Bioaerosol emission from MSW open dumpsites and the impact on exposure and associated health risks

by

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The candidate confirms that the work submitted is his own, except where work which has formed part of jointly-authored publications has been included. The contributions of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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In publication I and II the candidate planned, conducted the fieldwork, collected data, analysed the data, and draft of the manuscript. Louise L.A., and Evans B.E., reviewed and provided comments on the manuscripts. Peppers I and II have been reproduced in some aspects of chapter 4, 5 and 6.

Dedication

This thesis is dedicated to all the internally displaced persons in Nigeria, especially those scavenging at Olusosun dumpsite.

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I am grateful to God Almighty for making this dream come true. My sanity throughout the lonely journey can only be attributed to my deep connection him.

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Abstract

The activities associated with the open dumping of municipal solid waste emit air pollutants, including bioaerosols that contaminates the air around dumpsites, rendering it unsafe for dumpsite workers and residents living near dumpsites. Quantitative data on the exposure to bioaerosols from open dumpsites are scarce, thus impeding the development of effective interventions that would reduce the risk of respiratory diseases among dumpsite workers and residents living near dumpsites. The specific objectives for this study included (i) to identify the key working areas and activities of the workers at open dumpsites; (ii) to identify the most important groups of local residents that may be affected by contaminated air due to the waste management activities carried out at open dumpsites; (iii) to obtain background information regarding the respiratory health condition of the workers and the local residents in order to determine the extent to which they suffer respiratory diseases that may be related to exposure to the contaminated air from dumpsite; (iv) to measure the concentrations of bioaerosols at key locations on the open dumpsite to determine the impact of different waste management activities and seasonal variations on bioaerosol concentrations; (v) to analyse the bioaerosol data and to compare the ambient concentrations to concentrations at the controls; (vi) to quantify the potential health risk associated with exposure to pathogenic bioaerosols from the open dumpsites using the Quantitative Microbial Risk Assessment (QMRA) tool.

A cross sectional respiratory health survey was conducted in the study area between 12th -27th January 2017 with a total 414 respondents (workers = 149, resident = 145 and control = 120). A six-stage Anderson sampler and the SKC button sampler were used to measure ambient bioaerosol concentration and exposure concentration during key activities at the dumpsite respectively. The four bioaerosols indicator groups (total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi) measured were expressed as cfu m^{-3}. Using the Markov chain model, the deposition of inhaled bioaerosols in the workers lungs was computed. The infection risk estimates were computed using the beta-Poisson dose response model and the results reported within the QMRA framework.

The result of the cross sectional survey shows that cough was the most reported by the respondents. In all, up to 27% of respondents reported one or more symptoms of cough and phlegm and up to 8.7% reported three or more symptoms (cough, phlegm, asthma etc.). On the dumpsite, while chronic cough particularly affected smokers, it had a

prevalence of 38%. Chronic phlegm and asthma was prevalent at 31% and 2% respectively. Only chronic cough and chronic phlegm showed prevalence that were significantly higher that the controls ($p < 0.001$). Daily exposure duration was associated with chronic cough with odds ratio of 1.2 (95% CI 1–1.4, $p < 0.05$) but not with chronic phlegm and asthma. Years of work >5 years showed was not associated chronic cough, chronic phlegm asthma. Among residents, chronic cough particularly affected the non-smokers and had the prevalence of 31.7%. Chronic phlegm and asthma was prevalent at 28.9% and 8.2% respectively. Only chronic cough and chronic phlegm showed significantly higher prevalence compared to the control ($p < 0.001$). Daily exposure duration was also associated with chronic cough with odds ratio of 1.2 (95% CI 1.1–1.3, $p < 0.001$) but not with chronic phlegm and asthma. The frequent visit of a resident to the dumpsite had an associated odds ratio of 3.8 (95% CI 1.6–8.4, $p < 0.001$), 4 (95% CI 1.1-14.4, $p < 0.05$) and 6.8 (95% CI 1.3-33, $p < 0.01$) for chronic cough, chronic phlegm and asthma respectively, when compared to the controls. Only years of work <10 years showed associated with chronic cough with odds ratio 4.2 (95% CI 1.4–12.4, $p < 0.01$) when compared to the controls.

At the 95th percentile, the ambient concentration of total bacteria was 2189 cfu m^{-3}, gram-negative bacteria 2352 cfu m^{-3}, total fungi 824 cfu m^{-3} and *Aspergillus fumigatus* 300 cfu m^{-3}, and were significantly higher in magnitude than the control by 2-3 log ($p< 0.05$). The concentration of bioaerosols at the active operational area was the highest in comparison to the other three sampling locations. However, there were no significant differences in concentration across the four sampling points for total bacteria, gram-negative bacteria and the total fungi. *Aspergillus fumigatus* on the other hand recorded a drastic decrease in concentrations up to 80-81% between the active operational area and the boundary. The particle size distribution shows that the workers were at risk of inhaling air contacting 41%, 46%, 63%, 76% of total bacteria, gram-negative bacteria, total fungi and *Aspergillus fumigatus* respectively, that were of sizes capable of penetrating deep into the tracheobronchial and the pulmonary region of the lungs, posing a greater human health risk.

This study has shown that exposure to bioaerosols were also associated with specific activities undertaken at the dumpsite. Workers were exposed to bioaerosol concentrations up to 10^6 cfu m^{-3} during scavenging, waste sorting and site monitoring. These concentrations were 3-log higher than the mean concentration measured in the ambient air. The result shows that on a daily basis, workers were likely inhaling bioaerosols at

concentrations ranging from 8.9×10^5 -1.8×10^7 cfu m^{-3} of total bacteria, 4.0×10^5-8.1×10^6 cfu m^{-3} of gram-negative bacteria and 3.29×10^5-1.5×10^6 cfu m^{-3} of *Aspergillus fumigatus* that were of sizes capable of penetrating deep into the tracheobronchial and the pulmonary region of the lungs when undertaking scavenging, waste sorting and site monitoring. These concentrations were higher than expected limit by the UK Environment Agency.

The result of the QMRA showed that that the activities at the dumpsite may contribute more to the likelihood of workers developing either respiratory infection or GI infection than anything else. The infection risk from inhaling contaminated air containing spores of *Aspergillus fumigatus* were in the magnitude of (10^{-1}) all locations and activity types on the dumpsite. However, the risk of infection from ingesting *E.coli* O157:H7 from ambient exposures across all locations on the dumpsite ranged from 10^{-3}-10^{-2} for the conservative and 10^{-4}-10^{-3} for the least conservative of pathogen-indicator ratio. While the risk of infection due to undertaking scavenging, waste sorting and dumpsite monitoring were in the magnitude of 10^{-1}.

Overall, this study suggests that the high prevalence of respiratory disease among the workers and the residents are indications of exposure to contaminants in the air from the dumpsite, which includes bioaerosols, as the prevalence were similar among the workers and the residents. The risk estimates show that of infection from bioaerosols were high irrespective the activity the workers undertook at the dumpsite.

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List of Acronyms

ABPA	Allergic Broncho-Pulmonary Aspergillosis
ANOVA	Analysis of Variance
ATS-DLD-78A	American Thoracic Society Division of Lung Disease questionnaire
BMW	biodegradable municipal waste
CAFOs	Concentrated Animal Feeding Operations
cfu	Colony forming unit
COPD	Chronic Obstructive Pulmonary Disease
D-R	Dose-Response
DNA	Deoxyribonucleic acid
EA	Environment Agency
ECP	Extracorporal Photopheresis
ECRHS II	European Community Respiratory Health Survey II
EU	Endotoxin Units
FEV	Forced Expiratory Volume
FVC	Forced Vital Capacity
GI	Gastrointestinal
GHG	Green House Gas
HAZ-ID	Hazard Identification
HIV	Human Immuno-deficiency Virus
HWE	Health Worker Effect
K-S Test	Kolmogorov-Smirnov Test
LRS	lower respiratory infection
LRS	Lower Respiratory Symptoms
MEF_{50}	Maximal Expiratory Flow
MSW	Municipal Solid Waste
OR	Odd Ratio
P: I	Pathogen-Indicator ratio
POPs	Persistent Organic Compounds
PPE	Personal Protective Equipment
QMRA	Quantitative Microbial Risk Assessment
RH	Relative Humidity
RHS	Respiratory Health Survey
RNA	Ribonucleic acid
RPE	Respiratory Protective Equipment
RR	Rate Ratio
SD	Standard Deviation
SDG	Sustainable development goal
SR	Sensitive Receptors
TLV	threshold limit values
TSP	total suspended particulates
TWA	Time Weighted Average
URS	Upper Respiratory Symptoms
USEPA	United states Environmental Protection Agency
UV	Ultraviolet
VOC	Volatile Organic compound
WBC	White Blood Cells
WFD	Waste Framework Directive
WMH	Waste Management Hierarchy

Chapter 1: Introduction

Background

1.1 Urbanization, open waste dumping and exposure

1.1.1 In a bid to balance the high global rate of urbanization with the rate of municipal solid waste (MSW) generation that results from urbanisation, the sustainable development goal (SDG) 11.6 aims to reduce the per capita environmental impact of cities by paying attention to air quality and municipal solid waste management (UN-Habitat 2018). It is estimated that the 3 billion urban residents all over the world generate around 1.2 kg per person per day (1.3 billion tonnes per year) of waste and in the year 2025, it is estimated that this figure will be around 4.3 billion tonnes per year (Hoornweg and Bhada-Tata 2012a). In sub-Saharan Africa, this figure is 62 million tonnes per year, with a corresponding annual rate of change of urban population at 2.27 percent per year (UN-HABITAT 2009). Despite recording the highest rate of urbanization in the world, most developing countries unfortunately do not have the infrastructure to properly manage and treat their municipal solid waste (Srivastava *et al.,* 2015). Hence, it is unsurprising that 17 of the world's 50 biggest dumpsites are located in the continent of Africa, of which 6 are in Nigeria (UNEP, 2015). This form of waste treatment involves the uncontrolled dumping of waste MSW on open land areas forming large waste hills with time.

Common at dumpsites are scavengers, individuals involved in the recovery of valuable and recyclable items from the waste pile at dumpsites for economic gains (WIEGO 2013; Simatele and Etambakonga 2015). The two obvious reasons why the trade is still popular in developing countries are, firstly, the economic benefits the scavengers gain and secondly, the cost-saving on the part of government authorities by the non-implementation of improved waste treatment methodologies (Medina 2007). There seems to exist a symbiotic partnership between the waste management agencies and scavenging population, where the scavengers carry out the tail-end clean-up of the solid waste, hence saving the government a huge cost (Simatele and Etambakonga 2015). The consequence of the existence of such an arrangement is that it can encourage further negligence on the part of government to improve the existing waste management system. Scavengers and other workers at the dumpsite in the course of their work are exposed to multiple disease-causing agents that could affect their health, one of which is bioaerosols. Microbial activities are central to the treatment of biodegradable MSW and agitation activities, such

as tipping, spreading and waste sorting have been shown to aerosolise these microbial agents, including pathogenic ones (Stagg *et al.*, 2010). Moreover, the analysis of the composition of MSW in sub-Saharan Africa have shown it to have high a proportion of biodegradables (40–60%) and moisture content (Ogwueleka 2009; Hoornweg and Bhada-Tata 2012b). Furthermore, these characteristics in combination with the hot and humid weather conditions in the region, favours the growth of microorganisms including pathogens that are eventually aerosolized during agitation activities at the dumpsite (Odewabi *et al.,* 2013a; Epstein 2015). The individuals working on dumpsites such as scavengers, waste workers and vendors are often exposed to elevated levels of these pathogenic microorganisms mainly by inhalation, as most have been noted to work in these conditions without personal protective equipment (Odewabi *et al.,* 2013b). Workers exposure to organic dust laden with bioaerosols have been reported from composting and landfills facilities typically associated to high emission of organic dust during agitation activities, a condition similar to open dumpsites (Ray *et al.,* 2005; Schlosser *et al.,* 2012). In addition to exposure by inhalation, other exposure routes such as ingestion and skin contact presents additional exposure risk to the workers. These workers have been reported to be at risk of contracting gastrointestinal diseases, blood infections such as HIV and hepatitis, physical symptoms like impetigo and musculoskeletal symptoms (Thirarattanasunthon *et al.,* 2012; Odewabi *et al.,* 2013a). Hitherto, respiratory health risk from exposure to bioaerosols at open dumpsite has received limited attention from researchers compared to that associated with landfills and the composting processes (Douwes *et al.,* 2003b; Heldal *et al.,* 2015; Van Kampen *et al.,* 2016a). Although activities such as tipping and spreading of waste may be common to landfills and dumpsites, the latter has greater environmental and public health impact as there are little or no controls over the safe handling, treatment and exposure limits to bioaerosols and particulate matter (UNEP 2005). Moreover, there are currently very limited literature on the exposure of dumpsite workers to bioaerosol emissions and the impacts on their respiratory health in a single study. As such, this research aims to investigate the degree of exposure to bioaerosols associated with working at open dumpsites and the potential impact this might have on the respiratory health of the workers. This particular piece of work will focus on bioaerosol exposure at Olusosun open dumpsite in Lagos, Nigeria.

1.1.2

Bioaerosols dispersion

There is strong evidence that bioaerosols are dispersed from source point downwind and may settle out at some distance away from the source. In one study, bioaerosols were

reported at concentrations up to 10^5 cfu m^{-3} at 250 m downwind from the composting facility (Herr *et al.*, 2003), while another had reported concentrations up to 4.8×10^4 cfu m^{-3} and 5.6×10^2 cfu m^{-3} for total mould and *Aspergillus fumigatus* respectively, at 200 m from the boundary of a non-hazardous landfill site (Schlosser *et al.*, 2016). Due to the small diameter of most bioaerosols (0.65-4 μm) and their low setting rates, they can remain aerosolised for long periods of time, travelling long distances before setting out. This is the reason why concerns of potential infection risks from inhalation of pathogens have been raised by regulatory bodies like the UK Environment Agency, recommending that bioaerosols background concentrations be maintained at 250 m or at the nearest sensitive receptor from landfill or composting facilities (Environment Agency 2010). In one the earliest reports of respiratory infection from pathogen exposures was of an asthmatic residing 80 m from an uncontrolled composting site showing symptoms of Allergic Bronchopulmonary Aspergillosis (Kramer *et al.*, 1989). Unfortunately, most open dumpsites in developing countries are usually located in the heart of the community they serve, with people living up to 50 m from the dumpsite (Sankoh *et al.*, 2013b), setting them for exposures to bioaerosols that may result in infection. It is important to note that it is difficult to prove from the current data in the literature that the respiratory symptoms experienced by occupants located close to dumpsites are solely the result of exposure to bioaerosols, except clinically proven to be symptoms associated with specific bioaerosols from dumpsite (Kramer *et al.*, 1989). Moreover, there are likely other sources of pollutants in the many neighbouring areas that can also be drivers of respiratory disease.

The health impacts of bioaerosols emission from dumpsites is the least publicized contributor to the environmental burden of disease from environmental pollution. Hence, the need to address some of the key questions that remains unanswered such as:

- What are the concentration of bioaerosols generated at dumpsites?
- What are the taxa of bioaerosols in the air around an open dumpsite?
- What are the health effects on the population on and around dumpsites when bioaerosols are inhaled?
- Is there a relationship between diarrhoea occurrences and aerosolized enteric pathogens at dumpsites?

Research Aim

1.2 The overall aim of this research was to evaluate the potential health risk posed to scavengers working at open dumpsites and residents living close to open dumpsites from exposure to bioaerosols emitted during waste management activities.

Research Objectives

1.3 For this aim to achieved, it was necessary to collect background information relating to the scavengers and the local residents alongside information regarding the emission of bioaerosols from open dumpsites. Therefore a number of objectives were identified to enable such information to be collected and ultimately to achieve the overall aim of this research. The objectives were defined as follows:

(i) To obtain and analyse information regarding the respiratory health of the dumpsite workers and the local residents to determine the prevalence of respiratory diseases that may be associated with exposure to bioaerosols from the open dumpsite.

(ii) Determine the overall concentration of bioaerosols in the ambient air and impact of seasonal variations on bioaerosol concentrations by measuring concentrations of bioaerosols at key locations around the open dumpsite over the dry and wet seasons.

(iii) Determine the level of exposure to bioaerosols associated with the different dumpsite activities by measuring bioaerosols concentration during these activities.

(iv) Determine the particle size distribution of bioaerosols from the ambient concentration and activities in other to compute deposition in the lungs of the dumpsite workers.

1.4 (v) To quantify the potential health risk associated with exposure to pathogenic bioaerosols from open waste dumpsites using the Quantitative Microbial Risk Assessment (QMRA) tool.

Scope of the Research

This study employed a mixed method (qualitative and quantitative) approach to achieve the aim and objectives. The study took place at Olusosun open dumpsite, Lagos Nigeria. A cross-sectional survey where structured questionnaires were issued to workers on the dumpsite and to residents located close to the dumpsite to collect respiratory heath

information over a period of 2 weeks in January 2017, while the ambient air sampling and activity related air sampling were carried out between April–August 2017 over 13 weeks .

Research Justification

1.5 The Sustainable Development Goal 11.6 of the United Nations outlines the need for member nations to reduce the per capita environmental impacts of cites, especially by improving air quality and municipal waste management (UN 2016), and this study is directly aligned with this goal. In order to address this goal, it was important to highlight the extent of the negative impact of the poor air quality resulting from poor management of municipal solid waste (open dumping). Hence this study. Furthermore, there are a number of key issues that will be addressed by this research regarding the exposure to bioaerosols emitted at open dumpsites.

The socio-economic benefits of scavenging currently ranks high on the list of waste management authorities on why open dumpsites should be sustained. However, the finding in this study is aimed at providing hard evidence of exposure to pathogens and the risk of infection the scavengers and waste workers are exposed to on a daily basis, hence discouraging the continued practice of open dumping by these states.

One of the consequence of a rapid growth in urban population is the increase in waste generation from the population. Consequently, the ever-expanding dumpsite encroaches into areas close to where the population reside. This research will provide data on the respiratory health conditions suffered by this population because of their proximity to the dumpsite.

Open dumpsites are most common in developing countries. Although the negative impact of open dumping on the environment are numerous, the quality of air on and around the dumpsite are of great importance, as air pollutants can be carried by wind across to places other than the dumpsite where they might be inhaled. This research will provide information on the possible risk of infection associated with pathogens from dumpsites, even at considerable distances away from the dumpsite.

The research will serve as a rich database, highlighting the urgency on the part of the government authorities to begin closure exiting open dumpsite and also start the

implementation of improved solid waste management system that are in line with the Sustainable Development Goals (SDGs).

Thesis Structure

1.6 This thesis is organized in nine (9) chapters with Chapter 1 highlighting the background to the research, stating the research questions, the aim and objectives of the study. Contained therein also is the scope of the research and the significance of the study to waste regulators in developing countries where open dumping are common practice.

Chapter 2 contains an in depth literature review of municipal solid waste treatment methods common in developed and developing countries that can lead to bioaerosol emissions in to the open air. The key focus is on composting, landfilling and open dumping. Also reviewed are reports of respiratory symptoms and health conditions experienced by workers as well as residents living close to these treatment facilities. Additionally, this chapter presents a summary of the knowledge gaps in the literature that informed the objectives that were set out in this study.

Chapter 3 describes the methods employed to achieved the set objectives in this study. This covers the study site selection, ethnographic study, qualitative respiratory health survey, bioaerosol air sampling, and laboratory analysis and data analysis, all in line with the research aim. In addition to the data analysis in the methodology, each results chapter (Chapters 4-7) contains detailed methodology specific to that aspect of the work presented in those chapters.

Chapter 4 is the first results chapter and contains elements of this study that have been published in a paper titled: '*Exposure to bioaerosols at open dumpsites: A case study of bioaerosol exposure from activities at Olusosun open dumpsite, Lagos Nigeria'* in Waste Management Journal (Akpeimeh *et al.*, 2019). The chapter contains the results and the discussion of the results of the respiratory health survey of the workers and residents located close to the dumpsite as compared to the control. Also assessed is the probability of acquiring respiratory symptoms and associated conditions by the members of the sampled population. Some of the limitations that are inherent in the methodology employed in this aspect of the study are also highlighted in this chapter.

Chapter 5 presents the findings from measuring the concentration of bioaerosols in the ambient air and from specific activities at Olusosun dumpsite. The results are presented

as concentration of total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi in comparison to concentrations at the control. One of the objectives of this study was to assess the effect of seasonal changes on the overall ambient concentration of bioaerosols at the dumpsite, and this has also been presented in this chapter. Some elements of this study have also been published in a paper titled: '*Exposure to bioaerosols at open dumpsites: A case study of bioaerosol exposure from activities at Olusosun open dumpsite, Lagos Nigeria'* in Waste Management Journal (Akpeimeh *et al.*, 2019). Some of the limitations that are inherent in the methodology employed in this aspect of the study are also highlighted in this chapter.

In Chapter 6, the focus is to present the results of the bioaerosol particle size distribution in the ambient air and in the emissions from specific activities at the dumpsite. Also contained is the assessment of the changes in the distribution as the particle travels downwind from the active operational area of the dumpsite. This chapter also formed the bases for the QMRA analysis presented in chapter 7. Some of the limitations that had arisen in the analysis were also highlighted in this chapter

Chapter 7 describes the quantitative microbial risk assessments (QMRA) carried out based on the results obtained from the ambient air sampling and activity-related sampling as presented in chapters 5 and 6 of the thesis. The results present probabilistic estimates of respiratory and gastrointestinal risks that can result from exposure to the doses measured at the dumpsite. Some of the limitations inherent with this methodology was also highlighted in this chapter.

Chapter 8 presents the general discussion of the data obtained from the both the respiratory health survey and bioaerosol air sampling carried out as part of the study, exploring how they fit into and build on the existing body of knowledge and the research questions highlighted in chapter 1. Also contained in this chapter is the discussion on the wider applicability of the results obtained.

Chapter 9 is the last chapter of the thesis, where a summary of the key conclusions and recommendations for future research are presented.

Literature Review

Chapter 2: Introduction

2.1 This chapter contains a review of the literature on the health and environmental impacts associated with different MSW management methods. The review has been divided into two sections; the first section contains the review of evidence of emissions resulting from waste management practices such as composting, solid waste recycling, landfill and opening dumping, highlighting their environmental and health impacts. The second section presents a review of existing literature on bioaerosols emissions, exposure concentrations, measured health impacts on the scavenger population and resident population close to dumpsites and lastly, identifying knowledge gaps in the literature on the practice of open dumping.

2.2

2.2.1 Review of the evidence of emissions resulting from waste management practices

Air Quality Standards

Exposure limits for bioaerosols is highly dependent on established exposure-dose relationships from either toxicological or epidemiological studies on the subject (Walser *et al.,* 2015). The constrains limiting a uniform standard by regulators have been published (ibid) and maybe responsible for the adoption of different exposure limits by different countries (Douwes *et al.,* 2003b; Hsu *et al.,* 2012). In the United Kingdom for instance, the Environment Agency had adopted the following acceptable levels within 250 m downwind from the source as an 'appropriately precautionary' guideline, owing to the limited data on bioaerosol exposure-dose relationships in occupational environments (Deed 2004; Frederickson *et al.,* 2013; Williams *et al.,* 2013b; Pearson *et al.,* 2015):

- Total Bacteria 1000 cfu m^{-3}
- Fungi (*Aspergillus fumigatus*) 500 cfu m^{-3}
- Gram-negative bacteria 300 cfu m^{-3}
- Total Fungi 1000 cfu m^{-3}
- Endotoxin 90 EU m^{-3}
- Glucan 10 ng/m^3

Although bioaerosols concentration in air has been widely accepted to have been reduced to background levels within the distance of 250 m, it has been evident from different publications that these concentrations may likely vary and elevated concentrations could be detected periodically during sampling (Stagg *et al.*, 2010; Williams *et al.*, 2013b).

2.2.2 MSW treatment methodologies associated with Bioaerosols Emissions in Europe

Developed countries in this report refers to countries with high income and high waste collection rates averaging between 70-98% (Hoornweg and Bhada-Tata 2012c). Countries in the EU zone are not exempted since the issuance of the European Landfill Directive (Council Directive 1999/31/EC) in 1999. The aim of the European Landfill Directive was to reduce waste sent to landfill to avoid the polluting effects and the adverse emission of greenhouse gases (GHG) by 12.5% below the 1990 levels by 2008-2012. Additional targets were also to reduce biodegradable municipal solid waste going to landfill to 35% of the total amount by weight of the MSW produced in 1995 by the year 2020 (Stagg *et al.*, 2010). Sequel to the Landfill directive, was the Waste Framework Directive (WFD) which spelt out the strategy adopted by the EU for the implementation of the Landfill directive by the EU member States (EU 2008). The major highlight in the WFD was the Waste Management Hierarchy (WMH), which prioritizes the waste management options thereby placing landfill as the least favourable option for waste

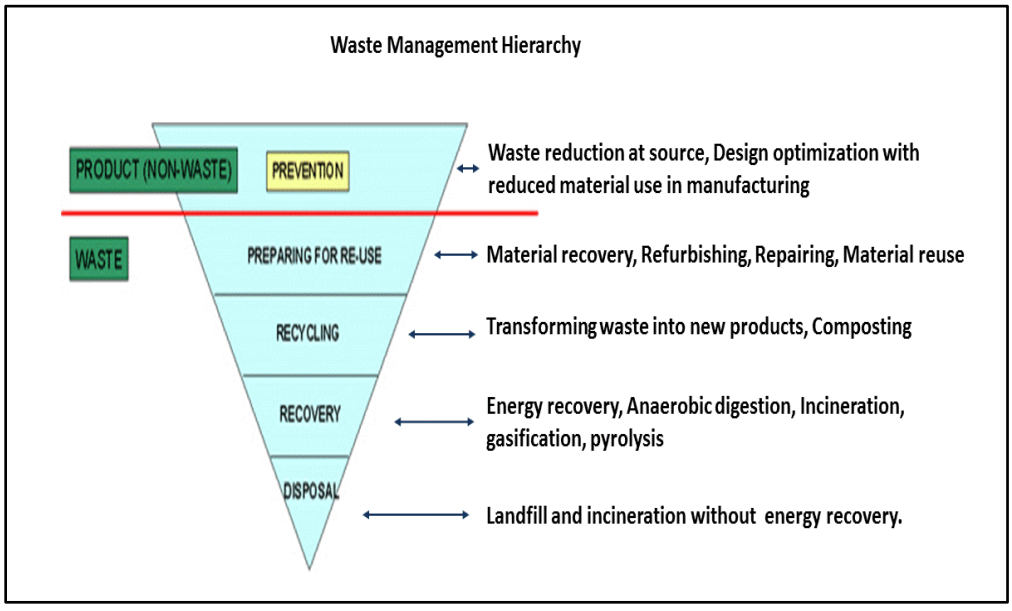

Figure-2-1 Waste Management Hierarchy (Stagg *et al.*, 2010; EU 2015)

treatment.

Among the treatment methods proposed in the WFD, composting and landfill treatment produces the highest microbial emission in the ambient air around the treatment facility due to the treatment process involved (Wéry 2014b). Sections 2.2.2.1 and 2.2.2.2 will review the current practices and standards in composting and landfill as obtainable in the UK.

Composting

2.2.2.1

Composting is a method of waste management that is based on biological process of decomposition and stabilization of organic matter. In the right environmental conditions, aerobic microorganisms that are present in or inoculated into the organic waste multiply and metabolize the organic matter, turning it into a stabilised product with high nutrients content that can be used for fertilizer (Stagg *et al.,* 2010; Wéry 2014b). Typically, when the organic waste arrives to the composting site, they are initially shredded and screened into smaller particles. These unit processes results in increasing surface area available to microbiological decomposition. The resulting materials are then further transferred to a open naturally aerated windrow or to an in-vessel system with mechanical aeration. Windrows are elongated piles of compost, shaped like a haystack in cross section and up to 100 m or more in length. Windrows can be operated in either enclosed or open-air system depending on the composting method used in such environment. The heat generation during the biodegradation of the waste encourages the growth of thermophilic species such as actinomycetes and thermotolerant fungi such as *Aspergillus fumigatus* (Swan *et al.,* 2003; Stagg *et al.,* 2010). On the other hand, in-vessel systems use horizontal (tunnels) and vertical (towers) reactors for the waste stabilization. Although the in-vessel composting was introduced primarily as result of the introduction of animal by-products composting regulations (DEFRA 2008), technology also minimises direct odour and bioaerosols emissions into the open air. However, there is a high capital and operational cost associated with in-vessel composting. Besides, the residence time in the reactors are rarely adequate to produce a mature compost, hence the in-vessel composting systems are mostly used at the early stages when odours and process control are absolutely critical (Stagg *et al.,* 2010). Thus, most composting facilities operating in-vessel composting still uses the windrow system for the maturation phase of the composting process in an enclosed environment fitted with bio-filters (EA 2010a).

Bioaerosol emission is greatest during unit operations such as shredding, screening and turning of the windrows (Persoons *et al.*, 2010). Since most large scale composting facilities in the UK are open-air windrow systems, the composting facilities continues to be a source of pollution and emission of bioaerosols to the environment (Wéry 2014b). In one case, Stagg *et al.*, (2010) reported bacteria in air in the excess of 10^5 cfu m^{-3} adjacent to the source point (windrow turning).

2.2.2.1.1 Evidence of health impacts of bioaerosols emission on compost workers

Several epidemiological studies have suggested that the generation of bioaerosols at composting facilities may pose occupational health risk to the workers and residents living close to the composting facility. Notable is the presence of opportunistic fungi such as *Aspergillus fumigatus*, that can take advantage of immunocompromised workers (Taha *et al.*, 2006). Taha *et al.*, (2005) recorded a high level of *A. fumigatus* and actinomycetes as high as 10^4-10^7 cfu m^{-3} during unit operations (i.e. screening, shredding and turning) and 10^3 cfu m^{-3} on the static windrow respectively. Table 2.1 shows the measurable occupational and respiratory health effects from workers exposure to thermophilic and thermo-tolerant species associated with composting, woodwork and MSW workers. These aerosolized pathogens are generally recognised as causative agents of allergic respiratory disease such as allergic alveolitis, allergic rhinitis and occupational asthma following excessive exposure of compost workers (Swan *et al.*, 2003; Bünger *et al.*, 2007). However, there are still limited data addressing exposure dose-response relationships from bioaerosol exposures, owing largely a lack of data on adequate exposure assessment, diversity in measuring methods employed for bioaerosols and a lack of firm health exposure limits for composting facilities (Walser *et al.*, 2015). Bünger *et al.*, (2007) for instance carried out one of the longest follow up studies where compost workers were observed for 5 years, only occupational symptoms were reported with no data on bioaerosols concentration the workers were exposed to in the same study. Heldal *et al.*, (2003) on the other hand may have delivered exposure data as indicator parameter but could not establish a clear dose-response relationship.

The toxic effects of endotoxins and beta(1→3) glucans have received more attention in reviews in recent years due to the establishment of a standard exposure limit by the Environment Agency (Frederickson *et al.*, 2013). Unfortunately, their detection upon sampling are cultivation-based (as required by Environment Agency), which in most cases underestimates the actual concentrations and diversity of the bioaerosols in the

sampled air. Albrecht *et al.,* (2007) had shown that only 1.5-15% of sampled airborne bacteria are viable to form countable colonies after incubation. Sadly, endotoxins and beta (1→3) glucans are present in both viable and non-viable samples. Hence, it's more reliable to use culture-independent approaches such as DNA-RNA sequencing for endotoxins and beta (1→3) glucans detection and analysis (Wéry 2014b). Sykes *et al.,* (2011) reported a consistently high exposure of workers at four composting facilities to inhalable organic dust containing endotoxins (74.51 EU m^{-3}) and β-(1→3) glucans (2.02 ng/m^3), a level that put the workers at high risk of triggering respiratory inflammatory diseases or possible chronic respiratory symptoms on the workers.

Table 2-1: Occupational health studies on bioaerosols exposure

Setting	Bioaerosols component	Study design	Study population	Mean exposure duration (years)	Exposure concentration	Measurable Health effects	Significant D-R relationship	Reference
Wood	Bacteria and Fungi	CS	28 wood trimmers; 19 controls	Wood timers: 13; Controls 13	**Bacteria**: Median 370 cfu m^{-3} **Mould spores**: Median 2950 cfu m^{-3}	Significant decrease in lungs function parameters (FEV_1, MEF_{50}) week correlation with mould exposure	Bacteria: No Mould: Yes	Dahlqvist *et al.*, (1992)
Wood	Gram negative Bacteria	CC	168 workers; 30 controls	9 -14	**Gram negative bacteria**: Sawmill mean: 0.87×10^4 cfu m^{-3}; Wood chip mean 1.41×10^4 cfu m^{-3}; Joinery mean: 0.74×10^4 cfu m^{-3}	**Chronic effects:** Significant decrease in lungs function parameters (FEV_1, FVC, FEV_1/FVC) **Acute effects:** Significant decrease in FVC, $FEF_{25\%-75\%;}$ effects more pronounced on joinery workers	Yes	Mandryk *et al.*, (1999)
Waste/ composting	Bacteria and fungi	CS	72 Workers	n.a	**Bacteria**: $< 4\times10^2 - 2.8\times10^5$ cfu $m^{-3;}$ **Fungi**: $< 4\times10^2$-5.0×10^5	Significant increase in $\%PEF_{var}$	Fungi :Yes Bacteria: No	Coenen *et al.*, (1997)
Waste/ composting	Total bacteria, fungi spores, Rod-shaped bacteria, Spherical bacteria	CS	31 waste handlers, 19	1.5	**Total Bacteria**: Median: 0.84×10^6 cfu m^{-3}; **Fungal spores**: median: 0.17×10^3 cfu m^{-3}; **Rod-shaped bacteria**: Median: 0.004×10^6 cfu m^{-3}; **Spherical bacteria:** Median: 0.8×10^6 cfu m^{-3}	Significant increase in inflammatory mediators in nasal lavage (neutronphils %, ECP) during working week and significant decline in TVL2 (rhinometry); but only associated with median fungal exposure and Wednesday fungal exposure.	Bacteria: No Fungi: Yes Rod shaped bacteria: Yes Spherical bacteria: No	Heldal *et al.*, (2003)

Table 2.1: Occupational health studies on bioaerosols exposure *(Continued)*

Setting	Bioaerosol component	Study design	Study population	exposure duration	Exposure concentration	Measurable Health effects	Significant D-R relationship	References
Waste/ composting	Filamentous fungi and actinomycetes	LO	218 compost workers; 66 controls	5 years	**Filamentous fungi**: 2-11,000 $\times 10^3$ cfu m^{-3}; **Actinomycetes:** 4-3500$\times 10^3$ cfu m^{-3}	Significant decline in FVC% (in smokers)	Actinomycetes : Yes Filamentous fungi: Yes	Bünger *et al.*, (2007)
Waste/ composting	β-(1→3) Glucan and Endotoxins	CS	117 Compost workers	12 months	**β-(1→3) Glucan**: Geometric Mean: 2.02 ng/m^3 **Endotoxins**: Geometric Mean 74.51 EU/m^3	No respiratory symptoms observed. Musculoskeletal symptoms were observed.	NO	Sykes *et al.*, (2011)
Waste recycling	β-(1→3) Glucan and Endotoxin	CS	159	n.a	**β-(1→3) Glucan**: 4.8-40.1 ng/m^3 **Endotoxin:** 17.7-114.3 EU/m^3	Significant increase cough with phlegm, chest tightness, gastrointestinal symptoms associate with higher exposed.	β-(1→3) Glucan: Yes Endotoxin: Yes	Gladding *et al.*, (2003)
Waste workers	Results associated with bioaerosols exposures	RCS	180= MSW Workers; 100= Controls	4 years	Not reported	**Waste workers:** URS 52%; LRS 57%; Abrasion 43%; Irritation of eyes 19%; Increased Ceruloplasmin oxidase activity (17%); decrease in Albumin by (4.55%); WBC count increases (9.85%) compared to controls **Controls:** URS 17%; LRS 23%; Abrasion 10.98;%; Irritation of eyes 19%	Between job duration and Health effects: Yes	Odewabi *et al.*, (2013a); Odewabi *et al.*, (2013b)

RCC=Retrospective case-control study, **CS**= Cross sectional study, **LS** =Longitudinal Study

Evidence of bioaerosols exposure to communities living close to composting plants

2.2.3 Community based studies are usually carried out in most cases as a result of complaints of odour nuisance caused by the existence of the waste treatment facility in close proximity to the community (Aatamila *et al.,* 2011). These studies are usually cross-sectional studies that mostly assess the impacts of causal agents on the given population at one specific time and may lack follow-up studies compared to what is obtainable with longitudinal studies. In one of the earliest published community-exposure reports by Kramer *et al.,* (1989), an asthmatic residing 80 m from a composting site showed symptoms of allergic broncho-pulmonary aspergillosis (ABPA), confirming bioaerosols dispersal downwind of waste facilities. More so, Herr *et al.,* (2003) reported bacteria exposures to the magnitude of 10^5 cfu m^{-3} at 250 m downwind of the composting site. Browne *et al.,* (2001) on the other hand used daily symptoms diaries from the residents to record the symptoms in relation to *Aspergillus fumigatus* spore counts, then comparing residents near the facility to those in a particular reference area. It was however observed that the residents recorded mostly respiratory symptoms, results of which was similar to what Herr *et al.,* (2003) observed from his study population (see Table 2.2).

