical incineration process of sharps HCW kept in plastic containers ranged 8.9 % to 32 %, with a mean value of 17.77 % and a standard deviation of 8.38. The smoke densities from incineration of sharps HCW kept in cardboard boxes ranged from 1.1 % to 14.3 %, with a mean value of 6.81 % and a standard deviation of 4.79. Box plots in figure 5 shows average Ringelmann smoke numbers and densities for plastic and cardboard sharps HCW containers.

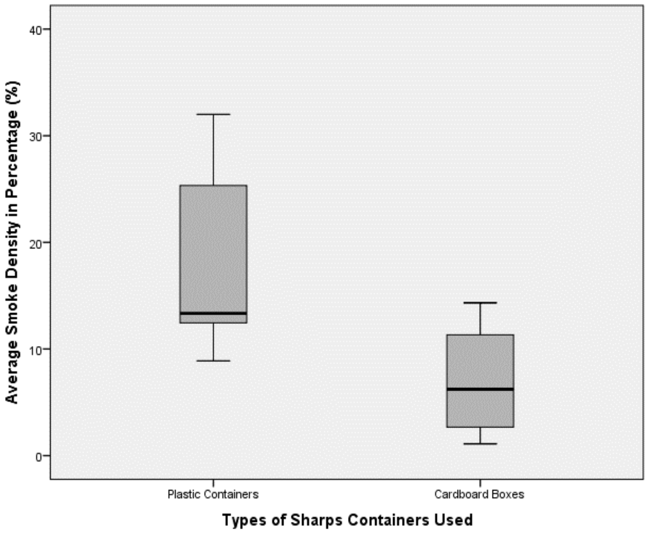

Figure 5: Box Plot of Mean Smoke Densities for Plastic and Cardboard Sharps HCW Containers.

It is important to point out that the quantities of sharps HCW incinerated ranged from 3 kg to 14.6 kg, with a mean value of 7.5 kg, and a standard deviation of 4. 59, as indicated in Table 7. Initial incineration operational temperatures for bottom burners ranged from 363 ^{0}C to 401 ^{0}C, with a mean value of 383.35 ^{0}C and a standard deviation of 11.55. Final bottom burner’s operational temperatures ranged from 851 ^{0}C to 1095 ^{0}C with a mean value of 935.85 ^{0}C and a standard deviation of 67.7.

Table 7

Quantities of Sharps HCW Incinerated and Operational Temperatures

Quantity/Temperature	*N*	Minimum	Maximum	Mean	Std. deviation
Quantities of Sharps HCW Incinerated (kg)	20	3.0	14.6	7.50	4.59
Initial Bottom Burner Temperature (^{0}C)	20	363	401	383.35	11.55
Final Bottom Burner Temperature (^{0}C)	20	851	1095	935.85	67.70

Note: Operational temperatures of incinerators (bottom burners) during incineration of sharps HCW of different quantities. Std. Deviation =Standard Deviation, *N* = Total sample, (%) = Percentage.

Sampling distribution. Descriptive statistics for secondary data on HCW incinerated weights indicated that the distribution is approximately normal. The Skewness is 0.146 with a standard error of 0.309, and Kurtosis is -1.106 with a standard error of 0.608. Similarly, the descriptive statistics for primary data on average smoke densities indicated that the distribution is approximately normal. The Skewness is 0.931 with a standard error of 0.512, and Kurtosis is 0.349 with a standard error of 0.992.

Sample Adequacy

As a rule of thumb, VanVoorhis and Morgan (2007) recommended a reasonable sample size of 50 to be adequate for the analysis of correlation and regression relationships. However, for this study, I statistically assumed that the sample size of 60 HCW incinerated weights within a span of 5 years would be sufficient in order to represent HCW incineration operations during an emergency situation. To confirm the required sample size, I used Tabachnick and Fidell (2007) formula (Equation 3) on page 70 for calculating sample size based on the desired power of 80 %.

$$N > 50 + 8m \qquad (3)$$

Where,

N = Total Sample size

m = number of independent variables (1)

Based on this analysis, the minimum required sample size to allow the rejection of the null hypothesis was 58.

Therefore, the sample size of 60 is above the minimum required sample size to reject the null hypothesis. Furthermore, I used the Equation 4 for calculating sample size based on the standard error of the mean and standard deviation.

$$n = \frac{\sigma^2}{SE^2} \qquad (4)$$

Where,

n = *S*ample size

σ = Standard deviation of outcome variable (196.219)

SE = Standard error of the mean (25.332)

Based on the Equation 4, I estimated a sample size of 59.9 for power of 80%. The two analyses, therefore, indicated that the sample size of 60 was above the minimum required to reject the null hypothesis at α = 0.05, with a statistical power of 80%.

For the primary data, the sample size of 10 incineration processes of sharps HCW kept in plastic containers and another sample size of 10 incineration processes of sharps HCW kept in cardboard boxes were assumed to be adequate. The assumption was based on the actual incineration processes on the ground, MediBurn incineration manual, and, smoke densities emitted from incineration processes. The purpose was not to emit higher smoke densities unnecessarily for the sake of data collection. I confirmed the sample size for primary data set based on the Equation 5.

$$n = 2\sigma^2 = (Z_\beta + Z_{\alpha/2})/difference^2 \qquad (5)$$

Where,

n = Sample size in each group (assumed equal for plastic and cardboard)

σ = Standard deviation of outcome variable (8.701)

Z_β = Desired power (0.84 at 80% power)

$Z_{\alpha/2}$ = Level of statistical significance (1.96 for $\alpha = 0.05$)

Difference = The difference in means (10.96)

In view of the Equation 5, I estimated a sample size of 9.88 for each group necessary for the power of 80 %. This analysis indicated that the sample sizes of 10 in each case for the two groups were above the minimum required sample size to reject the null hypothesis at $\alpha = 0.05$, with a statistical power of 80%.

Statistical Analyses for Secondary Data on HCW incinerated Weights

Analysis of the pattern of HCW incinerated Weights from 2009 to 2013. The first research question required an analysis of the pattern of HCW incinerated weights before and after the 2010 earthquake and cholera disasters in Haiti. I used Linear Regression Analysis (Frankfort-Nachmias & Nachmias, 2008; Green & Salkind, 2011) in order to determine the pattern of emergency HCW incinerated weights.

The null hypothesis to be tested here was that the pattern of HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti is linear. The alternate hypothesis was that the pattern of HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti is non-linear. I conducted a linear regression analysis by using SPSS Statistics 21 with a pre-specified error of 0.05. To start with, I had to check if there exist a significant correlation between HCW incinerated weights and the months under which it occurred (months before, during and after the 2010 cholera and earthquake disasters). I therefore, conducted a Pearson Correlation test. Table 8 summarizes the results of the test.

Table 8

Pearson Correlation Test for HCW Incinerated Weights

Variables	***N***	**r**	***p***
HCW Incinerated Weights (kg) and Period (months)	60	$.406^{**}$	.001

Note: Correlation between HCW incinerated weights and months in which they occurred (months before, during and after the 2010 earthquake and cholera disasters), r = Pearson Product-Moment Correlation Coefficient, p = probability, N = Total sample, ** = Correlation is significant at the $p = 0.01$ *level (2-tailed).*

As indicated in Table 8, there exist a significant correlation between HCW incinerated weights and the months they occurred (months before, during and after the 2010 cholera and earthquake disasters). The Pearson product-moment correlation coefficient (r) is .406, p = 0.001. Linear regression analysis was conducted following the existence of significant correlation in order to evaluate the linearity of HCW incinerated weights for the 60 months period. The model summary indicated R value of 0.406 and R square (R^2)

value of 0.164. Therefore, the independent variable (months before, during and after the 2010 cholera and earthquake disasters) included in the model explained 16 % variance (0.164 * 100%) in the dependent variable (HCW incinerated weights). I performed the analysis of variance (ANOVA) to check whether the model was significant (see Table 9).

Table 9

ANOVA for HCW Incinerated Weights

Model	*df*	*F*	*p*
Regression	1	11.419	.001
Residual	58		

Note: Analysis of Variance (ANOVA) of healthcare waste (HCW) incinerated weights (2009 – 2013). *df* = degree of freedom, *p* = probability, *F* = *F* statistical test, the model is significant at the *p* = 0.001 level.

Statistical results in Table 9 confirmed the model as a whole to be significant *F* (1, 58) = 11.419, *p* = 0.001. Therefore, approximately 16 % variance in the amount of HCW incinerated weights are explained by the months under which HCW incineration processes occurred (before, during and after the 2010 cholera and earthquake disasters). Table 10 shows the coefficients of linear regression analysis.

Table 10

Linear Regression Analysis for HCW Incinerated Weights

			95 % *CI*	
Model	$\boldsymbol{\beta}$	*p*	Lower bound	Upper bound
HCW Incinerated Weights (kg)	296.017	.000	201.342	390.692
Months Before, During and After the 2010 Earthquake and Cholera Disasters	4.557	.001	1.858	7.256

Note: Linear regression results of HCW incinerated weights (kg) based on months in which they occurred. $\boldsymbol{\beta}$= Unstandardized Coefficients, *p* = probability, *Cl* = Confidence Interval, R^2 = .164, (*p* = 0.001).

A linear regression analysis was conducted to evaluate the pattern of HCW incinerated weights or the prediction of HCW incinerated weights from the months in which they occurred (months before, during and after the 2010 cholera and earthquake disasters). The scatterplot for the two variables as is indicated in Figure 6 in the coming page did not show that the two variables are linearly related. The regression equation for predicting the HCW incinerated weights is indicated in Equation 6.

$$Predicted\ HCW\ Incinerated\ Weights = 4.56\ Months\ They\ Occured + 296 \qquad (6)$$

The 95 % confidence interval for the slope, 1.858 to 7.256 does not contain the value of zero; thus, HCW incinerated weights are related to months in which they occurred. As hypothesized, the pattern of HCW incinerated weights is non-linear, the accuracy in predicting HCW weights was moderate. The correlation between HCW incinerated weights and the months in which they occured was 0.406. Approximately, 16 % variance of the HCW incinerated weights was accounted for by its linear relationship with the months under which HCW incineration processes occurred (before, during and after the 2010 cholera and earthquake disasters).

Based on this analysis, I retained the null hypothesis that the pattern of HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti is linear. The alternate hypothesis that the pattern of HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti is non-linear in this case is explained by 84 %.

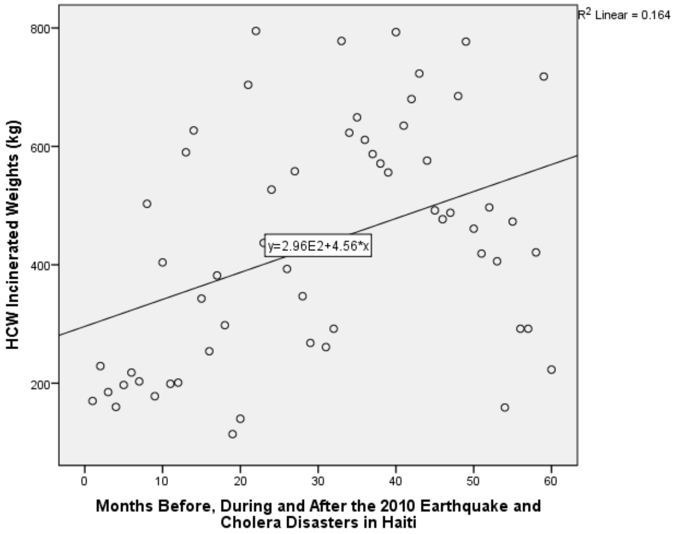

Figure 6: Scatterplot between HCW Incinerated Weights and Months They Occurred.

Monthly time series model in Figure 7 explains the observed variation in HCW incinerated weights from January 2009 to December 2013 (60 months period).

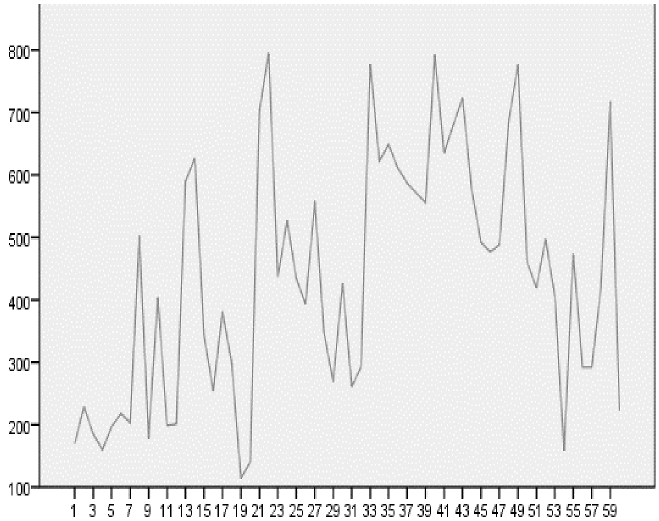

Figure 7: Time Series Model for HCW Incinerated Weights in kg (Y-Axis) and Months They Occurred (X-Axis).