Table 2-2 Community studies on bioaerosols exposures from composting facilities

Setting	Bioaerosol component	Study design	Study population	Exposure duration	Exposure concentration	Measurable Health effects	Significant D-R relationship	Reference
Residents 540m downwind waste composting facility	*A.fumigatus*	CS	63 living residents downwind; 82 controls	72 days	n. a	No significant association *A. fumigatus* and asthma or allergy	No	(Browne *et al.*, 2001)
Residents living near 5 composting facilities	Total bacteria, Thermophilic fungi and thermophilic actinomycetes	CS	365 residents: within 150-200m (n=82), within 200-400m (n=76), 400-500m (n=56)	n.a	**Total Bacteria:** 200m =5.1×10^4 cfu m^{-3} 250m =1.7×10^5 cfu m^{-3} 300m = 8.3×10^4 cfu m^{-3} **Moulds:** 200m =1.3×10^5 cfu m^{-3} 250m =4.6×10^4 cfu m^{-3} **Thermophilic actinomycetes:** 200m =5.5×10^5 cfu m^{-3} 250m =1.1×10^5 cfu m^{-3}	OR of Exposed vs. Unexposed for residence living between 150-200 m Bronchitis = 3.59 (1.40-9.47), Waking up due to coughing = 6.59 (2.57-17.73), Coughing on rising or during the day= 3.18 (1.24-8.36)	Yes	(Herr *et al.*, 2003)
Residents living near 5 waste treatment facilities	n.a	CS	1142 residents : ≤ 150 km(n=672), 1.5-3.0 km (n=253), 5 km (n=217)		**n.a**	OR by distance band ≤ 150 km vs. 1.5-3.0 km: Cough/phegm = 1.3 (1.0-1.8) OR by those annoyed by odour: Unusual shortness of breath =1.5 (1.0-2.2), hoarseness of dry throat = 1.5 (1.1-2.0)	No strong dose-response pattern observed	(Aatamila *et al.*, 2011)

RCC=Retrospective case-control study, **CS**= Cross sectional study, **LS** =Longitudinal Study, **OR=** Odds ratio

Landfills

2.2.3.1 Since the issuance of the Landfill directive (1999/31/EC) in 1999, the yearly amount of biodegradable municipal waste (BMW) going to landfill in the UK as at 2012 have been reduced to 29% of the baseline amount generated in 1995 (DEFRA 2015). By implication, the UK has met her projected target of reducing BMW going to landfill below the 50% base line as proposed by the Landfill directive (1999/31/EC), hence effectively reducing the rate at which new landfill sites are opened and emission of GHG and bioaerosols as shown in Table 2-3. However, if BMW is still a greater part of the waste going to landfill, then there is still a possibility of bioaerosols generation in landfills.

The day-to-day landfill operation could be grouped into four unit operations; weighing of collection vehicle, unloading of waste, spreading and compaction of waste and covering of waste. The waste collection vehicle on arrival is weighed and inspected for unacceptable waste content. Then waste vehicles are then directed to their expected tipping points where the waste trucks are unloaded and the waste are ready to be spread on the available space within the landfill. Usually the spreading within the landfill are carried out with the use of bulldozers and compactors. The last unit operation is carried out by covering of the waste with cover soil or the use tarpaulin. The primary purpose of the operation is to minimise windblown-litter, control odour emission, and prevent bird scavenging, reduce risk of fire and unauthorized scavenging by humans (ISWA 2010). The following sections will review possible emission from landfill sites and its impacts in the health of workers and community around the landfill site

Table 2-3 Municipal Waste and BMW to Landfill 1995, 2010-12 (DEFRA 2015)

Year	Operation	Amount of Waste (thousand tonnes)				
		UK	England	NI	Scotland	Wales
1995	Municipal waste to landfill					
	of which BMW to landfill	35,688	29,030	1,225	3,595	1,837
2010	Municipal waste to landfill	24,807	20,298	893	2,296	1,319
	of which BMW to landfill	12,982	10,339	558	1,406	678
2011	Municipal waste to landfill	22,432	18,421	734	2,113	1,164
	of which BMW to landfill	11,716	9,360	464	1,282	609
2012	Municipal waste to landfill	19,733	16,187	622	1,902	1,023
	of which BMW to landfill	10,293	8,129	394	1,170	599

2.2.3.1.1 Bioaerosols emission from Landfills and health of landfill workers

Landfills are one the highest emitters of GHG's, bioaerosols and VOC's and these have been linked to the biodegradable component of the landfill waste (Lis *et al.,* 2004; EA 2010c; Mansour *et al.,* 2012). GHG's such as methane (CH_4) are inevitable by-products of anaerobic decomposition of organic waste sent to landfills (EA 2010c; Stanisavljevic *et al.,* 2012). In properly managed landfills, the microbial sources are mostly from the waste arriving at the landfill and the microbial rich soil used for covering the waste during compaction. Bioaerosol emission pathways have been noted to be largely due to agitation during unloading, spreading and compaction of the MSW (Buczyńska *et al.,* 2005). Some studies have suggested that bacteria can be aerosolized alongside landfill gases from landfill surfaces with or without agitation (Moletta *et al.,* 2008). Bioaerosols emissions have been observed in a closed landfill site and to be still recording high concentration of bioaerosols years after its been out of use (Huang *et al.,* 2002; Frączek *et al.,* 2014). Microbial concentrations have also been reported at levels $>10^4$ CFU/m^3 in offices located 120 m from landfills (Lis *et al.,* 2004). A log higher than expected indoor microbial level (Ross *et al.,* 2004; Frederickson *et al.,* 2013). Pulmonary histoplasmosis is a respiratory infection acquired when aerosolized *Histoplasma capsulatum* spores are inhaled. This pathogen has been associated with areas with organic content in soil and have shown to infect landfill workers especially when aerosolized during soil covering and compaction at landfills (Huhn *et al.,* 2005).

There are also reports of the health effects of organic dust on landfill workers showing symptoms of multiple respiratory symptoms, low WBC and Monocyte counts (see Table 2-4). In most of the studies reviewed, bioaerosol emissions had adverse health effects not just on landfill workers but also the communities around the landfill. The reports further confirm that a large proportion of occupationally acquired infections associated with landfill workers were respiratory. Gelberg (1997) for instance, reported higher odds of respiratory symptoms (OR=2.14, 1.35-3.38, 95% CI) across all the groups of landfill workers than dermatological (OR=2.07, 1.11-3.38, 95%CI) and gastrointestinal (OR=1.26, 0.76-2.09, 95%CI) symptoms. In a similar study by Abdou (2007), 65.5% of examined landfill workers suffered multiple respiratory symptoms, eye infections 48.3% and gastrointestinal infection 20.7%. The report however did not contain information on the causative agents the workers were mostly exposed to.

Table 2-4 Occupational Health effects of bioaerosols exposure on landfill workers

Location	Study design	Setting	Study population	Study duration	Measured particles	Emission pathway	Health effects	Remarks	Reference
Toruń, Poland	LS	Landfill	Landfill site, Sorting, and weighing station	1 year	**On operating LF cell:** Bacteria: Mean=1939 cfu m^{-3} Molds: Mean = 2017 cfu m^{-3} **Indoor environment:** Bacteria: Mean= 12025 cfu m^{-3} Molds: Mean= 13574 cfu m^{-3} **Polluted air surroundings Area (300 m from LF)**: β-haemolytic Bacteria= 15.1% Actinomycetes = 3.6%	Tipping , compacting, and dumping	Not considered	Air surrounding the landfill had considerably lower microorganism, the air within the landfill was highly polluted (21.7% of the sampled air) especially observed during the spreading, compaction and unloading.	(Kalwasińska *et al.*, 2014)
Poland	LS	Landfill	Indoor office 120 m from landfill; outdoor landfill area closest to the office building.	6 months	**Bacteria:** Indoors 2.0 $\times 10^4$-7.2$\times 10^4$ cfu m^{-3} Outdoors: 6.4$\times$ 10^3-4.2$\times 10^4$ cfu m^{-3} **Fungi** Outdoors: 6.4$\times$ 10^3-4.2$\times 10^4$ cfu m^{-3}	Not considered	Not considered	High possibility of chronic health effect from endotoxins due to prolong inhalation of gram-negative bacteria.	Lis *et al.*, (2004)
India		Landfill			TSP (559-2082 μg/m^3)	Waste Spreading, off-loading, Scavenging, Wind action	89% = single /multiples RS; 72% suffer URS; 77% Suffer LRS Low WBC and Monocyte counts	Workers health impacts were largely attributed to TSP (Consist of dust, VOC's, Bioaerosols, and PM) as a whole.	Ray *et al.*, (2004)

RCC=Retrospective case-control study, **CS**= Cross sectional study, **LS** =Longitudinal Study, **OR=** Odds ratio

2.2.3.1.2 Evidence of health impacts on communities living close to landfills

There is evidence in the literature suggesting a link between a resident's proximity to a landfill, exposures from landfill and ill health. Fielder *et al.,* (2000) for instance, in the case study of Nant-y-Gwyddon landfill site in the UK, reported increased rates of maternal congenital anomalies (CA) in residents living near the site by 1.9 times (95% CI, 1.3-2.85, $p<0.001$) for the period from 1988-1996 after the landfill site was opened. In another study investigating the prevalence of CA among residents who lived close to 24 landfills in Wales between 1983-1997, Palmer *et al.,* (2005) also noticed that the odd ratio for CA in these residents had increased from 0.87(95% CI, 0.75-1.00) to 1.21 (95% CI, 1.04-1.40), an indication of increased risk of congenital anomalies. He however acknowledged a lack of data for confounding factors that may have influenced the result (Table 2.4). Another report by Elliott *et al.,* (2001) recorded excess risk of birth defects and low weight birth after examining the 80% of the British population living within 2 km of landfill sites, but no clear cause was explained for his claim. However, since the control population was essentially rural, it could possibly be that the difference between the study and the control groups could account for his findings. It is worth mentioning that Mattiello *et al.,* (2013) had established that the risk of congenital anomalies and respiratory disease have been the most consistent evidence in the literature over the years and may likely indicate the true nature of the impacts of landfills on the health of residents living close to landfills. Noted also was that none of the health symptoms were clearly stated to be associated with bioaerosols emission from the landfill sites, thereby suggesting insufficient data on bioaerosol exposure and dose response data on the impact of bioaerosols on the community living near landfill sites.

Table 2-5 Community studies on the effect of landfill emissions

Location	Study design	Setting	Study population	Exposure duration	Exposure concentration	Measurable health effect	Sig. D-R Relationship	Reference
Wales	RCC[a]	Landfill	Residents within 2 km from 24 landfill sites in Wales for the years 1983-1997	15 years	Not reported	**Congenital Anomalies:** Observed to expected rates ratio increased from **0.85** (95% CI, 0.75-1.00) before landfill opening to **1.21**(95% CI, 1.04-1.40) after opening, with higher standardized risk ratio of **1.39** (95% CI, 1.12-1.72) compared to **1.04**(95%, 0.88-1.21) for 1998-2000.	Not reported	Palmer *et al.*, (2005)
England and Wales	RCC	Landfill	Residents within 2 km from landfill (58% on the population in England and Wales) for the years 1989-1998.	9 years[b]	Not available	**Downs Syndrome:** No significant excess risk of Down syndrome in population living near landfill.	No	Jarup *et al.*, (2007)
California, USA	RCC	Landfill (Hazardous Waste site)	Racial or Ethnic minority living near hazardous waste sites in California	6 years		**Birth defects:** OR= 1.12 (95% CI, 0.98-1.27) showing increased risk. **Neutral tube defects:** OR= 1.54 (95% CI, 0.93-2.55) Showing increased exposure risk. **Anencephaly:** OR= 1.85 (95% CI, 0.62-2.27) This indicates Higher risks associated with exposure.	Not reported	Orr *et al.*, (2002)

New York	RCC	Hazardous waste site (HWS)	Women living near 818 hazardous waste sites in New York.	16 years	Potential exposure to POPs[c] and VOCs[d] as classed by the NYSDEC[e]	**VOCs**: RR[f] 1.056 (95%CI, 1.008-1.107; p<0.023) **POPs:** RR 1.014 (95% CI, 0.967-1.064; p<0.557) **Breast Cancer**: There is a close association between the emission of VOC's and POP's from HWS and the rate of development of reported breast cancer. **Impact:** The result also shows that VOCs had the greater impact as compared to POP's emitted from the HWS's.	Yes	Lu *et al.*, (2014)

[a] **RCC**=Retrospective case-control study, **CS**= Cross sectional study, **LS** =Longitudinal Study
[b] All data for 1991 discarded because of maternal age miscoding in the live and stillbirth data
[c] persistent organic pollutants (POPs) like dioxins, polychlorinated biphenyls, polycyclic aromatic hydrocarbons and chlorinated pesticides
[d] Volatile Organic Compounds like chloroethenes, chloroethanes, chloromethanes, chlorobenzenes, benzene, toluene, xylene, etc
[e] NYS Department of Environmental Conservation (NYSDEC)
[f] RR=Rate ratio

Waste collection and recycling

2.2.3.2 Health symptoms related to waste collection and recycling have been reported to include musculoskeletal problems, pulmonary disease, gastrointestinal problems, and eye and skin irritation (Poulsen *et al.*, 1995). Workers exposure routes have mostly been through skin contact and inhalation. In two contradictory reports by Odewabi *et al.*, (2013b) and Garrido *et al.*, (2015), the earlier reported that 71% of the workers suffered from single or multiple respiratory symptoms, 66.67% musculoskeletal as compared to the control group with 32% and 21% respectively. The latter, on the other hand, reported a prevalence of musculoskeletal at 67% and respiratory symptoms at 13%, hence contradicting several reports establishing respiratory symptoms as the prevalent health symptoms observed among waste workers (Heldal *et al.*, 2003; Ray *et al.*, 2004; Abdou 2007; Bünger *et al.*, 2007; Walser *et al.*, 2015). Garrido *et al.*, (2015) however, acknowledged the limitations of the report by only including work-related respiratory complaints in the CSS and possible logistic regression adjustment due the high presence of confounding factors like smoking 35.4%, obesity 29.2% and mean BMI 28.2 kg/m^2. Odewabi *et al.*, (2013b) using biomarkers attributed the appearance of Immunoglobulin A in seromucous secretions from the workers as a typical indication of the immunological defence of exposed external surfaces against attack by microorganisms, in this case inhaled bioaerosols.

2.2.3.3

Bioaerosol exposures in agricultural operations

Agricultural activities such as crop production and livestock production are important sources of exposure to bioaerosols (Lanier *et al.*, 2010; Hansen *et al.*, 2011). During crop production, planting, threshing, harvesting often causes disturbance of the crops and the soil, enough to detach the microorganism attached to these surfaces, thus aerosolizing them (Jones and Harrison 2004; Tarigan *et al.*, 2017). As shown in previous studies, the agricultural workers are at high risk of exposure to bioaerosols, not just because of the high bioaerosols concentration associated with the specific task/activities, the workers are generally unaware of these risks, thus taken no precaution to prevent them (Lis *et al.*, 2008; Lee and Liao 2014; Tarigan *et al.*, 2017). Tarigan *et al.*, (2017) for instance reported fungi concentration in the magnitude of 10^4 cfu m^{-3} in a mushroom and vegetable farm in Taiwan, and workers diagnosed with decreased lungs function. Moreover, hypersensitivity pneumonitis have been reported among mushroom farmers exposed to fungi spores in France and Japan (Tanaka *et al.*, 2001; Ampere *et al.*, 2012). Workers cultivating crops in green house are at higher risk of bioaerosol exposure compared to

compare to open air (Hansen *et al.,* 2011). This also raises a major health concern as greenhouse farming is increasingly being adopted for the growing of vegetables and flowers (Thilsing *et al.,* 2014).

Livestock and poultry operations have continued to increase globally in responds to demographic pressure, land pressure and economic developments. These have also lead to the increase trend in animal confinement as a way to cope with these external pressures (Millner 2009). The direct consequence of this is an increase in the overall airborne microbial load in the immediate environment by virtue of the increase feed volumes, number of animals and the organic waste produced by the animal. Workers in pig farm in Switzerland have been reported to be exposed to fungi and endotoxin concentrations up to 5.7×10^3 cfu m^{-3} and 1.3×10^3 EU m^{-3}, values the at higher the Swiss recommended Occupational exposure limits (Masclaux *et al.,* 2013). In a different setting, Lanier *et al.,* (2010) have reported fungi concentration up to 1.7×10^6 cfu m^{-3} using a personal sampler worn by workers during feeding operation in a cattle farm in Normandy (France). Although on the surface there might be a morally justifiable to engaging in agricultural activities compared to waste management, however, previous reports shows bioaerosols concentration values similar to those recorded in waste management facilities.

Residences located near these agricultural farms have also been exposed high concentration of airborne contaminants (particulate matter, bioaerosols and dust). Elevated levels of cow allergens like Bos d 2 and ammonia were in home located within 400 m from a dairy farm in Washington, USA (Williams *et al.,* 2011). In another isolated case, Pavilonis *et al.,* (2013) reported that children located at near animal farm and are exposed to contaminants from swine animal feeding operations in Iowa USA, had higher risk of asthma (OR 1.51 95 CI 1.08-2.09, p= 0.014) and/or would have been on diagnosed of asthma or medication for wheeze (OR 1.38 95 CI 1.04-1.81, p= 0.023).

In all the reports evaluated, what is most consistent is the elated level of exposure to bioaerosols and other airborne contaminants during agricultural operations, levels comparable to what is measured in waste treatment operations.

Open dumping

Open Dumping as a solid waste management practice

2.3

2.3.1 Open dumping has the greatest impacts on the environment and public health compared to other forms of waste-to-land treatment of MSW (Hoornweg and Bhada-Tata 2012c; ISWA 2015). Although not an acceptable waste management method for global best practices, it is however the most common practice in developing countries. It involves the designation of a piece of land where indiscriminate deposit of solid waste can take place with none or limited control measures over its operation and the protection of the environment surrounding it (ISWA 2015). In general, the impact of open dumping on the environment and quality of life is mainly felt as a result of air, water and soil contamination (Karak *et al.,* 2012). This section will review the impacts of open dumping on the environment and public health.

2.3.1.1

Environmental Impacts of open waste dumping

Methane (CH_4) is the second most prevalent GHG emitted due to anthropogenic activities, contributing about 60% to the CH_4 generated globally and has 25 times greater impact on global warming over a 100-year period than CO_2 (Yusuf *et al.,* 2012; EPA 2014). Of the 20.61% global methane emissions from waste, landfilling and open dumping of solid waste (59.07%) and wastewater (40.81%) are the two largest emission sources in the sector (Karakurt *et al.,* 2012). Moreover, methane is lighter than air and can easily build up pressure during its formation, resulting in an upward movement through the soil via the path of least resistance for some time, before breaking through the surface (ISWA 2015). Additionally, methane is highly flammable, and it is largely responsible for the self-ignitions and open fires commonly found in open dumpsites. A substantial increase in CH_4 emissions is projected in Africa (77%), South- East Asia (34%) and Latin America (53%) if substantial effort is not put to the diversion of waste from dumpsites and establishing an improved waste management system (Yusuf *et al.,* 2012).

Other environmental impacts include leachate from the decomposed waste percolating downwards into the soil. Leachates are liquids that contain biological and chemical constituent of the waste that are in the form of dissolved suspended solids containing heavy metallic compounds from metal like Zinc: Zn, Cadmium: Cd, Chromium: Cr, Nickel: Ni, and others. These compounds, if not controlled, can percolate deep, contaminating the sources of drinking water as well as surface water. Karak *et al.,* (2013)

reported a high concentration of Fluoride (F^-) at 2.98-24.39 mg/L and Chlorine (Cl^-) at 1.23×10^{-3} mg/L in the leachate sample from the Garchuk dumpsite, a concentration higher than recommended for F^- level in ground water by WHO (Brouwer *et al.,* 1988). Most interesting is the contamination of the nearby water source (Deeper Beel River, 250 m from Garchuk dumpsite) by Zinc and other heavy metals. They had reported up to 1.2 µg/L at points closest to dumpsite and even higher values (Zn: 60.3 µg g^{-1}; Cd: 1.10 µg g^{-1}) in vegetables (*C.antiquorum schott*) grown close to the dumpsites. A similar of high concentration of heavy metals was also reported in the soils at dumpsites in Islamabad by Ali *et al.,* (2014), with Zn: 632 µg g-1; Cd: 6.17 µg g-1 suggesting soil contamination and high uptake by vegetation in such area.

2.3.1.2 Public health impact of open waste dumping

The practice of open dumping can only negatively affect public health either directly or indirectly. Directly in the sense that humans can get sick or develop chronic illnesses due to prolonged inhalation or contact with microbial and chemical emissions from dumpsites. Indirectly, suggests that ingestion of contaminated plant or animal or water as a result of the dumpsites, humans can still be affected by the practice of open dumping (Sankoh *et al.,* 2013a).

Common at open dumpsites are scavengers (people who make their livelihood recovering valuable materials from waste by ravaging the waste pile). These people live in unhygienic conditions close to the dumpsites, and from the nature of their jobs are exposed to every possible emission from the waste dumpsite (Thirarattanasunthon *et al.,* 2012). Respirable particles such as VOCs and bioaerosols are disease causing and have been reported to be present in high concentrations in landfills (Table 2-4). VOCs however, are aromatic compounds that are also emitted alongside landfill gases. While CH_4 and CO_2 contribute significantly to global warming, prolonged exposure to VOCs emissions have been reported to have carcinogenic properties as well as non-cancer hazards to landfill workers and dumpsite scavengers (Majumdar *et al.,* 2014). Additionally, blood infection such as Hepatitis B, HIV and physical symptoms such as skin rashes, low back pain and sprains, headaches and impetigo have been reportedly found in dumpsite scavengers (Kungskulniti *et al.,* 1991; WB 2005; Thirarattanasunthon *et al.,* 2012). The greatest risk relates to wounds and cuts, exposure and contamination of which subsequently may lead to infection. Other types of accidents may involve fires, explosions,

machine accident and landslide of waste (Greedy and Thrane 2012). Although landfill workers and dumpsite scavengers may share a similar occupational hazard (see section on landfills), there is generally a lack of data on exposure-dose relationship making a competent assessment of the exposure effects extremely difficult.

Often observed as visual signs common to dumpsites are smoke from the burning of the waste (Greedy and Thrane 2012). The most common reason for open burning at dumpsites is to reduce the waste volume on site except for occasions where burning is required for resource recovery e.g. the burning of wires to remove insulations from copper cables and other electronic waste (Lemieux *et al.*, 2004; Asante *et al.*, 2012). Open waste burning have been reported to release some of the world's most toxic pollutants such as PCDD/Fs, PBDD/Fs, DL-PCB's, PCBs and VOCs in large quantities, some of which have been recommended for inclusion into the WHO Toxicity Equivalent Scheme (Van den Berg *et al.*, 2006; van den Berg *et al.*, 2013). The ash dust from the combustion are easily inhaled in high concentrations since the burning takes place at low heights and can easily settle out several miles away from source. Interestingly, high concentration of PBDs, PCBs and heavy metals have been detected in blood samples of children scavengers between 11-15 years old in dumpsites of Managua in Nicaragua (WIEGO 2014). It is no surprise that lower respiratory infection (LRI) is one of the highest contributing to global environmental burden of disease, only second to diarrhoea among children (0-14 years) (WHO 2006). Moreover in a study of 328 children at Dandora dumpsite in Kenya, 154 (46%) of ages 2-18 years showed observable symptoms of multiple respiratory infection, adding to the evidence supporting frequent occurrence of respiratory symptom among dumpsite scavengers (UNEP 2014).

2.3.2 Review of the relationship between bioaerosols emissions, exposure concentrations, and measured health impacts of open dumpsites

This section contains reviews of publications on bioaerosols emissions from dumpsites, evidence of health symptoms resulting from exposure and the existing knowledge gaps in the literature. The review was developed from the research questions already established in Chapter 1 of this thesis, and knowledge gaps identified as an attempt to answer these questions from the literature. These are the review questions:

- What are the concentration of bioaerosols generated at dumpsites?
- What are the taxa of bioaerosols in the air around an open dumpsite?

- What are the health effects on the population on dumpsites when bioaerosols are inhaled?
- Is there a relationship between diarrhoea occurrences and aerosolized enteric pathogens at dumpsites?

What are the concentration of bioaerosols generated at landfills and open dumpsites?

2.3.2. Evidence of emission of particulate matter from landfills and dumpsites have been widely reported by various authors, however it was observed that bioaerosols emissions have been given less attention compared to particulate matter emission in the literature in the past (Vrijheid 2000; Watanabe *et al.,* 2005; Chow *et al.,* 2006; Watanabe *et al.,* 2006; Watanabe *et al.,* 2010; Bastian *et al.,* 2013; Majumdar *et al.,* 2014; Weichenthal *et al.,* 2015). No fewer than 10 epidemiological studies alluded to bioaerosols as the cause for various health symptoms observed in landfill workers/dumpsites scavengers, yet little was mentioned regarding bioaerosols emission concentrations (Fedorak and Rogers 1991; Kungskulniti *et al.,* 1991; Poulsen *et al.,* 1995; Bünger *et al.,* 2000; Ray *et al.,* 2004; Ray *et al.,* 2009; Thirarattanasunthon *et al.,* 2012; Odewabi *et al.,* 2013a; Odewabi *et al.,* 2013b; Garrido *et al.,* 2015).

Among the 5 articles reporting emission levels, Kalwasińska *et al.,* (2014) and Lis *et al.,* (2004) reported the highest sampled values with airborne bacteria concentrations $> 10^4$ CFU/m^3 and fungi concentrations $> 10^3$ CFU/m^3 for indoor air (in offices, weighing station 120 m away from landfill) and between 10^3-10^4 CFU/m^3 for bacteria and 10^3-10^4 CFU/m^3 for fungi concentration in outdoor air. They generally reported high concentration of bioaerosols at landfills, values higher than expected background levels (Pearson *et al.,* 2015). In a similar report of a 3-year longitudinal study by Huang *et al.,* (2002) bioaerosols emissions were found to be far above 10^3 CFU/m^3 (i.e. 9.8×10^3 -1.1 $\times10^4$ CFU/m^3 and 5.6×10^3 -6.4 $\times10^3$ CFU/m^3 for fungi and bacteria respectively) with thermos-tolerant species like *Cladosporium spp, Aspergillus spp, Penicillium, Alernaria* and *Drechslera* accounting for 65% of all the fungi colonies on the sampling plates. This was the longest study on bioaerosol emission at landfills, showing seasonal variation on bioaerosol concentration. Odeyemi (2012) also reported a significant amount of bacteria in air around the studied dumpsite (*E.coli* 37%, *Klebsiella* spp 19%, *Pseudomonas* spp 13%, *Serratia* spp 15% and staphylococcus spp 8%) however, because of the sampling method employed (passive sampling) the published results may be an underrepresentation of the microorganisms in the air of the dumpsite where the study was based.

Amongst the fungi population detected in the outdoor air around landfills, *Cladosporium, Aspergillus* spp., *Penicillium* and yeast have been observed to be commonly sampled.

(Huang *et al.,* 2002; Kaźmierczuk and Bojanowicz-Bablok 2014). Although true, however it is established that certain fungi species are commonly associated with specific waste treatment methods. For instance, *Aspergillus* spp. are commonly associated with composting plants (Browne *et al.,* 2001; Herr *et al.,* 2003; Deed 2004), and *Cladosporium* can be found in outdoor air independent of the type of environment. Hence, in an environment with several treatment facilities employing more than one MSW treatment method, it is possible that sampled results could be unclear and inconclusive. For this reason, Kaźmierczuk and Bojanowicz-Bablok (2014) proposed the use of *Enterbacteriaceae spp*, β-haemolytic bacteria and yeast as indicator organisms for landfill bioaerosols emissions since they are rarely isolated from clean air and are often isolated in air samples around landfills (Flores-Tena *et al.,* 2007; Kalwasińska and Burkowska 2013; Kalwasińska *et al.,* 2014).

Knowledge gaps

There were a few knowledge gaps identified that possibly could be filled by this research

- There was only one report on seasonal variation and its impact on bioaerosol concentrations in the air at landfills, and none for dumpsites.
- The sampling methods employed can influence sampling results. Some of the literature reviewed did not mention the standard or protocol used for the sampling of bioaerosols (e.g. UK Environment Agency (2017) M9 Technical guidelines), hence raising a question of the reliability of their published data.
- Literature on bioaerosol concentrations in the air at dumpsites is scarce.

What are the taxa of bioaerosols in the air around landfills and open dumpsites?

2.3.2.2 Lis *et al.,* (2004) upon measuring microbial indoor and outdoor air quality in landfills in Poland, found more Gram-positive bacteria in the air than Gram-negative bacteria. In the outdoor air, twenty-four species were identified, but only eight were gram-negative. A similar result was also reported by Kalwasińska and Burkowska (2013) in Toruń, Poland, where 58.5% of bacterial isolates were Gram-positive bacilli (*Bacillus* spp., *Brevibacillus* spp., *Geobacillus* spp.) and 3.5% Gram-negative bacilli (*Pseudomonas* spp.). However, in a contrary report by Flores-Tena *et al.,* (2007), higher concentrations of gram-negative bacteria compared to gram-positive bacteria were observed in San Nicolás landfill site in Mexico. Incidentally, only *Entrobactrum amnigenus, Ochrobactrum* and *Pasteurella haemolytica* were the isolated species common to both Poland and San Nicolás. In a different report published 7 years after Flores-Tena *et al.,* (2007), Hurtado *et al.,* (2014) refuted the earlier findings about San Nicolás landfill, stating an overall higher count of gram-positive bacteria (62% of sampled bacteria) as compared to gram-negative bacteria (38% of sampled bioaerosols). This discrepancy could perhaps be explained by the sampling procedure used where the latter study took extra caution to ensure high microbial viability (low microbial losses due to impact stress) during bioaerosols air sampling.

Aboagye-Larbi *et al.,* (2014) and Odeyemi (2012) had reported a high prevalence of gram-negative bacteria compared to the gram-positive in the air around dumpsites in Ghana and Nigeria respectively. Gram-negative bacterial like *E.coli, Klebsiella* spp, *Salmonella* spp and *Pseudomonas* spp (73% bacterial isolates in Nigeria) and gram-positive bacteria like *Enteroccus spp* and *Staphylococcus spp* (27% of the bacterial isolates in Nigeria) were common to both Ghana and Nigeria. An interesting explanation for this could be due to a high volume of non-segregated waste received at these dumpsites, since these kind of waste have been observed to cause the highest gram-negative bacteria exposure during sorting of waste (Marchand *et al.,* 1995; Park *et al.,* 2011). Another possible explanation could be the climatic conditions found in these tropical countries as gram-negative bacteria have thermo-tolerant properties making likely to survive longer in air in regions with warmer climates, unlike Poland and Mexico with colder climates (Fang and Wong 2000).

Knowledge gaps

- There appears to be a relationship the between airborne microbial population, bioaerosol species and climatic conditions of the environment where the landfill/dumpsite is located, however, this has not been made clear in the literature.

2.3.2.3 What are the health effects on the dumpsite population when bioaerosols are inhaled?

Six articles on the health effects of respirable pathogenic aerosols released from dumpsites were reviewed (Kungskulniti *et al.,* 1991; Ray *et al.,* 2009; Thirarattanasunthon *et al.,* 2012; Karak *et al.,* 2013; Sankoh *et al.,* 2013b; Weichenthal *et al.,* 2015). Although the health effects (especially respiratory symptoms) observed in landfill workers were similar to those experienced by dumpsite scavengers, the lack of administrative controls at dumpsites aggravates the possible consequences from the exposure, as the dumpsite population were reported to be exposed to multiple diseases-causing agents. The characteristics of the waste arriving at open dumpsites are non-segregated, making it sometimes difficult to draw clear conclusions on the level of impact each confounding factor has on the exposed person. The following confounding factors were identified to be common among the literature reviewed:

- Chemical exposure due to emission $PM_{2.5}$ to PM_{10} from the waste (Kungskulniti *et al.,* 1991)
- Toxic exposure due to landfill fire (Weichenthal *et al.,* 2015)
- Smoking habits (Ray *et al.,* 2009)
- Bio-medical waste as a source of infection (Kungskulniti *et al.,* 1991; Sankoh *et al.,* 2013a)

Ray *et al.,* (2009) reported increased alveolar marcrophages, neutrophils, eosinophils and lymphocytes in the sputum samples of examined female waste pickers, suggesting airway inflammation as compared to the controls in his study. Although the study had not reported the possible exposure concentration, they however concluded the biomarkers from the bodies of the female waste pickers were indications of a stimulated immune defence to combat invading pathogenic microorganisms such as bacteria, endotoxins and viruses. There is growing evidence that attached to suspended particulates (in the inhalable organic dust particles) are viable and non-viable microorganisms and other components such as endotoxins and mycotoxins (Krajewski *et al.,* 2002; Lane *et al.,*

2004). These particles are aerosolized mostly during spreading, compacting of waste and the hand picking/sorting by the scavengers (Buczyńska *et al.*, 2005). There are observed instances where exposure to total suspended particulates (TSP) are as high as 559-2082µg/m^3, a concentration 10 times greater than the 150 µg/m^3 24-hr exposure limit recommended by the USEPA (Kungskulniti *et al.*, 1991; EPA 2015). Thus explaining the reasons for the observed elevated levels of MRS recorded among waste pickers and scavengers (Odewabi *et al.*, 2013a).

Knowledge gaps

- Material reviewed reported either on the health symptoms experienced by the workers or the bioaerosols concentrations, and not both. Thus relating the impacts of exposure to morbidity is difficult. This may be due to the short duration of most of the studies.
- No clear adjustment of confounding factors were undertaken, especially for open dumpsites where workers exposure is from multiple sources.

2.3.2.4

Is there a relationship between diarrhoea occurrences and aerosolized enteric pathogens at dumpsites?

Diarrhoea and lower respiratory infection are two of the largest disease burdens attributable to modifiable environmental factors. The WHO (2006) estimates that 94% of the diarrhoeal burden of disease can be attributed to environmental risk factors such as unsafe drinking water and poor sanitation, thereupon putting children aged 0-14 years old the most vulnerable (ibid). Although a larger portion of diarrhoea is water borne, the lack of proper environmental sanitation has also plays a significant role as well. Mengistie *et al.*, (2013) in his study established that households with open refuse dumps close by had 2.22 times higher odds of contracting diarrhoea (OR=22.2, 95% CI 1.2 – 4.03) than households who do not (OR=1.74, 95% CI 1.33-2.28). Although his study only covered diarrhoeal occurrences within two weeks prior to the study, it however was able to identify a close association of diarrhoea with refuse dumps. In another study of residents living close to dumpsites in Salvador, Rego *et al.*, (2005) established the prevalence of diarrhoea among children exposed to the waste dumpsite to be 3.98 times (OR=3.98, 95% CI 1.56-10.13) higher as compared to those who were not. Moreover, a common source of faecal matter at dumpsites are children's diapers and the faeces of animals that are dispose at the dumpsite (Limpurb 1999). Hence there may be increased risk of direct

human-human transmission especially if a member of the household participates in scavenging at these dumpsites (Rego *et al.,* 2005). Living in close proximity to dumpsites can pose some level of risks attributable to vectors. Flies for example, are vectors common to refuse dumps and dumpsites and are known to spread enteric bacteria (Oo *et al.,* 1989; Chavasse *et al.,* 1999; Curtis *et al.,* 2000).

There is emerging evidence that inhaled aerosolized enteric bacteria could subsequently be swallowed, thereby increasing the gastrointestinal pathogen load. Jahne *et al.,* (2014) and Dungan (2014) had attributed this to inhaled enteric pathogens that are deposited in the upper respiratory tract and then swallowed. Usually large particulate matter (dust clusters) that do not move down to the alveoli area could be deposited in the upper respiratory tract and then swallowed. And contained therein are pathogens from the dusty environment (Buczyńska *et al.,* 2005). This is contrary to the WHO (2006) report, stating that the airborne pathway of enteric bacteria are of very little consequence and may not be a significant contributor to disease burden attributable to diarrhoea.

Knowledge gaps

- The infection probabilities from inhalation of enteric microorganisms from dumpsites were not found in literature.

Review of quantitative microbial risk assessment as a tool for infection risk calculation

2.3.3 The use of quantitative microbial risk assessment (QMRA) as a tool to assess public health risks from pathogenic microorganisms is widely accepted across public health intuitions and in epidemiological studies (Haas *et al.*, 1999). The framework is such that it utilizes mathematical models and quantitative data to examine the exposure, characterize the spread of the pathogenic agents and assesses the infection risk from such exposure (Beaudequin et al. 2015). The four-tiered approach commonly used for microbial risk assessment are hazard identification (HAZ ID), dose response assessment, exposure assessment and risk characterization. QMRA has been used to assess faecal-oral exposures to gastrointestinal microorganisms from water sources (Machdar *et al.*, 2013; Sunger and Haas 2015), respirable bioaerosols from manure application sites (Jahne *et al.*, 2014), irrigated diary waste water (Dungan 2014), wastewater treatment works (Medema *et al.*, 2004) , and the case of Homeland security (Bartrand *et al.*, 2008; Huang and Haas 2009). The main advantage of QMRA is that it provides researchers with readily available analytical models that can mimic the human response to pathogen exposure, without over reliance on existing animal models, which may have ethical implications and are expensive to run. One of the limitations with QMRA is that the approach does not take into account crucial behavioural dimensions that may affect either the vulnerability or resilience of the sub-population to the infection risk (Nguyen-Viet *et al.*, 2009). However, over the past 50 years with the increasing recognition of the quantitative relationship that exist between risk levels and dose levels, multiple generational models have emerged incorporating factors like host factors (e.g. age, immune status), pathogen factors (e.g. particle size) and the rate at which the probable effect would develop i.e. epidemic curve, to fix this limitation (Haas 2015).

Infection probability can be estimated using dose-response models. The theory that each single organism inhaled by the host, has the potential to initiate an infection is what most dose-response models are based on (Rubin 1987). This is unlike the concept of threshold, where a certain minimum number of microorganisms are required to act cooperatively to overcome the host's immunity to initiate an infection (Haas *et al.*, 1999). The earlier, can explain why sporadic infections happen. However, this must be interpreted in cognisance that the probability of a single microorganism evading the host defence is very small; hence, more than one is needed to successfully initiate infection (Rubin 1987). Table 2-5

describes cases where QMRA was applied and dose-response models used to estimate infection risk from exposure to the pathogenic agents. In all the cases reviewed, β-Poisson and the exponential model were the most common, especially for enteric pathogens (Bacteria and virus). Furthermore, β-Poisson model seems to show best-fit compared to others when used for estimating infection risk from bioaerosols (Bartrand *et al.*, 2008).

Table 2-6 Cases where QMRA have been applied and the dose-response models used for respiratory risk estimation

Setting	Pathogen	Particle diameter (µm)	Best fit D-R model	D-R model parameter	Exposure period	Infection probabilities	Reference
Waster irrigation with sprinkler	*Campylobacter jejuni*	0.5-1.5	β-Poisson	$\alpha = 0.145$, $\beta = 7.59$	8 hours	At 1 km, infection risk ranged from 10^{-6}-10^{-1}.	Dungan (2014)
Cattle Manure application to land	Nontyphoid *Salmonella* spp.	-	β-Poisson	$\alpha = 0.3.126$, $\beta = 2884$	8 hours	Between 100-1000 m, infection risk range 10^{-6}-10^{-8}.	Jahne *et al.*, (2015)
Waster irrigation with sprinkler	*E.coli* O157:H7	0.25 µm	β-Poisson	$\alpha = 0.2241$, $\beta = 4.8807$	8 hours	At 1 km, infection risk ranged from 10^{-6}-10^{-1}	Dungan (2014)
Best-fit from animal models (mouse)	*Aspergillus fumigatus*	2-3.5 µm	β-Poisson	$\alpha = 1.1$, $\beta = 20$	60 mins	The risk estimate was 2.2×10^{-5}	Leleu *et al.*, (2013)
Best-fit from animal models (Rhesus monkey, Guinea Pig)	*Bacillus anthracis*	< 5 µm	Exp. β-Poisson	$k = 7.51\times10^{-5}$ $\alpha = 0.549$, $N_{50} = 28{,}472$	-	Infection risk ranged between 0.128 - 0.699	Bartrand *et al.*, (2008)
Best-fit from animal models (Mice, Guinea Pig)	*Coxiella burnetii*	0.2-0.4 µm	Exp. β-Poisson	$k = 7.79$ $\alpha = 0.492$, $N_{50} = 28$	-	-	Tamrakar *et al.*, (2011)
Biosolids application to land	adenovirus	90–100 nm	Exp.	k = 6.07E-01	1 hour	At 100 m downwind of application site, infection risk was 3×10^{-4}- 4×10^{-3}	Brooks *et al.*, (2012)

Knowledge gaps identified

2.3.4 At the end of the literature review a number knowledge gaps were identified and have been highlighted below:

- It was discovered that the relationship between seasonal variation and impact on bioaerosols concentration at dumpsites were not fully detailed in most of the reports reviewed, and this is likely due to the short duration of most of the studies.
- It was discovered that the bioaerosols sampling standard/protocol employed were not stated in most of the report examined, which may raise question on the reliability of the reported data.
- It was also discovered that the microbial species that appeared to be predominant in the environment studied depended on the type of waste treatment plants and the treatment method as well as the climatic condition of area the sampled area. Hence, indicator microorganisms sampled in one part of the world may not be the case in another part, depending on the climatic condition.
- It was also observed that the materials reviewed either reported on the health symptoms or bioaerosols emission concentrations and not both, hence, making it difficult to relate the exposure with morbidity in one setting. This was mainly due to due to the short duration of most of the studies reviewed.
- There no clear adjustment of confounding factors, especially in the case open dumpsites where there are multiple sources of emission.
- That a clear quantitative risk evaluation of bioaerosols impact on health of worker/scavengers/residence have never been carried out, especially in an environment with multiple environmental exposures.

Material and Methods

Chapter 3: Introduction

3.1 The chapter describes the samples, materials used and the methodology adopted during the investigation of the bioaerosols emission from open dumpsites in developing countries. The study involved a qualitative health survey, bioaerosol air sampling, laboratory analysis and data analysis. In this chapter, the research approach used is divided into four sections, which includes:

a. Respiratory Health Survey of participants in the study area
b. Bioaerosols air sampling: Sampling of ambient air with the Anderson six-stage impactor.
c. Bioaerosols air sampling: Activity based sampling with the use of the SKC Personal aerosol sampler.
d. Quantitative Microbial Risk Assessment

3.2

3.2.1 Case study area

Site Description and Activities

Olusosun open dumpsite is located in Ojota, Lagos State, Nigeria. Lagos State has a population of 21 million people with an annual population growth of rate of 3.2% (Buttner and Stetzenbach 1993; LBS 2013). Of the three principal dumpsites serving the urban population of Lagos i.e Ewu Elepe, Solous and Olusosun dumpsites, Olusosun is the biggest with a size of 42.7 hectares (105.5 Acres), and is located at 6°35'40.9"N and 3°22'38.4"E (Oyeku and Eludoyin 2010; LAWMA 2016), (See Plate 3-1). Olusosun is estimated to receive about 2,100,000 tons of municipal solid waste, construction and E-waste per year and has received about 17,150,000 to 24,500,000 tons of waste already since it became active in 1992 (D-Waste 2014). Olusosun dumpsite was chosen because it receives about 40% of the total municipal solid waste deposits in Lagos, operates on a 24-hour work cycle, every day of the year (Idehai and Akujieze 2015) and is surrounded by sensitive receptors located as close as only 50 m to its boundary (Sankoh *et al.*, 2013a). The waste characterization of Olusosun open dumpsite shows that 43% of the waste deposits were organic, hence a significant source of organic dust and bioaerosols (LAWMA 2017).

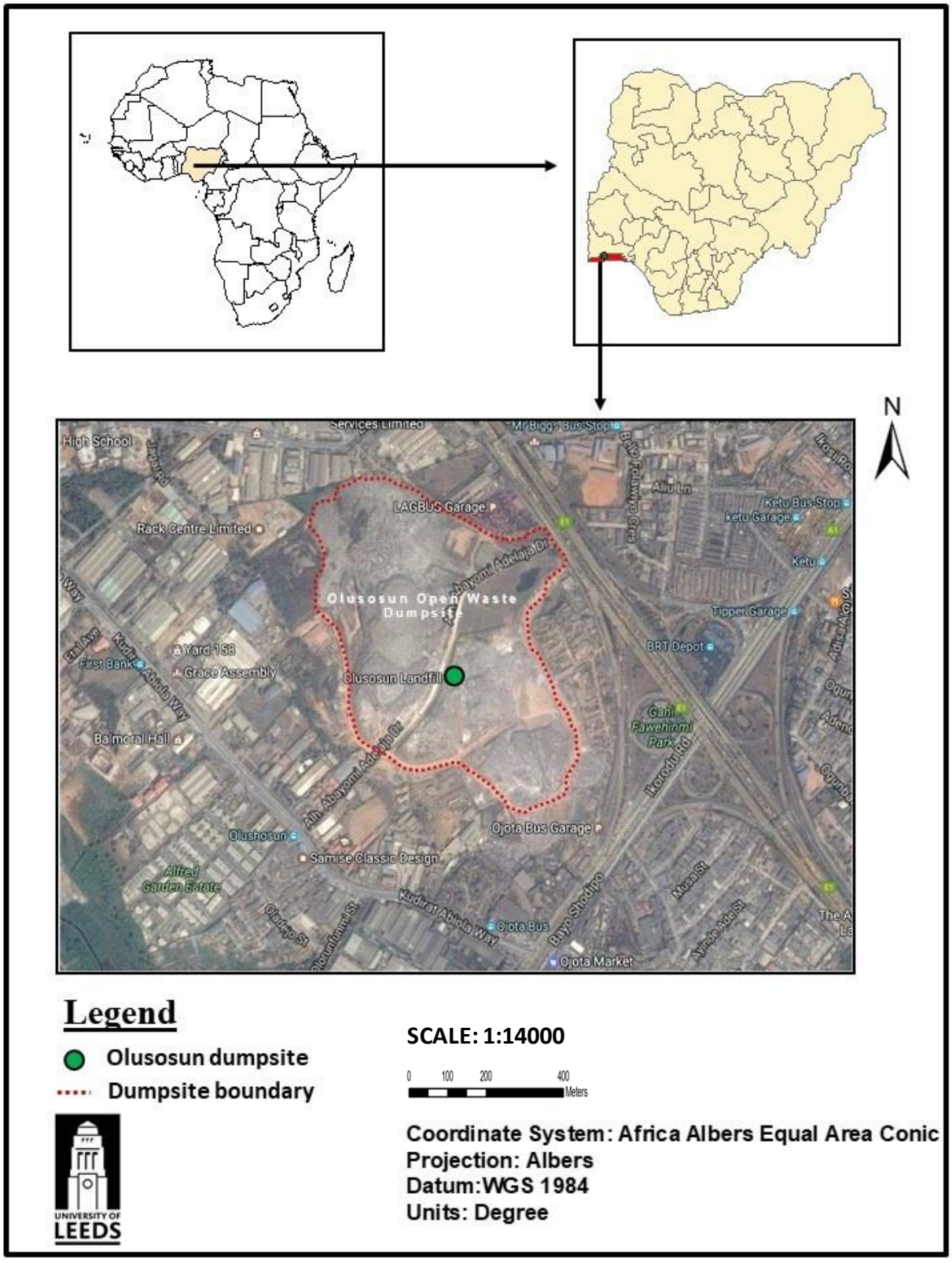

Plate 3-1: Location of Olusosun open dumpsite, Lagos, Nigeria.

Sensitive receptors

3.2.2 Sensitive receptors (SRs) were classed as neighbouring homes, businesses and other occupied buildings near the dumpsite that might be affected by the activities at the dumpsite (AfOR 2009; Environment Agency 2017). As a guideline for siting waste treatment facilities, it is recommended that they be sited at least 250 m away from the closet sensitive receptor (UNEP 2005; EA 2010b). On the contrary, Olusosun dumpsite is surrounded by several sensitive receptors within 50-150 m with some even sharing the same boundary with the dumpsite irrespective of the wind direction (See Plate 3-2 and 3-3). Among the sensitive receptors are residential buildings, primary schools, office complexes and parks. These neighbouring buildings served as points for conducting the close-to-site health survey where participants were either a resident or a worker in the area and would have been located at the space for at least 8 hours daily during workdays.

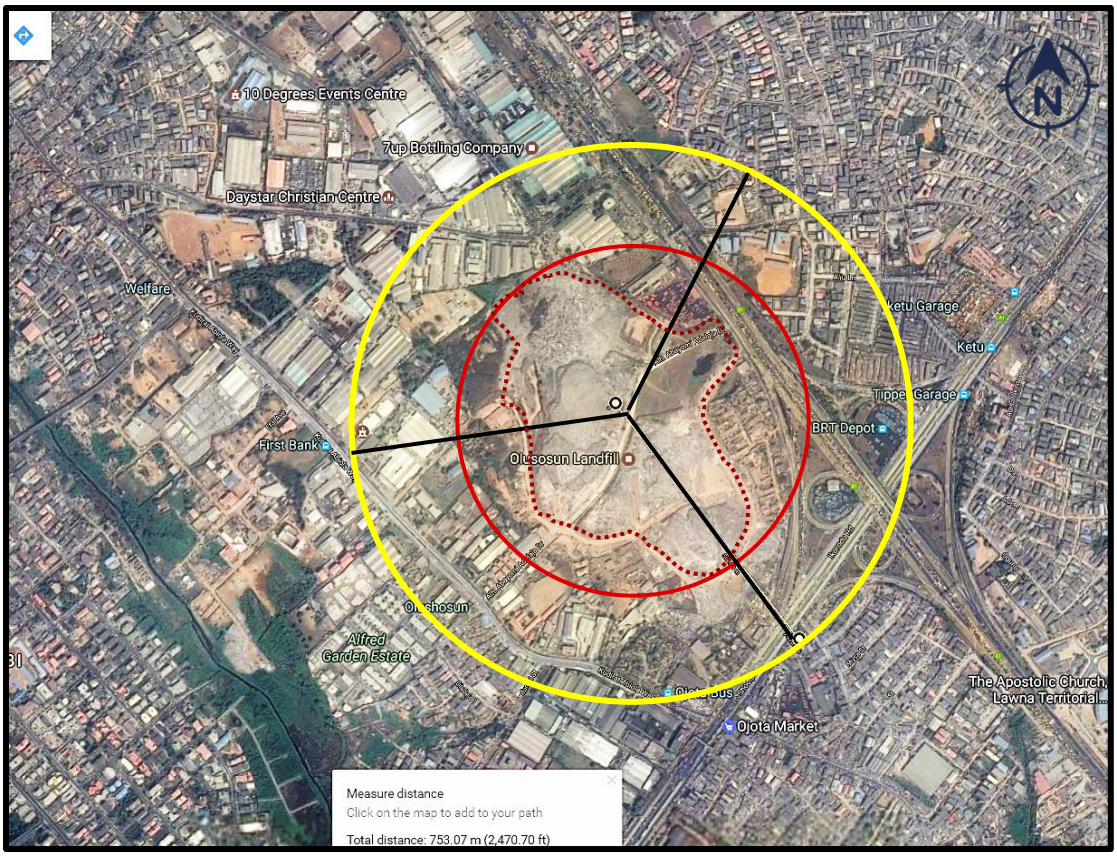

Plate 3-2 Aerial Map showing the location of sensitive receptors as located at different distances from OOWD, Red band: Within dumpsite boundary; Yellow band: 0- 250 m from boundary, adapted from Google Maps (2017).

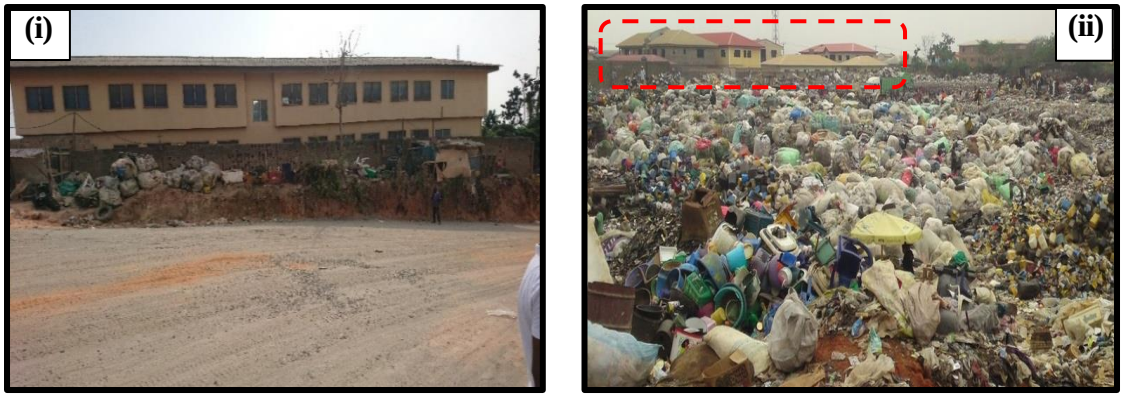

Plate 3-3: Sensitive receptors around Olusosun Dumpsite (i) Private Primary School (ii) Residential Buildings

3.2.3 Ethnographic study

The ethnographic study was carried through careful observation of day-to-day activities at the site in order to have an in-depth understanding of the behaviour and perception that occur within members of the population operating at the dumpsite (Reeves *et al.*, 2008). The ethnographic study took place between the 9th and the 13th January 2017 and observations were recorded in an activity logbook. The physical layout of the dumpsite was observed and documented. The researcher also obtained appropriate operational guidelines regarding the daily activities at the dumpsite and attended mandatory safety briefings organized by the management of the dumpsite. The two key constituted authorities managing the dumpsite were identified; these were the Scavenger's Association and the Lagos State Waste Management Agency (LAWMA). The information obtained served as a source of caution during sampling. On few occasions, randomized sampling was carried out based on word of mouth for clarity about the daily activities at the dumpsite.

Furthermore, the physical survey at the sensitive receptors was also carried out as part of the ethnographic study. Information obtained served as a guide during the Respiratory Health Survey activity in the area. Using Google Maps (2017) for navigation, interview points were identified, marked and recorded in preparation for the interview. These were all areas the fell within 250 m downwind from the dumpsite's boundary.

3.2.4 Control site

A residential area located approximately 10.79 km away from Olusosun open dumpsite was used as control for the study (Plate A-1). Prior to selecting this location, a visual

inspection of the area within 1500 m around the sampling locations for dumpsites, landfill, waste treatment facilities and factories was carried. This action was to reduce the possibility of co-founding factors of anthropogenic origin influencing the result of the respiratory health survey as well as the ambient air sampling. A total of 120 participants were interviewed at the control site and were not included in the sampled population on-dumpsite and near the dumpsite. The median age of the sampled population also matched a national demographic characteristic: 70% of adult population in Nigeria are less than 30 years in age (Reed and Mberu 2014). The sampling method employed for the Respiratory Health Survey (RHS) was similar to that used for on-dumpsite and close-to-dumpsite RHS, as described in section 3.5.2 and 3.5.3.

Ambient air sampling was carried out in the two stations at the control (Plate 3-6 C and D). These were located within 6°29'58.9"N 3°22'47.5"E and 6°29'45.3"N 3°22'45.0"E. The air sampling method employed is similar to the method employed at the dumpsite, as described in section 3.5. The microorganisms, agar type, growth inhibitants, incubation temperature and duration for bioaerosols are shown in Table 3-1.

3.3 Climatic conditions of the study area

The climatic condition of Lagos was assesses owing to its possible influence during bioaerosol sampling. Lagos is characterized by a tropical climate with two distinct seasons, the dry and wet seasons. The dry season is characterized by reduced rainfall (monthly average <120 mm) from late October through to March, with the lowest rainfall in January (monthly average <14.3 mm). However, heavier rainfalls are experienced in the wet season from April through to October, with the heaviest precipitation in June (see Table B-5). The mean annual rainfall range is 1635 mm-1800 mm while the mean annual temperature and relative humidity is 27 ^{o}C and 83 % respectively (Udo 2015; WMO 2017).

3.4 Respiratory Health Survey of participants in the study area

3.4.1 Ethical Approval

Ethical approval was obtained from the Engineering Faculty Research Ethics Committee, University of Leeds (Ethics Reference: MEEC 16-004), before carrying out the respiratory health survey at the dumpsite and its environs. The ethical approval clearly stated how the health data should be obtain, managed and stored securely.

Sample Size Estimation

3.4.2 Sample size was calculated using the metrics as recommended by WHO (1991). The size estimation was calculated for participants on-site and those close-to-site. On-site participants were those working on the dumpsite at the time of the survey, while the close-to-site participants were either residing or working close to the dumpsite at the time of the survey. For the former, the prevalence of respiratory symptoms in landfill workers in India at 65 % was used to calculate sample the size (Ray *et al.*, 2004; 2005). This prevalence figure was used because there are currently no figures in the literature for Nigeria. With a confidence level at 95%, bound on error at 5%, and statistical power at 80%, the sample size was 145 ±4 to account for attrition (see Table A-2). For the latter, due to the lack of appropriate records of the population size of the study area, a decision to recruit 145 participants was referenced from the sample size used in the on-site recruitment of participants, with a ±5 % error threshold.

3.4.3

Selection of On-dumpsite participants

A total of 149 participants were recruited for the study between the 12th and the 20th January 2017. For the purpose of the research, five major occupations were identified among the on-site participant namely: Scavengers (Those who ravage the waste pile with tongs for recyclable resources); Waste workers (Government workers in charge of the safe disposing of waste and the maintenance of OOWD); Business Owners (those with kiosk rendering different services to other members of the population); Middle Men (Those who buy the recovered recyclable materials from the scavengers); Food vendors (those who sell food to the other members of the population). Participants were selected at random and were required to have worked for at least one year at the dumpsite to be eligible to take part in the survey. More so, a written or verbal informed consent was sought from all participants before administering the questionnaires. Participants that

3.4.4 were unwilling to participate were appreciated for their listening time and the researchers moved on to the next available participant; see Plate 3-4 A and B. A copy of the consent form and questionnaire used is found in Plates A-2 and A-3.

Selection of Close-to-dumpsite Participants

A non-probability, convenience-sampling technique was used to recruit close-to-site participants. Due to the lack of appropriate records of the population size of the study area, a decision to recruit 145 participants was referenced from the sample size used in

the on-site recruitment, with a ±5% error threshold. Participants were selected at random and a written informed consent was sought from all participants. The participants were recruited only if they were either a resident (those who reside at study area), worker (those who come to work at study area but resides away from the study area) or a business owners (those with kiosk or small to medium scale businesses rendering services to the population in the study area) and would have spent an average of 8 hours per day for at least 4 days a week at the interview location. There were a few refusals to participate, however the overall responses were generally cooperative. A copy of the questionnaire used is found in Plate A-4.

The predominant wind direction was the main criteria for selecting the area covered during the qualitative research. As indicated in the UK Environment Agency (2017) technical note, sensitive receptors located downwind are more at risk than those upwind. A wind rose identifying the average wind direction over a period of 30 years was obtained from the World Meteorological Organization (WMO 2017) and Metroblue (2017) in order to select the primary area of study (Figure 3-1). Shown in Plate 3-5 are points on the map where the interviews took place and the number of participants at each location.

3.4.5 These points were generated using participant's addresses and location coordinates.

Operational definition of study outcome

These definitions were adapted from the operation guidelines of the European Community Respiratory Health Survey (ECRHS II), and American Thoracic Society Division of Lung Disease questionnaire (ATS-DLD-78A) (Ferris 1978; ECRHS 2002; Birring 2011; Shaikh *et al.,* 2012; Gibson *et al.,* 2016). **Chronic cough** was defined as a consistent cough as much as 4 to 6 times a day, 4 or more days a week or a cough first thing in the morning or both for at least 3 months. **Chronic Phlegm** was defined as expectoration of sputum for as much as twice a day for at least 4 days a week or expectoration of sputum first thing in the morning or both for at least 3 months. **Chronic wheezing** was defined as wheezing in a dusty environment that would have triggered 2 or more episodes of shortness of breath. **Asthma** was classified as at least two reported asthma attacks of shortness of breath with wheezing in the past two months with normal breathing between episodes of shortness of breath or a diagnosed asthmatic by a physician.

Plate 3-4: Respiratory Health Survey (A) On-site participant Scavenger during an interview session (B) Researcher with scavengers who participated in one of the On-site Respiratory Health Survey sessions after distributing protective nose mask to participants.

Plate 3-5: Interview locations, number of participant at each location during the close-to-site respiratory health survey.

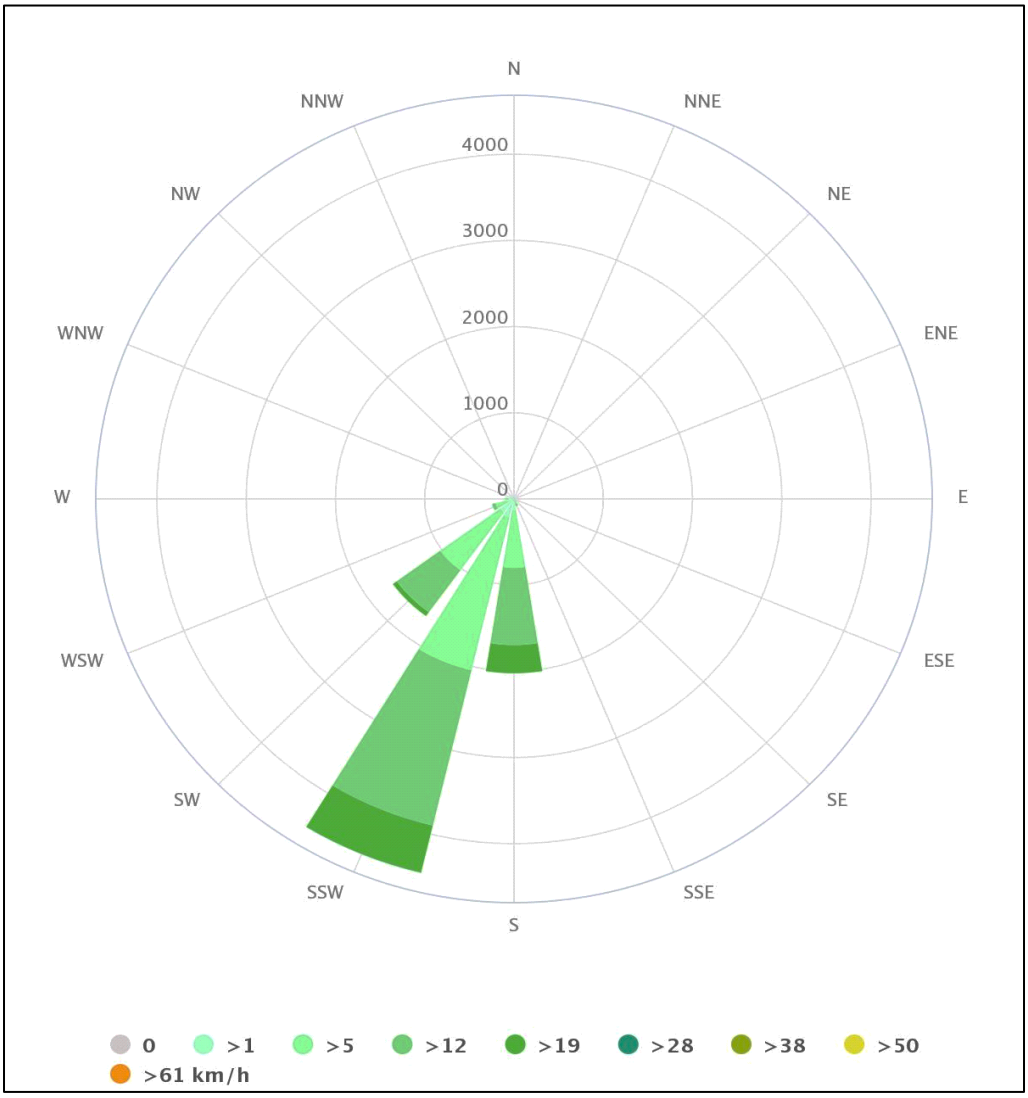

Figure 3-1 Wind rose showing the predominant wind direction of the north-eastern wind flowing across Olusosun dumpsite Metroblue (2017)

Bioaerosols air sampling: Sampling of ambient air with Anderson six-stage impactor.

3.5 Procedure for media preparation

3.5.1 A series of selective media was used for the bioaerosol sampling. The following indicator microorganisms were sampled; Total Bacteria, Gram-negative bacteria and *Aspergillus fumigatus* and Total fungi. These indicator microorganisms were used because they were widely reported in the literature on bioaerosols emission from waste management facilities and were also recommended by the UK Environment Agency (2017) Technical Guidance Note (M9) on environmental monitoring in regulated facilities (Drew *et al.,* 2009; Fletcher *et al.,* 2014; Wéry 2014b; Environment Agency 2017). Below is a summary of the selective media used

Total bacteria: Total bacteria were cultured on half-strength nutrient agar. 14 g of nutrient agar (Sigma-Aldrich) and 10 g bacteriological agar (Oxoid) were dissolved in 1 L of distilled water, then autoclaved at 121^{o}C for 15 mins. After cooling the media in a water bath to 50^{o}C, 100 mg/L of cycloheximide was added and mixed thoroughly. The media was subsequently poured into pre-sterilized 90 mm Petri-dishes in preparation for sampling.

Aspergillus fumigatus: *Aspergillus fumigatus* was cultured on malt-extract agar. The media was prepared by dissolving 15g of malt extract (Sigma-Aldrich) and 20g of bacteriological agar (Oxid) in 1 L of distilled water, then autoclaved at 121^{o}C for 15 mins. After cooling the media in a water bath to 50^{o}C, a supplement solution of 50 mg L^{-1} of Streptomycin, and 10 mgL^{-1} of Novobiocin was added and mixed thoroughly. The media was subsequently poured into pre-sterilized 90 mm Petri-dishes in preparation for sampling.

Gram-negative bacteria: Gram-negative bacteria were cultured on MacConkey agar. 20g of MacConkey agar (Sigma-Aldrich) was dissolved in 1 L of distilled water and mixed thoroughly, then autoclaved at 121^{o}C for 15 mins. Upon cooling to about 50^{o}C, 200mg/L of cyclohexamide for selective inhibition was added and then mixed thoroughly. The media was subsequently poured into pre-sterilized 90 mm Petri-dishes in preparation for sampling.