Statistical Analyses for Primary Data on Average Smoke Densities

Comparison of average smoke densities emitted during the incineration process of plastic sharps HCW containers and cardboard boxes. The second research question required a comparison of average smoke densities emitted from incineration of plastic and cardboard containers. The assigned null and alternate hypotheses for the second research question included:

- Null hypothesis (H_o): The average densities of BC emissions (smoke) during the incineration process of plastic sharps HCW containers and cardboard boxes are similar.
- Alternate hypothesis (H_a): The average density of BC emissions (smoke) is significantly lower during the incineration process of cardboard box sharps HCW containers.

I used an independent samples *t-test* (Frankfort-Nachmias & Nachmias, 2008; Green & Salkind, 2011) in order to evaluate the difference between the means of the two independent groups by using SPSS Statistics 21 with a pre-specified error of 0.05. Table 11 summarizes the results of this analysis.

Table 11

Independent Samples t-test for Average Smoke Density from Incineration of Plastic and Cardboard Sharps HCW Containers

	Levene's Test for Equality of Variances					95 % *CI*	
Assumption	*F*	*Sig.*	*t*	*df*	Sig. (2-tailed)	Lower	Upper
Equal variances assumed	6.133	.023	3.590	18	.002	4.544	17.367
Equal variances not assumed			3.590	14.305	.003	4.423	17.488

Note: Comparison of average smoke densities emitted during practical incineration processes of plastic and cardboard sharps HCW containers.
df = degree of freedom, *t* = *t* statistical test, *F* = *F* statistical test, sig. = significant or probability *(p)* level, *Cl* = Confidence Interval.
Mean difference = 10.96 % average smoke density, 95 % *Cl* (4.4, 17.5), *p* = 0.003 level.

As indicated in Table 11, Levene's test for equality of population variances yielded a significance of 0. 023, which is less than 0.05. Consequently, this observation is significant and, therefore, the equality of variance assumption inherent to the *t-test* is violated. In this test, the variances are very similar and both the *t-test* for equal variances, $t(18) = 3.59$, $p = 0.002$ and the *t-test* for unequal variances $t(14) = 3.59$, $p = 0.003$, yield comparable results. The use of unequal variance's *t-test* is valid for this analysis.

The independent samples *t-test* was significant, $t(14) = 3.59$, $p = 0.003$, thus, the rejection of null hypothesis that the average densities of BC emissions (smoke) during the incineration process of plastic sharps HCW containers and cardboard boxes are similar. The test indicated that the average density of smoke is significantly lower during the incineration process of cardboard box sharps HCW containers ($M = 6.81$, $SD = 4. 79$) than plastic sharps HCW containers ($M = 17.77$, $SD = 8.38$). The 95 % confidence interval for the difference in means was quite wide, ranging from 4.42 to 17.49, and reflecting the large disparity in average smoke densities emitted from incineration of different sharps HCW containers (cardboard boxes and plastic containers).

Based on this analysis, there is a significant difference between the average smoke densities from the incineration process of cardboard and plastic sharps HCW containers. The average density of smoke is significantly lower during the incineration process of cardboard box sharps HCW containers.

In order to rule out the probability that the differences in smoke densities may have been associated with poor segregation of sharps HCW, I conducted an independent samples *t-test* in order to evaluate the difference in smoke means for empty plastic and cardboard sharps HCW containers. I used the Equation 5 to confirm the required sample size. The results of indicated the sample size of 1.733 to be sufficient for the analysis. Therefore, sample sizes of 4 in each case for the two groups were above the minimum required sample size to reject the null hypothesis at $\alpha = 0.05$, with a statistical power of 80 %. In this instance both Table 12 and 13 summarize the descriptive and statistical results of the independent samples *t-test*.

Table 12

Group Statistics for Smoke from Incineration of Empty Plastic and Cardboard Containers

Variables	*n*	Minimum	Maximum	Mean	Std. deviation
Smoke density (%) for empty plastic containers	4	8.9	13.56	12.06	2.14
Smoke density (%) for empty cardboard boxes	4	1.1	3.11	2.28	0.86
Total (*N*)	8	1.1	13.56	7.17	5.44

Note: Average smoke densities emitted during practical incineration processes of empty sharps HCW containers and their mean values.
Std. Deviation =Standard Deviation, *n* = Proportion of the sample, *N* = Total sample.

As indicated in Table 12, the smoke densities emitted from practical incineration process of empty sharps HCW containers ranged from 1.1 % to 13.56 %, with a mean value of 7.17 % and a standard deviation of 5.44. The smoke densities emitted from practical incineration process of empty plastic sharps HCW containers ranged 8.9 % to 13.56 %, with a mean value of 12.06 % and a standard deviation of 2.14. The smoke densities from incineration of empty cardboard sharps HCW boxes ranged from 1.1 % to 3.11 %, with a mean value of 2.28 % and a standard deviation of 0.86.

Table 13

Independent Samples t-test for Average Smoke Density from Incineration of Empty Plastic and Cardboard HCW Containers

	Levene's Test for Equality of Variances					95 % *CI*	
Assumption	*F*	*Sig.*	*t*	*df*	Sig. (2-tailed)	Lower	Upper
Equal variances assumed	2.547	.162	8.474	6	.000	6.955	12.601
Equal variances not assumed			8.474	3.939	.001	6.555	13.001

Note: Comparison of average smoke densities emitted during practical incineration processes of empty plastic and cardboard sharps HCW containers.
df = degree of freedom, *t* = *t* statistical test, *F* = *F* statistical test, sig. = significant or probability *(p)* level, *Cl* = Confidence Interval.
Mean difference = 9.78 % average smoke density, 95 % *Cl* (6.96, 12.6), $p < 0.001$ level.

As indicated in Table 13, Levene's test for equality of population variances yielded a significance of 0.162, which is greater than 0.05. Accordingly, this observation is non-significant and, therefore, the equality of variance assumption inherent to the *t-test* is not violated. Therefore, the use of equal variance's *t-test* is valid for this analysis.

The independent samples *t-test* was significant, $t(6) = 8.47$, $p < 0.001$. The test indicated that the average density of smoke is significantly lower during the incineration process of empty cardboard sharps HCW containers ($M = 2.28$, $SD = 0.86$) than empty plastic sharps HCW containers ($M = 12.06$, $SD = 2.\ 14$). The 95 % confidence interval for the difference in means was quite wide, ranging from 6.96 to 12.6, and reflecting the large disparity in average smoke densities emitted from incineration of empty sharps HCW containers (cardboard boxes and plastic containers). Based on this analysis, the difference in smoke densities during the incineration process of cardboard and plastic sharps HCW containers is not subjected to poor segregation.

Furthermore, I conducted an independent samples *t-test* in order to evaluate the difference between the final operating temperatures for the bottom burners to see whether the average smoke densities can be caused by the final operating temperatures of the bottom burners. In using the Equation 5 to confirm the required sample size, the results indicated a sample size of 4.539 to be sufficient for the analysis. Therefore, sample sizes of 10 in each case for the two groups were above the minimum required sample size to reject the null hypothesis at $\alpha = 0.05$, with a statistical power of 80 %. Table 14 and 15 are both presenting the results of the analysis.

Table 14

Group Statistics for Final Bottom Burner's Temperatures

Variables	*n*	Minimum	Maximum	Mean	Std. deviation
Final Bottom Burner temperature (^{0}C) for plastic HCW containers	10	881	1095	971.40	72.96
Final Bottom Burner temperature (^{0}C) for cardboard HCW containers	10	851	950	900.30	39.29
Total (*N*)	20	851	1095	935.85	67.70

Note: Incinerator operational temperatures for the bottom burner, recorded during practical incineration processes of sharps HCW containers and their mean values.
Std. Deviation =Standard Deviation, *n* = Proportion of the sample, *N* = Total sample,
(%) = Percentage.

As indicated in Table 14 above, the final temperatures of the bottom burners ranged from 851 ^{0}C to 1095 ^{0}C, with a mean value of 935.85 ^{0}C and a standard deviation of 67.7. The final temperatures of the bottom burners during the practical incineration process of plastic sharps HCW containers ranged from 881 ^{0}C to 1095 ^{0}C, with a mean value of 971.40 ^{0}C, and a standard deviation of 72.96. The final temperatures of the bottom burners during the practical incineration process of cardboard sharps HCW containers ranged from 851 ^{0}C to 950 ^{0}C, with a mean value of 900.3 ^{0}C, and a standard deviation of 39.29.

Table 15

Independent Samples t-test for Final Bottom Burners' Temperatures during Incineration of Plastic and Cardboard Containers

Assumption	Levene's Test for Equality of Variances				Sig. (2-tailed)	95 % *CI*	
	F	*Sig.*	*t*	*df*		Lower	Upper
Equal variances assumed	4.193	.055	2.713	18	.014	16.044	126.156
Equal variances not assumed			2.713	13.816	.017	14.824	127.376

Note: Comparison of final bottom burners' temperatures (^{0}C) during practical incineration processes of plastic and cardboard sharps HCW containers. *df* = degree of freedom, *t* = *t* statistical test, *F* = *F* statistical test, sig. = significant or probability *(p)* level, *Cl* = Confidence Interval.
Mean difference = 71.1 (^{0}C), 95 % *Cl* (16, 126. 2), *p* = 0.014 level.

As indicated in Table 15 above, Levene's test for equality of population variances yielded a significance of 0.055, which is greater than 0.05. Accordingly, this observation is non-significant and therefore, the equality of variance assumption inherent to the *t-test* is not violated. Therefore, the use of equal variance's *t-test* is valid for this analysis.

The independent samples *t-test* was significant, *t*(18) = 2.71, *p* = 0.014. The test indicated that the average final temperatures of the bottom burners is significantly lower during the practical incineration process of cardboard sharps HCW containers *M* = 900.3, *SD* = 39.29) than for plastic sharps HCW containers (*M* = 971.40, *SD* = 72.96). The 95 % confidence interval for the difference in means was quite wide, ranging from 16 to 126.2, and reflecting the large disparity in average final temperatures of the bottom burners during the practical incineration process of cardboard and plastic sharps HCW containers. Therefore, it is unlikely that the average smoke densities are caused by the final operating temperatures of the bottom burners.

Chapter 4 Summary

Linear regression analysis conducted to evaluate the pattern of HCW incinerated Weights from 2009 to 2013 indicated that the pattern of HCW incinerated weights before, during and after the 2010 earthquake and cholera disasters in Haiti is linear. I was unable to confirm that the quantities of HCW incinerated before, during and after the January 2010 earthquake and October 2010 cholera disasters in Haiti did not depend on the months they occurred.

Also, the independent samples *t-test* conducted to evaluate the difference between the mean of smoke densities emitted during the incineration process of plastic and cardboard sharps HCW containers. The results of the independent samples *t-test* indicated the average density of BC emissions (smoke) is significantly lower during the incineration process of cardboard box sharps HCW containers than is the case in plastic containers incineration. I was, therefore, able to confirm that the use of cardboard sharps HCW resulted into the release of lower smoke emission into the atmosphere as compared to plastic containers. Additionally, in order to rule out any question of the effects of a possible poor segregation situation, I conducted an independent analysis for empty containers. The test apparently revealed that the results were similar.

From sheer personal curiosity, I had to run the independent samples *t-test* for the average final temperatures of the bottom burner for the purposes of checking whether the average smoke densities are caused by the final operating temperatures of the bottom burners. The results indicated lower bottom burner's final temperatures during the practical incineration process of cardboard sharps HCW than for plastic sharps HCW containers. From this analysis, it was discovered that temperatures had no relationship with the final average smoke densities. Thus, it is unlikely that the average smoke densities are caused by the final operating temperatures of the bottom burners.

Apparently, these results provide the basis for several key factors and recommendations discussed in Chapter 5. Specifically, Chapter 5 includes an interpretation of the results, limitations, and implications of the study, and recommendations stemming from the collection of primary data and analysis during this study.

Chapter 5: Discussion, Conclusions, and Recommendations

Introduction

The purpose of this study was to analyze the emergency HCW incineration trends and BC emissions or smoke from HCW incineration processes in Haiti. This study provided a quantitative demonstration of fluctuating trends of HCW incinerated weights during the emergency situation in Haiti. Also, the study provided a quantitative illustration of the reduction in BC emissions during sharps HCW incineration activities by using cardboard sharps HCW containers. Likewise, the study provided empirical evidence on health and climate change impacts of BC emissions. In addition, the study has generated data that may be used to guide policy formulation and safe management of HCW disposal in Haiti and other countries where emergency and humanitarian efforts could similarly be taking place. The reduced HCW incineration emissions could result in positive social change for healthier communities following a drop in BC emission exposure and associated health risks.