Procedure for Ambient air sampling

3.5.2 Ambient air sampling involved collecting air samples at specific locations on Olusosun dumpsite using an Anderson six-stage impactor by Tisch Environmental, Inc, U.S.A. Four fixed sampling points were identified in relation to the predominant wind direction (EA 2009; Environment Agency 2017), these were; upwind, active point, dormant point and the boundary. The active area was considered as the point source as activities such as spreading, tipping, scavenging and sorting mainly took place here. The sampling points and their distances away from the active part of the dumpsite are shown in **Plate 3-5**. Air samples were collected one day a week, for 13 weeks from the 25th April to the 28th August, 2017. Due to the limited number of sampling equipment available to the researcher, sampling did not take place concurrently at all sampling points.

3.5.3 At the sampling point, a set of six prepared media plates were aseptically transferred into the Anderson six-stage sampler which was mounted at a height of 1.5 m from the ground **(Plate 3-6 A and B).** Then air was drawn in at the rate of 28.3 L min^{-1} with a sampling time of 2.45 mins to avoid overloading of the plates. Duplicate samples were collected for each of the indicator microorganisms at each location , and the plates were stored in sterile sealed bags for no more than 8 hours at 4^{o} C while being transferred to the laboratory for incubation and enumeration (Jahne *et al.*, 2014).

Post-sample handling

Bioaerosol quantification, identification and enumeration were based on the protocol stated in the Technical Guidance Note (M9) for monitoring of bioaerosols at regulated facilities (Environment Agency 2017). The microorganisms, agar type, growth inhibitants, incubation temperature and duration for bioaerosols are shown in **Table 3-1.** *Aspergillus* fumigatus identification was based on colony characteristics (e.g. morphology, shape, size, pigment) while the gram-negative bacteria was further confirmed by gram staining. Total fungi was a sum of all the fungal colonies on the malt-extract media, inclusive of *Aspergillus fumigatus*. After enumeration, a positive-hole correction was carried out to adjust the colony counts and account for multiple impaction as recommended by Macher (1989) and Buttner and Stetzenbach (1993) and results were recorded in colony-forming units per cubic meter of air sampled (CFU).

Table 3-1 Specific incubating conditions regarding sampled microorganisms (Environment Agency 2017)

Bioaerosols	Agar	Specific growth inhibitants	Incubation Temperature	Duration of incubation
Total Mesophilic bacteria	14 g L^{-1} nutrient agar (Sigma-Aldrich) and 10 g L^{-1} bacteriological agar (Oxoid)	Cyclohexemide, 100 mg L^{-1}	37°C	48 h
Gram negative bacteria	52 g L^{-1} MacConkey Agar (Sigma-Aldrich)	Cyclohexemide, 200 mg L^{-1}	37°C in the dark	3 -7 days
Aspergillus fumigatus	20 g L^{-1} each of malt extract agar (Sigma-Aldrich) and bacteriological agar (Oxoid).	Streptomycin, 50 mg L^{-1} and Novobiocin, 10 mgL^{-1}	40°C	48 h
Total fungi	20 g L^{-1} each of malt extract agar (Sigma-Aldrich) and bacteriological agar (Oxoid).	Streptomycin, 50 mg L^{-1} and Novobiocin, 10 mg L^{-1}	40°C	48 h

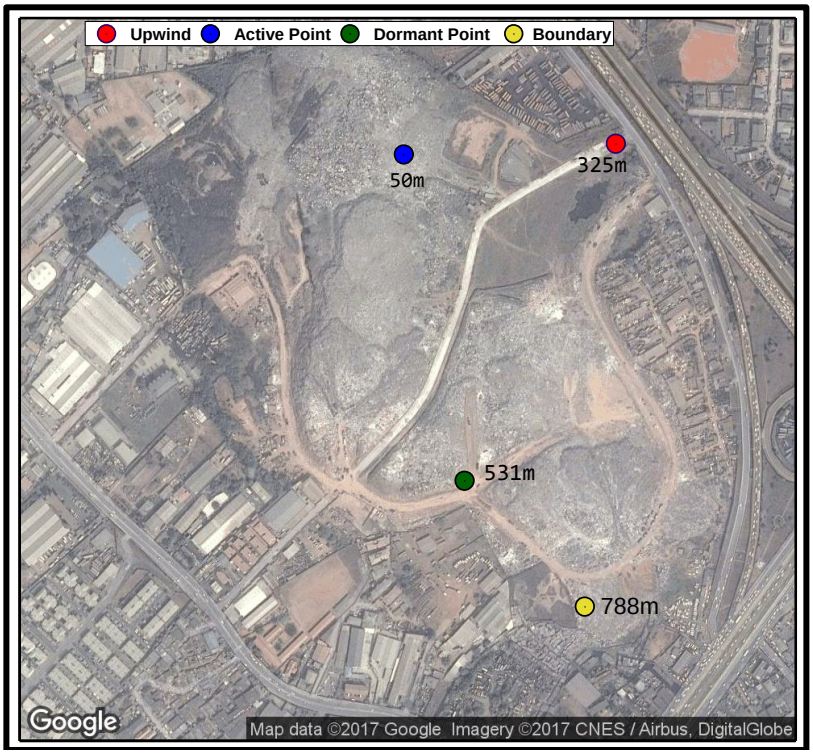

Plate 3-5 Sampling points on Olusosun dumpsite showing distances from active point.

Plate 3-6: Researcher carrying ambient air sampling using the Anderson six-stage sampler (A) Bioaerosol sampling at dormant point (B) Bioaerosol sampling at active point (C) Bioaerosol sampling at Control Location 1 (D) Bioaerosol sampling at Control location 2

Activity-based Air sampling

Sample collection

3.6

3.6.1 Activity-based air sampling measured bioaerosols exposure from specific activities engaged in by members of the population at the dumpsite. Three volunteers were recruited and they were involved in scavenging, waste sorting and site monitoring on the sampling days. The personal air sampler (Button Aerosol Sampler, SKC Inc., PA USA) mounted vertically on the volunteers, was operated by drawing sampled air using a personal pump (AirChek XR 5000, SKC Inc., USA) at 4 L/min through a stainless cassette containing a 0.8 µm pore size gelatin filter while they work **(Plate 3-7)**. The decision to use gelatin filter was informed by the literature as it has proven to increase the survival of stress-sensitive microorganism during sampling viable bioaerosols when compared to other sampling methods and filters (Wu *et al.*, 2010; Wang *et al.*, 2015). The sampler captured air around the breathing zone for 30 mins for the three activities measured. All samples were transported to the laboratory within 24 h and stored at 4°C for extraction within 48 hours. Before each sampling activity, the metal part of the Button sampler was sterilized by autoclaving at 121°C for 15 mins and all the other parts were cleaned with 70% isopropyl alcohol. It is worthy of note that albeit the activity-related samplings took place only on days the volunteers were available to mount the sampler, they were carried out concurrently with the static ambient sampling.

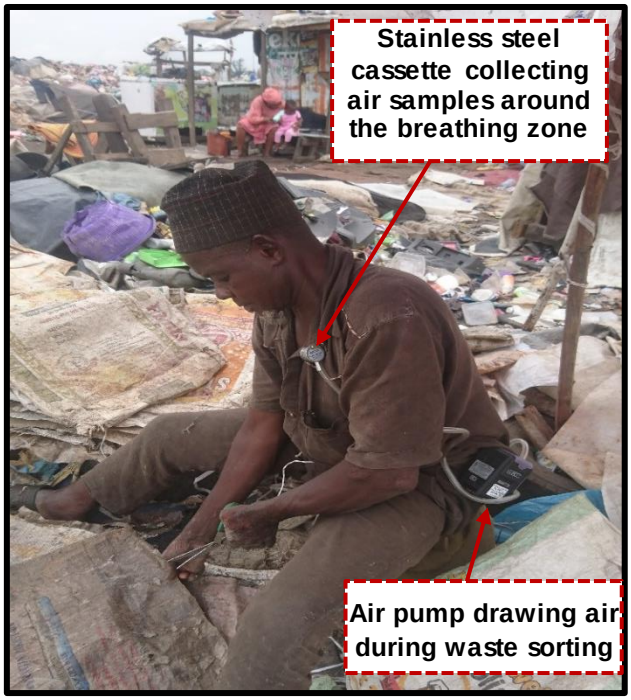

Plate 3-7 Waste sorter (Volunteer) at Olusosun Dumpsite during the activity-based air sampling

Post-sampling handing

3.6.2 After each sampling, the gelatin filters were removed from the sampler and dissolved directly in 30 ml of sterile extraction fluid (0.01% Tween 80 in distilled water) (Wang *et al.*, 2015) and was followed by a serial dilution performed on all raw samples using sterile buffered fluid (0.01% Tween 80 in distilled water). To do this, 1 ml of the sample was pipetted into a dilution tube containing 9 ml of the sterile buffered fluid and vortexed for 2 min. After vortexing, 1 ml of this was pipetted into a second dilution tube containing 9 ml of the sterile buffered fluid. This process was repeated until the forth dilution (10^{-4} or 1 in 10,000 dilution). Subsequently, 10 µl from each diluted sample was dropped in each quadrant of the selective media using a pipette, where each quadrant was reserved for one dilution in the series. Agar preparation and sample incubation processes were similar for both samples from Anderson sampler and the button sampler (**see Table 3-1**), however, the bioaerosol density (CFU/m^3) in the raw sample was calculated using the following equation (Herigstad *et al.*, 2001):

$$Density\ (CFU\ m^{-3}) = \frac{TC}{VP} \times DF \times BV \qquad [1]$$

TC: total bacteria count in each quadrant, *VP*: Plated volume, *DF*: Dilution factor, *BV*: Volume of the raw sample.

Plate 3-8: Researcher in the laboratory during enumeration and identification of microbes

Statistical Analysis

3.7 ***Qualitative health Survey***: Epi infor™ 7 by the Centre for Disease Control and Prevention (CDC), USA., was used for preliminary data processing which were later transferred to Microsoft Excel for further processing. The relationship between independent variables and dependant such as chronic cough, chronic phlegm, wheezing and asthma were analysed using logistic regression statistic model. Covariates such as age, sex and smoking status, were adjusted for. Chi-square goodness-of-fit test was used to determine statistical significant difference in the prevalence of the respiratory disease between the cases reported in the dumpsite and control, close-to-dumpsite and control. Similarly, the Chi-square goodness-of-fit test was applied when the prevalence data was compared to national data.

Bioaerosol Analysis: The test for normality was assessed by Kolmogorov-Smirnov test and nonparametric statistical tests were applied to the data set that violated the rule. The differences between the bioaerosols concentration for the upwind, active area, dormant area and the boundary were assessed using the one-way ANOVA/ Wetch ANOVA of normality. The homogeneity of variance was assessed by Levene's test of homogeneity of variance. If violated by any of the variables, Krustal-Wallis test was conducted to determine difference in means across the sampling points at the dumpsite. Generally, statistical analysis was carried out using IBM SPSS Statistics 22 for Windows (Version 22.0. Armonk, NY: IBM Corp., USA), Microsoft Excel and graphs generated using Origin (2015b, Origin Lab Corp., Northampton, MA, USA).

QMRA analysis: Details of the QMRA framework used in this study can be found in chapter 7 of this thesis.

Respiratory Health Survey

Chapter 4: Introduction

4.1

This chapter details the findings relevant to research objectives 1-3, as presented in section 1.3 (Chapter 1) of this thesis. These objectives were developed under the following hypothesis:

i. Olusosun dumpsite is a significant source of aerosolised pollutants in its vicinity; and
ii. There is a prevalence of respiratory health problems within the population located on and near Olusosun dumpsite.

It is important to note that it is difficult to establish from the existing literature that the respiratory diseases experienced by the exposed workers are solely the result of exposure to bioaerosols, as they are exposed to multiple sources of pollutants at dumpsites. Moreover, there are likely to be other drivers of respiratory disease and sources of pollutants in the neighbouring areas where the residents live. Nevertheless, the methodology employed in this study was designed to try as much as possible to account for these factors, especially in the statistical analysis. Thus, this chapter sets out the results of a survey to establish the respiratory status of workers and residents living in the vicinity of the dumpsite.

The methodology employed to achieve these objectives is described in detail in Chapter 3. This chapter contains the results of the statistical analysis and a graphical computation of the respiratory health survey carried out at Olusosun dumpsite and among the population living near the dumpsite (especially those living downwind of the dumpsite). These results are presented in comparison with the data collected at the control area, which was located in a residential area, 10.79 km from Olusosun dumpsite. The implications of these results are discussed in section 4.4 of this chapter. For the reasons stated above, is important to note that the results presented in this chapter are only indicative of the possible respiratory health effects from exposure to multiple aerosolised causative agents (i.e. not exclusive to bioaerosols) from Olusosun dumpsite. Data on the level of bioaerosol exposure and probable health implication have been presented in subsequent chapters of this thesis.

4.2 Socio-demographic characteristics of the study groups

A total of 149 people were interviewed as part of the cross-sectional respiratory health survey (RHS). Key socio-demographic data describing the sample are shown in Table 4-1. Further details are in Table A-2 (Appendix A).

4.2.1 Study group working on Olusosun dumpsite

Amongst the respondents working on the dumpsite, the majority were male (87%). Participants spent a total of 11 hours (mean) each day at the dumpsite and the median period of time that they had been at the location was 5 years. The median age of the participants was 30 years. 47% of the respondents had moved to the current location within the last 5 years, and 73.9% moved in the last 10 years (Figure 4-1). 41% reported that they were smokers, while 56% identified as non-smokers. In terms of employment, 61% were scavengers, with waste workers, businessmen, middlemen and food vendors making up the remaining 39%. The rate of smoking was highest amongst the scavengers (25%), with lower rates amongst waste workers (8%), middlemen (5%) and small-business owners (3%). The majority of those surveyed (46%) had only completed secondary education, while 32 %, 8% and 14% had completed primary, tertiary, and no formal education respectively. Regarding the use of PPE at work, 50% and 34% indicated to have used safety shoes and gloves respectively at least once in < 6 months, while 10% and 2.7% indicated to the use of respirators and goggles respectively in the same period.

4.2.2 Study group near Olusosun dumpsite

Described also in Table 4-1, are the key demographic characteristics of the sampled population located near Olusosun dumpsite. Male and female accounted for 69% and 31% of those surveyed respectively. The median age of those surveyed was 32 years, with a minimum at 18 and a maximum of 67 years. Over 50% had moved to the current location within the last 5 years, and 73.5% had in the last 10 years (Figure 4-1). The respondents were classified based on their occupation at the study location; Worker, Resident and Business Owner. The majority of the respondents identified as “Workers” (42.7%), while “Residents” and “Business owners” were 29.6% and 27.5% respectively. This was not surprising as Ojota is a part of the flourishing central business district in Lagos State (Oladapo *et al.*, 2012). Smokers accounted for 23% of the sampled population, of which 50% were “Workers”. The

longest daily hours (median) spent at the interview location was recorded by "Residents" (16 hours), followed by "Business Owners" (12 hours) and "Workers" (10 hours) (Appendix A-3). Moreover, on the kind of cooking method used by the respondents, 52% used primarily a kerosene stove, while 43%, 2.7% and 1.8% used a gas stove, electric stove and solid fuel respectively, irrespective of their occupation category.

Table 4-1 Key demographic indicators for participants' On-dumpsite, Close-to-dumpsite and Comparison group

Sample Characteristics	Category	On-dumpsite (N=149)	Close-to-dumpsite (N= 145)	Control (N= 120)
		n	n	n
Age	Median	30 years	32 years	30 years
Gender	Female	19 (13%)	45 (31%)	66 (55%)
	Male	130 (87%)	100 (69%)	54 (45%)
Level of Education	No formal	21 (14.1%)	5 (3.5%)	0
	Primary	47 (37.5%)	17 (11.7)	9 (7.5%)
	Secondary	68 (45.6%)	71 (48.9%)	56 (46.7%)
	Tertiary	13 (8.7%)	51 (35.2%)	55 (45.8%)
Hours at location per day	Mean (SD)	10.7 (2.6) hours	12 (3.3) hours	10.3 (1.6) hours
Years in current Location	1-5yrs	70 (47%)	79 (54.5%)	23 (19.3%)
	6-10yrs	40 (26.9%)	29 (20%)	51 (42.7%
	11-15yrs	17 (11.4%)	7 (4.8%)	18 (15%)
	16-20yrs	19 (12.8%)	16 (11%)	19 (15.8)
	21+	3 (2%)	14 (9.7%)	9 (7.5%)
	Median	5 years	5 years	8.5 years
Smoking Status	Smoker	61 (42.1%)	34 (23.5%)	21 (17.5%)
	Non-smoker	84 (57.9%)	108 (74.5%)	99 (82.5%)
Use of Respirators	< 6 months	15 (10%)	--	--
Safety gloves	< 6 months	50 (34%)	--	--
Safety googles	< 6 months	4 (2.7)	--	--
Safety Shoes	< 6 months	74 (50%)	--	--

Respiratory Health Symptoms and Conditions

Respiratory health symptoms and conditions on Olusosun dumpsite

4.2.3

4.2.3.1 Table 4-2 shows the prevalence of self-reported respiratory conditions from workers at Olusosun dumpsite in comparison to the data reported at the control site. Of the five categories of respiratory symptoms, reported cough was the most prevalent, followed by phlegm. In all, 26.2% of respondents at the dumpsite reported one or more symptoms of cough and phlegm and 8.7% reported three or more (cough, phlegm, asthma etc.).

Chronic cough was reported by 38% of the respondents on the dumpsite, while 34.6% and 2% reported symptoms of chronic phlegm and asthma respectively. When compared to the control, chronic symptoms at the dumpsite like chronic cough was higher by 31.3 percentage points, chronic phlegm by 28.8 percentage points and asthma by 1.5 percentage points. Chi-square (χ^2) test of association was conducted to establish if there was an association between the data obtained at the dumpsite and the control, the result returned showing no statistically significant association between reported respiratory symptoms from the two groups (see Table 4-2). Further statistical test was carried out using the chi-square goodness-of-fit test to determine if the differences in the prevalence of chronic symptoms reported at the dumpsite and the control were statistically significant. The result showed that reports of chronic cough ($\chi^2 = 237.7$, $p < 0.001$) and chronic phlegm ($\chi^2 = 461.5$, $p < 0.001$) were significantly higher among the respondents working on the dumpsite than at the control, while asthma ($\chi^2 = 1.77$, $p > 0.05$) showed the opposite, no significant difference (Table 4-2).

As shown in Figure 4-1 (A), smoking was associated with higher reported rates of chronic cough and chronic phlegm (21% and 15% amongst smokers compared to 15% and 13% for non-smokers). However, smokers reported lower rates of chronic wheezing and asthma. Figure 4-1 (B) shows reported symptoms among the non-smokers in relation to their duration (in years) at the study location. Non-smokers that have been located at the dumpsite between 1-5 years reported the rates of chronic cough (10%) and chronic phlegm (10%). Chronic phlegm was also noticed to be consistently reported to varying degree, by non-smokers, irrespective of their years of work at the dumpsite. Overall, the rate of reported chronic respiratory symptoms were observed to have reduced as the years of spent at the dumpsite increased.

Table 4-2 Respiratory health conditions and symptoms of sampled population on dumpsite

Sample Characteristics	Control (*N*= 120)		On-dumpsite (*N*=149)		χ^2
	n	Weighted % (95% CI)	*n*	Weighted % (95% CI)	
Cough (YES)	43	36 (27.3, 45)	75	50 (41.7, 58.2)	$p < 0.001$
Cough as much as 4 to 6 times a day	12	10 (5.3, 16.8)	68	45 (37.2, 53.6)	
Cough first thing in the morning	36	30 (21.9, 39)	60	40 (32.1, 48.3)	
Chronic Cough	8	6.7 (1.8, 12.4)	56	38 (33.3, 49.7)	$p < 0.001$
Phlegm (YES)	45	37.5 (28.8, 46.8)	73	48.6 (40.4, 56.9)	$p < 0.01$
Phlegm as much as twice a day, 4 or more days a week	8	6.7 (2.9, 12.7)	64	42 (34.6, 50.9)	
Phlegm first thing in the morning	39	32.5 (24.2, 41.7)	57	38 (30.2, 46.3)	
Chronic Phlegm	4	3.3 (0.9, 5.9)	52	31.3 (27, 42)	$p < 0.001$
Wheezing (YES)	12	10 (5.3, 16.8)	29	19.3 (13.3, 26.5)	$p < 0.001$
When cold	11	9.2 (4.7 15.8)	28	18.6 (12.7, 25.8)	
Occasionally in a dusty enviro	12	10 (5.3, 16.8)	29	19.3 (13.3, 26.5)	
Wheezing that causes short breath	6	5 (1.9, 10.6)	16	10.7 (6.2, 16.7)	
Chronic Wheezing	1	0.8	9	6	
Ever told have Bronchitis (YES)	4	3.3 (0.9, 9.31)	22	14.6 (9.4, 21.3)	
Bronchitis confirmed by a Doctor	7	5.8 (2.4, 11.7)	16	10.6 (6.2, 16.7)	$p < 0.05$
Ever told have Asthma (YES)	15	12.5 (7.2, 19.8)	36	24 (17.4, 31.6)	
Asthma confirmed by a Doctor	15	12.5 (7.2, 19.8)	21	14 (8.8, 20.6)	$p >0.05$
Asthma with shortness of breath	5	4.2 (1.3, 7.6)	3	2 (0.7, 3.5)	$p >0.05$
Acquired when you started working in current location	2	1.67 (0.2, 5.9)	3	2 (0.4, 5.7)	

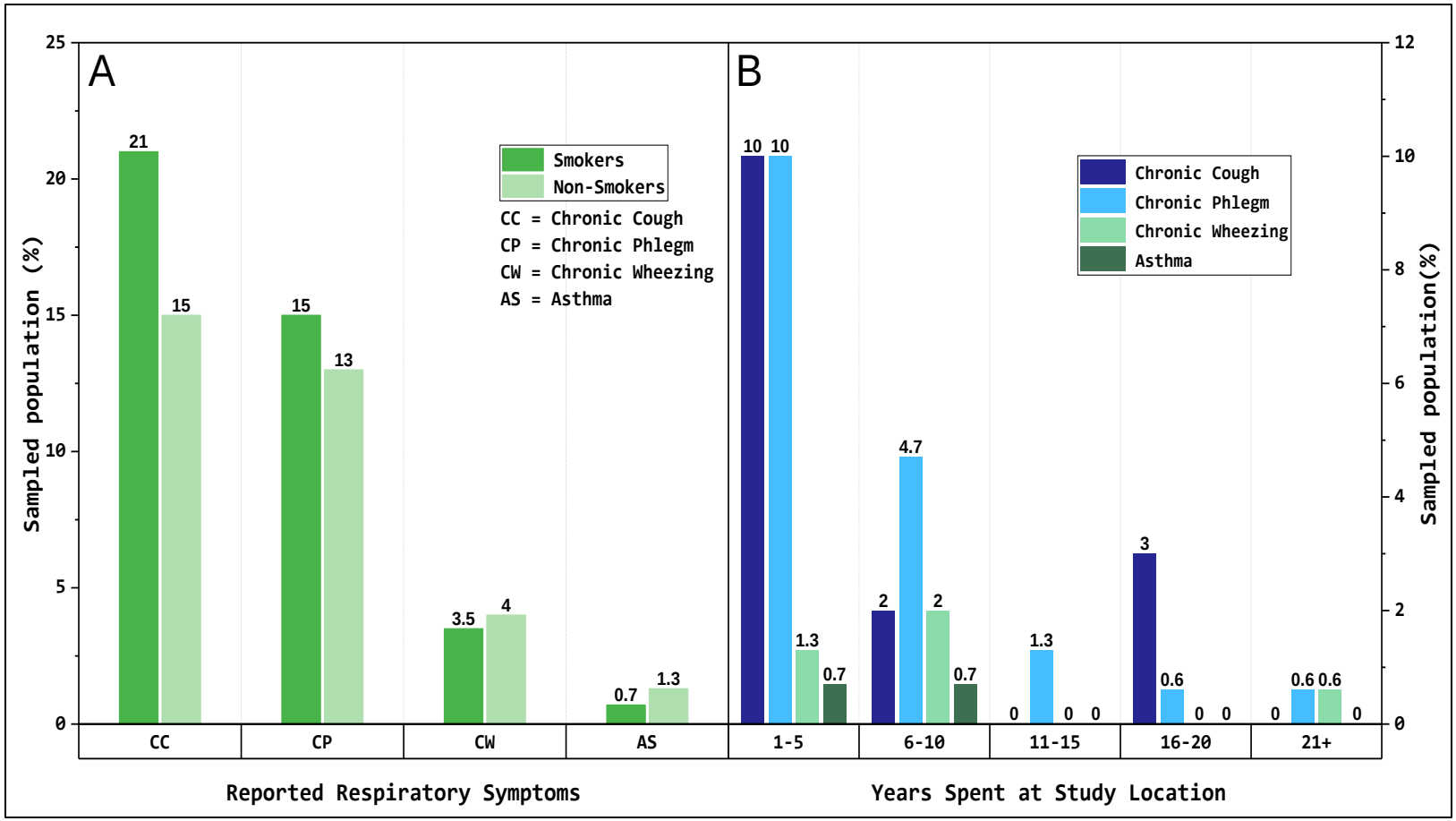

Figure 4-1 Prevalence of chronic respiratory symptoms among on-dumpsite population (A) Smokers and Non-Smokers; (B) Non-smokers and years of stay at current location

Odds of acquiring chronic respiratory symptoms by workers on Olusosun dumpsite

4.2.3.2 Table 4-3 shows a logistic regression to predict the odds of developing a chronic respiratory symptom within the studied populations. A logistic regression was conducted to assess if the use or non-use respirators by the workers (as part of their PPE) during their daily work at the dumpsite was associated with the prevalence of chronic cough, chronic phlegm and asthma. The result showed a weak association ($p>0.05$) between the 'Use of Respirators' and odds of developing chronic cough and asthma, but not enough statistical power to evaluate chronic phlegm. The result of the regression on chronic cough and asthma is however uncertain due to the very low rate of respirator use (10%, $n = 15$), and that those that had them, used them occasionally. A corresponding logistic regression was not carried out on the control (for comparison purposes) because the control was in a residential area, and the population do not need nose masks.

'Years spent at dumpsite' showed no statistically significant association with chronic cough, chronic phlegm and asthma for those located at the dumpsite > 5 years after the logistic regression ($p>0.05$). This result was similar to what was obtained at the control. It could be inferred from this result that the individuals located at the dumpsite or the control beyond 5 years, would have either had heightened immunity to cause of chronic symptoms, or were less willing to indicate they had the condition at the time of the interview.

Lastly, the logistic regression conducted to test the association between the independent variable 'daily exposure hours' and chronic cough, chronic phlegm and asthma, showed the workers daily duration at the dumpsite was only significantly associated with prevalence of chronic chough (OR 1.2, 95% CI 0.87-1.4, $p<0.05$). Of the two time-dependant independent variables, it was obvious the daily exposure hours the workers spent on the dumpsite was a better predictor of the odds of acquiring chronic symptoms such as chronic cough than the overall years they had been working on the dumpsite.

Table 4-3 Odds of acquiring Chronic Respiratory Health Symptoms from Olusosun dumpsite

Independent Variables	Category	Control (N= 120)			Olusosun On-dumpsite (N=149)		
		Chronic Cough	Chronic Phlegm	Asthma	Chronic Cough	Chronic Phlegm	Asthma
		OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]
Use of Respirators	--	--	--	--	0.8(0.19, 3.4)	--	0.5(0.15-6.6)[d]
Daily Exposure Hours	Hours	0.9 (0.7, 1.2)[d]	0.9 (0.7, 1.1)[c]	0.9 (0.7, 1.2)	1.2 (1, 1.4)*[,e]	1.02 (0.87, 1.2)	0.9 (0.8, 1.1)[d]
Years spent at dumpsite	1-5	Ref	Ref	Ref	Ref	Ref	Ref
	5-10	3.1 (0.4, 21.9) [d]	0.5 (0.2, 2.2) [d]	5.4 (0.6, 49.6)[e]	1.0(0.3,2.8)	1.2 (0.4,3.4)[d]	1.8(0.6,5.2)[e]
	11-15	6.2 (0.6, 60.6) [d]	1.2 (0.3, 5.6) [d]	1.6 (0.3, 9.8)[e]	0.6(1.9,2.6)	0.5(0.1,2.3)[d]	2.8(0.7,10.2)[e]
	16-20	0.3 (0.04, 1.8) [d]	1.2 (0.2, 6.7) [d]	-	1.4(0.3,6.6)	0.5(0.08,3.7)[d]	1.2(0.2,5.4)[e]
	21+	1.1 (0.3, 4.4)[d]	0.3 (0.1, 2.4) [d]	0.3 (0.04, 2.2)[e]	-	-	-

a = Adjusted for Age, Smoking status and Gender

***$p \leq 0.001$, **$p \leq 0.01$, *$p \leq 0.05$

c = $p \leq 0.001$ (Wald, χ^2), d = $p \leq 0$ .01 (Wald, χ^2), e = $p \leq 0.05$ (Wald, χ^2)

Respiratory health symptoms and conditions near Olusosun dumpsite

4.2.3.3 Table 4-4 shows the prevalence of self-reported and physician-diagnosed respiratory conditions and symptoms related to sample population located close to Olusosun dumpsite. Chi-square test of independence ran the independence of the datasets from respondents at the control and those close to the dumpsite, showed no statistical significant association (p>0.05) between the two datasets (see Table 4-4). In other words, the result obtained at the control was independent of possible co-variates from the dumpsite or location near the dumpsite. Table 4-2).

Of the five categories of respiratory symptoms, reported cough was the most prevalent (52%). In all, 27% of respondents near the dumpsite reported one or more symptoms of cough and phlegm and 4.1% reported three or more (cough, phlegm, asthma etc.). Chronic cough was reported by 31.7% of the respondents, while 28.9%, 18.5% and 8.2 % reported symptoms of chronic phlegm, chronic wheezing and asthma respectively. When the prevalence of chronic cough and chronic phlegm among respondent near the dumpsite was compared to the control, it was higher by 25 and 20.9 percentage points respectively. Moreover, analysing further to determine if these differences in the prevalence were of any statistical significance, a chi-square goodness-of-fit test was carried out. The result showed that prevalence of chronic cough (χ^2 = 145.3, p< 0.001) and chronic phlegm (χ^2 = 416.7, p< 0.001) and asthma (χ^2 = 24.3, p< 0.001) were significantly higher among the respondents located near the dumpsite than at the control (Table 4-4).

Chronic wheezing and asthma were 2.8 and 6.3 percentage points higher than that rates reported by workers on the dumpsite. As can be seen, the percentage differences in the rate of reported chronic conditions among the workers and the residents are marginal; suggesting that the resident's proximity to the source of pollutants causing the symptoms may play an important role in the likelihood of acquiring these conditions.

When the respondents were asked about how they felt overall about their chest symptoms for at least a week away from the interview location, 34.4% reported improvements while 43.5% on the other hand, reported they felt no difference in chest symptoms (see Appendix A-4).

Moving away from the dumpsite may have alleviated some of the respiratory symptoms experienced by the respondents, although the data is not conclusive.

Chronic respiratory conditions such as chronic cough, chronic wheezing and asthma had higher prevalence among non-smokers compared to smokers within the residents group (Figure 4-2 C). However, the difference was only significant among respondents reporting a chronic cough ($p < 0.001$), suggesting exposure to pollutants in neighbouring areas of the dumpsite that could also contribute to the prevalence of chronic cough. Among non-smokers, chronic cough was higher by 3.3 percentage points compared to those on the dumpsite, but was however lower by 10.7 percentage points for smokers than reported by the workers on the dumpsite. In a similar fashion, asthma among resident non-smokers and smokers were higher by 5.5 and 0.7 percentage points respectively, compared to the rates reported by the workers on the dumpsite. Figure 4-2 (D) further shows reported symptoms among the non-smokers in relation to how long the members have been at the study location. Respondents that have been located near the dumpsite between 1-5 years, reported a higher occurrence of chronic cough, chronic phlegm, chronic wheezing and Asthma. Non-smokers, irrespective of the years spent at the study location, consistently reported symptoms of chronic cough and chronic phlegm although to varying degree. Moreover, a similar trend was observed from the population on the dumpsite, but was limited to chronic phlegm.

Table 4-4 Respiratory health conditions and symptoms of sampled population close-to-dumpsite

Sample Characteristics	Control (*N*= 120)		Close-to-dumpsite (*N*= 145)		χ^2
	n	Weighted % (95% CI)	*n*	Weighted % (95% CI)	
Cough (YES)	43	36 (27.3, 45)	76	52.4 (43.9, 60.7)	$p< 0.001$
Cough as much as 4 to 6 times a day	12	10 (5.3, 16.8)	66	45.5 (37.2, 53.9)	
Cough first thing in the morning	36	30 (21.9, 39)	69	47.9 (39.5, 56.3)	
Chronic Cough	8	6.7 (1.8, 12.4)	46	31.7 (24.2, 39.9)	$p < 0.001$
Phlegm (YES)	45	37.5 (28.8, 46.8)	55	37.9 (30.0, 46.3)	$p > 0.05$
Phlegm as much as twice a day, 4 or more days a week	8	6.7 (2.9, 12.7)	42	28.9 (21.7, 37.1)	
Phlegm first thing in the morning	39	32.5 (24.2, 41.7)	43	29.9 (22.3, 37.8)	
Chronic Phlegm	3	2.5 (0.4, 5.9)	42	28.9 (21.7, 37)	$p < 0.001$
	12	10 (5.3, 16.8)	26	17.9 (12.1, 25.2)	$p < 0.001$
Wheezing (YES)					
When cold	11	9.2 (4.7 15.8)	22	15.7 (9.7, 22)	
Occasionally in a dusty enviro	12	10 (5.3, 16.8)	26	17.9 (12, 25.1)	
Wheezing that causes short breath	6	5 (1.9, 10.6)	18	12.4 (7.5, 18.9)	
	4	3.3 (0.9, 9.31)	9	6.21 (2.8, 11.4)	
Ever told have Bronchitis (YES)					
Bronchitis confirmed by a Doctor	7	5.8 (2.4, 11.7)	7	4.8 (1.9, 9.69)	$p > 0.05$
	15	12.5 (7.2, 19.8)	14	9.6 (5.3, 15.6)	
Ever told have Asthma (YES)					
Asthma confirmed by a Doctor	15	12.5 (7.2, 19.8)	12	8.2 (4.3, 14)	$p > 0.05$
Asthma with shortness of breath	5	4.2 (1.3, 7.6)	18	12.4 (9.3,14.6)	$p < 0.001$
Acquired when you started working in current location	2	1.67 (0.2, 5.9)	0	-	-
	3	2.5 (0.52, 7.1)	72	49.6 (41.2, 58.1)	$p < 0.001$
Sneezing/Runny Nose (YES)					
Nose problem with itchy eyes	3	2.5 (0.52, 7.1)	65	44.8 (36.5, 53.3)	$p < 0.001$

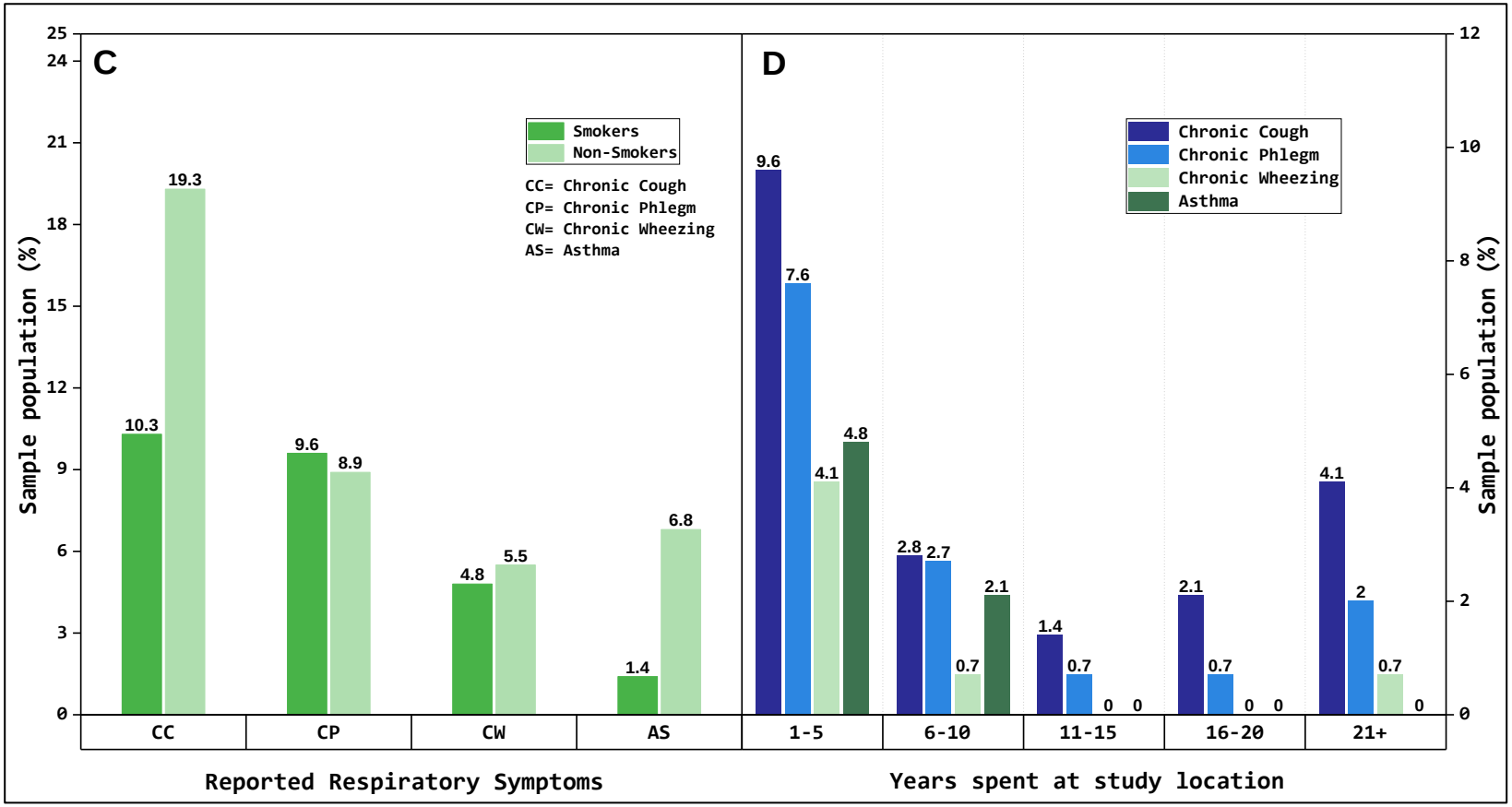

Figure 4-2 Prevalence of chronic respiratory symptoms among Close-to-dumpsite population (C) Smokers and Non-Smokers; (D) Non-smokers and years of stay at current location

Odds of acquiring Chronic Respiratory Symptoms by Residents located close to Olusosun Dumpsite

4.2.3.4 Table 4-3 describes the results of the logistic regression carried out on the independent variables to predict the odds of acquiring any of the chronic respiratory conditions by residents located near the dumpsite. The result showed that the occasional interaction of the residents with the dumpsite was significantly associated with chronic cough, chronic phlegm and asthma (Table 4-3). Thus implying that the odds of acquiring any of the three chronic conditions will increase as the frequency of interactions with the dumpsite increases. The second variable tested was the 'daily exposure hours' which showed strong association only with chronic cough ($p<0.001$) and not with chronic phlegm and asthma. Meaning the odds of acquiring chronic cough will increase as the individual spends longer time being exposed to the disease causing agents. The third variable 'Years at current Location' was only statistically associated with chronic cough for individual that had been located between 1 to 10 years ($p<0.01$). Chronic phlegm and asthma did not fit the test model and not reported. The control however, showed no significant association between chronic symptoms tested years the respondents spent at the control.

Table 4-5 Odds of acquiring Chronic Respiratory Health Symptoms residents close to Olusosun dumpsite

Independent Variables	Category	Comparison (N= 120)			Olusosun Close-to-site (N= 145)		
		Chronic Cough	Chronic Phlegm	Asthma	Chronic Cough	Chronic Phlegm	Asthma
		OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]
Occasional Interaction with Dumpsite	--	0.4 (0.03, 7.1) [d]	0.9 (0.5, 18.6)[e]	--	3.8 (1.6,8.4)***[,c]	4 (1.1,14.4)*[,c]	6.8(1.3,33)**[,d]
Daily Exposure Hours	Hours				1.2 (1.1,1.3)***[,c]	0.98 (0.8, 1.1)[c]	1 (0.9, 1.2)
Years in current Location	1-5	Ref	Ref	Ref	Ref	Ref	Ref
	5-10	3.1 (0.4, 21.9) [d]	0.5 (0.2, 2.2) [d]	5.4 (0.6, 49.6)[e]	4.2(1.4,12.4)**[,c]	--	--
	11-15	6.2 (0.6, 60.6) [d]	1.2 (0.3, 5.6) [d]	1.6 (0.3, 9.8)[e]	2.3(0.36,15.6)[c]	--	--
	16-20	0.3 (0.04, 1.8) [d]	1.2 (0.2, 6.7) [d]	--	0.3(0.59,1.82)[c]	--	--
	21+	1.1 (0.3, 4.4)[d]	0.3 (0.1, 2.4) [d]	0.3 (0.04, 2.2)[e]	1.9(0.41,9.0)[c]	--	--

a= Adjusted for Age, Smoking status and Gender

*** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$

c = $p \leq 0.001$ (Wald, χ^2), d = $p \leq 0.01$ (Wald, χ^2), e = $p \leq 0.05$ (Wald, χ^2)

Discussion of findings

Prevalence of respiratory symptoms among workers on the dumpsite

4.3

4.3.1

The high prevalence of respiratory symptoms among workers on Olusosun dumpsite is not unexpected, as previous researches have also reported similar respiratory symptoms among waste workers, scavengers and landfill workers alike (Ray *et al.,* 2004; Darboe *et al.,* 2015; Garrido *et al.,* 2015). Ray *et al.,* (2009) reported increased alveolar macrophages, neutrophils, eosinophils and lymphocytes in the sputum samples of examined female rag pickers (female scavengers) working on a waste dumpsite in Kolkata, eastern India. The research suggests significantly higher cases of airway inflammation when compared to the controls in their study. Although the study did not report the possible exposure concentration, the observed biomarkers from the body of the female rag pickers were evidence indicating heightened immune system, which would suggest that they have been exposed to bacteria, endotoxins and viruses.

Chronic respiratory symptoms are most of the time, associated with a smoking lifestyle (Abramson *et al.,* 2002; Frank *et al.,* 2006; Garrido *et al.,* 2015), an observation that is equally depicted in this study among respondents working on the dumpsite (Figure 4-1). Moreover, since the differences in percentage points in the prevalence of reported respiratory symptoms between the smokers and the non-smokers were in this study were marginal (chronic cough-6%, chronic phlegm-2%, and asthma-0.6%) the results suggests that the causes of the reported respiratory symptoms cannot be attributed solely to lifestyle. Additionally, there is growing evidence showing that the prevalence of respiratory diseases among workers in occupational settings (e.g. occupational asthma) may have been caused or worsen from exposure to causative agents at workplaces and these evidences are well documented (Balmes *et al.,* 2003; Matheson *et al.,* 2005; Henneberger *et al.,* 2011).

Unfortunately in this study, the effect of the use of reusable or disposable respirators (part of a PPE kit) on the respiratory health of the workers on the dumpsite could not be determined because the sampled data did not have enough statistical power to do so. However, as described in Appendix A-2, the responses from scavengers and waste workers reveal that they would rather own safety shoes and gloves than respirators and safety googles as they were more easily obtained. Thus, suggesting the workers are generally aware of the benefits

from the use of PPE, but their inability to access respirators either due to cost or supply may be contributing to the high rate of non-use of respirators (i.e. 90%) by the respondents. Scavengers are ranked economically low in the society because their income barely carters for their basic needs, thus prioritizing earnings from working in a high-risk environment over safety is not surprising (KENAO 2007; Bleck and Wettberg 2012; WGEA 2016). It must however be noted that studies assessing the low compliance to the use of respiratory protective equipment by workers in other 'better-regulated' industrial sectors such as composting, material recovery facilities etc. have been previously documented (Salazar *et al.*, 2001; Bryce *et al.*, 2008; Tam and Fung 2008; Guseva Canu *et al.*, 2013; Robertsen *et al.*, 2018). Hence, beyond the reasons stated earlier, the non-use of the respiratory protective equipment by some of the workers in Olusosun dumpsite is common in this sector. However, it thus provide an opportunity for implementation of interventions that can increase PPE use in general and to regulate workers exposure in such environments.

Another likely reason for this observation is the inherent bias of 'healthy worker effect' (HWE) in the design of cross-sectional studies as it could result in an underestimation of the studied respiratory symptoms (MEIJERS *et al.*, 1989; Radon *et al.*, 2002). Because this study only included active participants at the dumpsite, most of which had been working there for a short time since "first time of hire", in this case 1-5 years (i.e. 47%, see Table 4.1), hence, HWE biases maybe strong in this study (Le Moual *et al.*, 2008). Prior to this study, there was no morbidity record for the workers thereby making it difficult to compare the number of those who would have left the dumpsite due to ill health from exposure, with those currently working at the dumpsite within the same period. In other words, the workers would have appeared healthy at the time of hire (employer had no record of pre-existing conditions) and during their work at the dumpsite. Some might have left the dumpsite without any record of the health problems they acquired while working at the dumpsite. All of these factors together may underestimate the poor health outcomes reported in this study. Moreover, gender has also shown to play a role in HWE bias outcomes, as "healthy hire effect" (a component of HWE) is stronger for males than females (Lea *et al.*, 1999). Notably in this study, the ratio of female to male respondents was 1:7, a scenario that can favour a stronger effect of HWE bias in the outcome of this study.

The result also showed that no respiratory health outcomes were associated with 'Years in current location' greater than 5 years (see Table 4-3). In their study of the respiratory health of brick kiln workers, Shaikh *et al.*, (2012) observed a similar result, but in this case, the chronic respiratory outcomes were not significantly associated with workplace exposure of over 10 years. In this study, the median years of work at Olusosun dumpsite was 5 years, representing 46% of the participants (See Table 4-1). By implication, the majority of the participants who had reported to suffer chronic respiratory symptoms would have contracted them within the first 5 years of working at Olusosun open dumpsite. In a different report of a 5-year follow-up study of compost workers, Bünger *et al.*, (2007) observed a significant increase in the number of workers with chronic bronchitis (RR 1.41; 95% CI 1.3-1.6) over the study period. Van Kampen *et al.*, (2016b) also observed an increased relative risk for cough (RR 1.28; 95% CI 1.2-1.5) and phlegm (RR 1.32; 95% CI 1.2-1.5) among compost workers working for at least 5 years at the composting facility irrespective how long their years of work was. They however, reported COPD as having no significant association with longer years of work. Matheson *et al.*, (2005) in a different study reported an increase in risk of COPD among adults in Melbourne Australia exposed to biological dust (OR 2.70, 95% CI 1.39-5.23) than to mineral dust (OR 1.13, 95% CI 0.57- 2.27) or gases (OR 1.63, 95% CI 0.83-3.22). They however observed no increase in risk of COPD with duration of exposure to biological dust above 12 years. The reason for this observation was not clear in the report, as COPD usually develops in subjects with long-term exposure to causative agents (Blanc and Toren 2007). Overall, the one thing these report have in common is that the reported respiratory diseases were associated with exposure some form of organic dust or biological aerosols.

The findings in this study suggest that the duration of exposure to causative agents is an important factor in assessing the odds of developing chronic respiratory symptoms, a result comparable to that reported by Balmes *et al.*, (2003). They argued that, for an accurate estimation of airway disease burden on a population, exposure information on the duration, rate, level (concentration/doses) and type of exposure were necessary. In this study, the odds of developing chronic cough was significantly associated with the daily exposure duration of workers on the dumpsite (OR 1.2; 95% CI 1-1.4, $p< 0.05$), see Table 4-3. The mean (SD) exposure time on the dumpsite was 10.7 (2.6) hours, which is higher than the expected 8-

hour TWA within an environment with high respirable dust (HSE 2018). Thus, longer exposure will have workers coming down with chronic cough sooner. There is a need for strict adherence to the recommended work exposure limits for environments with high exposure such as Olusosun dumpsite. Such administrative intervention has the potential to reduce the odds of acquiring chronic cough.

Prevalence of respiratory symptoms among residents close to dumpsite

4.3.2 The respiratory health data collected in the area downwind of the dumpsite was considered in this study to be a reflection of the highest exposure to dumpsite emissions by residents located close to the dumpsite. The data confirms that there are chronic respiratory symptoms and conditions present among the study population. The prevalence of chronic cough for instance, was significantly higher than the control ($\chi^2 = 145.3$, $p < 0.001$) and the average across Nigeria ($\chi^2 = 125.9$, $p < 0.001$), which is 10% (Song *et al.*, 2015). It was also observed that, although the prevalence of asthma among respondents near the dumpsite were significantly higher than the control ($\chi^2 = 24.3$, $p < 0.001$), there were no significant differences observed ($\chi^2 = 0.776$, $p > 0.05$) when compared to the average across Nigeria (10.2%) (Musa and Aliyu 2014). This finding is important because it support the first and second hypothesis in this study, that Olusosun dumpsite was a major source of airborne pollutants in its vicinity and the pollutants that could be responsible for the high rates of respiratory symptoms by both workers on the dumpsite and resident living near the dumpsite. It is difficult establish the degree to which the exposure to pollutants from Olusosun dumpsites may have contributed to the prevalence of respiratory diseases, however, these results provide substantial evidence that, for the two study groups (i.e. workers on the dumpsite and residents near the dumpsite) to have suffered similar respiratory ailments with prevalence that were significantly higher than the control, must have been exposed to varying degree, to similar kinds of aerosolised pollutants. This finding agrees with evidence established in the existing literature that residents near waste treatment facilities, especially those using an open air treatment methodology such as composting, landfilling and open dumping, are likely to suffer increased respiratory ailments and sometimes cancer, than those who do not reside close (Herr *et al.*, 2003; Mattiello *et al.*, 2013; Ancona *et al.*, 2015; Mataloni *et al.*, 2016). Mataloni *et al.*, (2016) and Blanes-Vidal *et al.*, (2014) for instance, established an association between living near a landfill and biodegradable waste site with

reported respiratory diseases and higher rates of hospitalization of the residents. Mattiello *et al.,* (2013) also concluded in a systematic review that the risk of respiratory disease was one of the compelling and consistently reported evidence of health effects of living close to landfills.

Three of the four chronic symptoms assessed in this study had higher prevalence among those who were non-smokers than smokers, even though they spend on average, the same amount of hours each day at the study location. Moreover, there is growing evidence that chronic cough and phlegm are risk factors for COPD and that reported cases of COPD among non-smokers are on the rise in developing countries (de Marco *et al.,* 2007; Salvi and Barnes 2009). In a similar manner, reported cases of asthma, although higher among non-smokers by 5.4 percentage points, the difference was not statistically significant compared to smokers. Moreover, the high prevalence of reported asthma among non-smoking residents near the dumpsite compared to those working on the dumpsite, rules out the exposure to emissions from Olusosun dumpsite as the sole cause of asthma (Eisner *et al.,* 2010). Furthermore, 42.7% and 27.5% of the sampled population identified as workers and business owners respectively, and by implication, resides elsewhere outside the study area. Hence, presenting the possibility of external exposure to other cofounding factors not considered in this study.

Some of the participants indicated they regularly visited the dumpsite either to meet with friends working on the dumpsite or to carry out legitimate business transactions on the dumpsite. This singular factor increased the odds of acquiring chronic cough, chronic phlegm and asthma by 3.8 (95 % CI 1.6, 8.4, $p< 0.001$), 4 (95% CI 1.1, 14.4, $p<0.05$) and 6.8 (95% CI 1.3, 33, $p< 0.01$) respectively. By implication, they would have increased the odds of acquiring these respiratory diseases or aggravated their pre-existing respiratory conditions by interacting with the activities at the dumpsite (regardless of the frequency of these interactions) than they would at the control (Table 4-5). The result also suggests that the residents would have moved from areas with lower levels of air pollution (areas near the dumpsite) to that dumpsite with higher levels air pollution, thus resulting in the higher odds ratios recorded in this study. This further supports the hypothesis that Olusosun dumpsite is a major source of airborne pollutants in its vicinity.

There could be cases where other sources of pollutants found in the surrounding areas where the residents are located, that could contribute to the prevalence of respiratory diseases. In this study for instance, we did not consider other outdoor potential sources of emissions such as vehicular emissions and other co-morbidities that might cause respiratory diseases, which would result in an over estimation of symptoms attributed to a single source. However, in adjusting for cofounders like gender, age, smoking status and cooking method (indoor exposures), has provided to a great degree a substantive evidence that have not been undermined by the influence of other cofounders in the study area. In a contrary report by Kret *et al.,* (2018), the differences in the prevalence of asthma and COPD between the residents within a 3.2 km radius of Bridgeton landfill perimeter and the control group was not statistically significant, even after detectable odour levels were recorded a year before. However the authors not only quickly acknowledged possible misclassification by defining exposure as living within 3.2-km radius of the landfill, but also using a household sampling method rather than individual-based randomised sampling. However, in this study, classification of the study area was within 50 – 400 m downwind of the dumpsites boundary, and individual based randomised sampling was employed.

Although the scope of this study did not include infants, children and young adults less than 18 years of age, there is growing evidence suggesting that chronic respiratory conditions in children and adults may be likely linked to ambient environmental exposure during foetal development and post-natal life (Soto-Martinez and Sly 2010; Ramsey *et al.,* 2014). Moreover, early life exposure predisposes the developing foetus, infant, child, adolescent and adult to a variety of respiratory conditions including COPD later in life (Maisonet *et al.,* 2004; Harding and Maritz 2012; Stocks and Sonnappa 2013; Goldizen *et al.,* 2016). In view of the above, one could attribute one of the likely causes of the high prevalence of chronic respiratory symptoms and conditions among adult residents close to the Olusosun dumpsite to their predisposition to lung diseases from early life exposure. There is a likelihood that the infants that are born and raised within the study area will have the predisposition to lung and respiratory diseases.

4.4 Research Limitations

In undertaking the health survey, there were some limitations, which were largely due to the limited resources available for the study. Firstly, the findings of this study were largely based on a subjective inquiry without a complementary objective clinical measure. Spirometry and haematological profiling could not be carried out to assess the lung functions and detect inhaled particulate matter in the blood. Moreover, since there was no record of morbidity resulting from occupational exposure on the dumpsite, this would raise some uncertainty in establishing the exact diagnosis of the disease.

The second limitation was that only the areas downwind of the dumpsite (selection based on the predominant wind direction across the dumpsite) was selected for the sample group near the dumpsite. This may present a bias in the data, as there was regular swirling in the local wind during the survey activity, hence a possible exclusion of some exposed groups may have occurred.

Lastly, the study is not generalizable to all parts of the city of Lagos or the Lagos state as a whole as the statistical power for this study was calculated based on the population size of the workers on Olusosun dumpsite alone.

In spite of the stated limitations, the findings from this study can be relatable to settings with similar characteristics, such as landfills and dumpsites. This is because, the waste composition and the activities at these locations are similar, thus the composition of the contaminated air and consequently the type of respiratory symptoms reported by workers.

4.5 Chapter Summary

Cough was the most prevalent respiratory symptom reported by the workers on the dumpsite and the residents near the dumpsite. The prevalence of chronic cough and chronic phlegm were significantly higher in both study groups, compared to the control, while the rate of asthma was only significantly higher among residents residing close to the dumpsite. When the prevalence of chronic cough and asthma from the two study groups were compared to the national prevalence (in Nigeria), only chronic cough showed a significantly higher rate of reported cases.

The study also showed that the duration of daily exposure of the workers and residents to aerosolised pollutants from the dumpsite were significantly associated only with chronic cough (OR 1.2, 95% CI 1-1.4), but not with asthma and chronic phlegm. Thus, potentially the longer the exposure to aerosolised pollutants the sooner they will succumb to a chronic cough.

Smoking was associated with higher rates of chronic cough and chronic phlegm among the workers on the dumpsite. Conversely, higher rates of chronic cough and chronic phlegm were associated with non-smokers who were residents, suggesting that there may be other possible pollutant sources in the neighboring area responsible for these high rates.

For every instance, a resident interacted or visited Olusosun dumpsite, the odds of acquiring chronic cough, chronic phlegm and asthma increased by 3.8, 4 and 6.8 respectively. The result suggests that these residents were exposed to pollutants at levels higher than where they came from, levels that could exacerbate their exiting respiratory conditions.

The result of this research agrees with the null hypothesis, that Olusosun dumpsite is a significant source of aerosolised pollutants in its vicinity; and that there is a prevalence of respiratory health disease among the workers and residents located near Olusosun dumpsite.

Bioaerosols Concentration at Olusosun Dumpsite

Chapter 5: Introduction

5.1 This chapter presents the results of the statistical and graphical analysis of the concentrations of bioaerosols measured in the ambient air and generated from the activities being undertaken at Olusosun dumpsite. Hitherto, a qualitative respiratory health survey of the workers on the dumpsite and residents located near the dumpsite was carried out to determine the prevalence of respiratory symptoms in the sample population, the results of which were presented in Chapter 4.

Ambient air sampling with the use of a 6-stage Anderson sampler was carried out at four locations across the dumpsite for 13 weeks. Activity-related sampling was carried out during scavenging, waste sorting and dumpsite supervision by scavengers and waste workers. Scavenging was predominant at the active operational area, waste sorting was carried out partly near the active operational area and dormant area, while site monitoring activities was mostly carried out by the waste workers moving from one end of the dumpsite checking to ensure all the activities at the dumpsite ran smoothly. Details of the methodology can be found in sections 3.5 and 3.6 (Chapter 3) of this thesis. The results are presented as mean concentration of duplicate samples of total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi and are compared to the concentrations measured at the control site.

The statistical analysis presented in the sections below are:

i. The differences in the ambient concentration of bioaerosols across the four sampling locations around the Olusosun dumpsites (Section 5.2.1)
ii. Comparison between bioaerosol concentrations within the Olusosun dumpsite and at the control site (Section 5.2.2)
iii. Impact of prevailing environmental conditions within the Olusosun dumpsite on the bioaerosol concentrations (Section 5.2.3)
iv. Impact of different activities on bioaerosol exposure (Section 5.2.4)

Each aspect of the results will be discussed in the context of the acceptable exposure limits as stipulated in the UK Environment Agency bioaerosol monitoring guidelines. This has been done due to the fact that Nigeria does not have a regulatory framework for

most aerosolised pollutants, including bioaerosols. Further discussion regarding the particle size distribution of the bioaerosols measured at the dumpsite will be presented in chapter 6 of this thesis.

Results

5.2 Bioaerosol concentrations at different sampling locations around Olusosun dumpsite

5.2.1 Total bacteria

5.2.1.1

Table 5-1 shows the descriptive statistics of the concentration of bioaerosols at all four locations of the dumpsite calculated from the data obtained from the 13 sampling visits. The concentration of total bacteria was highest at the active operational area, recording concentrations up to 2.99×10^3 cfu m^{-3} on sample visit day 4 (22/05/17), while the lowest was at the boundary (194.7 cfu m^{-3}) on sample visit day 8 (23/06/17) (see Figure 5-4 and Table B-3, 4).

Further evaluation of the dataset to determine if the differences in mean concentrations of total bacteria across the four sampling locations were significant, was done using a one-way ANOVA. There were no outliers as assessed by the boxplot; data was normally distributed as assessed by Kolmogorov-Smirnov test ($p > 0.05$); and there was no homogeneity of variance as assessed by Levene's test of homogeneity of variance ($p > 0.05$). The one-way ANOVA showed no statistical significant difference ($F = 1.144$, $p > 0.05$) in the mean concentration of total bacteria between the four sampling locations at the dumpsite. This implies that the total bacteria concentration measured at the four sampling locations were similar regardless of the downwind distance of the sampling location from the active operational area.

Assessing the ambient concentration against the Environment Agency (EA) emission limits of 10^3 cfu m^{-3}, the total bacteria concentration at the dormant area exceeded the most frequently although the concentrations were only marginally above the EA limit on most occasions. The measured concentration at the dormant area exceeded the EA emission limits on 12 sampling occasions out of the 13 (Figure 5-4 C). The concentrations at the entrance exceeded the EA limits on 10 sampling occasions out of 13 (Figure 5-4 B). At the active operational area, the concentration had exceeded the EA limits on 9 sampling occasions out of 13 (Figure 5-4 D), while the concentrations boundary were

either lower or very close to the EA limit, except for visit 4, which recorded values higher than the expected limits (Figure 5-4 D).

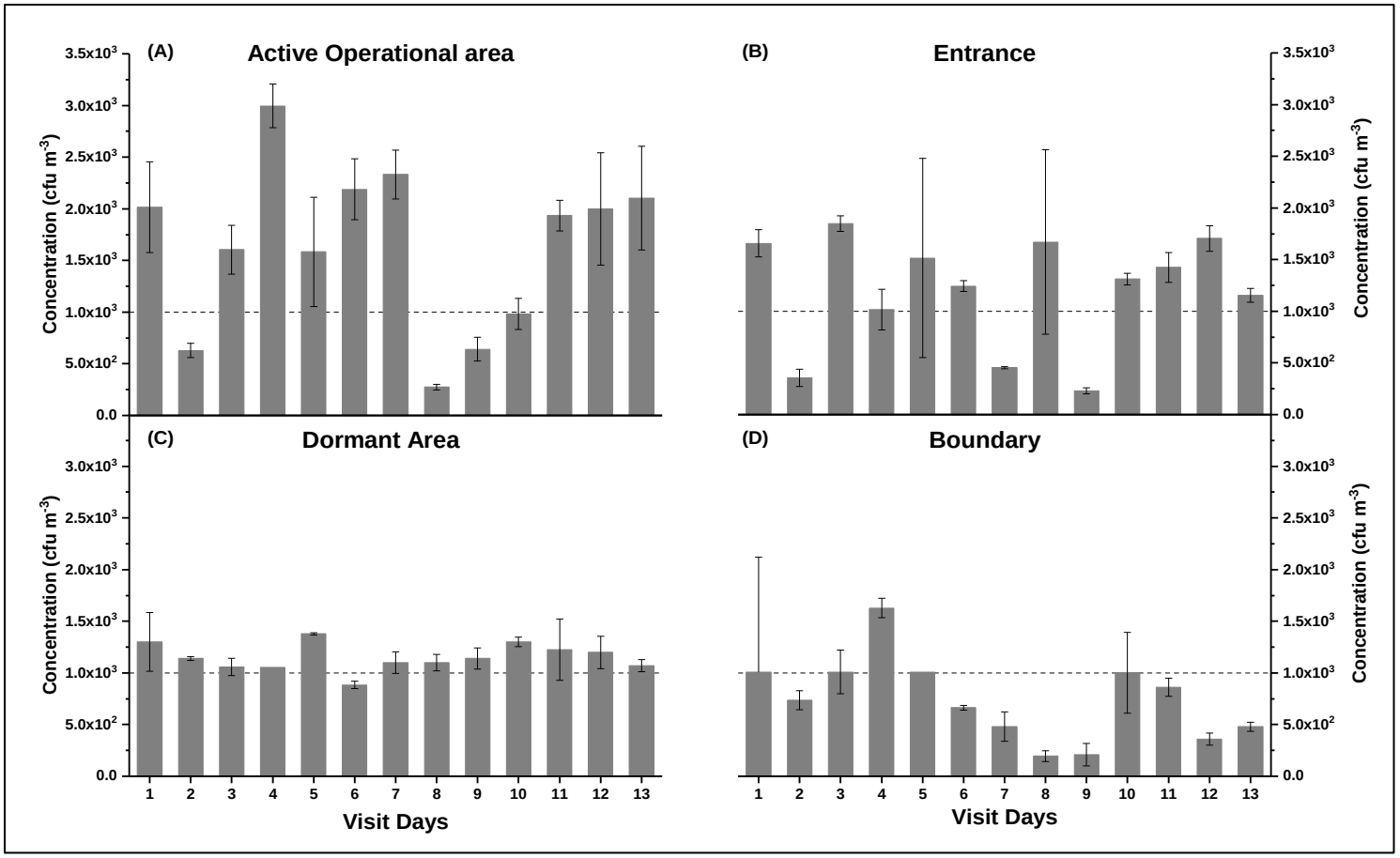

Figure 5-1: Mean concentration of Total mesophilic bacteria in ambient air of dumpsite, showing EA emission limit (A) Active area (B) Entrance (C) Dormant Area (D) Boundary

Gram-negative Bacteria

5.2.1.2

Table 5-1 shows the descriptive statistics of the gram-negative bacteria concentration measured at all four locations of the dumpsite during the 13 sampling visits. The concentration of gram-negative bacteria at the active operational area was highest overall, recording concentrations up to 2.45×10^3 cfu m^{-3}. However, there was an instant on sample visit day 4 (22/05/17) where the gram-negative bacteria concentration at the dormant area was in excess of 2.5×10^3 cfu m^{-3} (Figure 5-5 C and Table B-3, 4). The lowest concentration of gram-negative bacteria was recorded at the boundary (310.8 cfu m^{-3}) on sample visit day 6 (23/06/17) (see Figure 5-5 D and Table B-3, 4). The median concentration of gram-negative bacteria at the entrance was similar to that recorded at the active operational area (Table 5-1). Although located 325 m (eastward) of the tipping face of the dumpsite, the entrance recorded the second highest concentration of bioaerosols overall after the active operational area. This result was rather a surprise; as concentrations like this would most likely be recorded at locations downwind of the operational area.

Using a one-way ANOVA to examine if the differences in the means of the ambient concentration of gram-negative bacteria between the sampling locations were statistically significant, the analysis showed no statistically significant difference ($F= 2.463$, $p > 0.05$). This implies that as with the total bacteria, the concentration of gram-negative bacteria measured at the four sampling locations were similar and may not have been affected by dilution or dry deposition as the particles travelled from the active operational area downwind.

Assessing the ambient concentration against the EA emission limits of 3×10^2 cfu m^{-3}, the concentration from all four sampling locations exceeded the expected limits during the 13 sampling visits by 3-8 folds in most cases (see Figure 5-5 A-D).

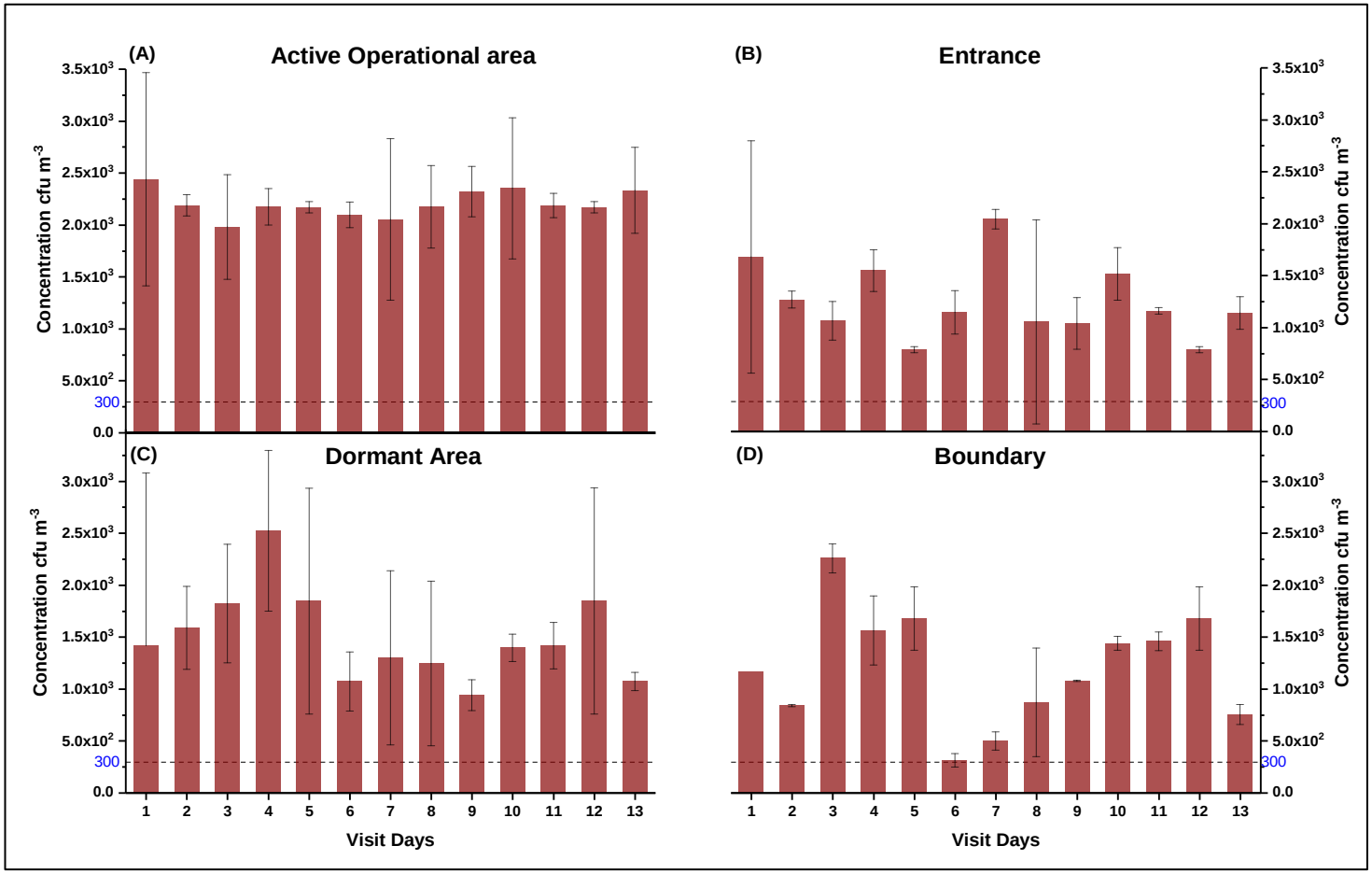

Figure 5-2: Mean concentration of Gram-negative bacteria in ambient air of dumpsite, showing EA emission limit. (A) Active area (B) Entrance (C) Dormant area (D) Boundary

Aspergillus fumigatus

5.2.1.3 Table 5-1 shows the descriptive statistics of the concentration of *Aspergillus fumigatus* measured at all four locations of the dumpsite during the 13 sampling visits. The concentration of *Aspergillus fumigatus* was highest at the active operational area, recording concentrations up to 479 cfu m^{-3} on sample visit day 2 (05/05/17), while the lowest was recorded at the entrance (5.89 cfu m^{-3}) on the same day (see Figure 5-6 and Table B-3, 4).