I relied on the conceptual framework that based on both adverse health effects from BC emissions exposure and climate change potential of BC emissions. I used both secondary data on HCW incinerated weights by MINUSTAH at the 5-year scope beginning from January 2009 to December 2013, and primary data on smoke densities collected from practical incineration processes at MINUSTAH incineration facilities. I addressed two research questions. The first research question was whether HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti follow a linear pattern. The second research question was whether cardboard HCW sharps containers emit lower BC emissions to the atmosphere during the incineration process, relative to the plastic sharps containers.

In this result discussion chapter, I discuss and interpret the findings, as well as verify the working hypotheses as they appeared in Chapter 4 of this study. Likewise, I also make recommendations informed by a number of findings in this study, point out areas that need further research, and provide conclusions stemming from the whole stream of research activities right from the beginning to the end of this dissertation. This chapter is broadly subdivided into five major parts that include the interpretation of research findings, study limitations, recommendations, implications and conclusions.

Interpretation of the Study Findings

Under this section, I interpret the research findings in agreement to the two research questions that were guiding this study. In the course of this research, I made a number of observation from literature review and data collection. Subsequently, I have included the interpretation of such observation in this chapter. Similarly, I have interpreted a number of findings of statistical analyses conducted with regard to the two research questions. Further discussion of the said findings is elaborated under the subheadings.

Healthcare Waste Incineration Pattern during Emergency Situation

Studying HCW incineration before, during and after emergency situations in Haiti. As is discussed in Chapter 3, my study of secondary data from MINUSTAH that spread-out for a period of 60 months, led me into discovering a number of features which are either positive or negative to healthcare facilities in Haiti. As at MINUSTAH, I found a well-organized database which gave day-to-day account of HCW incineration activities including HCW incinerated weights (kg).

However, in a number of hospitals visited outside MINUSTAH, they neither had any HCW incineration records at all to rely on, incinerators nor other disposal facilities standing within their premises. Likewise, these hospitals did not have any HCW disposal services contracted to them from any other location. To be particular, for the case of Haiti National Hospital (Haiti State's Hospital University), a hospital that offer referral services to other public hospitals throughout the country, did not have incineration facility at all. I was given explanation that their not having incineration facility was due to the January 2010 earthquake in Haiti that destroyed their entire incineration unit of which has since not been put up together again.

Consequently, the hospital had no formal alternative for HCW disposal instead they turned in for open-air burning at the main dump site in Port au Prince called Trutier as discussed in Chapter 4. I had the opportunity to visit the site where Haiti State's Hospital University was practicing her open burning activities. What I witnessed was a haphazardly instead of the pit burning as is recommended by WHO (2014c) only for emergency operations. It is important to note that I visited the said hospital 4 years after the 2010 earthquake in Haiti. In this instance, it must be remembered that it was no longer an emergency period. In reviewing the WHO (2014c) guidelines on emergency HCWM, I revealed that even the WHO itself has not specifically defined what span of time qualifies to be *an emergency period* in the strict sense of the term. In my view, this technical miss-out has since caused unnecessary laxity and excuse of a hit from a particular emergency, thus, the perpetual lack of functional HCW disposal facility in place.

In spite of the situation elaborated above, in my case as a researcher, my objective was to know what the situation was with other hospitals in the country. For this reason, I had to ask for a document from the MSPP which gave me a list of hospitals (both public and private) with incineration attached to them (see Appendix F). Apart from listing those hospitals with functional incinerators, and those with non-functional incinerators (reason not attached), elsewhere, the MSPP could not tell whether the incinerators in some of the hospitals are either functional or not. This was evidenced by a question mark that they had placed on their document against incineration status of certain hospitals. For this last point, the unclear status of incinerators at certain hospitals drew doubts and curiosity as to who should provide this answer if MSPP itself cannot do that. I upgraded the document provided by the MSPP into a global positioning system [GPS] accessible map which provides the specific hospital, location, and the said incineration unit attached (see Appendix F). In my view, this map will make the work of future researchers in this area more convenient and to the point.

Based on the observation above, HCW disposal in Haiti seems to lack proper coordination, monitoring, and maintenance strategies thus inadequate HCW disposal infrastructure at its disposal. Open-air burning practice observed seems to be one case of haphazard open burning that is compensating for the incineration facility inadequacy pointed above. According to the Making Medical Injection Safer [MMIS] project, over 90 % of healthcare facilities in Haiti dispose of its sharps HCW ineffectively through open-air burning, burial and disposal in unsupervised areas (MMIS, 2010). Wilburn (2012) also reported open-air burning of HCW in Haiti. The observed open-air burning of sharps HCW in Haiti tallies with the conceptual framework of the study that based on health and climate change potential of smoke. In summary, what the prolonged haphazard open-air burning may mean to the cost of health and climate change impacts is not clear and can only be a subject of another research and policy actions.

Pattern of HCW incineration during the 2010 earthquake and cholera emergencies in Haiti. The cardinal point of the first research question was to analyze the pattern of HCW incinerated weights during the 2010 earthquake and cholera emergencies in Haiti. The descriptive statistics of 60 months secondary data from MINUSTAH showed that the HCW incinerated weights were normally distributed, thus, supporting the use of linear regression analysis.

From a number of my statistical analyses, the study revealed that there was a significant correlation (Pearson product-moment correlation coefficient, $r = 0.406$) between HCW incinerated weights and months in which the incineration processes occurred (before, during and after the 2010 cholera and earthquake disasters). Linear regression analysis indicated that the pattern of HCW incinerated weights was linear (R =0.406, $R^2 = 0.164$), with a significant analysis of variance (ANOVA) results of F (1, 58) = 11.419, $p = 0.001$. From the statistical findings above, the independent variable (in which the incineration processes occurred) included in the model explained 16 % variance (0.164 * 100%) in dependent variable (HCW incinerated weights). In short, approximately 16 % variance in the amount of HCW incinerated weights is explained by the months under which HCW incineration processes occurred.

Even though the statistical findings could not allow the rejection of the null hypothesis that the pattern of HCW incinerated weights before and after the January 2010 earthquake and October 2010 cholera disasters in Haiti is linear, the small R-value of 0.406 explained fluctuations that existed. This is evidently represented by 84 % non-linearity (which agrees with the alternate hypothesis) and 16 % accounting for the linearity of the trend. This way, I can say that even though the alternate hypothesis is statistically been disapproved from the analysis findings, it is largely valid.

As hypothesized, the pattern of HCW incinerated weights is non-linear, the accuracy in predicting HCW weights was moderate (*r* = 0.406). The increase in months caused an increase in HCW incinerated weights (4.56 kg each month) as indicated in the Equation 6. The evidence of fluctuating trends in HCW incinerated weights during emergency is well-explained in Chapter 4 under Figure 4. From the figure, it is evident that the year 2009 had the lowest mean HCW incinerated weights standing at 237.25 kg with a sharp rise of almost doubling HCW incineration weights by the year 2010 (434.25 kg). This sharp trend is because January 2010 was a crisis moment when earthquake had hit Haiti and before long, cholera called in by October 2010. The effects of these two emergency factors should be responsible for the sharp trend observed, with a slight rise between 2010 and 2011 standing at 470.08 kg as the situation was still volatile.

However, there is another sharp rise between the year 2011 (470.08 kg) and 2012 (605.25 kg), before the trend experienced a sharp decline in 2013 (428.17 kg). The second sharp rise in the trend of HCW incinerated weights is a representation of incineration of written off emergence pharmaceuticals due to both the expiration and wrongful storage under higher temperature. These pharmaceuticals came from other organizations asking for incineration assistance by MINUSTAH. The reason for the other agencies asking for assistance by MINUSTAH to help incinerating pharmaceuticals was because they lack incineration facilities.

MINUSTAH had to help other agencies in disposing of pharmaceuticals for the reason that it was unsafe to leave the materials unattended any longer. MINUSTAH incinerators meet the WHO (1999, 2014c) requirement of emergency pharmaceutical disposal in double chambered incinerators at a temperature of 850 ^{0}C -1100 ^{0}C, except for the case of the cancer treatment medication that need much higher temperatures of above 1200 ^{0}C (WHO, 2014c). It is fortunate that none of cancer treatment medications had ever been brought for incineration by MINUSTAH. It is important to know that, I was one of the United Nations Volunteers with MINUSTAH from November 2008 to June, 2014 serving as environmental quality control volunteer.

The incineration of the said pharmaceuticals is counted as a wastage, and, Hicks (2013) and WHO (2014c) argued that the cost of wastage is one of the biggest expenditure in the healthcare system. Karlsson and Pigretti Öhman (2005) concluded that significant reductions in climate change impacts could be attained by reducing inefficient consumption trends in healthcare sector. Though Hicks (2013) recommended the use of inventory technologies in demand forecasting and other inventory monitoring techniques in order to reduce HCW volumes, it was evidence that the two emergencies could not allow deployment of such techniques. As for the case of pharmaceutical disposal in 2012 by MINUSTAH, the wastage could not be apportioned to MINUSTAH since the latter was only charged by the responsibility to dispose of what was brought in from other agencies.

Effective planning and coordination during emergency medical responses reduce quantities of expired pharmaceuticals, leading to lowered BC emissions and fuel consumption. Based on these research findings, it is clear that coordination during emergency medical mission and policy intervention are necessary in order to avoid similar situations or even worse in the future. Such policy guidelines should be able to provide strict guidelines on what should be done during an emergency and period after as far as pharmaceutical handling is concerned. Reduction in emergency pharmaceutical HCW will result into considerable reductions in health and climate change potential of BC emissions.

Comparing the Average Smoke Densities during Sharps HCW Incineration Processes

The core objective of the second research question was to compare the average smoke densities emitted during the practical processes of incinerating plastic and cardboard sharps HCW containers. I conducted 20 practical incineration processes of both empty plastic and cardboard sharps HCW containers, and those with full contents. The quantities incinerated ranged from 3 kg to 14.6 kg, with a mean value of 7.5 kg and a standard deviation of 4. 591 as indicated in Table 7. During that time, I conducted a total of 20 Ringelmann smoke readings during the incineration of sharps HCW kept in plastic and cardboard containers (10 tests for plastic and 10 for cardboard containers). The average smoke densities emitted from practical incineration process of plastic and cardboard sharps HCW containers were normally distributed, thus, supporting the use of parametric statistics in the analysis.

As summarized in Table 6, the smoke densities emitted from practical incineration process of sharps HCW containers ranged from 1.1 % to 32 %, with a mean value of 12.29 % and a standard deviation of 8.701. The smoke densities emitted during incineration processes of plastic sharps HCW containers ranged 8.9 % to 32 %, with a mean value of 17.77 % and a standard deviation of 8.38. The smoke densities from incineration of cardboard sharps HCW containers ranged from 1.1 % to 14.3 %, with a mean value of 6.81 % and a standard deviation of 4.79. Initial incineration operational temperatures for bottom burners ranged from 363 ^{0}C to 401 ^{0}C, with a mean value of 383.35 ^{0}C and a standard deviation of 11.55. Final bottom burner's operational temperatures ranged from 851 ^{0}C to 1095 ^{0}C with a mean value of 935.85 ^{0}C and a standard deviation of 67.7.

In applying the above data in summary form, I performed an independent samples *t-test* with the intention of comparing the mean smoke densities emitted during incineration of plastic and cardboard HCW containers. The test was significant, $t(14) = 3.59$, $p = 0.003$, thus, resulting in the rejection of null hypothesis that the average densities of BC emissions (smoke) during the incineration process of plastic sharps HCW containers and cardboard boxes are similar. The test indicated that the average density of smoke is significantly lower during the incineration process of cardboard box sharps

HCW containers (*M* = 6.81, *SD* = 4. 79) than plastic sharps HCW containers (*M* = 17.77, *SD* = 8.38). The difference between the sample mean smoke densities was 10.96 %.

The 95 % confidence interval for the difference in means ranged from 4.42 to 17.49, reflecting the large disparity in average smoke densities emitted from incineration of different sharps HCW containers (cardboard boxes and plastic containers). From the statistics above, it is evident that the average density of smoke during incineration of plastic sharps HCW containers is 2.61 times of what comes out during cardboard sharps HCW containers implies that the impact of cardboard containers on reducing BC emissions is significant .