Analyzing the dataset for *Aspergillus fumigatus*, Kruskal-Wallis test (unlike ANOVA used for bacteria) was conducted to evaluate the differences in means of the concentration between the four sampling points in order to establish a statistical significance because the dataset was not normally distributed (assessed by Kolmogorov-Smirnov test, $p < 0.05$). The result showed that the concentrations of *Aspergillus fumigatus* were not similar for all sampling locations, as assessed by visual inspection of the boxplot. Furthermore, the mean concentration of *Aspergillus fumigatus* was significantly different between the sampling locations, [χ^2 (3) =14.725, $p = 0.002$]. Further analysis using Tukey's post hoc test revealed that, the statistically significant difference lay between the concentration at the active and dormant area ($p = 0.002$), the boundary ($p = 0.026$) and entrance ($p = 0.003$). By implication, the mean concentration of *Aspergillus fumigatus* at the entrance, dormant area and boundary were significantly lower than what was measured at the active operational area of the dumpsite.

Assessing the ambient concentration against the EA emission limits of 5×10^2 cfu m^{-3}, the ambient concentration of *Aspergillus fumigatus* was below expected limits for all sampling location (see Figure 5-6).

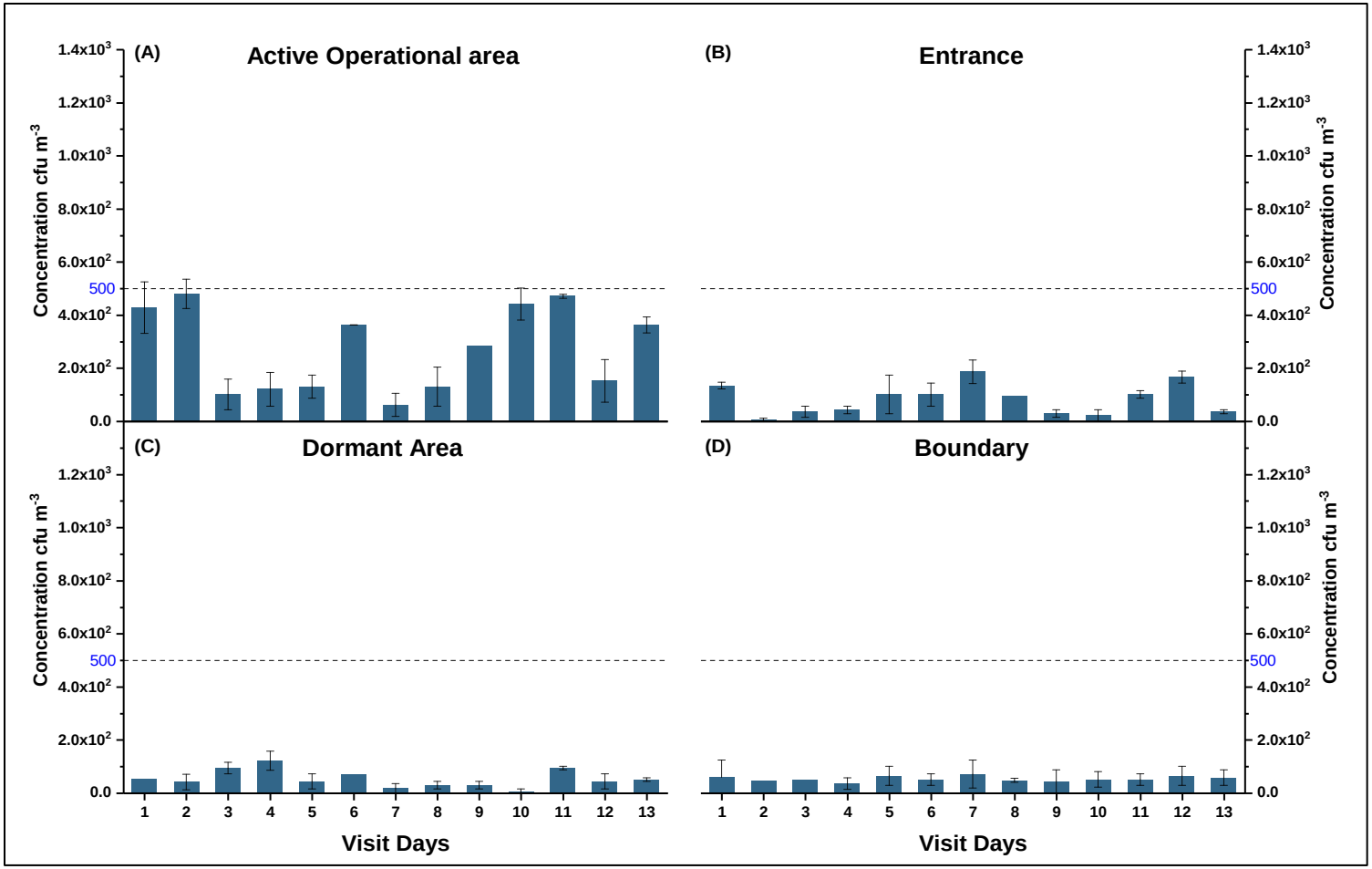

Figure 5-3: Mean concentration of Aspergillus fumigatus in ambient air of Olusosun dumpsite showing EA emission limit. (A) Active area (B) Entrance (C) Dormant area (D) Boundary

5.1.1.1 Total Fungi

Presented in Table 5-1 are the descriptive statistics of the ambient concentration of total fungi for the four sampling locations over the 13 sampling visits to Olusosun dumpsite. In general, the active operational area recorded the highest ambient concentration of total fungi, as high as 1.1×10^3 cfu m^{-3} on visit day 13. The entrance and dormant area on the other hand recorded the lowest concentration, with values as low as 189 cfu m^{-3} on sample visit day 2 (05/05/2017) (see Figure 5-7 and Table B-3, 4).

Because the data was not normally distributed (Kolmogorov-Smirnov test, $p < 0.05$), a Kruskal-Wallis test was used to assess the difference in means of the concentration between the four sampling points.The result showed that the total fungi concentrations were similar regardless of location and the differences between the four sampling locations were not statistically significant [χ^2 (3) = 5.799, p = 0.122].

The total fungi concentration at Olusosun were within the EA emission limits of 10^3 cfu m^{-3}, except for visit day 13 (04/08/2017) at the active operational area, which recorded values higher by 117 cfu m^{-3} (Figure 5-7). *Aspergillus fumigatus* on the other hand recorded a concentration 2-log lower compared to total bacteria (See Table 5-1).

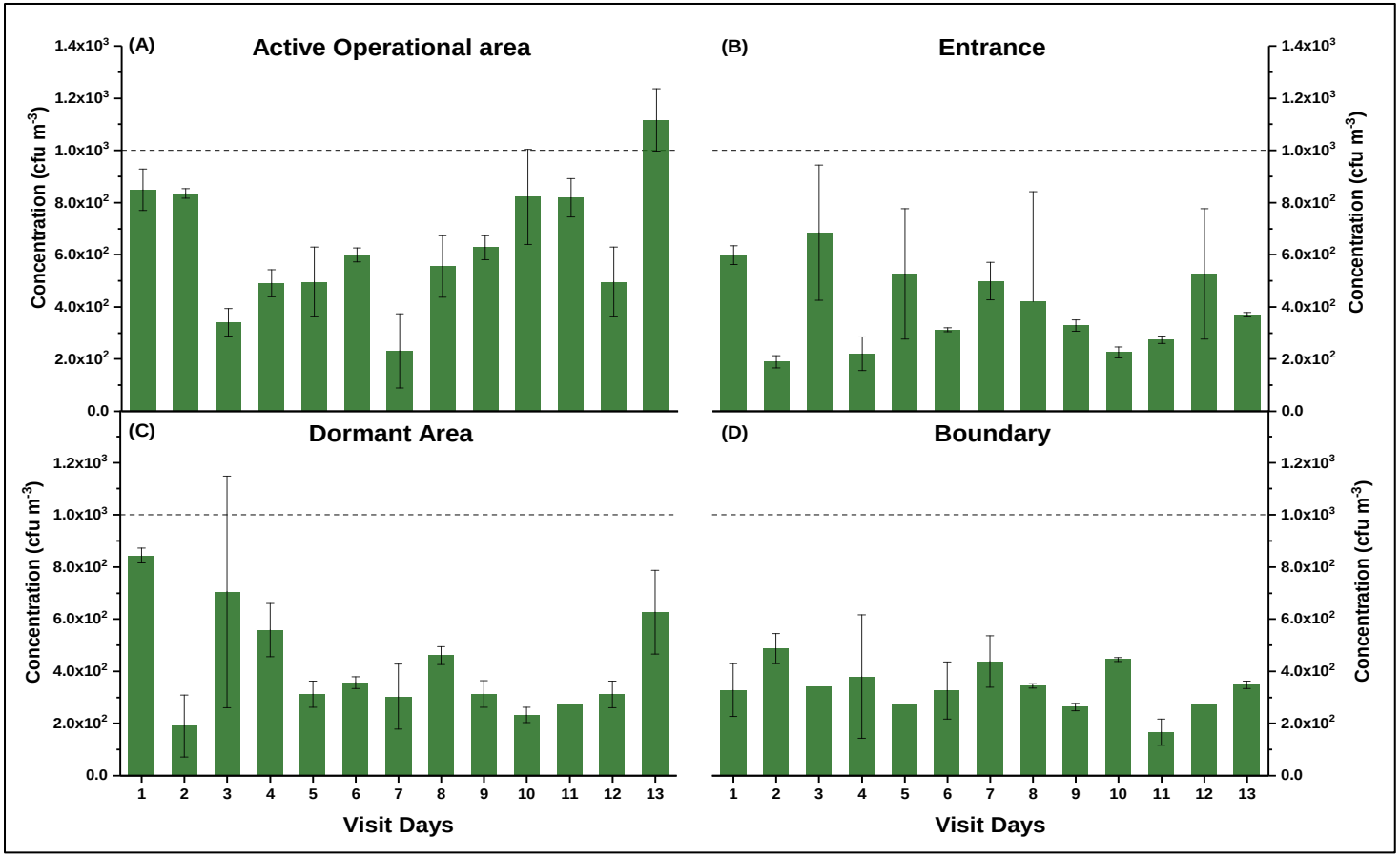

Figure 5-4: Mean concentration of total fungi in ambient air of dumpsite, showing EA emission limit; (A) Active area (B) Entrance (C) Dormant Area (D) Boundary

Table 5-1: Descriptive statistics of bioaerosol concentration the various sampling locations with the Anderson 6-stage sampler

Bioaerosol	*N*	Active area (50m from Active point) (cfu/m^3)			Entrance (325 m from active point) (cfu/m^3)			Dormant area (531 m from Active point) (cfu/m^3)			Boundary (788 m from Active point) (cfu/m^3)		
		Mean± SD	Median	Min-Max	Mean± SD	Median	Min-Max	Mean± SD	Median	Min-Max	Mean± SD	Median	Min-Max
Total Bacteria	13	1637±790.9	1.93×10^3	274-2994	1199 ±541	1.3×10^3	231-1849	1150±131	1.1×10^3	884-1379	741.9±403.2	7.4×10^2	195-1630
Gram-negative	13	2203±128.2	2.2×10^3	1980-2439	1248±360	1.1×10^3	786-2043	1497±428.8	1.4×10^3	939-2521	1199±545.1	1.2×10^3	311-2257
A. fumigatus	13	271.2±159	283	62-479	81.3±58	95	5.9-186.4	53.5±33.1	43.3	7.2-121	53.2±9.8	51	35-71
Total Fungi	13	636.2±242	599	231-1116	397.5±158	369	189-684	421.1±201	312	189-842	338.7±85.6	339	116-485

N = Total number of measurements

Comparison between bioaerosol concentration within Olusosun dumpsite and the control site

5.2.2 Figure 5-5 compares the overall median ambient concentration of bioaerosols measured at the Olusosun dumpsite with the control site. This was derived by computing the median of all the bioaerosol measurement across all four sampling locations throughout the 13 sampling visits to the dumpsite, then comparing this to the median from the control site. The result showed that bioaerosols concentrations at the dumpsite were tenfold, ninefold, twentyfold and twofold greater than the control for total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi respectively.

To evaluate further the differences between the concentration at the control site and the locations on the dumpsite, a one-way ANOVA was carried out. Only the data for total bacteria and gram-negative were normally distributed as assessed by Kolmogorov-Smirnov test ($p > 0.05$) and showed no outliers as assessed by a boxplot. However, the assumption of Homogeneity of variances as assessed by Levene's test was violated ($p < 0.05$) by the total bacteria and gram–negative bacteria; hence, the Welch's one-way ANOVA was used to assess the mean differences in concentration between the two locations. The data showed that there was a statistically significant difference between ambient concentration of total bacteria at the control and the dumpsite [Welch's $F(1, 52.38)=158.47$, $p < 0.0005$] as well as the gram-negative bacteria at the control and the dumpsite [Welch's $F(1, 13.4)=112.75$, $p <0.0005$].

The non-parametric test Kruskal- Wallis H test was run instead of ANOVA on the dataset for *Aspergillus fumigatus* and total fungi because their data were not normally distributed (Kolmogorov-Smirnov test, $p < 0.05$). The distribution of *Aspergillus fumigatus* was dissimilar between the control and dumpsite, total fungi on the other hand, showed a similar distribution between the control and the dumpsite as assessed by visual inspection of a boxplot. The result shows that the mean rank of *Aspergillus fumigatus* [$\chi^2(1) = 15.071$, $p < 0.0005$] and total fungi [$\chi^2(1) = 6.651$, $p = 0.01$] were statistically significantly different between the control and the dumpsite.

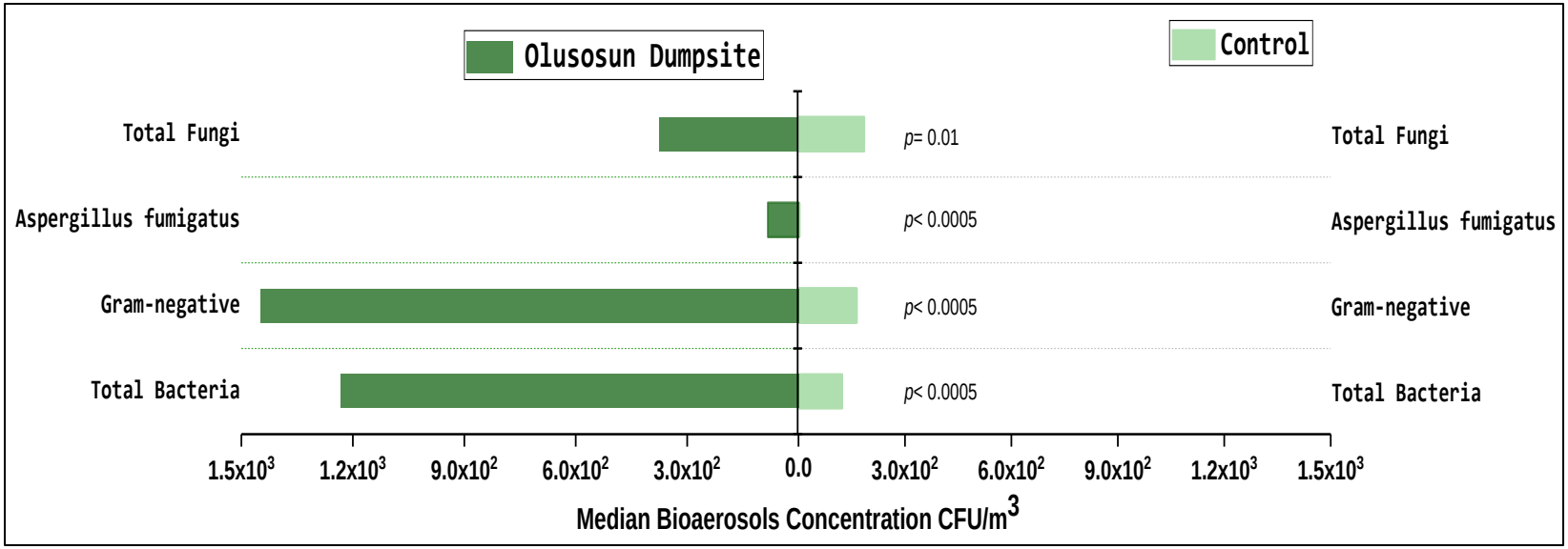

Figure 5-5: Comparison of the median ambient concentration of bioaerosol at the control and Olusosun dumpsite

Impact of prevailing environmental conditions on bioaerosol concentrations

5.2.3 Table 5-2, 5-3 and 5-4 presents the meteorological conditions that pertained during each sampling event. The potential contribution of three key meteorological conditions to the variability in bioaerosol concentrations at each sampling location and the impact of seasonal changes to the bioaerosol concentration overall are presented below in Sections 5.2.3.1-4.

5.2.3.1 Relationship between atmospheric temperature and bioaerosol concentrations

The mean ambient temperature at the dumpsite ranged between 27°C to 35.7°C during the sampling period (see Table 5-2). Temperature fluctuations on the sampling days were not drastic, as the highest deviation from the mean recorded was 2.9 on visit day 2 (05.05.2017). During the 13-week sampling period, temperatures remained high with a maximum temperature range of 36-37.8°C until sampling visit 6 (9th June, 2017), where the maximum ambient temperature started declining, recording a new range of 29.1-33.3°C for the remaining sampling visits. This divide indicates the peak of the rainy season, characterised by increased rainfall (Mean daily rainfall: June= 312.2 mm, July= 256.9 mm, August = 112.4 mm) and lower mean temperature are commonly recorded (WMO 2017).

A Pearson's product moment was used to assess the relationship between temperatures and ambient bioaerosol concentration at the four sampling points at the dumpsite. Preliminary analysis shows the relationship to be linear with all variables normally distributed, as assessed by Kolmogorov-Smirnov test ($p > 0.05$). The results show that, overall, there was a weak positive correlation between the ambient temperature and bioaerosol concentration across the dumpsite, however, the bacterial concentration showed a strong positive correlation at the dormant area and the boundary. Total bacteria sampled at the boundary ($r = 0.624$, n= 13, $p = 0.023$) and gram-negative bacteria at the dormant area of the dumpsite ($r = 0.604$ n= 13, $p = 0.029$) were strongly positive correlated to ambient temperature at those sampling locations throughout the sampling period. Hence, an increase in ambient temperature at the boundary and the dormant area would have favoured the growth in the bacterial population at those specific locations, as the air sampling at the dormant area and boundary were usually carried out by mid-day or the early afternoon when the temperatures were high (See Table 5-2). Further analysis

using the multiple regression model to assess if there ambient temperature was a predictive independent variable in relation to the overall concentration at the dumpsite, again, temperature did not significantly influence the overall concentration of bioaerosol in the ambient air at the dumpsite ($p>0.05$).

Table 5-2: Temperature of ambient air during outdoor sampling

Visit days	Date	Temperature (°C)						
		Active Operational area	Entrance	Dormant Area	Boundary	Mean	Min-Max	SD
1	25.04.17	33.4	32	35.4	37.05	34.5	32.0-37.1	2.2
2	05.05.17	37.4	31.5	36	37.8	35.7	31.5-37.8	2.9
3	12.05.17	34.4	31.7	33.2	36.3	33.9	31.7-36.3	1.9
4	22.05.17	32.2	35.2	33.7	36.8	34.5	32.2-36.8	2.0
5	02.06.17	36.1	34.6	35.1	32.0	34.5	32.0-36.1	1.7
6	09.06.17	30.0	29.1	31.2	32	30.6	29.1-32.0	1.3
7	16.06.17	31.3	32.4	30.2	31.1	31.3	30.2-32.4	0.9
8	23.06.17	31.9	29.1	33.9	33.2	32.0	29.1-33.9	2.1
9	07.07.17	25.1	26.7	27.2	29.1	27.0	25.1-29.1	1.6
10	14.07.17	29.3	30.1	28.7	29.9	29.5	28.7-30.1	0.6
11	21.07.17	31.2	30.5	31.9	32.5	31.5	30.5-32.5	0.9
12	28.07.17	28.4	29.5	28.1	30.2	29.1	28.1-30.2	1.0
13	04.08.17	25.7	27.1	28.9	29.6	27.8	25.7-29.6	1.8

5.2.3.2 Relationship between prevailing wind speed and bioaerosol concentrations

Table 5-3 describes the wind speed at the four sampling locations, the daily average, daily maximum and minimum and the standard deviation for the 13 sampling visits to Olusosun dumpsite. The mean wind speed ranged between 1.2 m s^{-1} to 4.2 m s^{-1}. The change in wind speed during the sampling events was not drastic as the highest deviation from the mean was 1.9 on 12th May 2017, 16th and 23rd June 2017.

A Pearson's product moment was used to assess correlation between wind speed and the concentration of bioaerosols at the dumpsite. The result showed a weak negative correlation overall; total bacteria (r= -0.0948, n=52, p >0.05), gram-negative bacteria (r = -0.1855, n = 52, p .0.05), *Aspergillus fumigatus* (r = - 0.13197, n = 52, p > 0.05) and total fungi (r = -0.152, n = 52, p > 0.05) (see Figure B-1 A-D). However when assessed by sampling locations, wind speed showed a significantly strong positive and negative correlation with the concentration of *Aspergillus fumigatus* at the boundary (r = 0.571, n =13, p < 0.05) and dormant area (r = -0.57, n= 13, p < 0.05) respectively. Our findings align well with the literature which suggests that increases in wind speed will in turn increase turbulence and dilution, leading to reduced concentration of bioaerosols in the ambient air, see for example Jones and Harrison (2004).

Table 5-3: Wind Speed during outdoor sampling

Visit days	Date	Wind Speed (m s^{-1})						
		Active Operational area	Entrance	Dormant Area	Boundary	Mean	Min-Max	SD
1	25.04.17	2.1	2.7	3.5	3.6	2.9	2.1-3.6	0.7
2	05.05.17	1.6	2.3	1.5	0.7	1.5	1.6-2.3	0.7
3	12.05.17	1.2	2.1	1.5	5.3	2.5	1.2- 5.3	1.9
4	22.05.17	2.5	0.9	1.0	3.0	1.8	0.9-3.0	1.1
5	02.06.17	1.2	3.2	1.3	1.1	1.7	1.1-3.2	1.0
6	09.06.17	1.2	1.7	2.2	1.5	1.7	1.2-2.2	0.4
7	16.06.17	0.8	4.3	4.9	3.9	3.5	0.8-4.9	1.9
8	23.06.17	1.3	0.7	2.2	5.0	2.3	0.7-5.0	1.9
9	07.07.17	0.8	2.6	3.7	4.1	2.8	0.8-4.1	1.5
10	14.07.17	5.5	4.6	3.8	2.8	4.2	2.8-5.5	1.2
11	21.07.17	1.1	0.9	1.3	1.5	1.2	1.1-1.5	0.3
12	28.07.17	2.5	2.9	1.9	2.1	2.4	1.9-2.9	0.4
13	04.08.17	3.5	2.6	2.1	2.6	2.7	2.1-3.5	0.6

Relationship between relative humidity and bioaerosol concentrations

5.2.3.3. Table 5-4 shows a descriptive statistics of the values of relative humidity (RH) recorded during the 13 sampling to Olusosun dumpsite. The mean RH ranged between 64.3-88% during the sampling events. RH with minimum values greater than 70% was recorded from sample visit day 7 (16/06/17) until visit day 13 (04/08/17), except for visit day 12 (28/07/2017) with recorded a minimum of 68% during sampling at the active operational area. The result of the standard deviation showed drastic changes in the RH values on the following sampling days 05/05/17, 22/05/17, 02/06/17, 23/06/17 and 07/07/17, recording deviations ranging from 4.1-7.2.

Using a Pearson's product moment to evaluate the correlation between RH and overall concentration of bioaerosols on the dumpsite, the result showed a strong negative correlation with total bacteria ($r = -0.4406$, $n = 52$, $p < 0.05$) (Figure B-2 A), while gram-negative bacteria, *Aspergillus fumigatus* and total fungi on the other hand, showed a weak inverse correlation (Figure B-2 B-D). With regard to bioaerosol concentration at locations, the result showed no statistically significant correlation in the relationship between bioaerosol concentration and relative humidity.

However, upon conducting a multiple regression to further examine the overall changes in the concentration of bioaerosol across the dumpsite in response to the three key meteorological factors considered in this study, i.e. temperature, wind speed and RH; only RH added statistically significantly to the prediction ($p < 0.01$) overall, and total bacteria concentration was the most affected by RH [$F(3, 48) = 4.140$, $p < 0.05$, adj. $R^2 = 0.156$].

Table 5-4: Relative Humidity of ambient air during outdoor sampling

Visit days	Date	Relative Humidity (%)						
		Active Operational area	Entrance	Dormant Area	Boundary	Mean	Min-Max	SD
1	25.04.17	70	71	75	74	73	70-75	2.4
2	05.05.17	75	62	60	60	64.3	60-75	7.2
3	12.05.17	69	70	70	71	70	69-71	0.8
4	22.05.17	72	76	65	68	70.1	65-76	4.8
5	02.06.17	76	66	69	67	70	66-76	4.5
6	09.06.17	65	68	70	70	68.3	65-70	2.4
7	16.06.17	78	74	74	76	76	74-78	1.9
8	23.06.17	91	88	83	81	86	81-91	4.6
9	07.07.17	83	93	88	88	88	83-93	4.1
10	14.07.17	73	75	73	73	72	73-75	1.0
11	21.07.17	75	72	73	72	73	72-75	1.4
12	28.07.17	68	71	69	70	70	68-71	1.3
13	04.08.17	70	71	75	74	73	70-75	2.4

5.2.3.4 Effect of seasonal changes on bioaerosol concentration

Figure 5-9 shows the concentration of total bacteria and total fungi from all the air samples collected from the 13 sampling visits to Olusosun dumpsite. Sampling Visits 1-6 took place within the tail end of the dry season while sampling visits 7-13 took place when the wet season had begun, commonly marked by reduced ambient temperatures and increased humidity (see section 3-4 and Table 5-2,4). The dry season is characterized by reduced rainfall (monthly average <120 mm) from late October until March, with its lowest in January (monthly average <14.3 mm). However, heavier rainfalls are experienced in April through to October, with the heaviest rainfall in the month of June (see Table B-5) (Udo 2015). Also highlighted in Figure 5-9 are the periods marking the beginning of the rainy season, coinciding with sampling visit day 6 (09.06.17) and visit day 7 (16.06.17). The area showing the general drop in concentration for total bacteria and total fungi due mostly to rainfall experienced during sampling, this is marked in red.

In general, it was observed that slightly higher bioaerosol concentrations were recorded during sampling visits 1-6 compared to visits 7-13. This observation was further assessed using a one-way ANOVA to determine if the change in concentration of bioaerosols before rainy (visits 1-6) season and during the rainy season (visits 7-13) was statistically significant. Only Total bacteria and gram-negative bacteria were normally distributed when assessed by the Shapiro-Wilk test ($p > 0.05$); and there was no homogeneity of variances, as assessed by Levene's test of homogeneity of variances ($p > 0.05$). It was noticed that for total bacteria and gram-negative bacteria, the differences in concentration between the dry and rainy season was not statistically significant; Total bacteria: $F(1, 50) = 1.934$, $p = 0.170$; gram-negative: $F(1, 50) = 2.848$, $p = 0.098$. Furthermore, *Aspergillus fumigatus* and total fungi also showed no statistical significant difference between the two periods when tested with Kruskal-Wallis test; *Aspergillus fumigatus*: $\chi^2(1) = 0.002$, $p = 0.962$; total fungi: $\chi^2(1) = 1.032$, $p = 0.310$.

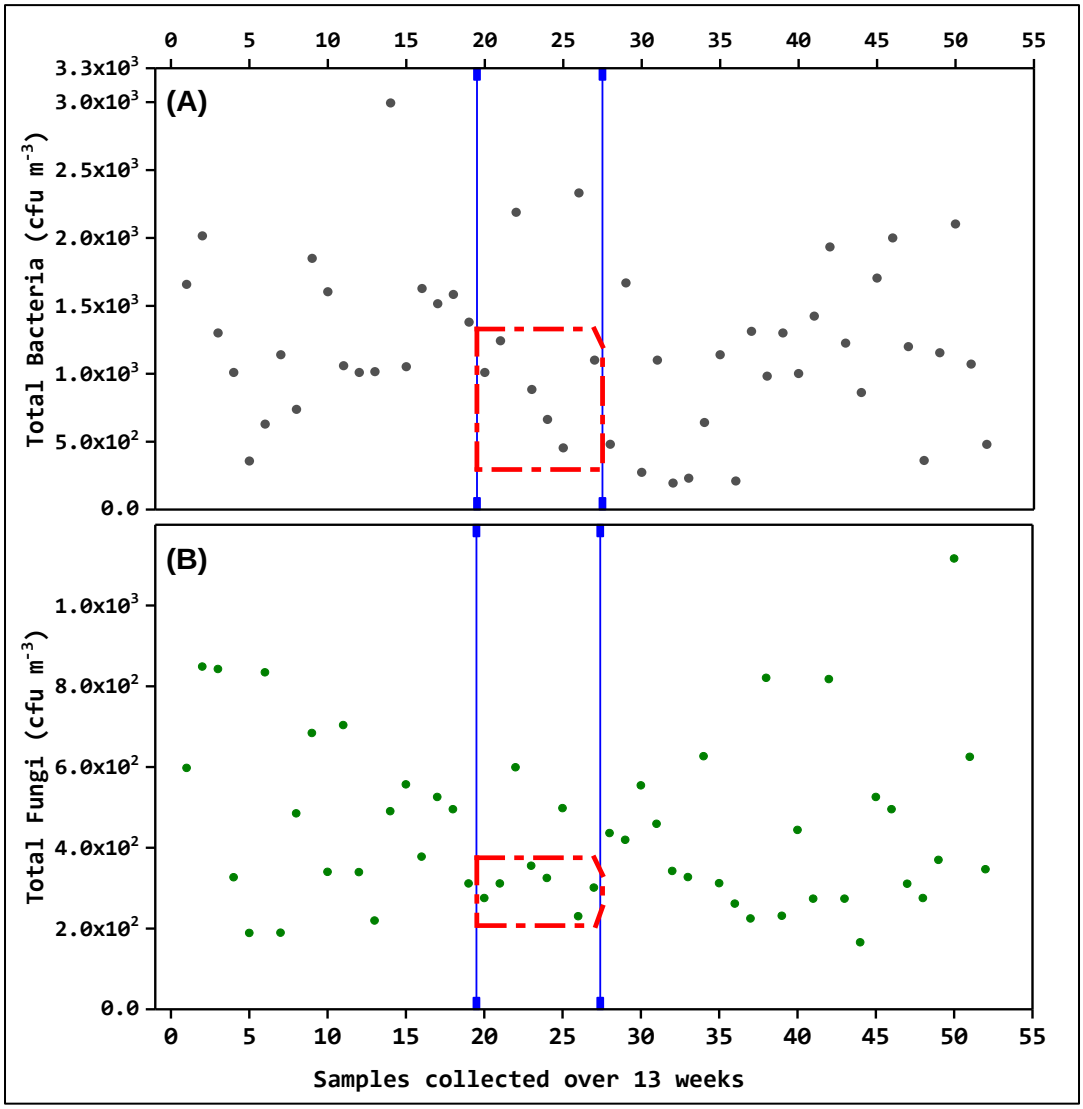

Figure 5-6: Variation of Bioaerosol concentration between dry season and rainy season (A) Total bacteria (B) Total fungi

Impact of different activities at the dumpsite on bioaerosol exposure

5.2.4 Table 5-5 show the mean bioaerosol concentration workers on the dumpsite were exposed to as they were engaged in scavenging, waste sorting and site monitoring/supervision activities on the dumpsite. In general, scavengers were exposed to the highest concentration of bacteria in the magnitude of 10^6 cfu m^{-3}, while site monitoring activities recorded the highest exposure level to *Aspergillus fumigatus* in the magnitude of 10^5 cfu m^{-3}. Moreover, Figure 5-7 shows a radar graph comparing bioaerosol exposure from the activity-related sampling with overall mean concentrations in the ambient air. The result indicates higher exposure to total bacteria and gram-negative bacteria from scavenging up to 10^6 cfu m^{-3}. In comparison to ambient concentrations, bacteria exposure from scavenging were 2-3 log higher. Exposure concentration to *Aspergillus fumigatus* on other hand, was found to be highest when undertaking site-monitoring/supervision activities (3×10^5 cfu m^{-3}), while exposure from waste sorting and scavenging were a log lower and within the same logarithmic scale (Table 5-5). Similar to the bacteria concentration, exposure to *Aspergillus fumigatus* from the three activities were 2-3 log higher compared to ambient concentration. Overall, the ambient concentration at the control was generally lower by magnitude for bacteria (3-4 log) and fungi (4-5 log) when compared to results from ambient sampling and activity-based sampling (see table 5.5).