For the purposes of clearing any doubt that the differences in smoke densities may have been associated with poor segregation of sharps HCW, I conducted an independent samples *t-test* in order to evaluate the difference in smoke means for empty plastic and cardboard sharps HCW containers. According to Table 12, the smoke densities emitted from practical incineration process of empty sharps HCW containers ranged from 1.1 % to 13.56 %, with a mean value of 7.17 % and a standard deviation of 5.44. The smoke densities emitted from practical incineration process of empty plastic sharps HCW containers ranged 8.9 % to 13.56 %, with a mean value of 12.06 % and a standard deviation of 2.142. The smoke densities from incineration of empty cardboard sharps HCW boxes ranged from 1.1 % to 3.11 %, with a mean value of 2.28 % and a standard deviation of 0.86. The independent samples t-test was significant, $t(6) = 8.47$, $p < 0.001$, thus, it indicated that the average density of smoke is significantly lower during the incineration process of empty cardboard sharps HCW containers (*M* = 2.28, *SD* = 0.86) than is the case with empty plastic sharps HCW containers (*M* = 12.06, *SD* = 2. 14). The difference between the sample mean smoke densities was 9.78 %.

The 95 % confidence interval for the difference in means was quite wide, ranging from 6.96 to 12.6 which reflected the large disparity in average smoke densities emitted from incineration of empty sharps HCW containers (cardboard boxes and plastic containers). From the above analysis findings, I was able to verify that poor segregation is not responsible for the difference in smoke densities during the incineration processes of cardboard and plastic sharps HCW containers. Also, I evaluated the difference in final incineration temperature for the bottom burners. The independent samples *t-test* (see Table 15) indicated higher mean final temperature during incineration of plastic containers (*M* = 971.40, *SD* = 72.961), as compared to cardboard containers (*M* = 900.3, *SD* = 39.294). Therefore, I ruled out the temperature effect on the average smoke densities based on the results of the test with 95 % *Cl*(16, 126. 2) and *p* = 0.014.

A closer observation during data collection revealed that carton boxes burn faster than is the case with plastic containers that start burning after an average of 3 minutes with the observed higher initial smoke levels (Level 3 and 4 of the Ringelmann smoke chart). This was incomparable to the average initial smoke Level 1 for cardboard containers. Cardboard boxes are made of cellulose fibers that originate from wood whereas plastic containers originate from petroleum products (Marsh & Bugusu, 2007; Tan & Khoo, 2006). Although both plastic and cardboard materials contain carbon compounds, plastic materials are harder and requires higher energy to burn as compared to cardboards (Pan, Houck, Clark, & Pinnick, 2013). Niu, et al. (2013) found that that burning fires or fuel mass loss of cardboard boxes correlate with time, and, the higher initial burning occurred prior to the inception of full flaming combustion. In view of the fact that cardboard boxes burn much faster than plastic containers, the contents in the box (sharps HCW) scatter-off and start burning too immediately owing to the increased burning surface area and ample air circulation.

However, a look at plastic container's incineration processes revealed that the contents are confined and the containers do not allow faster scattering of the sharps HCW in the entire incinerator chamber. For this reason, the contents burn slowly thus higher smoke levels. The burning test results of plastic identification indicated that most thermoplastics and thermoset plastics emit black smoke during combustion (Boedeker Plastics, Inc., 2014). Gullett, Tabor, Touati, Kasai and Fitz (2012) reported that burning of used pesticide plastic containers caused PM emission. The emission factors for $PM_{2.5}$ ranged from 9-35 mg/g of carbon burned, and, 6-43 mg/g of carbon burned for $PM_{10.}$

As is indicated in Table 4, incineration of 10 kg of sharps HCW and above in plastic containers emitted average smoke densities higher than (20%) or darker than Level 1 of Ringelmann smoke chart as opposed to the case with cardboard containers. Saxe (2008) and Slette (1999) reported higher emissions from plastic burning. This implies that a continued use of plastic sharps HCW containers in incineration processes is more likely to cause higher BC emissions.

In summary, the incineration processes smoke tests have revealed the increasing scientific significance of BC emissions especially from plastic sharps HCW containers. BC emissions have got both health and climate change effects, the basis of the conceptual framework as explained in the literature review. In this regard, this study provided a quantitative data as a basis for further research and policy formulation towards lower BC emissions.

Comparing the Observed Smoke Densities and Health-Based Threshold

The researcher revealed higher initial smoke levels (Level 3 and 4 of the Ringelmann smoke chart) during incineration processes of plastic sharps HCW containers. Correspondingly, the incineration of equal or more than 10 kg of plastic HCW containers emitted smoke levels darker than Level 1 of Ringelmann smoke chart as indicated in Table 4. Smoke or BC emissions of higher than Level 1 have got health and climate change effects hence prohibited.

According to the New Jersey Administrative Codes [NJAC] Title 7, Chapter 27 emission of smoke darker that Level 1 of the Ringelmann smoke chart or 20 % opacity is considered illegal (NJAC, 2009). British smoke law prohibits darker smoke of more than shade 2 of the Ringelmann smoke chart (BSI British Standards 2009; SOLiFTEC, 2010). Furthermore, the United States Bureau of Mines (1967), the Scottish Environmental Protection Agency (SEPA, 2014), and various maritime departments in the globe (Anonymous, 2014) prohibit *dark smoke* (shadier than or similar to Level 2 of the Ringelmann smoke chart) for a maximum of 3 minutes.

Health effects of smoke or BC emissions. BC emissions have got effects as conceptualized in the framework of this study. The literature review identified experimental, long and short-term exposure effects to different sources of BC emissions. According to the experimental studies, exposure to $PM_{2.5}$ and PM_{10} of more than 200 μg/m^3 caused airway inflammation, higher blood coagulation tendency, elevated levels of serum amyloid and increase in mucosal irritation among subjects (Barregard et al., 2006, 2008; Riddervold et al., 2011; Sällsten et al., 2006; Sehlstedt et al., 2010; Solomon et al., 2003).

Epidemiological studies on association between health effects and PM including BC showed an association between mortality rates and BC emissions among subjects (Hoek et al., 2011; Jiang et al., 2011; Jansen et al., 2005). The said association based on the season, location, and source mortality difference (Grigg, 2011; Maciejczyk et al., 2010; Park et al., 2007). Likewise, short and long -term exposure effects of BC emissions are reported to be: acute bronchitis low birth weights and premature deaths, reproductive effects, reduced lung functions, development of chronic bronchitis and cancer, asthma attack and increase susceptibility to respiratory infections (USEPA, 2013; WHO, 2012, 2013, 2014b).

According to the Capital Allergy and Respiratory Disease Center (2013), asthma is a persistent chronic illness in Haiti. Approximately 235 million people in the world suffer from asthma illness with most deaths being in the global South countries (WHO, 2013). Systematic review of studies on health effects of BC emissions as performed by the WHO (2012) concluded that reducing exposure to BC would reduce health effects related to PM exposure, with major effects in the global South countries (WHO, 2014a).

Climate change potential of smoke or BC emissions. The literature review based on the climate change potential of BC emissions as among key issues in formulating the conceptual framework of this study. Smoke or BC emissions from different sources as indicated in Figure 1, contribute to climate change. Although climate change mitigation measures had been focused on curbing CO_2 emissions as the major climate change pollutant (Hansen et al., 2007, 2013; USEPA, 2014), researchers released scientific evidence that BC emissions heat the earth twice as much than initially thought (Bond et al., 2013; Deangelis, 2011; Santisi, 2012). BC emissions absorb heat radiation from the sun and reduce the sunlight's reflecting ability of snow and ice upon its deposition, thus causing global warming (Ban-Weiss et al., 2012; Kirkevåg et al., 2008; Kuo, 2009; NRC, 2002). When BC emissions get entrapped into clouds, they increase the level and degree of cloud formation (make the clouds darker) which in turn warms the earth by reducing sun's reflectivity (Deangelis, 2011; Foster, 2007; Mahajan et al., 2013; Santisi, 2012). BC emissions cause approximately 60% of the global warming effects of CO_2 (Bond et al., 2013; Deangelis, 2011; Santisi, 2012), making it the second most important climate change pollutant.

Climate effects of BC emissions depend on their altitudinal position in the atmosphere (Ban-Weiss et al., 2012; Bond et al., 2013; Mahajan, 2013), and their deposits on the Arctic ice have caused 0.5 to 1 .4 ^{0}C warming over the past 100 years (Deangelis, 2011). Ice melting following BC deposits in the Arctic and Himalaya because of its proximity to larger BC emitters, India and China has threatened the water supply of more than 10% of the world population (Deangelis, 2011).

There is a need in the world for reducing BC emissions in order to mitigate climate change effects (NRC, 2010; Spotts, 2013; Stott, 2006; Tollefson, 2012). The results of this study would inform decision makers on BC emissions from HCW incineration activities, their climate change potential, and, their mitigation measures towards policy formulation and action.

Comparing Incineration Emission Limits and Air Quality Standards

In comparing the established incineration emission limits and the accepted air quality standards, I find the established HCW incineration emission limits to be unusually much higher than air quality standards recommended in many places. For example, the USEPA (2012) and WHO (2014a) recommended daily air quality standards for PM ranging from 10 μg/m^3 to 150 μg/m^3 as is indicated in Table 1. In their recommendations, the USEPA (2010) and WHO (2014c) recommended incineration emission limits for PM ranging from 10 mg/m^3 (10000 μg/m^3) to 66 mg/m^3 (66000 μg/m^3) as is indicated in Table 2. Therefore, given the huge variation above, it is evident that, the geographical distribution of incinerators in the global South countries, as is for the case of Haiti (See Appendix F), have got higher impacts of the quality of air in such locations.

Alternatively, if the use of centralized higher temperature incineration facilities were in place, this would mean that the effects of incineration emissions per cubic meters of air quality would likewise lower and thus provide a relief. A scattered distribution of small-scale incineration facilities, given the variations above, infers that the impacts of air quality per cubic meters is equally widespread over the large area than would be the case with a centralized incineration facility. Small scale incinerators have got higher emission rates as compared to large-scale incinerators (Rogers & Brent, 2006).

However, it is important to note that the MINUSTAH incineration facilities that I used for the purposes of generating data for this study meet the emission limits set by the

USEPA and WHO with test emission values ranged from 9.84 mg/m^3 to 18.5 mg/m^3 as indicated in Appendix E.

Study Limitations

There were a number of limitations in the course of conduction this study. These ranged from man-made and natural challenges which I had to overcome in order to achieve objectives of this study. First, lack of acceptable BC or EC standard measurement methods in the world as reported by the WHO (2012). As a result, in this study I had to opt for the use of Ringelmann smoke charts, which are regarded as valid smoke measurement tool. The said tool help me to measure the average smoke densities emitted during incineration of sharps HCW in plastic and cardboard containers. I performed inter-rater reliability test in order to determine the reliability of the Ringelmann and miniature smoke charts before performing the actual incineration processes. In order to increase efficiency of the results from Ringelmann smoke charts, I had to train 2 smoke readers who had to record independent observations, alongside myself, from the same incineration process after which I had to find the average.

Likewise, I had to perform a number of pilot smoke reading tests in order to increase the efficiency in using the Ringelmann and miniature smoke charts among the newly trained smoke readers. For the purposes of guarding against any bias from smoke readers, I gave them the leeway to record what they independently see from the incineration process. Again, apart from my having being one of the supervisors during my time as a volunteer, it is important to point out that this study was conducted long after I had finished my contract with MINUSTAH. That is to say the relationship was purely that of the researcher and her assistant in the field. There was neither compensation nor inducement of any kind in the course of data collection. Elsewhere, challenges of weather vagaries during smoke emission reading had forced me to postpone smoke reading test on a number of days that were either cloudy or highly windy.

Second, lack of HCW incineration facilities nor records at Haiti State's Hospital University, the location at which MSPP permitted me to conduct my research. One more feature about this location is that it is a national hospital that reflects the best of the country's public hospital health services and also a potential high generator of HCW. Therefore, the second study objective to measure the average smoke densities from incineration of plastic and cardboard sharps HCW containers from this hospital could not be achieved. Thus, I had to rely only on the MINUSTAH HCW incinerated weights and incineration facilities.

To overcome this stagnation, I had to visit their improvised open-air burning alternative at Truiter dump site in Port au Prince from there the best I could get was only to observe how the process was being conducted. On another hand, from a few private hospitals visited, not anyone of them could permit me to conduct my research. The reason for their not being ready to allow me to conduct my study was on the ground that they don't do any incineration instead they outsource. However, to whom do they outsource incineration activities, by how much and at what frequency were inadequately disclosed. After this hurdle, I had to request the MSPP for a list of both public and private hospitals with incinerators in the country and their functionality status (see Appendix F).

Third, I could not visit health facilities located in Cite Soleil because of insecurity impediments of this specific location in Haiti. It is possible that some hospitals in said locale could, perhaps, have different insights in regard to HCW incineration in the country.

Last, the challenge of the absence of air quality standard for smoke or PM in the global South countries, Haiti for one, thus, relying on international standards and standards set by other institutions in the developed world. Likewise, challenge of non-existence of occupation PM or smoke standards as highlighted in Chapter 2 of this study is a challenge that is affecting both the developed nations, and the global South countries.

Recommendations

Based on this study, I have proposed several recommendations for further research and actions. First, I recommend that BC emissions or smoke from HCW incineration activities in the global South countries be reduced, monitored and regulated.

Second, I recommend the WHO to revise the guidelines on HCWM by specifying cardboard boxes as environmental friendly sharps HCW containers suitable for incineration with lower BC emissions. Plastic containers should remain as reusable containers during automatic incineration processes that allow automatic emptying of the contents into the incinerators. In this regard, I equally recommend that MINUSTAH stops use of plastic containers in view of scientific reasons earlier mentioned in this study.

Third, I recommend that the WHO revise the emergency HCW disposal guidelines to redefine the specific time span that an emergency situation ought to stand active and valid beyond which everything ought to go back to normal in relation to HCW disposal processes and requirements.

Fourth, I recommend that relevant international agencies should support the establishment of specialized autonomous HCWM agencies, attached to each hospital, to be specifically responsible for proper HCWM in the global South countries including Haiti. On the same note, I similarly recommend the instituting of policy guidelines in every country to provide HCW incineration framework including air pollution control systems.

Fifth, there should be effective guidelines on logistics and pharmaceutical management and coordination during an emergency medical mission in order to avoid huge wastage in pharmaceuticals. Based on the research findings above, it is clear that coordination during emergency medical mission and policy intervention are necessary in order to avoid similar situations or even worse in the future. Such policy guidelines should be able to provide strict guidelines on what should be done during an emergency and period after as far as pharmaceutical handling is concerned.

Last, the concerned international agencies should revise incineration emission limits for PM based on locations and to be current and realistic with present industrial developments and urbanization rates in the world.

Implications for Positive Social Change

A number of significant implications stemmed from this study, contributing to positive social change, theoretical and empirical contexts for future research towards BC emissions curb from HCW incineration activities during emergency situations.

First, this is the first research to analyze HCW incinerated weights by MINUSTAH around the most fatally catastrophic 2010 earthquake, and the resultant cholera disasters. Thus, it has provided an evidence-based account of fluctuating trend in HCW incineration during emergency with a peak sharp rise in 2012; a representation of the incineration of unwanted emergency pharmaceuticals due to poor storage under extreme heat. It is optimistic that the observed pattern of HCW incinerated weights have provided information useful to most humanitarian agencies on effective coordination and planning of emergency medical responses in the future in order to avoid expired pharmaceuticals, leading to lowered BC emissions and fuel consumption.

Second, the information obtained from data collection process indicated that HCW incineration facilities in Haiti lack air pollution control systems, thus, agreeing with the IMF (2008) report. Equally, the study indicated that the problem of smoke from HCW incineration facilities in Haiti had been escalated by the January 2010 earthquake that left the national hospital (HUEH) without incineration facility at all, following the collapse of the incinerator building. Open burning disposal option remained an interim disposal option practiced by HUEH from the January 2010 earthquake emergency to-date. This information, therefore, suggested the need to review the WHO guidelines on emergency HCWM in order to specifically define what span of time qualifies to be *an emergency period* in the strict sense of the term. Also, the information is a wake-up call to help the HUEH and other hospitals with a similar problem in Haiti towards proper HCW disposal in the country.

Third, the study revealed that the established HCW incineration emission limits are much higher than air quality standards recommended in many places, suggesting the review of such limits, and use of centralized higher temperature incineration facilities for lower incineration emissions per cubic meters of air quality.

Fourth, this study provided quantitative evidence of the benefits of cardboard sharps HCW containers in reducing BC emissions during HCW incineration activities. This has provided potential data basis for policy formulation and emphasized the need for review of existing HCW guidelines in relation to sharps HCW containers. Furthermore, it informed the need for the purchase and use of cardboard boxes (greener sharps HCW containers) by MINUSTAH, other peacekeeping missions in the world and hospitals in the global South countries, as among climate change mitigation measures.

Fifth, the study findings on the challenges of emergency HCW incineration process provided an informed basis for robust policy formulation and safe management of HCW disposal in Haiti and other countries where emergency and humanitarian efforts could similarly be taking place.

The above mentioned study implications have a significant impact on social change for healthier communities related to reducing BC emissions and associated health risks, while contributing theoretical and empirical contexts for future research. Key contributions, therefore, include the significance of reducing, regulating and monitoring BC emissions from HCW incineration activities in the global South countries.

Conclusions

The findings of this study are in agreement with the conceptual framework which presupposed that smoke or BC emissions are a growing threat to human health and climate change with extreme impacts in the global South countries where over three quarters of BC emissions are produced (Deangelis, 2011; PAHO, 2012; WHO, 2012, 2014b). The analysis of HCW incineration pattern of periods before, during and after the 2010 earthquake and cholera disaster in Haiti revealed a relatively linear pattern ($R^2 = 0.164$) with fluctuating scenarios (peak sharp rise in 2012); a representation of the incineration of unwanted emergency pharmaceuticals due to poor storage under extreme heat. Also, the study supported the IMF (2008) observation which pointed out on the lack of air pollution control systems in HCW incineration facilities in Haiti. The study demonstrated that the average density of smoke is significantly lower during the incineration process of cardboard sharps HCW containers as compared to plastic containers. In providing quantitative evidence of the benefits of cardboard sharps HCW containers in reducing BC emissions during HCW incineration activities, and, fluctuating pattern of HCW incinerated weights, this study provides data which can potentially provide the basis for policy formulation needs, and, future research on potential health impacts of emergency HCW disposal and BC emissions.

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Appendix A: Ministry of Public Health and Population (MSPP) Haiti Research Approval

REPUBLIQUE D'HAITI

MINISTÈRE DE LA SANTÉ PUBLIQUE
ET DE LA POPULATION

Direction Générale

DG.-12-13 1757
Nº. ....

Port-au-Prince, le 03 JAN 2014

AUTORISATION

La Direction Générale du Ministère de la Santé Publique et de la Population autorise Madame **Emilia Mmbando RAILA'S**, étudiante à Walden University des USA à faire des recherches pour un travail de fin d'études sur la « gestion des déchets issus des activités de soins » au niveau des services à l'Hôpital de l'Université d'Etat d'Haïti (HUEH),

Cette autorisation lui est délivrée pour servir et valoir ce que de droit.

Dr. Mie Guirlaine Raymond CHARITE
Directeur Général

Cc : Dr. Maurice MAINVILLE
Directeur Exécutif HUEH

md

Appendix B: MINUSTAH Healthcare Waste Incineration Data Use Approval

UNITED NATIONS
United Nations Stabilization
Mission in Haiti

MINUSTAH

NATIONS UNIES
Mission des Nations Unies pour la
Stabilisation en Haïti

MEMORANDUM

Date: 22 August 2014
Ref: DMS/14/OM/308

To: Ms. Emilia Mmbando Raila
New Jersey, USA
emiliaroi@yahoo.co.uk

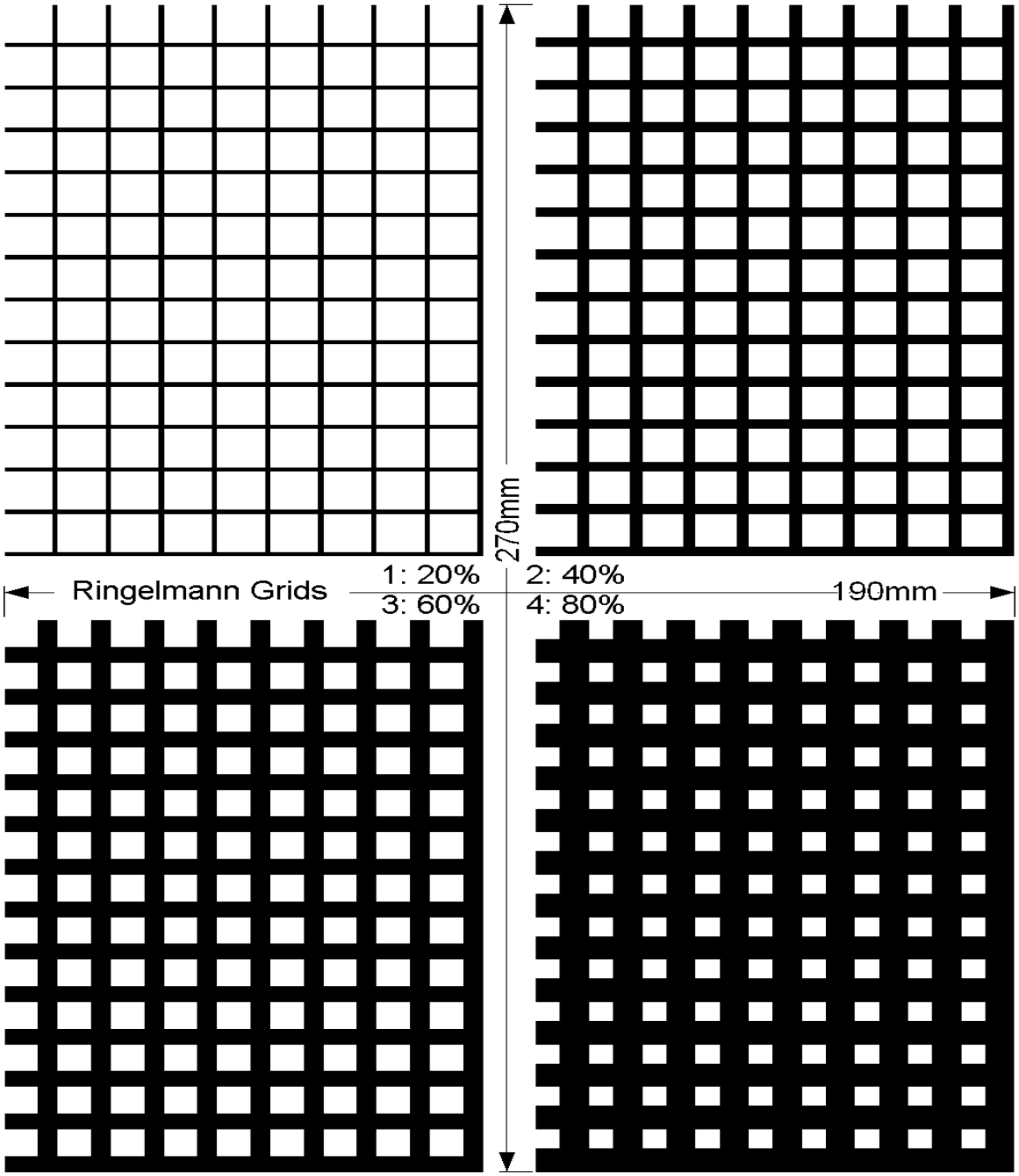
From: Wallace Divine
Director of Mission Support

SUBJECT: **Authorization to use MINUSTAH/PMS/PDU data on Healthcare Waste Incineration from 2009-2013 for PhD Dissertation**

1. Reference is made to your memorandum dated 26 June 2014 (attached), requesting MINUSTAH's approval to use Property Disposal data from 2009-2013, for the purpose of your PhD Dissertation on Public Health with the Walden University in Minneapolis, USA.
2. Please be advised that you are hereby granted the requested authorization to perform your study.
3. We take note that the results of your research will be shared with MINUSTAH prior to being published.

Best Regards.