Table 5-5: Mean bioaerosol concentration from activity-related sampling, ambient sampling and control

Microorganism (cfu m^{-3})	Control site [a]	Ambient sampling (Olusosun dumpsite) [b]	Activity-related sampling [c]		
			Site monitoring	Sorting	Scavenging
Total bacteria	1.3×10^2	1.3×10^3	6.0×10^5	4.8×10^5	1.17×10^6
Gram-negative bacteria	3.1×10^2	1.6×10^3	2.1×10^5	1.7410^6	3.0×10^6
Aspergillus fumigatus	6.9×10^0	1.19×10^2	3.0×10^5	9.0×10^4	6.75×10^4

[a] Number of measurements = 3

[b] Number of measurements = 13

[c] Number of measurements = 2

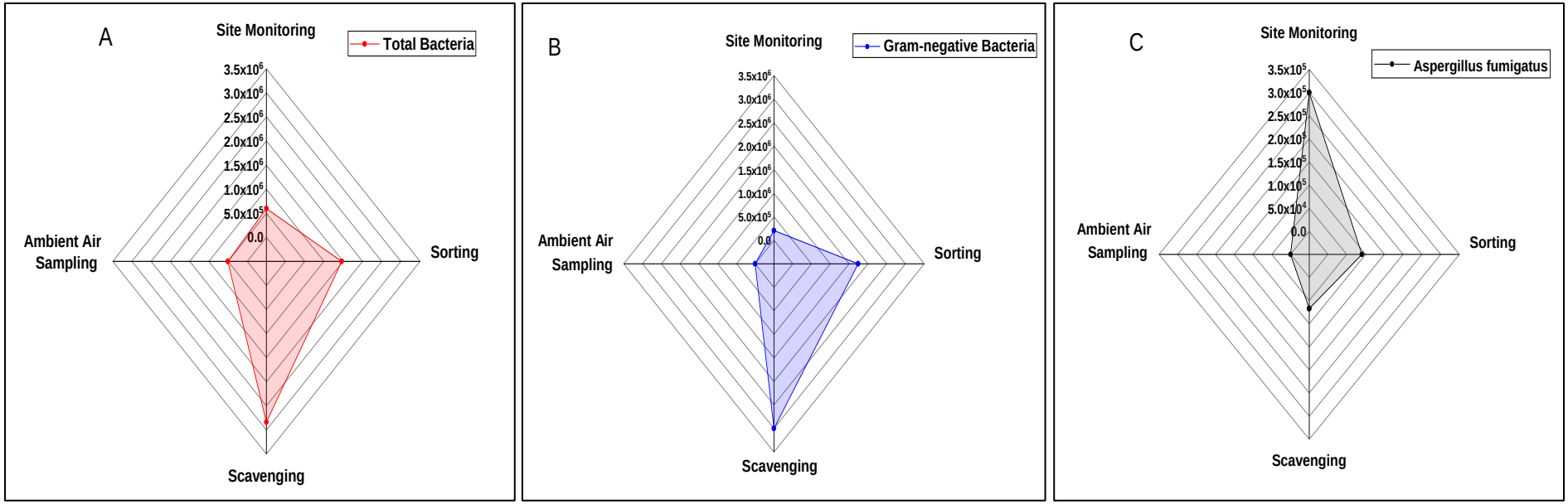

Figure 5-7 Comparison of exposure of (A) Total Bacteria, (B) Gram-negative (C) Aspergillus fumigatus from activities at Olusosun dumpsite to environmental sampling.

Discussion of Findings

5.3 Impact of location within Olusosun dumpsite on the concentration of bioaerosols in measured in the ambient air

5.3.1 The results in this chapter are consistent with the hypothesis that activities, such as tipping, spreading and waste sorting can aerosolise microorganisms attached to the waste pile, serving as a source of bioaerosols, including pathogenic ones (Stagg *et al.,* 2010). The result of the ambient air sampling shows that the active operational area where most agitation activities like tipping, spreading and compacting took place, recorded the highest mean concentration for the four indicator bioaerosols compared to other sampling locations on the dumpsite (See Table 5-1). When the MSW arrives at the dumpsite, it is tipped by the waste trucks, spread and compacted by the bulldozer machines. In doing so, the waste pile becomes agitated, favouring aerosolisation of microorganism as they become detached from the surfaces of the waste pile, hence the higher concentration of bioaerosols in locations where these activities take place compared the locations where they do not (Schlosser *et al.*, 2016; Gladding and Gwyther 2017). Moreover, the mean ambient concentration of bacteria and fungi at the active operational area of Olusosun dumpsite were (i.e. 10^3 cfu m^{-3}) comparable to the concentrations reported at the active operational areas in previous studies on landfill sites. Kalwasińska *et al.,* (2014) for instance recorded 1.9×10^3 cfu m^{-3} (bacteria) and 2.07×10^3 cfu/m^3 (fungi) in Poland; Breza-Boruta (2016) recorded 21.31×10^3 cfu m^{-3} (bacteria) and 4.18×10^3 cfu m^{-3} (fungi) in Poland , while Huang *et al.,* (2002) recorded 3.76×10^3 cfu m^{-3} (bacteria) and 6.0×10^3 cfu m^{-3} (fungi) in Taiwan.

The composition of the incoming MSW in sub-Saharan Africa have shown it to have a high proportion of biodegradables up to 60%, and that they are usually high in moisture content (Ogwueleka 2009; Hoornweg and Bhada-Tata 2012b). These characteristics in combination with the hot and humid weather conditions in the region, would favour the growth of microorganisms with higher concentration in the ambient air. However, when the result obtained from activity-related sampling were compared to the ambient sampling, the ambient concentrations were 2-4 log lower, an indication that the differences in the sampling method would contribute to the low ambient measurement. Cartwright *et al.,* (2009) had reviewed for the UK Environment agency the methods of collection of bioaerosols highlighting their advantages and disadvantages. Consequently, the Anderson impactor sampler was recommended as one of the standard method for bioaerosol

measurements in waste composting facilities. However the device is vulnerable to overloading quickly in areas with high concentration bioaerosols, e.g. the point source (Williams *et al.,* 2013a). Thus, as was the case in this study, the Anderson sampler may have been insensitive to sampling occasions where higher concentrations was expected, thereby resulting an underestimation the real concentration of bioaerosols in the ambient air.

The median concertation for total bacteria and gram-negative bacteria at the entrance and dormant area were similar (Table 5-1), despite the entrance being located eastward, off the prevailing wind direction (south-west) where the dormant area is located (Plate 3-4 and 3-5). The direction of the prevailing wind is usually the direction of travel for most aerosolised pollutants as the wind transports both aerosol particle and moisture in its path (Elminir 2005). Thus, measuring concentrations at the entrance that were similar to the dormant area, could be because of the swirling wind locally during sampling, which meant the wind direction would have varied. This could mean that some sampling locations may have been influenced by emission from other places and that would not have happened if the prevailing wind direction was maintained throughout the sampling period. Another reason for this phenomenon would have been the contribution from bioaerosols attached to dust particles that would have arisen from adjoining busy roads, since this entrance was about 70 m away from the busy Lagos-Ibadan expressway. There are evidence of pathogenic bioaerosols being transported in mineral-dust particles and causing increase in incidence of asthma when inhaled (Jones and Harrison 2004; Ichinose *et al.,* 2005; Jeon *et al.,* 2011; Maki *et al.,* 2014).

The sampling point at the dormant area and boundary were the furthest away from the active operational area (see Figure 3-5). The activities at the dormant part of the dumpsite were primarily sorting and loading of recovered recycled materials into trucks. Scavenging was also observed, but sparsely. Because of the low volume of agitation-causing activities at this location, it could be assumed that the primary source of bioaerosol in this location would have been from the active operational area. The dormant area recorded peak concentrations up to 1371 cfu m^{-3} and 2521 cfu m^{-3} for total bacteria and gram-negative bacteria respectively, and levels higher than the acceptable limits by the UK and Wales Environment Agency used in this study (Frederickson *et al.,* 2013; Pearson *et al.,* 2015). Food vendors, middlemen and owners of small business mostly occupy this area of the dumpsite. They spend between 9.7-12.8 hours daily at this location

(see Appendix A-2). There is a high risk of exposure to pathogenic bioaerosols just from working at this location for close to 13 hours daily. Presented in Chapter 4 are details of the reported respiratory symptoms experienced by dumpsite workers and residents near Olusosun dumpsite. Furthermore, probable risk of morbidity from exposure to pathogenic bioaerosol have been presented in Chapter 7.

Overall, it was observed that the concentration of bacteria measured at the dumpsite were 1-2 logs higher than the concentration of fungi from all the sampling locations. This may be explained by the sampling method used, as Xu and Yao (2013) observed that higher viable bacteria concentrations when compared to viable fungi concentrations are usually collected when using an Anderson impactor for air sampling.

5.3.2 Impact of downwind distance on the concentration of bioaerosols in the ambient air

In general, the ambient concentrations of bacteria and fungi shows a progressive decline in concentration with distance, from the source point (active operational area), downwind to the boundary. However, the one-way ANOVA indicated no statistically significant difference in mean concentrations for total bacteria ($p>0.05$) and gram-negative bacteria ($p>0.05$) between the active area and other three sampling locations. This was unexpected, given that some of the sampling points were located at considerable distances from the active operational area (see Plate 3-5). The result suggests a 'fairly-uniform' concentration for total bacteria and gram-negative bacteria across the dumpsite, which may be due to either meteorological factors such as short-term increase in wind speed aiding release of more bacteria at the sampling location or further bioaerosol emission from other source location or both (Ogden *et al.*, 1969; Giner *et al.*, 1999). Although the statistical analysis showed relative humidity (64.3-88%) had the greatest influence overall on the bacteria concentration, when however considered in combination with temperature (27^oC - 35.7^oC) and wind speed, a favourable condition for holding a high level of bioaerosol for longer in the ambient air must have been created.

At the boundary, the mean concentration of total bacteria and gram-negative bacteria were of the same magnitude (10^3) as observed in previous studies on landfill bioaerosols emissions (Reinthaler *et al.*, 1999; Breza-Boruta 2016). However, in this study, peaks for total bacteria and gram-negative bacteria of up to 1630 cfu m^{-3} and 2257 cfu m^{-3} respectively were measured, at a distance of 788 m from the active operational area of the

dumpsite. In an analysis carried out in a different study of a landfill, Reinthaler *et al.,* (1999) reported similar peak concentrations of mesophilic bacteria comparable to this study at distance 450-1200 m from the active tipping point (2×10^3-2.7×10^3 cfu m^{-3}). This observation is consistent with the postulation by Tellier (2006) that bioaerosol particles may take longer (at least 62 mins) to settle due to their size. The possible implication of this is that the bioaerosols will eventually transport beyond the boundary to adjoining areas near the dumpsite where local residents are mostly located, thus exposing them to possible pathogenic bioaerosols. Furthermore, because Olusosun dumpsite is surrounded by residents located between 50-100 m from the boundary of the dumpsite, see Figure 3-1 (Odeyemi 2012), ambient bacteria concentration may not have reduced to background in these areas.

Aspergillus fumigatus showed a similar decrease in concentration with distance downwind as was observed with bacteria. In this case, however, the differences in the concentration between the active operational area and the boundary was significant. The decline in the concentration of *Aspergillus fumigatus* between the active area (Median: 283 cfu m^{-3}), the dormant area (median: 43 cfu m^{-3}) and the boundary (51 cfu m^{-3}) showed an 80-81% reduction in concentration downwind, further confirming the result of the one-ANOVA in section 5.4.3. This behaviour of *Aspergillus fumigatus* was similar to what was observed by Schlosser *et al.,* (2016) where the decline was up to 77% between the tipping face (mean: 1100 cfu m^{-3}) and the at landfill boundary (mean: 140 cfu m^{-3}). Reinthaler *et al.,* (1999) also reported a similar significant reduction in the concentration of *Aspergillus fumigatus* from the landfill centre to the boundary; however, the reported concentration was lower than observed in this study. The discrepancies may likely be due to the effect of wind dilution as the conidia dispersed. It is worth noting that *Aspergillus fumigatus* conidia are thermotolerant and have some UV protection due to the melanin pigmentation in their cells, and thus can survive longer even as a single cell and can be re-suspended after settling, creating mini burst of spores (Rhame 1991; O'Gorman 2011). These characteristics places them as a significant health hazard to the both the workers on the dumpsite and residents of the surrounding should they travel beyond the boundary of the dumpsite.

5.3.3 Comparison of ambient concentration with control

In this study, the mean concentrations for total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and the total fungi at all the sampling locations at the dumpsite

were significantly higher than concentrations at the control site (see Figure 5-5). The maximum concentration of total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi at the control did not exceed 165 cfu m^{-3}, 708 cfu m^{-3}, 16 cfu m^{-3} and 396.7 cfu m^{-3} respectively, although bacteria and fungi are reported to routinely occur naturally at concentrations of 1000 cfu m^{-3} and that concentrations near 10,000 cfu m^{-3} were not uncommon in the summer months, subject to the sampling method used (Cox and Wathes 1995; Macher 1999). Indicated in Table 5-6, are the maximum bioaerosol concentrations recorded in outdoor air as reported in the literature, however there were exceptions in areas with high vehicular movement recording higher maximum values for mesophilic bacteria and fungi (Fang *et al.*, 2008; Haas *et al.*, 2013). With that said, the concentration recorded in this study for total bacteria, total fungi and *Aspergillus fumigatus* at the control site were lower than most literature reviewed, thereby placing it within the acceptable concentration limits of the UK and Wales Environment Agency for 1000 cfu m^{-3}, 1000 cfu m^{-3} and 500 cfu m^{-3} respectively. Comparatively, at the 95th percentile, the concentrations of total bacteria (2189 cfu m^{-3}), gram negative bacteria (2352 cfu m^{-3}), *Aspergillus fumigatus* (300 cfu m^{-3}) and total fungi (824 cfu m^{-3}) at the dumpsite were 2-3 log higher than the control. These differences in the concentration were significant (p>0.05), further supporting the assumption that Olusosun dumpsite was a major contributor to air pollution and bioaerosol emission within its vicinity (Figure 5-5). Caution must be observed when interpreting the result of this study because of differences in the sampling approach and the influence of meteorological conditions during sampling. In this study, the closest location to the active operational area was 50 m downwind, as opposed to other studies where sampling was either carried out at the working area or a distance of 20 m away (Liao and Luo 2005; Burkowska *et al.*, 2011; Breza-Boruta 2012; Sangkham *et al.*, 2014; Schlosser *et al.*, 2016; Agarwal 2017). This approach inherently creates room for the effects of wind dilution, thereby underestimating the concentration of bioaerosols emitted at the active operational area.

The overall mean ambient concentrations of total bacteria and gram-negative bacteria were higher than the acceptable limit set by the UK and Wales Environment Agency, and were also observed to have exceeded the limits for most sampling days at the four sampling locations (Figure 5-1,2,3,4). These results can serve as an indication of an excess risk to the health of nearby residents and the workers on the dumpsite, as longer exposure hours beyond the recommended 8-hour TWA were observed in both

populations (HSE 2014) Conversely, the mean ambient concentration of *Aspergillus fumigatus* and total fungi never exceeded the acceptable limits for all the days sampled. It is important to state that from an environmental health viewpoint, the concentration *Aspergillus fumigatus* is probably not relevant as the values measured in this study were comparable to expected background levels.

Table 5-6: Maximum value of mesophilic bacteria and fungi and Aspergillus fumigatus in outdoor air reported in literature (cfu m^{-3})

Study Location	Total bacteria	Total fungi	*Aspergillus fumigatus*	Sampling method	Reference
Ireland		6800		Impaction (SAS Sampler, Italy)	O'Gorman and Fuller (2008)
United Kingdom		7200		Impaction (2-Stage Anderson Sampler)	Jones and Cookson (1983)
USA, CT		>8200		Impaction (Anderson six stage sampler)	Shelton *et al.*, (2002)
Brazil		39,000		Impingement (AGI-4, VA)	Gonçalves *et al.*, (2010)
Austria	2500[c]	2300[c]		Impaction (One-stage MAS 100 sampler)	Haas *et al.*, (2013)
China, Beijing	22000[c]	13,690[c]		Impaction (Anderson 6-stage sampler)	Fang *et al.*, (2008)
USA			290	Impaction (Anderson 6-stage sampler)	Spicer and Gangloff (2005)
USA, Islip, NY			300[a]	Centrifugal impaction (Reuter Centrifugal sampler)	Recer *et al.*, (2001)
USA, Islip, NY			890[b]	Centrifugal impaction (Reuter Centrifugal sampler)	Recer *et al.*, (2001)
Lagos, Nigeria	165[b]	396.7[b]	16[b]	Impaction (Anderson 6-stage sampler)	This study

[a] Airport

[b] Residential area

[c] City Center with high vehicular movement

5.1.2 Impact of meteorological conditions and other determinant factors on bioaerosol concentration

Most studies on bioaerosol emissions have been carried out in regions with temperate climates i.e. with four distinct seasons, making it difficult to have a direct season-on-season comparison with this study, which was carried out in a tropical region with two distinct seasons. It is a known fact that there are usually higher concentrations of airborne microorganisms in warm seasons as opposed to cold seasons (O'Gorman and Fuller 2008; Hurtado *et al.*, 2014; Breza-Boruta 2016). In contrast, this study showed no significant difference in the concentration of total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi between the rainy season (cold) and the dry season (warm) when tested with the one-way ANOVA and Kruskal-Wallis statistical analysis. Although there was a notable drop in the concentration at the onset of the rainy season (see Figure 5-6), this did not last long as the concentration was up again to levels similar to the dry season. Some studies have attributed the high concentration of bioaerosols observed in cold seasons as opposed to the warm season, to the high level of agitation activities taking place in the vicinity of the sampling location (Huang *et al.*, 2002), while others have demonstrated that the ambient concentration of *Aspergillus fumigatus* was unaffected by seasonal variations (Li and Kendrick 1995; Sautour *et al.*, 2009; Alshareef and Robson 2014; Schlosser *et al.*, 2016). The findings in this study are consistent with both conclusions. Firstly, it affirms the results of the statistical analysis showing no significant differences in the concentration of bioaerosols between the two seasons. Secondly, it explains the reason why bioaerosol concentrations are unaffected by the seasonal variations. Olusosun dumpsite for instance operates on a 24-hour work cycle (Idehai and Akujieze 2015), that is 24 hours of regular agitation-related activities taking place on the dumpsite, thus replenishing the airborne microbial concentration even after dilution or dry deposition have taken place. This would record high bioaerosol concentration all year round, with changes in seasons having little impact on concentration.

The effects of metrological conditions on bioaerosol production, dispersal and deposition are known and established (Jones and Harrison 2004). In this study, relative humidity had the highest overall seasonal effect on the concentration of bioaerosol on the dumpsite and was negatively correlated with bioaerosol concentrations (see section 5.2.3). A similar observation by Frączek *et al.*, (2017) and Jones and Harrison (2004) showed that during high relative humidity, spore-forming fungi increases in growth, forming compact

colonies, which results in lower release of spores and conidia. This phenomenon is however reversed when the relative humidity is lower, causing environmental stress on the fungi, hence higher release of spores. The higher atmospheric temperature and lower relative humidity observed during visit days 1-6 before the wet season had fully set in, may have favoured the higher concentration of total bacteria and total mesophilic fungi at the dumpsite.

Aside seasons and the meteorological factors considered in this study, some studies have considered the waste tonnage as a possible determinant factor. Schlosser *et al.,* (2016) found a correlation between the concentration of *Aspergillus fumigatus* and total mesophilic mould at the tipping face and downwind with the waste tonnage supplied. Unfortunately, it was not possible to consider this factor in this study because of lack of access to data regarding the daily tonnage of was MSW supplied to the dumpsite.

5.1.3 Exposure to bioaerosols resulting from different activities at Olusosun dumpsite

The result of the activity-based air sampling shows that the scavengers and workers alike were exposed to bioaerosols concentrations up to 3-log higher than the mean concentration measured during the static ambient air sampling (see Table 5-5). The activity-based bioaerosol exposure sampling was designed not just to capture the bioaerosols around the breathing zones of the workers, but capture exposure from the activities they were most associated with on the dumpsite. Although there have been reports of high bioaerosol exposure levels coupled with work task analysis, these studies were mostly limited to activities in composting facilities (Fischer *et al.,* 2000; Sánchez-Monedero *et al.,* 2005; Persoons *et al.,* 2010; Sykes 2011). Moreover, in a different study of MSW collectors, Wouters *et al.,* (2005) observed that workers exposure levels to bioaerosols and endotoxins were associated with the task they were involved in and not the type of waste. In addition, the report also indicated that agitation activities and the times when the waste was extensively disturbed recorded high exposure levels. In this study, the agitation activities were identified as the tipping, spreading, compacting, scavenging and sorting of waste. It is a fact that agitation-related activities increases bioaerosol exposure levels, however this may not always be the case, as there are some reports of activities that are in themselves of 'lower agitation', but records of high bioaerosols exposure concentration were still observed (Wouters *et al.,* 2005; Sykes 2011). It must be noted that in the cases referred to, the workers mere physical presence

in the vicinity where agitation activities took had probably exposed them to high bioaerosol concentrations. Scavengers and the site supervisors/operators are the two groups of people mainly directly involved in the activities which are agitation-related. As the site supervisors coordinate the tipping, spreading and compacting operations, the scavengers ravages the waste pile while the aforementioned activities take place. Presented in Figure 5-10 is a radar graph comparing the exposure levels associated with the tasks considered in this study with the mean ambient bioaerosol concentration. The result suggests scavenging as the activity with the highest exposure to bacteria (total bacteria and gram-negative bacteria) while site monitoring presented the highest exposure levels to *Aspergillus fumigatus*. Although the reason for his discrepancy is not certain, it could be that the waster worker, while carrying out the site supervision on the day of the sampling happened to be in an area where waste with high concentrations of *Aspergillus fumigatus* was tipped, as such peaks were not observed in the other samples collected. The high bioaerosol exposure concentration levels from scavenging in this study is not surprising, as scavengers are not only exposed to bioaerosols from agitation caused by the tipping and spreading of the waste, but also as they ravage the waste pile seeking recyclables.

Other authors have published bioaerosol concentration data from activity-related exposures, and the measured concentrations in this study were within the same order of magnitude of 10^4-10^6 cfu m^{-3} (See Table 5-7). There are very few publications on outdoor activity-related exposure to bioaerosols, as some have reported low bioaerosol concentrations (Wouters *et al.,* 2005). In contrast, all the activities assessed in this study were carried out outdoors, yet measurements comparable with published data of bioaerosol exposure indoors were observed. The use of a personal sampler in this study reduced the effect of dilution due to wind and immediate dry deposition, as the workers would already have inhaled high concentration of bioaerosols before such effects, because of their close association with the activity. This can be partially explained by the high variability observed between the bioaerosol concentrations in the ambient air and activity-related sampling (see Table 5-4). These results further affirms the call by HSE (2003) and Persoons *et al.,* (2010) not only to assess occupational bioaerosol exposure by ambient air monitoring, but also the influence of process engineering in reducing bioaerosol exposure.

Nigeria, as with most developing countries, does not have a regulatory framework for bioaerosol exposure in occupational environments. Hence, there is no substantial driver for accountability to health of bioaerosol-exposed workers on the part of both their employers and the regulatory organizations. Moreover, this may not only be unique to developing countries, as there are only a few developed countries that have had their regulatory organizations adopt occupational exposure limit(s) to bioaerosols exposure in different occupational setting (Eduard *et al.*, 2012). This has been further complicated by the heterogeneous nature of the exposure agents, which has shown high variability in the results reported in previous studies (Douwes *et al.*, 2003a). In this study interestingly, the results of the bioaerosols exposure concentrations from the activities related sampling were higher than acceptable occupational exposure limits for countries as reviewed in this report (See Table 5-8). The result for total bacteria and gram-negative bacteria were 6-times higher than the occupational exposure limits set by the Environment Agency for England and Wales. Similarly, *Aspergillus fumigatus* also exceeded by a magnitude of 4 than the occupational exposure limits acceptable by the Environment Agency for England and Wales. From an environmental health viewpoint, these exposure concertation are hazardous to the health of the workers at the dumpsite. The consequence of such magnitude of exposure is that the workers will eventually develop acute and eventually chronic respiratory diseases especially those with compromised immune system as has been reported in the respiratory health survey, presented in Chapter 4. The results further accentuate the urgency of developing regulatory framework to protect and reduce workers exposure to bioaerosols and other hazardous biological agents in Nigeria.

Table 5-7: Reported bioaerosol exposure from municipal solid waste treatment and task/activities involved

Activities	Setting	Agitation level	Workers directly Exposed	Maximum Bioaerosols	References
Tipping	Landfill, Dumpsites	High	Waste workers, Truck/Bulldozer drivers, Scavengers	Fungi: 5.8×10^{4} cfu m^{-3} *A. fumigatus*: 1.1×10^{3} cfu m^{-3}	Schlosser *et al.*, (2016)
Turning	Composting	High	Compost workers	Total Bacteria: 7.4×10^{3} cfu m^{-3} Fungi: 1.5×10^{4} cfu m^{-3} *A. fumigatus*: 1.1×10^{4} cfu m^{-3}	Persoons *et al.*, (2010)
Shredding	Composting	High	Compost workers	Total Bacteria: 3.8×10^{4} Fungi: 6.8×10^{4} *A. fumigatus*: 4.1×10^{4}	Persoons *et al.*, (2010)
Waste transportation	Composting, Waste collection	Medium	Truck drivers, Waste collectors	Bacteria: 4.8×10^{4} cfu m^{-3} Fungi: 4.6×10^{6} cfu m^{-3} Dust: 9.1 mg m^{-3} Endotoxin: 7182 EU m^{-3} Glucan: 52.5 µg m^{-3}	Madsen *et al.*, (2016) Wouters *et al.*, (2005)
Scavenging	Dumpsites	Medium	Scavengers	Total Bacteria: 1.17×10^{6} cfu m^{-3} *A. fumigatus*: 6.75×10^{4} cfu m^{-3}	This Study
Sorting	Composting, material recovery facilities	Low	Waste workers	Dust: 11.92 mg m^{-3} Endotoxin: 1954 EU m^{-3} Glucan: 127.42 µg m^{-3}	Sykes (2011)
Sorting	Dumpsite	Medium	Scavengers	Total Bacteria: 4.8×10^{5} cfu m^{-3} *A. fumigatus*: 9.0×10^{4} cfu m^{-3}	This Study
Site monitoring/ supervision	Compositing, dumpsites	Low	Site workers and Site supervisors	Total Bacteria: 6.0×10^{5} cfu m^{-3} *A. fumigatus*: 3.0×10^{5} cfu m^{-3} Dust: 22.8 mg m^{-3} Endotoxin: 1678 EU m^{-3} Glucan: 10.38 µg m^{-3}	This Study Wouters *et al.*, (2005)

Table 5-8: Occupational limits for bioaerosols exposure for different countries, in comparison to exposure in this study.

Country	Bacteria	Gram-negative	Fungi	*A. fumigatus*	Endo toxin	B(1→3) - glucans	References
UK	1000 cfu m^{-3}	300 cfu m^{-3}	1000 cfu m^{-3}	500 cfu m^{-3}	90 EU m^{-3}	10 ng m^{-3}	Frederickson *et al.*, (2013); Pearson *et al.*, (2015)
Denmark	10^3-10^4 cfu m^{-3}	10^3 cfu m^{-3}	-	-	0.1 µg m^{-3}	-	(Malmros *et al.*, 1992)
Netherland	-	-	-	-	90 EU m^{-3}	-	Eduard *et al.*, (2012)
Russia	-	-	10^3-10^4 cells m^{-3}	-	-	-	SCHES (1993)
Germany	-	-	5×10^4 cfu m^{-3}	-	-	-	BAuA (2018)
This Study	1.74×10^6 cfu m^{-3}	3.0×10^6 cfu m^{-3}	-	9.0×10^4 cfu m^{-3}	-	-	This Study

5.2 Research Limitation

There were some limitations in the course of carrying out this aspect of the research, one of which was the inability to collect bioaerosol samples at the sensitive receptor. Even though the UK Environment Agency (2017) M9 technical guidelines for bioaerosol monitoring used in this study required that air samples be collected at the sensitive receptor, some logistical limitations made it practically impossible to do so. However, the levels of bioaerosols concentration at the sensitive receptors were assumed to be similar to the levels at the boundary, as this was the sampling location nearest to the sensitive receptors.

The dust concentration would have been an interesting factor to be considered in this study, as some of the operations at the dumpsite (spreading, tipping and compaction of waste) that emits the highest dust concentration were also associated with the bioaerosol emission. Furthermore, since there is already an established relationship between cell count and dust particle abundance, collection of such data would have provided a better picture of the biodiversity and survival mechanism of the bioaerosols (Stres *et al.*, 2013).

Another limitation in the study lies in the underestimation of the total exposure to bioaerosols due to the uncultivatable and non-viable fraction of airborne microorganisms; a weakness inherent in the use of the impaction sampling technique (HSE 2003; Persoons *et al.*, 2010). Hence, it could be concluded that the data reported for the ambient bioaerosol concentration may be an underestimation of the actual ambient concentration at Olusosun dumpsite.

5.3 Chapter Summary and key observations

This results presented in this chapter has shown that bioaerosols are emitted during operational activities at Olusosun dumpsite. The maximum ambient concentration of bacteria and fungi for this study were within magnitude of 10^3 cfu m^{-3}.

The concentration of bioaerosols were the highest in the active operational area of the dumpsite and decreased with increasing distance downwind of the point source. No significant differences in concentration across the four sampling points for total bacteria, gram-negative bacteria and the total bacteria were observed. However, *Aspergillus fumigatus* concentrations were observed to have decreased up to 80-81% between the source point and downwind at the boundary.

Relative humidity was the most influential meteorological factor of the three factors considered in this study. The effect of season changes on the concentration of bioaerosols was minimal as no significant differences were observed in the concentrations between the end of the dry season and peak of the wet season.

Of the three activities examined, scavenging had the highest exposure concentration to bacteria, while site monitoring recorded the highest for *Aspergillus fumigatus*. Bioaerosol exposure concentration from all three activities ranged between 10^4 -10^6 cfu m^{-3}, which was 2-3 log higher than the ambient concentration. These activities required close proximity of the workers to the task which are point sources of bioaerosol emission.

Overall, ambient concentrations of bacteria exceeded the occupational exposure limits for UK Environment Agency, however fungi concentration were below the expected exposure limit. Exposure from all three activities assessed in this study (scavenging, waste sorting and site monitoring) exceeded the acceptable exposure limits by the UK Environment Agency by 2-4 log. Exposure concentration of this magnitude are hazardous to the health of the workers at the dumpsite.

Size distribution of bioaerosols at Olusosun dumpsite

Chapter 6: Introduction

6.1 This chapter reports on the distribution of particle sizes in the ambient air samples and bioaerosols at activity sites. The particle size distribution of the bioaerosols was analysed initially and then an exposure assessment was carried by relating bioaerosol particle size to the typical tidal volumes inhaled by humans. Samples were collected using a six-stage Anderson impactor sampler, a sampler designed to mimic the human respiratory system, and with six discrete collection stages, it captures progressively smaller particles. Stage 1 at the top represents the upper respiratory tract, while stage 6 at the bottom represents the lower respiratory tract and alveoli. Bioaerosols are deposited out onto separate agar plates at each of the six stages (Jensen *et al.*, 1992; Tisch Environmental Inc. 2018). Particles considered to be within the inhalable fraction with an aerodynamic diameter >4.7 µm are deposited in stages 1 and 2 and represent those that will undergo deposition in the nasal area. Those deposited onto stages 3 and 4 (thoracic fraction with an aerodynamic diameter 2.1 - 4.7 µm) represents those that will undergo bronchial deposition, while deposition in the alveoli is represented in stages 5 and 6 (respirable fraction with an aerodynamic diameter < 2.1 µm) (Andersen 1958; HSE 2003, 2014). In this study, the respirable band is considered for particles size range < 3.3 µm i.e. stage 3 and below, as there are chances that particles with grater aerodynamic diameter could still penetrate to the this region of the lungs in some instances (WHO 1999). The results are presented as the percentage of the total number of bioaerosols that fall into each size. The final sections include a discussion of the possible exposure impacts associated each indicator microorganism measured in this study.

6.2 Particle size distribution of bioaerosols in the ambient air at various locations around the Olusosun dumpsite

Size separation of bioaerosols was measured in the ambient air from each sampling location, and the results were classed into six size ranges according to the six- stages of the Anderson sampler as described in section 6.1. Data were collected on the presence of total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi particles.

The differences in bioaerosols particle size distribution from each sampling location as tested using a one-way ANOVA for dataset that were normally distributed. The Kolmogorov-Smirnov test for normality showed that the dataset for total bacteria and gram-negative bacteria were normally distributed ($p > 0.05$) while *Aspergillus fumigatus* and total fungi were not ($p < 0.05$). Because the data for *Aspergillus fumigatus* and total fungi were not normally distributed, a Krustal-Wallis test (instead of ANOVA) was conducted to determine if the difference in particle size distribution were significant. The dataset for total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi were homogeneous for most sampling locations except, total bacteria at entrance ($p< 0.05$), as assessed by Levene's test of equality of variance. In cases where there were significant differences between the particle sizes in the size distribution, further analysis using Post Hoc Test was carried out to establish the point of difference.

6.2.1 Total bacteria

Figure 6-1 presents the particle size distribution of total bacteria from the four sampling locations across the dumpsite. The analysis showed the potential for a high level of penetration to the lower respiratory tract of larger diameter bacteria. Up to 41% of the total bacteria sampled in the ambient air were < 3.3 µm, the size range capable of depositing beyond the bronchial region of the lower respiratory tract when inhaled, therefore of more concern regarding respiratory diseases.

The one-way ANOVA showed that the differences in the particle size distribution of total bacteria measured at the active area were not significant [$F (5, 72) = 1.657$, $p> 0.05$]. Moreover, the proportion of total bacteria that were of respirable size (<3.3 µm) was 41%. The workers exposed to these particles were scavengers and waste sorters commonly seen working at this location.

The result of the one–way ANOVA for the other three sampling locations indicated that there were significant differences between the size classes for samples of total bacteria collected at the entrance [Welch's $F(5, 32.925) = 7.174$, $p < 0.0005$], dormant area [$F(5, 72) = 2.387$, $p < 0.05$] and boundary [$F(5, 72) = 2.777$, $p < 0.05$]. Further analysis of the size distribution using a Post Hoc test shows that:

i. At the entrance, the concentration of bacteria with a particle size of > 7 µm, 4.7- 7 µm and 2.1-3.3 µm was significantly higher in the ambient air compared to the concentration of a smaller size range 0.65-2.1 µm. Meaning a higher proportion of bacteria with larger diameters were being inhaled by the workers, and were capable of being deposited in the bronchial region of the lower respiratory tract. However, the proportion of total bacteria of a size capable of penetrating deep beyond the bronchial region to alveoli (< 3.3 µm) was 35% of the total bacteria sampled. The waste workers/banks men directing the waste trucks into the dumpsite premises were the ones majorly at risk of exposure.

ii. At the dormant area and boundary, the difference laid between stage 1 (>7 µm) and stage 6 (0.65 µm). Implying that there were significantly higher number bacterial particles of diameter > 7 µm compared to those smaller diameter ranges between 0.65-1.1 µm. Overall, the result show that there were higher proportion of larger diameter bacteria that were inhaled by the waste sorters, middlemen and business owners commonly found working at this location of the dumpsite. Furthermore, the proportion of total bacteria of size capable of penetrating deep into to alveoli (< 3.3 µm) at the dormant area and boundary were 36.7% and 37% respectively (Figure 6-1).