Appendix C: The Ringelmann Smoke Chart



Appendix D: Purchased Right to Use Ringelmann and Miniature Smoke Charts

Invoice

Order No:	1847934
Order Date:	08/01/2014
Account No:	4398933

Corporate World Headquarters - 15 Inverness Way East - Englewood, CO 80112 USA

tel: 800-447-2273 fax: 303-397-2730 url: http://global.ihs.com

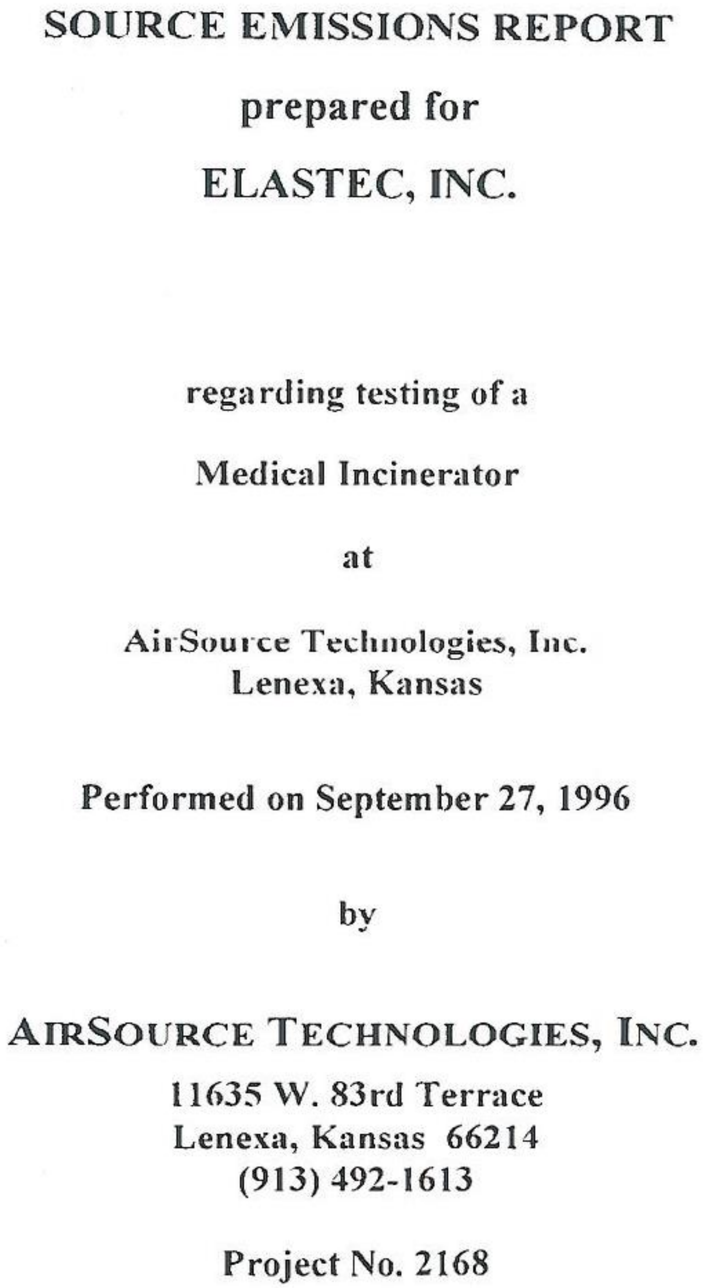
Bill to:	**Ship to:**
Emilia Raila Emilia Raila 87 Oregon Avenue Ewing,NJ 08638 UNITED STATES Email: emiliarci@yahoo.co.uk	Emilia Raila Emilia Raila 87 Oregon Avenue Ewing,NJ 08638 UNITED STATES Email: emiliarci@yahoo.co.uk

Qty	Description	Unit Price	Total
1	BS 2742- Complete Document Revision / Edition: 09 Org: WI REAF Date: 07/01/14 (Hardcopy) Regular Price:$139.00	$139.00	$139.00

Payment Type: Master Card
Payment No:

Subtotal:	$139.00
Taxes:	$10.78
Shipping:	$15.00
Total:	$164.78
Less Payments:	$164.78
Net Due:	$0.00

Appendix E: Incineration Source Emissions Report Prepared for Elastec, Inc



SOURCE EMISSIONS REPORT

prepared for

ELASTEC, INC.

regarding testing of a

Medical Incinerator

at

AirSource Technologies, Inc.
Lenexa, Kansas

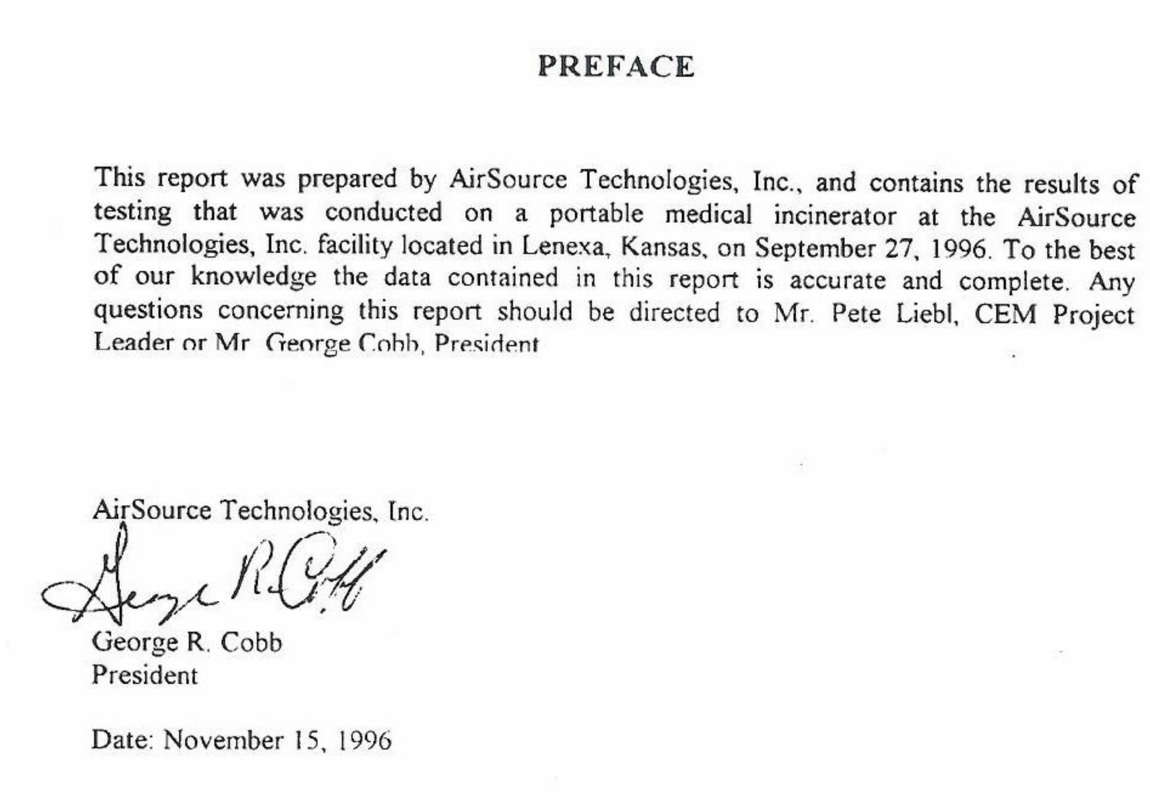
Performed on September 27, 1996

by

AIRSOURCE TECHNOLOGIES, INC.

11635 W. 83rd Terrace
Lenexa, Kansas 66214
(913) 492-1613

Project No. 2168



PREFACE

This report was prepared by AirSource Technologies, Inc., and contains the results of testing that was conducted on a portable medical incinerator at the AirSource Technologies, Inc. facility located in Lenexa, Kansas, on September 27, 1996. To the best of our knowledge the data contained in this report is accurate and complete. Any questions concerning this report should be directed to Mr. Pete Liebl, CEM Project Leader or Mr. George Cobb, President

AirSource Technologies, Inc.

George R. Cobb
President

Date: November 15, 1996

1. INTRODUCTION

AirSource Technologies, Inc. performed testing on a portable medical incinerator provided by Elastec, Inc. The tests were conducted at the AirSource Technologies, Inc. facility located in Lenexa, Kansas, on September 27, 1996. The tests were performed to collect information about emissions from the incinerator.

The scope of work included testing for the following parameters:

Particulate
Nitrous Oxides
Carbon Monoxide
Sulfur Oxides
Total Hydrocarbons

Mr. Pete Liebl, CEM Project Manager and Mr. George Cobb, Project Manager were responsible for conducting the testing.

Mr. Tony Glover of Elastec, Inc. operated the incinerator during the tests.

2. SUMMARY OF RESULTS

Three tests were conducted on the incinerator .Since this is for informational purposes, no regulatory limits are applicable at this time.

Table 1 provides the information that was used to calculate the heat value for each run. The solids heating value was determined from an EPA publication "Medical and Institutional Waste Incineration" EPA/625/4-91/030. The solid material incinerated during the test was assumed to be a type 2-refuse with 50% moisture content and a heating value of 4300 Btu/lb. The diesel heating value was provided to Elastec by the fuel distributor.

Table 2 summarizes the particulate emissions and supporting data which was used to arrive at these values. Heating value results which were used in this table were taken from Table 1. All runs met the 100±10 % criteria for isokinetic sampling as set forth in EPA Method 5. During run two, the unit ended it's cycle before the run could be completed. Since the run was very close (62.3 min) to the 64 minute run period, it was decided to treat it as a completed run. All computations are based on the 62.3 min sample period.

Table 3 provides the continuous emission monitor (CEM) results for each run. Carbon monoxide was not analyzed during Run 1 and the first half of Run 2.

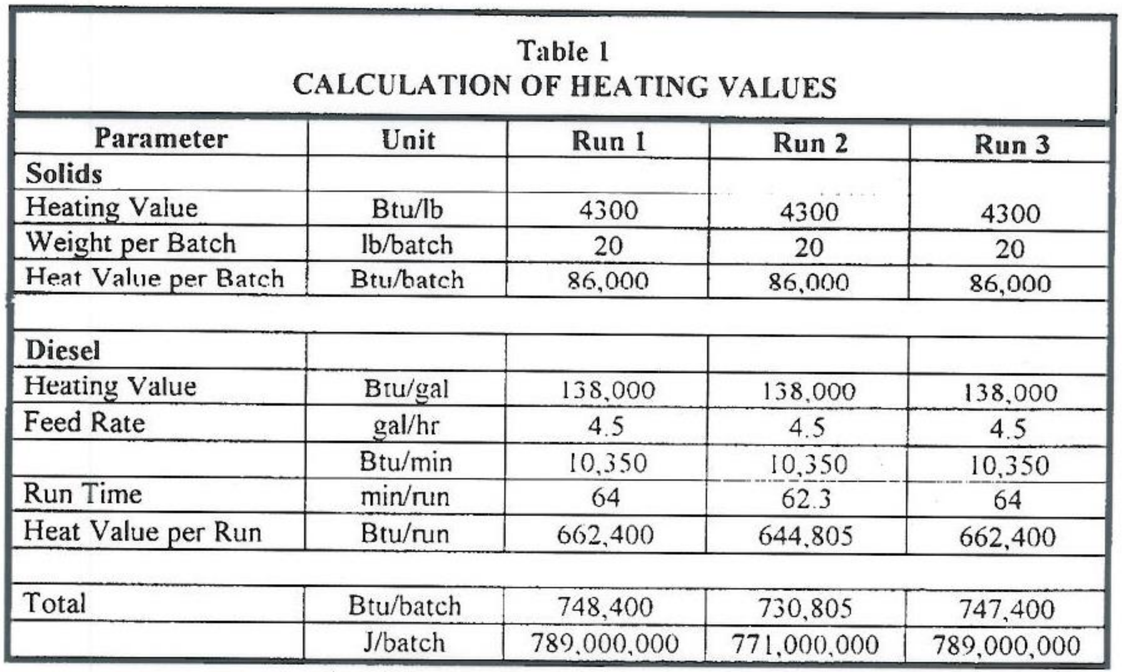


Table 1
CALCULATION OF HEATING VALUES

Parameter	Unit	Run 1	Run 2	Run 3
Solids				
Heating Value	Btu/lb	4300	4300	4300
Weight per Batch	lb/batch	20	20	20
Heat Value per Batch	Btu/batch	86,000	86,000	86,000
Diesel				
Heating Value	Btu/gal	138,000	138,000	138,000
Feed Rate	gal/hr	4.5	4.5	4.5
	Btu/min	10,350	10,350	10,350
Run Time	min/run	64	62.3	64
Heat Value per Run	Btu/run	662,400	644,805	662,400
Total	Btu/batch	748,400	730,805	747,400
	J/batch	789,000,000	771,000,000	789,000,000

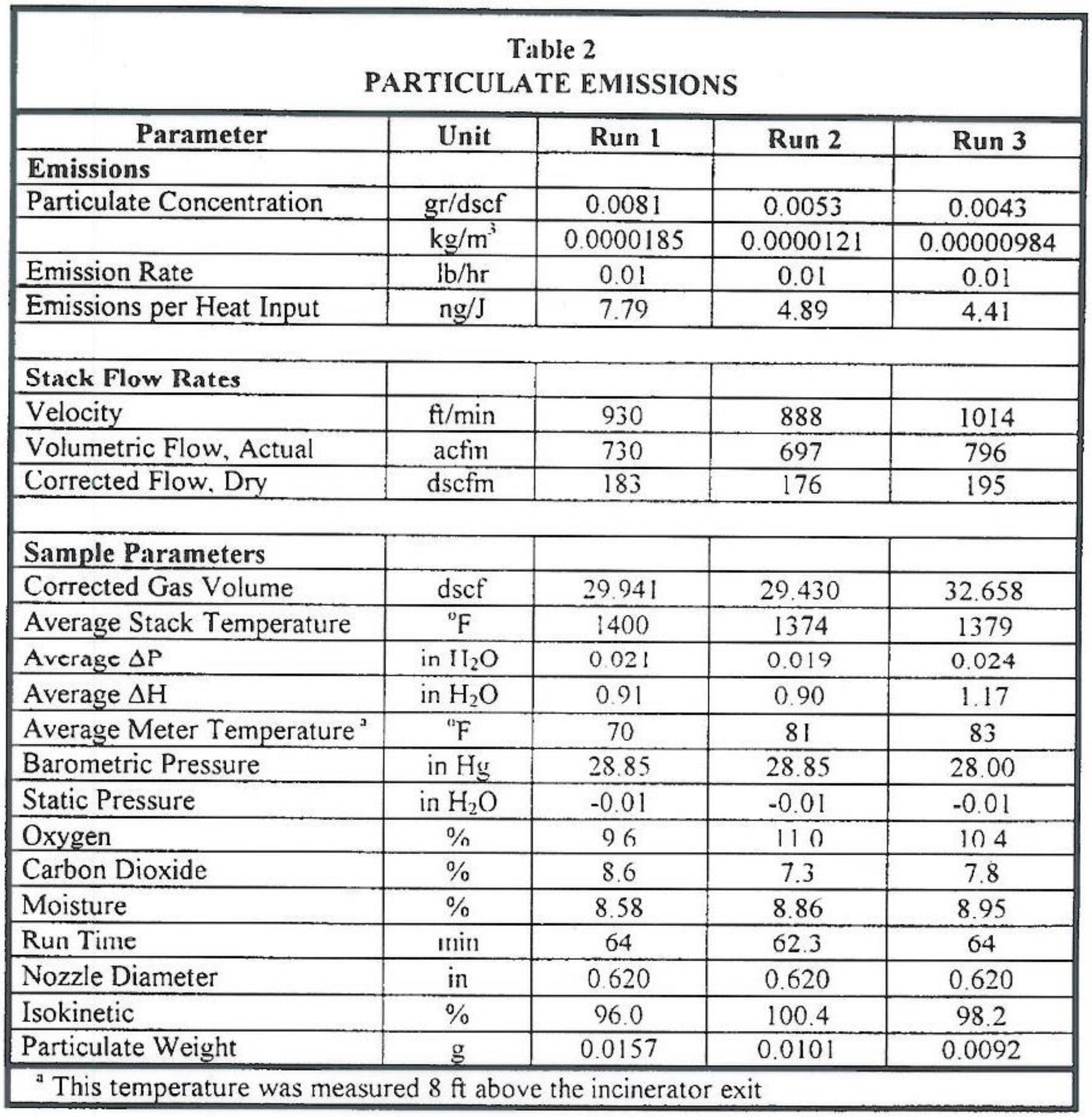


Table 2
PARTICULATE EMISSIONS

Parameter	Unit	Run 1	Run 2	Run 3
Emissions				
Particulate Concentration	gr/dscf	0.0081	0.0053	0.0043
	kg/m^3	0.0000185	0.0000121	0.00000984
Emission Rate	lb/hr	0.01	0.01	0.01
Emissions per Heat Input	ng/J	7.79	4.89	4.41
Stack Flow Rates				
Velocity	ft/min	930	888	1014
Volumetric Flow, Actual	acfm	730	697	796
Corrected Flow, Dry	dscfm	183	176	195
Sample Parameters				
Corrected Gas Volume	dscf	29.941	29.430	32.658
Average Stack Temperature	°F	1400	1374	1379
Average ΔP	in H_2O	0.021	0.019	0.024
Average ΔH	in H_2O	0.91	0.90	1.17
Average Meter Temperature [a]	°F	70	81	83
Barometric Pressure	in Hg	28.85	28.85	28.00
Static Pressure	in H_2O	-0.01	-0.01	-0.01
Oxygen	%	9.6	11.0	10.4
Carbon Dioxide	%	8.6	7.3	7.8
Moisture	%	8.58	8.86	8.95
Run Time	min	64	62.3	64
Nozzle Diameter	in	0.620	0.620	0.620
Isokinetic	%	96.0	100.4	98.2
Particulate Weight	g	0.0157	0.0101	0.0092

[a] This temperature was measured 8 ft above the incinerator exit

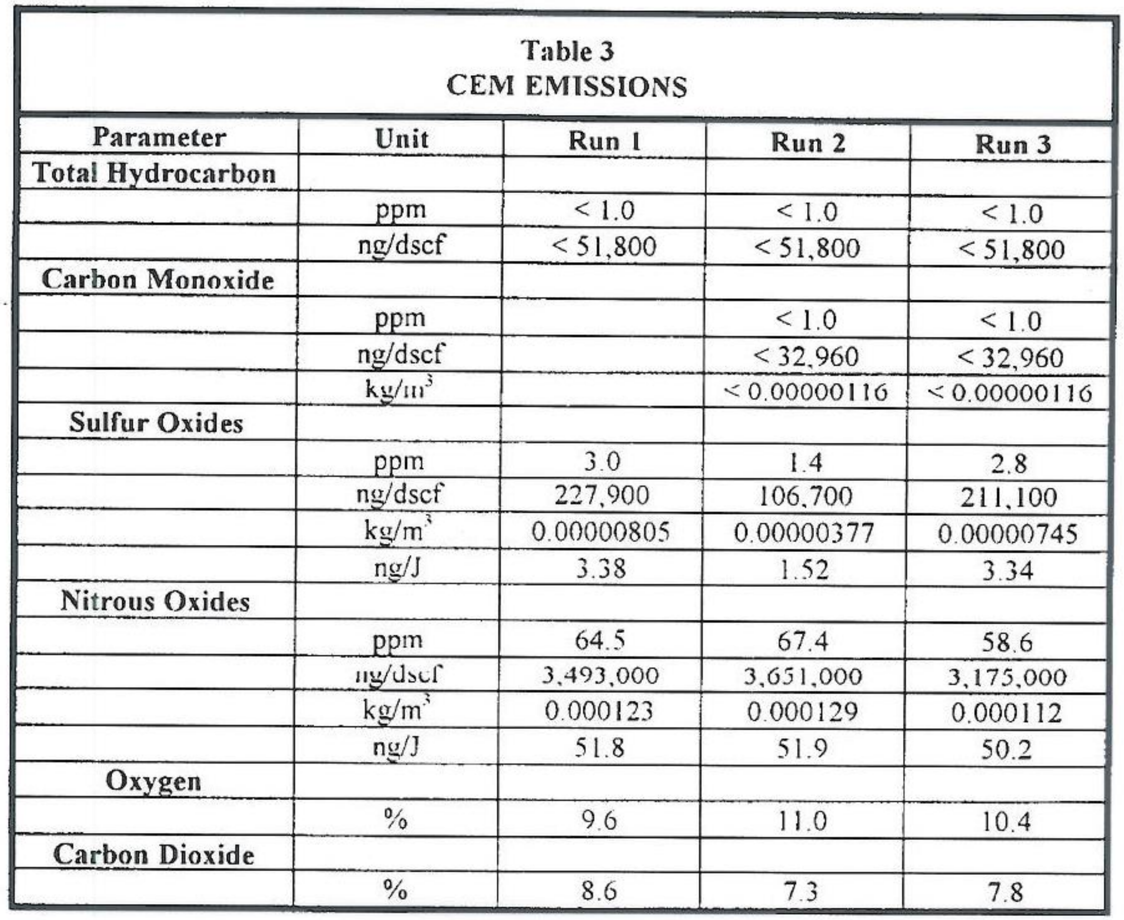
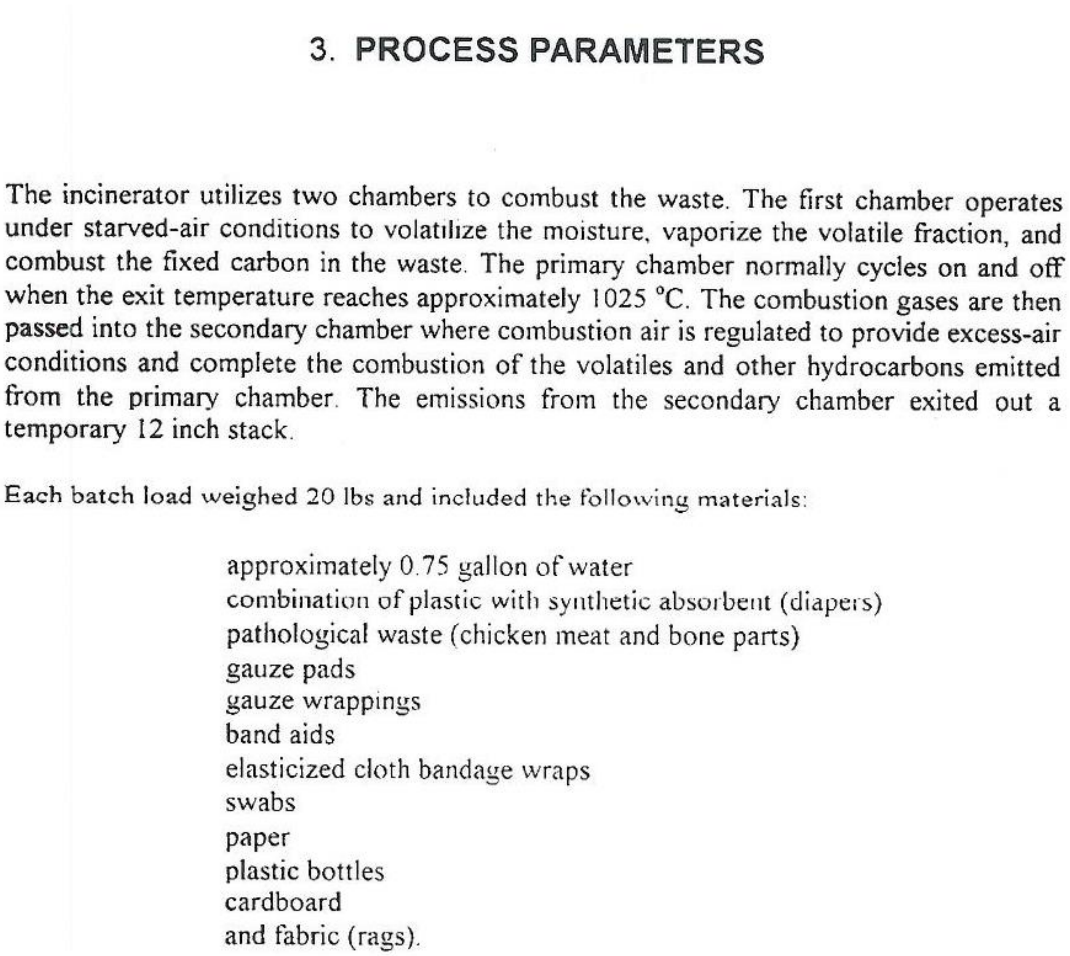


Table 3
CEM EMISSIONS

Parameter	Unit	Run 1	Run 2	Run 3
Total Hydrocarbon				
	ppm	< 1.0	< 1.0	< 1.0
	ng/dscf	< 51,800	< 51,800	< 51,800
Carbon Monoxide				
	ppm		< 1.0	< 1.0
	ng/dscf		< 32,960	< 32,960
	kg/m^3		< 0.00000116	< 0.00000116
Sulfur Oxides				
	ppm	3.0	1.4	2.8
	ng/dscf	227,900	106,700	211,100
	kg/m^3	0.00000805	0.00000377	0.00000745
	ng/J	3.38	1.52	3.34
Nitrous Oxides				
	ppm	64.5	67.4	58.6
	ng/dscf	3,493,000	3,651,000	3,175,000
	kg/m^3	0.000123	0.000129	0.000112
	ng/J	51.8	51.9	50.2
Oxygen				
	%	9.6	11.0	10.4
Carbon Dioxide				
	%	8.6	7.3	7.8



3. PROCESS PARAMETERS

The incinerator utilizes two chambers to combust the waste. The first chamber operates under starved-air conditions to volatilize the moisture, vaporize the volatile fraction, and combust the fixed carbon in the waste. The primary chamber normally cycles on and off when the exit temperature reaches approximately 1025 °C. The combustion gases are then passed into the secondary chamber where combustion air is regulated to provide excess-air conditions and complete the combustion of the volatiles and other hydrocarbons emitted from the primary chamber. The emissions from the secondary chamber exited out a temporary 12 inch stack.

Each batch load weighed 20 lbs and included the following materials:

approximately 0.75 gallon of water
combination of plastic with synthetic absorbent (diapers)
pathological waste (chicken meat and bone parts)
gauze pads
gauze wrappings
band aids
elasticized cloth bandage wraps
swabs
paper
plastic bottles
cardboard
and fabric (rags).

Appendix F (i): A List of Hospitals with Incinerators in Haiti

DIRECTION DE PROMOTION DE LA SANTE ET DE PROTECTION DE L'ENVIRONNEMENTSERVICE D'ASSAINISSEMENT

LISTE DES SITES D'INCINERATION

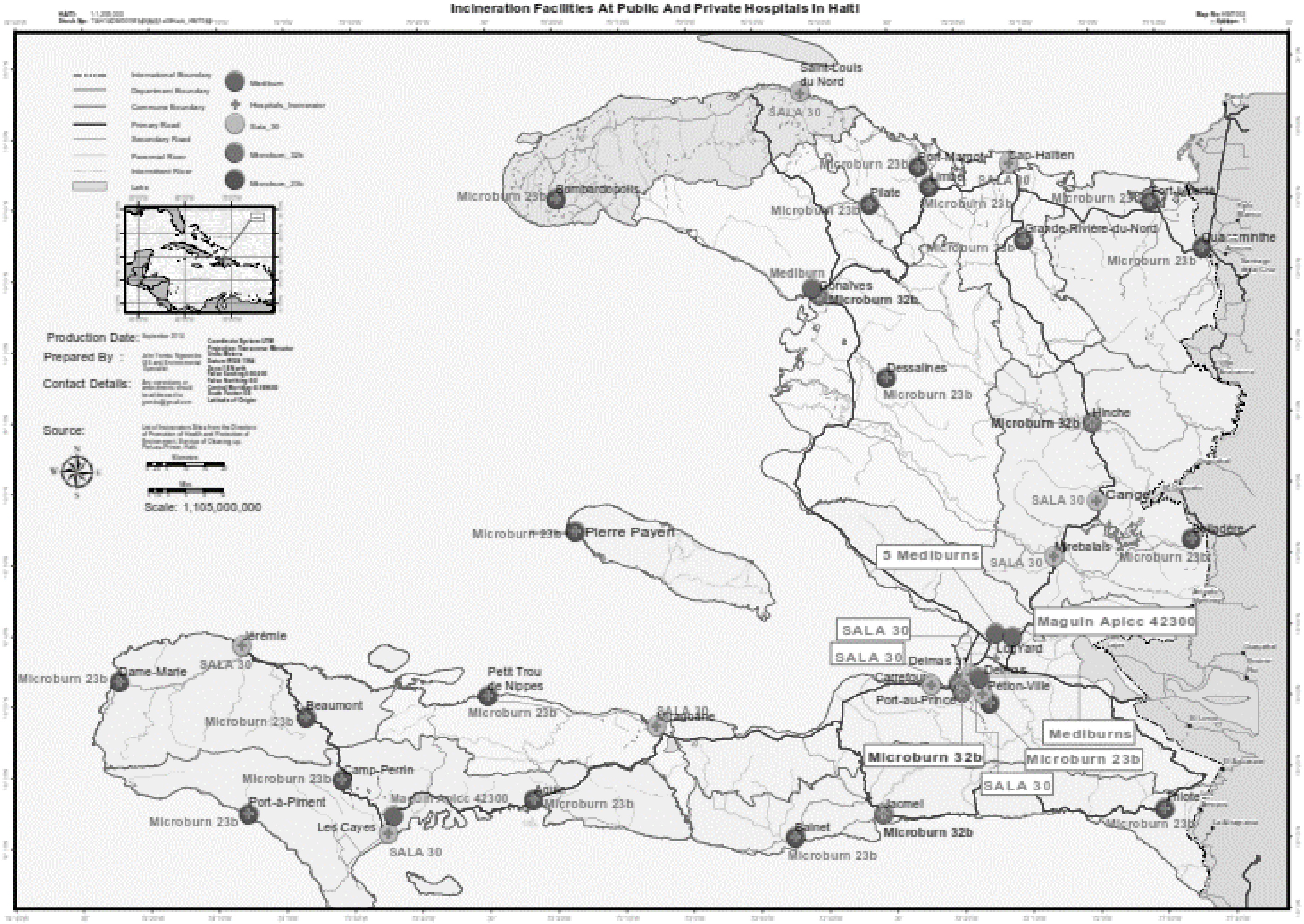
NO	MARQUE	NOM DE L'INSTITUTION	DEPARTEMENT	COMMUNE	REMARQUES
1	Microburn 23b	Hopital Notre Dame de la nativité	Centre	Belladère	Fonctionnel
2	Microburn 23b	CAL de Petit Trou de Nippes	Nippes	Petit Trou	Non Utilisé
3	Microburn 23b	CSL de Port Margot	Nord	Port-Margot	Non Utilisé
4	Microburn 23b	CAL de St jean de Limbé	Nord	Limbé	Fonctionnel
5	Microburn 23b	Hopital Esperance de Pilate	Nord	Pilate	Fonctionnel
6	Microburn 23b	CAL de la Grande Rivière du Nord	Nord	Grande Rivière	Fonctionnel
7	Microburn 23b	Hopital de Fort Liberté	Nord'Est	Fort Liberté	Fonctionnel
8	Microburn 23b	CAL de Ouanaminthe	Nort'est	Fort Liberté	Fonctionnel
9	Microburn 23b	Hopital C.H de Marchand Dessalines	Artibonite	Marchand Dessalines	Fonctionnel
10	Microburn 23b	Hopital Pierre-Payen	Artibonite	Pierre Payen	Fonctionnel
11	Microburn 23b	CAL de Bambardoplis	Nord'Est	Bombardopolis	Fonctionnel
12	Microburn 23b	CAL d'Aquin	Sud	Aquin	Fonctionnel
13	Microburn 23b	CAL de Port-a-Piment	Sud	Port-a-Piment	Fonctionnel
14	Microburn 23b	CAL de Camp Perin	Sud	Camp Perin	Fonctionnel
15	Microburn 23b	CAL St Agnès	Grand-Anse	Beaumont	Non Utilisé
16	Microburn 23b	CAL Comm. Dame Marienne	Grand-Anse	Dame-Marie	Fonctionnel
17	Microburn 23b	CSL de Chommeil	Sud'Est	Bainet	Non Utilisé
18	Microburn 23b	CAL de Thiotte	Sud'est	Thiotte	Fonctionnel
19	Microburn 23b	Hopital communauté Haitienne	Ouest	Petion-Ville	Fonctionnel

NO	MARQUE	NOM DE L'INSTITUTION	DEPARTEMENT	COMMUNE	REMARQUES
1	Microburn 32b	Hopital St Therese	centre	Hinche	Fonctionnel
2	Microburn 32b	Hopital St Michel	Sud'Est	Jacmel	en panne
3	Microburn 32b	Hopital OFATMA	Ouest	Port-au-Prince	?
4	Microburn 32b	MIJ	Ouest	Port-au-Prince	Fonctionnel
5	Microburn 32b	Hopital CARE	Artibonite	Gonaives	?

NO	MARQUE	NOM DE L'INSTITUTION	DEPARTEMENT	COMMUNE	REMARQUES
1	SALA 30	Hopital Justinien	NORD	Cap-Haitien	Fonctionnel
2	SALA 30	Hopital communautaire	Centre	Cange	Fonctionnel
3	SALA 30	Hopital Zanmi lasanté	Centre	Mirbalais	Fonctionnel
4	SALA 30	Hopital Saint-Antoine	Grand-anse	Jeremie	Fonctionnel
5	SALA 30	Hopital Ste-Therese	Nippes	Miragoane	en panne cheminé
6	SALA 30	Hopital Grace Children	Ouest	Delmas	Fonctionnel
7	SALA 30	Hopital Food for the poor	Ouest	Carrefour	Fonctionnel
8	SALA 30	Hopital de Fermathe	Ouest	Petion-ville	Fonctionnel
9	SALA 30	HIC	Sud	Cayes	Fonctionnel
10	SALA 30	Hopital Beraca	Nord'Ouest	St louis du Nord	Fonctionnel

NO	MARQUE	NOM DE L'INSTITUTION	DEPARTEMENT	COMMUNE	REMARQUES
1	MEDIBURN	Laboratoire Nationale de Santé Publique	Ouest	Delmas	Fonctionnel
2	MEDIBURN	Hopital CARE (ST CHARLES)	Artibonite	Gonaives	?

Appendix F (ii): A Map of Hospitals with Incinerators in Haiti



Appendix G: Photos of Sharps HCW Containers Used within MINUSTAH

Appendix H (i): Permission to Use Incineration Emission Report

From: Jeremy Pretzsch <jpretzsch@elastec.com> [mailto:Jeremy Pretzsch <jpretzsch@elastec.com>]
Sent: Monday 03 March 2014 3:49 PM
To: "'Emilia Raila'" <raila@un.org>
Cc: "MINUSTAH-PDU%UNFIELDMISSIONS@un.org" <MINUSTAH-PDU%UNFIELDMISSIONS@un.org>
Subject: RE: Requesting permission to use both the incineration manual and source emission report from Elastec, Inc for my research

Sounds good. I look forward to it.

Jeremy

Jeremy Pretzsch
Sales Manager
Elastec/American Marine

From: Emilia Raila [mailto:raila@un.org]
Sent: Monday, March 03, 2014 2:11 PM
To: Jeremy Pretzsch
Cc: MINUSTAH-PDU%UNFIELDMISSIONS@un.org
Subject: RE: Requesting permission to use both the incineration manual and source emission report from Elastec, Inc for my research

Dear Jeremy,

I appreciate very much for the permission. There is no problem to providing a copy and will discuss with my dissertation chair to know exactly at what stage I can share it prior to publishing.

Best Regards!

Emilia Mmbando Raila
Property Disposal Unit
Ext. 6794

From: Jeremy Pretzsch <jpretzsch@elastec.com> [mailto:Jeremy Pretzsch <jpretzsch@elastec.com>]
Sent: Monday 03 March 2014 10:15 AM
To: "'Emilia Raila'" <raila@un.org>
Cc: "'MINUSTAH-PDU%UNFIELDMISSIONS@un.org'" <MINUSTAH-PDU%UNFIELDMISSIONS@un.org>
Subject: RE: Requesting permi! ssion to use both the incineration manual and source emission report from Elastec, Inc for my research

Dear Emilia,

I agree to allowing you to use the information as requested. I would like to ask for an advanced copy of your report to make sure no sensitive material is included but certainly look forward to reading it.

Jeremy

Jeremy Pretzsch
Sales Manager
Elastec/American Marine

-----Original Message-----
From: Emilia Raila [mailto:raila@un.org]
Sent: Monday, March 03, 2014 9:08 AM
To: Jeremy Pretzsch
Cc: Emilia Raila; MINUSTAH-PDU%UNFIELDMISSIONS@un.org
Subject: Requesting permission to use both the incineration manual and source emission report from Elastec, Inc for my research

Dear Jeremy,

I am Emilia Mmmbando Raila, working with MINUSTAH as Environmental Quality Control Assistant/Volunteer. Currently, I am doing my PhD dissertation on medical waste incineration in Haiti and will be analyzing MINUSTAH's incineration process. I am therefore requesting your company to grant me a permission to use the incineration manual and source emission report as among reference materials for my research. Kindly let me know as well if I can include them in my appendices.

Kindly be informed that I am officially authorized to use the MINUSTAH incineration data for my dissertation.

Best regards!
Emilia Mmbando Raila
Property Disposal Unit
Ext. 6794

Appendix H (ii): Permission to Reprint Figure 1

On Thu, Oct 16, 2014 at 3:05 PM, Bond, Tami C <yark@illinois.edu> wrote:

Hello Emilia,
Thanks for your inquiry. I believe I do not have copyright to the figure and you need to contact American Geophysical Union. However, if it matters, you have my permission

Best regards,

Tami Bond

On Oct 16, 2014, at 3:08 PM, Emilia Raila <emilia.raila@waldenu.edu> wrote:

Dear Professor Bond,

My Name is Emilia Raila. Currently, I am a Ph.D. candidate at the Walden University. In my dissertation, I am analyzing black carbon emissions from waste incineration activities and its climate change impacts.

I am kindly requesting permission to reprint and use the figure on 'sources of Black carbon aerosol and co-emitted species' from your journal article titled "Bounding the role of black carbon in the climate system: A scientific assessment". Journal of Geophysical Research: Atmospheres, 118, p. 5390, doi:10.1002/jgrd.50171

If permitted, I will change the color to be black and white, and put a heading at the bottom in accordance to the APA citation.

Anticipating your favorable replies.

Stay Blessed.

Professor, University Scholar 2012-2015
Dept. of Civil & Environmental Engineering
University of Illinois, Urbana-Champaign
Newmark Civil Engineering Laboratory, MC-250   (1)217-244-5277
205 N. Mathews Ave., Urbana, IL 61801   USA

'Revolutionary' discipline depends on political consciousness-- on an understanding of why orders must be obeyed; it takes time to diffuse this, but it also takes time to drill a man into an automaton on the barrack-square. --George Orwell, Homage to Catalonia