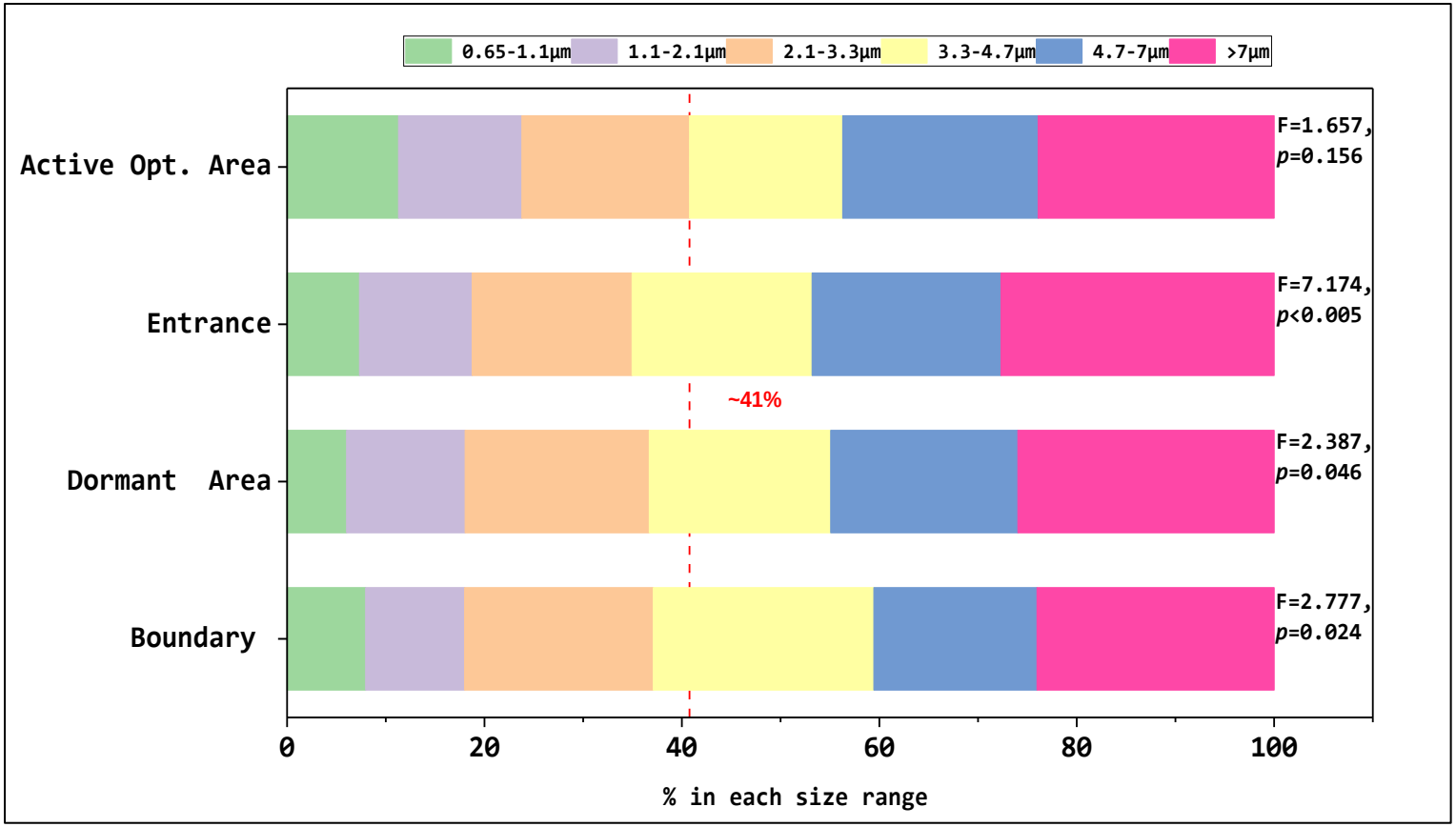

Figure 6-1: Particle Size Distribution of Total Bacteria in the ambient at Olusosun dumpsite

6.2.2 Gram negative Bacteria

Figure 6-2 presents the particle size distribution of gram-negative bacteria from the four sampling locations across the dumpsite. The analysis showed a high level of penetration to the lower respiratory tract of larger diameter gram-negative bacteria. The result further confirms that proportions up to 46% of total bacteria sampled in the ambient air were < 3.3 µm, size range capable of depositing beyond the bronchial region of the lower respiratory tract when inhaled.

The one-way ANOVA showed that, within sample locations, there were no significant differences in the particle size distribution of gram-negative bacteria; active operational area [$F(5,72) = 1.132$, $p > 0.05$], dormant area [$F(5,72) = 4.519$, $p > 0.05$] and the boundary [$F(5,72) = 0.714$, $p > 0.05$].

However, the result of the one–way ANOVA carried out on the sampled data at the entrance indicated that there were significant differences between the size classes [$F(5, 72) = 5.872$, $p < 0.005$]. Further analysis of the size distribution using a Tukey's Post Hoc Test shows that gram-negative bacteria with an aerodynamic diameter > 2.1 µm were significantly higher at the entrance compared to those with diameter ranging 0.64-1.1 µm. This means that a higher proportion of gram-negative bacteria with larger diameter were being inhaled by the workers at this location. This proportion were capable being deposited in the bronchial region of the lower respiratory tract when inhaled. However, the proportion of total bacteria of size capable of penetrating deep beyond the bronchial region to alveoli (< 3.3 µm) was 38% of the gram-negative bacteria sampled.

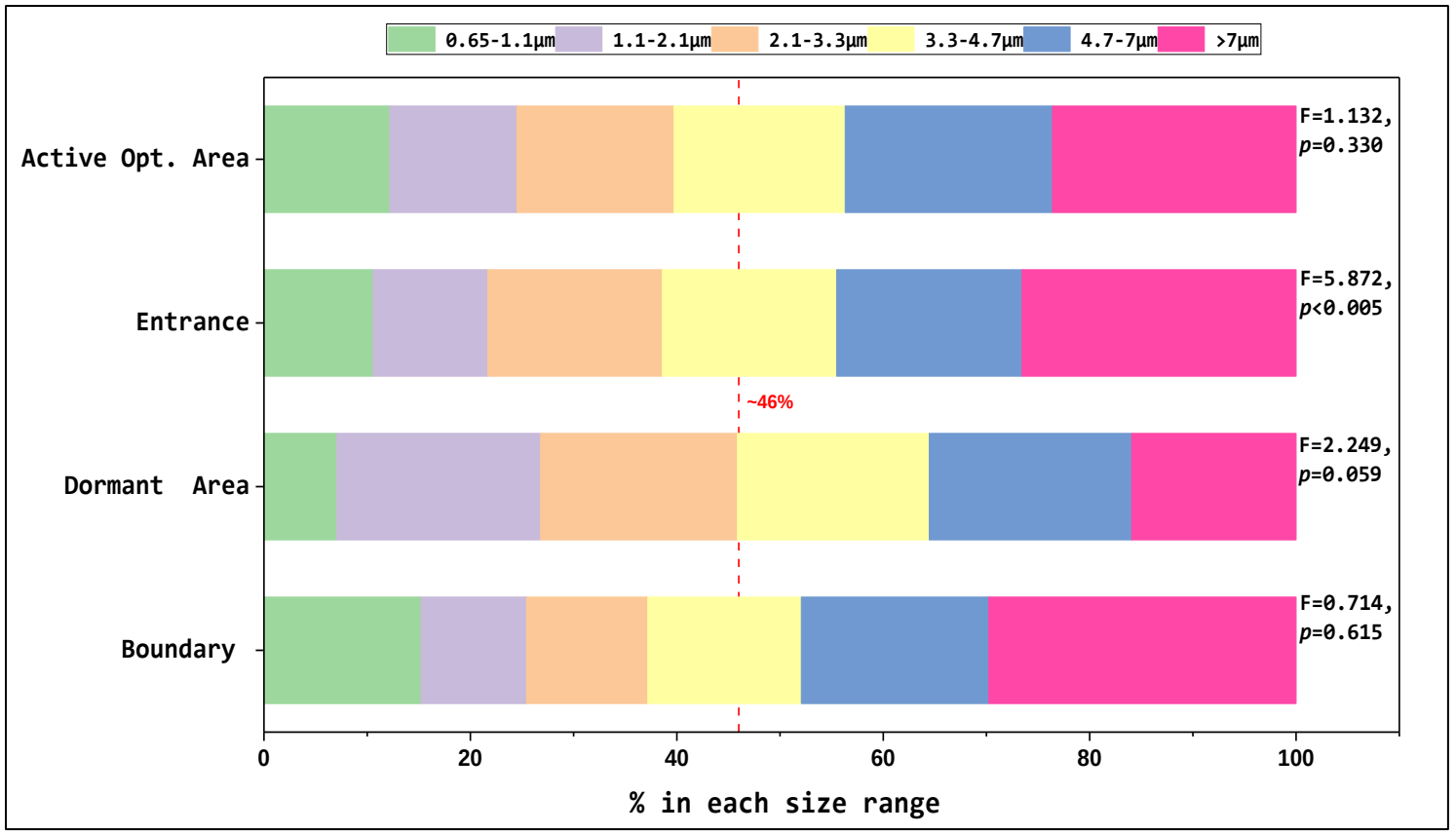

Figure 6-2: Particle Size Distribution of Gram negative bacteria from four sampling locations at Olusosun dumpsite

Aspergillus fumigatus

6.2.3 Shown in Figure 6-3 are the particle size distribution of *Aspergillus fumigatus* from the four sampling locations across the dumpsite. The analysis showed a high level of penetration to the lower respiratory tract of smaller diameter spores of *Aspergillus fumigatus*. The proportions that were of respirable size (<3.3 µm) were up to 76% of the overall samples of *Aspergillus fumigatus* collected in the ambient air.

A Kruskal-Wallis Test of the sample data collected indicated there were significant differences between the particle size classes within the four sample locations; active operational area $\chi^2(5) = 17.705$, $p = 0.003$; entrance $\chi^2(5) = 17.094$, $p = 0.003$; dormant area $\chi^2(5) = 23.647$, $p < 0.0005$; boundary $\chi^2(5) = 15.214$, $p = 0.009$. Pairwise comparison of the data shows that:

i. At the active operational area, *Aspergillus fumigatus* with a size of range 1.1-2.1 µm were significantly higher compared to those with diameter range 4.7-7 µm ($p = 0.009$) and > 7 µm ($p = 0.018$). The implication of this finding is that a higher proportion of *Aspergillus fumigatus* with smaller diameters were being inhaled by the workers at this location. The workers exposed to these particles were scavengers and waste sorters. Moreover, the proportion of *Aspergillus fumigatus* sampled at this location capable of penetrating deep into to alveoli (1.1-2.1 µm inclusive) was 76%.

ii. At the entrance, *Aspergillus fumigatus* with a size of range 1.1-2.1 µm were significantly higher compared to *A. fumigatus* with a diameter > 7 µm ($p < 0.032$). Similar to the active area, a higher proportion of *Aspergillus fumigatus* with smaller diameter were being inhaled by the workers at this location which were mostly waste workers and banksmen directing the waste trucks into the dumpsite premises and these were the ones majorly at risk of exposure at this location. However, no significant differences were noticed between other particle size classes. Furthermore, the proportion of *Aspergillus fumigatus* of a size capable of penetrating deep into to alveoli (< 3.3 µm) at the entrance was 67%.

iii. At the dormant area, smaller diameter *Aspergillus fumigatus* < 3.3 µm were significantly higher in the air samples compared to those between 4.7-7 µm ($p<0.002$). The implication were similar to what has been stated in i and ii above. The proportion of *Aspergillus fumigatus* of size capable of penetrating deep into to alveoli (< 3.3 µm) at the entrance was 72%.

iv. At the boundary of the dumpsite, smaller diameter *Aspergillus fumigatus* with a size range 1.1-2.1 µm were significantly higher in the air samples compared to those ranged 4.7-7 µm (p<0.008). Although, the result shown Figure 6-3 suggest the presence of higher particles of 4.7-7 µm at the boundary, the overall mean of the samples from the 13-sampling visits was smaller, and is consistent with the statistic. The skewed graph is the result of the air sample from on visit day-3 (12/05/2017) where of *A. fumigatus* of size range 4.7-7 µm were measured in high concentration, and was a onetime occurrence. The middlemen and business owners and food vendors were the workers majorly at risk of exposure at this location.

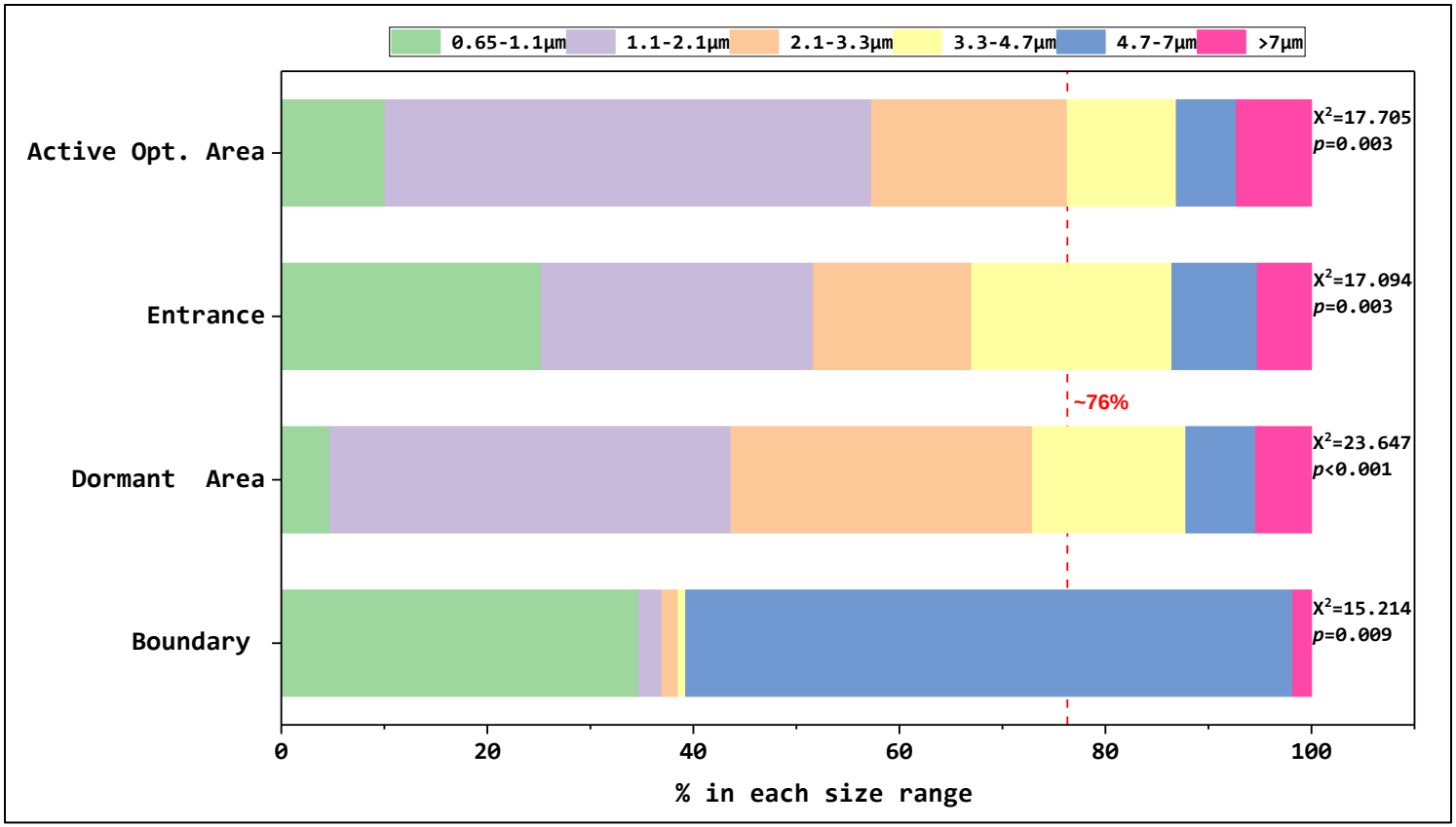

Figure 6-3: Particle size distribution of Aspergillus fumigatus at the four sampling locations at Olusosun dumpsite.

Total Fungi

6.2.3.1 Figure 6-4 shows a graphical representation of the particle size distribution of total fungi from the four sampling locations across the dumpsite. The analysis showed a high level of penetration to the lower respiratory tract of smaller diameter of spores of total fungi. The proportions that were of respirable size (<3.3 µm) were up to 63% of the overall samples total fungi collected in the ambient air.

Similar to the result obtained for *Aspergillus fumigatus*, the Kruskal-Wallis test conducted on the sampled data, indicated that there were significant differences in the particle size distribution at the four sampling locations; active operational area, χ^2 (5) = 18.141, p = 0.003; entrance, χ^2 (5) = 16.2774, p = 0.006; dormant point χ^2 (5) = 18.474, p = 0.002; boundary χ^2 (5) = 15.337, p = 0.009. Furthermore, a pairwise comparison of the data showed that:

i. At the active operational area, Total fungi with a size of range 1.1-2.1 µm were significantly higher compared those with a diameter 4.7-7 µm (p = 0.032). The implication of this finding is that a higher proportion of total fungi with smaller diameters were being inhaled by the workers at this location which were mostly waste workers/banks men directing the waste trucks into the dumpsite premises. Moreover, the proportion of Total fungi sample at this location capable of penetrating deep into to alveoli (1.1-2.1 µm inclusive) was 62%.

ii. At the entrance, total fungi with a size of range 1.1-2.1 µm and 2.2-3.3 µm were significantly higher than those with a diameter 0.65-1.1 µm with p = 0.012 and p = 0.013 respectively. The finding shows that total fungi with a smaller diameter that were < 3.3 µm made up largely the proportion of fungi inhaled by the workers and banksmen directing the waste trucks into the dumpsite premises seen working at this location. Furthermore, the proportion of Total fungi of size capable of penetrating deep into to alveoli (< 3.3 µm) at the entrance was 63%.

iii. At the dormant area, smaller diameter total fungi range of 2.1-3.3 µm were significantly higher in the air samples compared to those of larger diameter range 4.7-7 µm (p=0.032). The implication of the result shows that smaller diameter total fungi of respiratory size were being inhaled by the waste sorters, middlemen and business owners commonly found working at this location. Furthermore, the

proportion of total fungi of size capable of penetrating deep into to alveoli (< 3.3 µm) at the dormant area was 62%.

iv. At the boundary of the dumpsite, smaller diameter total fungi with a size range 1.1-2.1 µm were significantly higher in the air samples compared to those ranged 4.7-7 µm ($p=0.03$). Although, the result shown Figure 6-3 suggest the presence of higher particles of 4.7-7 µm at the boundary, the overall mean of the samples from the 13-sampling visits was smaller, and is consistent with the statistic. The skewed graph is the result of the air sample from on visit day-3 (12/05/2017) where of total fungi of size range 4.7-7 µm were measured in high concentration, and was a onetime occurrence. The middlemen, business owners and food vendors were the workers majorly at risk of exposure at this location.

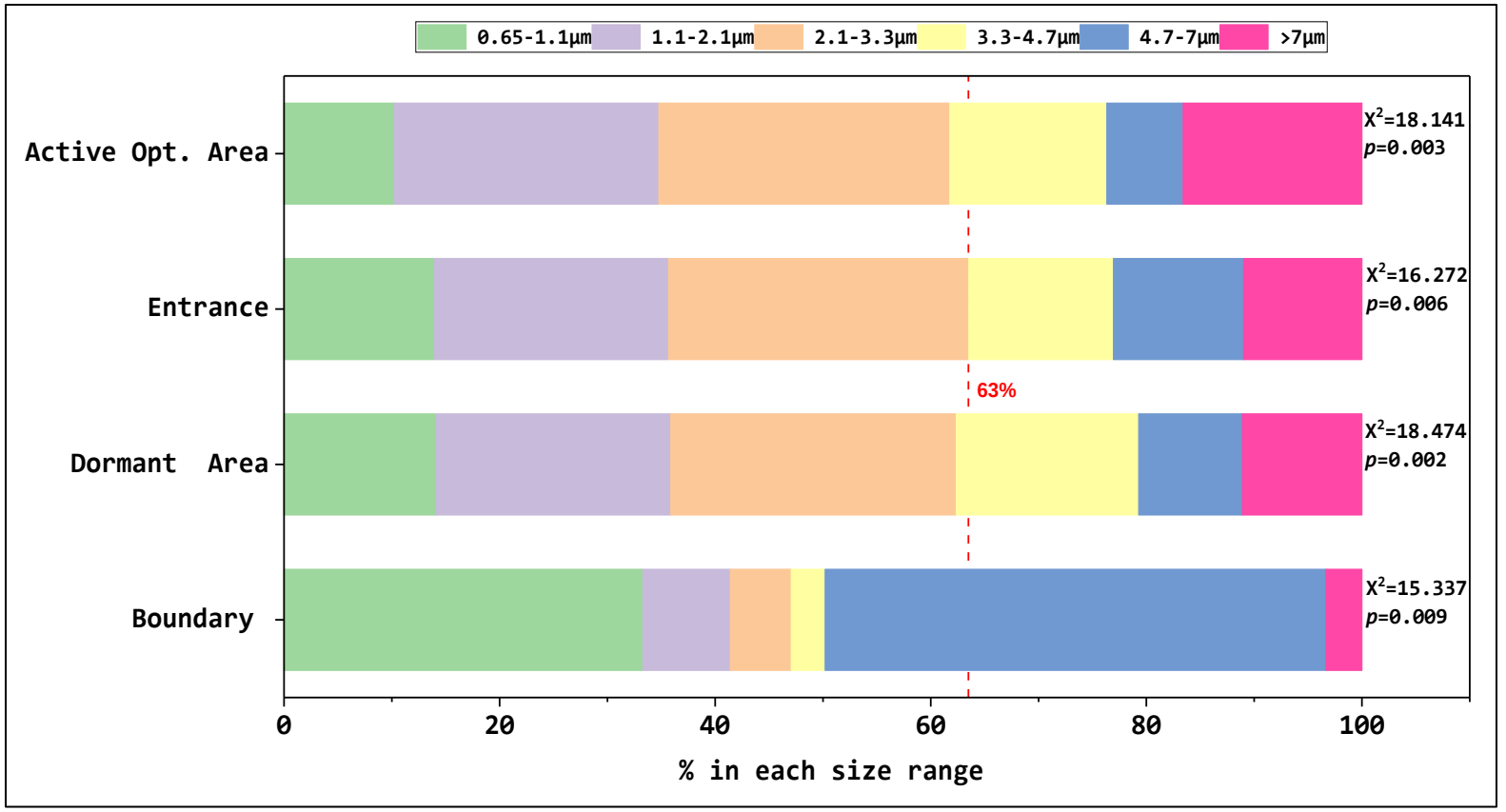

Figure 6-4: Particle size distribution of total fungi at the four sampling locations at Olusosun dumpsite

6.3 Size distribution of bioaerosols emitted from activities carried out at Olusosun dumpsite

Featured in this section are the size separation of bioaerosols measured during specific activities carried out at the dumpsite including scavenging, waste sorting and site monitoring. Data were collected on the presence of total bacteria, gram-negative bacteria, *Aspergillus fumigatus* particles and the results classed in six size ranges, the size associated with the six-stages of the Anderson sampler. Sections 5.2.4 and 5.3.5 have previously discussed the bioaerosol concentrations and resulting exposure from these activities. This sections highlights the particle size distribution (percentage) for each indicator microorganism in relation to the specific activity examined in this study.

6.3.1 Scavenging

Shown in Figure 6.5 A and B is the graphical description of the particle size distribution exposure concentration of total bacteria, gram-negative bacteria and *Aspergillus fumigatus* sampled during scavenging activities. Scavenging is associated with a higher level of total and gram-negative bacteria with larger diameter penetrating to the lower respiratory tract, unlike *Aspergillus fumigatus* where lungs penetration are largely of smaller diameter.

The particle size distribution showed total bacteria were predominantly composed of sizes within ranges > 7 µm (27%) while the 1.1-2.1 µm being the lowest (11%). Total bacteria that were of a respirable size (0.65-3.3 µm) were up to 48%, translating to total bacteria concentration up to 5.79×10^5 cfu m^{-3}. This proportion were capable of penetration beyond the bronchial region into the alveoli in the pulmonary region of the lungs.

Gram-negative bacteria on the other hand were comprised predominantly of bacteria with an aerodynamic diameter range 2.1-3.3 µm (21%). The cumulative percentage gram-negative bacteria with aerodynamic diameter of respirable size was 48%, thereby translating to concentrations up to 1.44×10^6 cfu m^{-3} that would have been inhaled by the scavengers while working at the dumpsite.

The particle size distribution for *Aspergillus fumigatus* was highly disproportionate compared to the result for total bacteria and gram-negative bacteria. It was comprised largely of smaller *Aspergillus fumigatus* particles of which the size range 1.1-2.1 µm were predominant in the air sample. Furthermore, the particles of respirable size range were up

to 87%, thereby translating to concentrations up to 5.82×10^{4} cfu m^{-3} that would have been inhaled by the scavengers while working at the dumpsite.

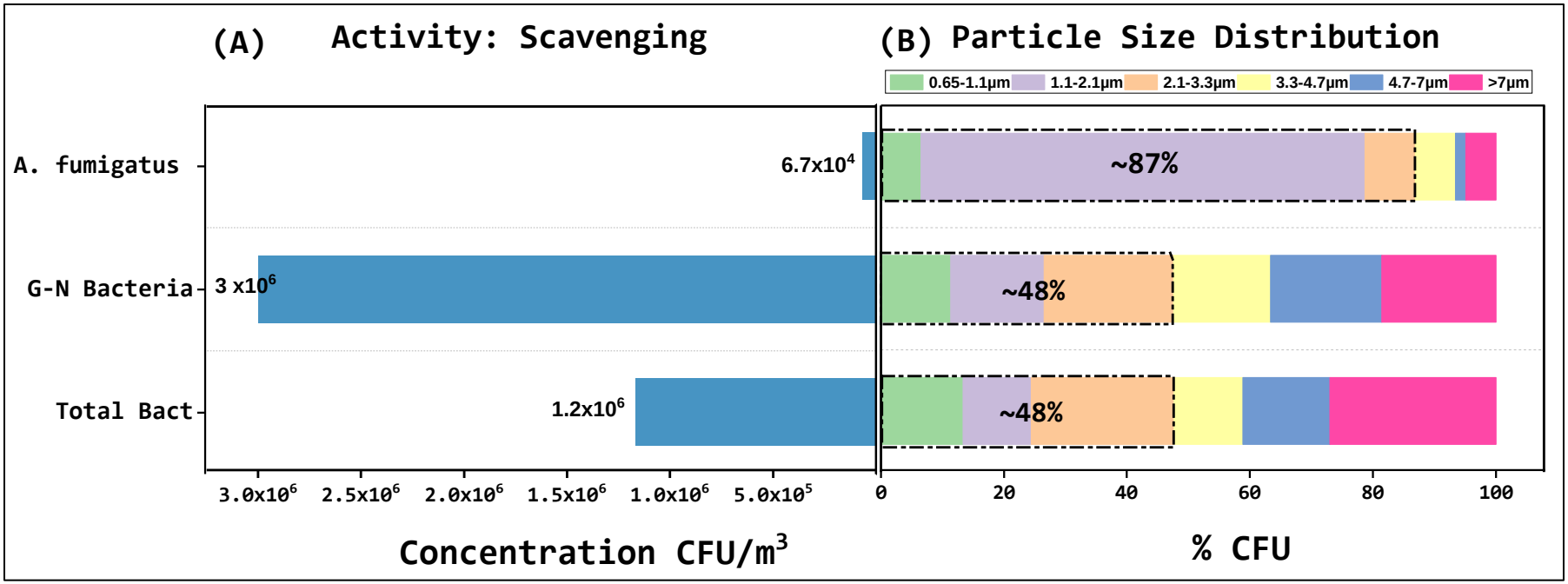

Figure 6-5: Bioaerosol concentration (A) and particle size distribution (B) emitted during scavenging activity at Olusosun dumpsite

Waste sorting

6.3.2 Shown in Figure 6.6 A and B is the graphical description of the particle size distribution exposure concentration of total bacteria, gram-negative bacteria and *Aspergillus fumigatus* sampled during waste sorting activities. This activity is associated with a higher level of total and gram-negative bacteria with larger diameter penetrating to the lower respiratory tract, unlike *Aspergillus fumigatus* where lungs penetration composed largely of smaller diameter.

The particle size distribution showed total bacteria with aerodynamic diameter range of 4.7-7 µm were predominant (33%), while the size range 0.65-1.1 µm was the least (3%). Total bacteria that were of respirable size (0.65-3.3 µm) were up to 36%, thereby translating to concentration up to 1.72×10^{5} cfu m^{-3} inhaled by the waste sorters, capable of penetration beyond the bronchial region the alveoli in the pulmonary region of the lungs.

Gram-negative bacteria on the other hand composed of bacteria with sizes that were in close proportion. However, bacteria of aerodynamic diameter > 7 µm were highest (31%) while the size range 0.65-1.1 µm was the lowest (9%) in the air sample. Moreover, the cumulative percentage gram-negative bacteria with aerodynamic diameter of respirable size was 33%, thereby translating to concentrations up to 5.61×10^{4} cfu m^{-3} inhaled by the waste sorters while working at the dumpsite.

In a similar way to the trends observed for scavenging activity, the size distribution of *Aspergillus fumigatus* showed that the *A. fumigatus* with smaller diameter 1.1-2.1 µm, were predominant (41%), while those with larger diameter were lower, with size >7 µm being the lowest (1%) in the air sample. Furthermore, the particles of respirable size range were up to 75%, translating to concentration up to 6.75×10^{4} cfu m^{-3} of *Aspergillus fumigatus* inhaled by the waste sorters while working at the dumpsite.

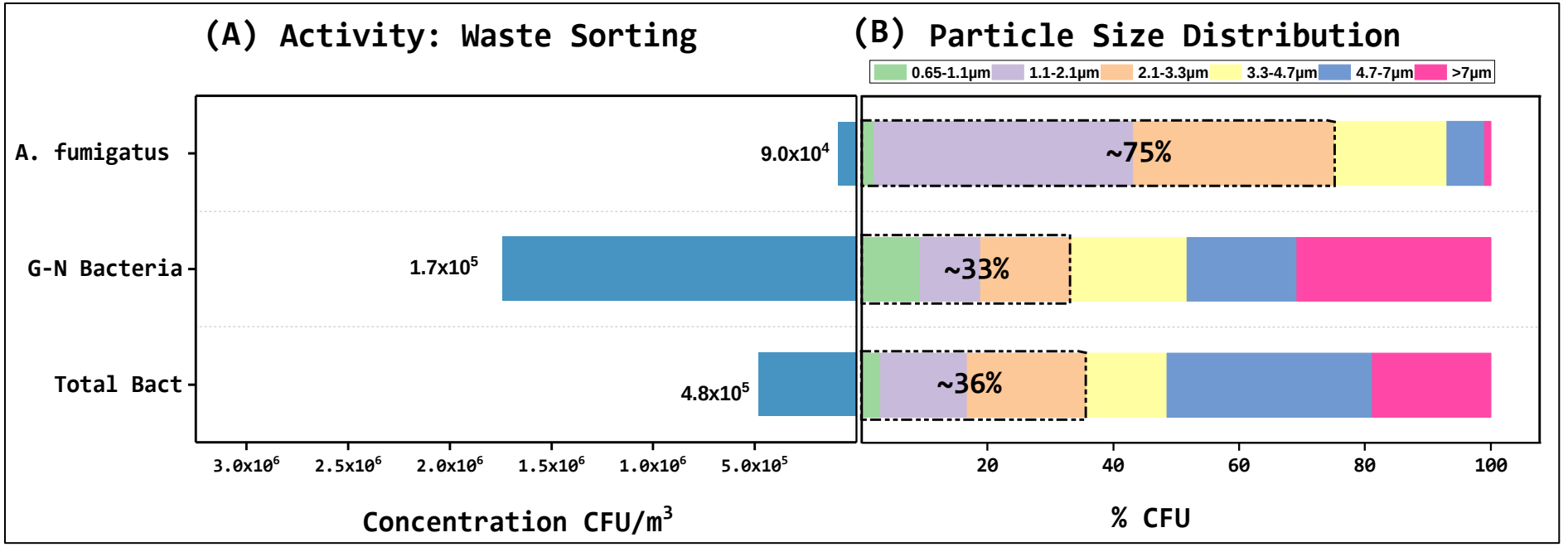

Figure 6-6: Bioaerosol concentration (A) and particle size distribution (B) emitted during Waste sorting activity at Olusosun dumpsite

Site monitoring

6.3.3 Figure 6.7 A and B shows a particle size distribution exposure concentration of total bacteria, gram-negative bacteria and *Aspergillus fumigatus* sampled during waste sorting activities at the dumpsite. This activity is associated with greater proportion of total and gram-negative bacteria with larger diameter penetrating to the lower respiratory tract, unlike *Aspergillus fumigatus* where lungs penetration composed largely of smaller diameter.

The particle size distribution for total bacteria indicates that total bacteria with a size range >7 µm (40%) were predominant, while the size range 3.3-4.7 µm was the least (6%). The cumulative percentage of total bacteria of respirable particle size (<3.3 µm) was 41%, thereby translating to concentration up to 2.46×10^4 cfu m^{-3} cfu m^{-3} inhaled by the waste workers, capable of penetration beyond the bronchial region the alveoli in the pulmonary region of the lungs.

Gram-negative bacteria during measured during site monitoring activity composed bacteria with aerodynamic diameter > 7 µm (25%), while the particle size range 2.1-3.3 µm was the lowest (7%). The cumulative percentage of gram-negative bacteria of respirable size was 34%, of which those of aerodynamic diameter 0.65-1.1 µm made up 20%. Thus, the concentration of gram-negative bacteria that would have been inhaled by the waste workers was 7.1×10^4 cfu m^{-3}.

In a similar way to the trends observed for scavenging and waste sorting activities, the particle size distribution of *Aspergillus fumigatus* during site monitoring activities was highly disproportionate compared to the result for total bacteria and gram-negative bacteria. *Aspergillus fumigatus* with aerodynamic diameter 1.1-2.1 µm were predominant (77%) while particles with aerodynamic diameter 3.3-4.7 µm were the lowest (1%). Cumulative percentage of *Aspergillus fumigatus* of respirable size (0.65-3.3 µm) was 89%, translating to concentration up to 2.67×10^5 cfu m^{-3} of *Aspergillus fumigatus* inhaled by the waste workers carrying out site monitoring activities at the dumpsite.

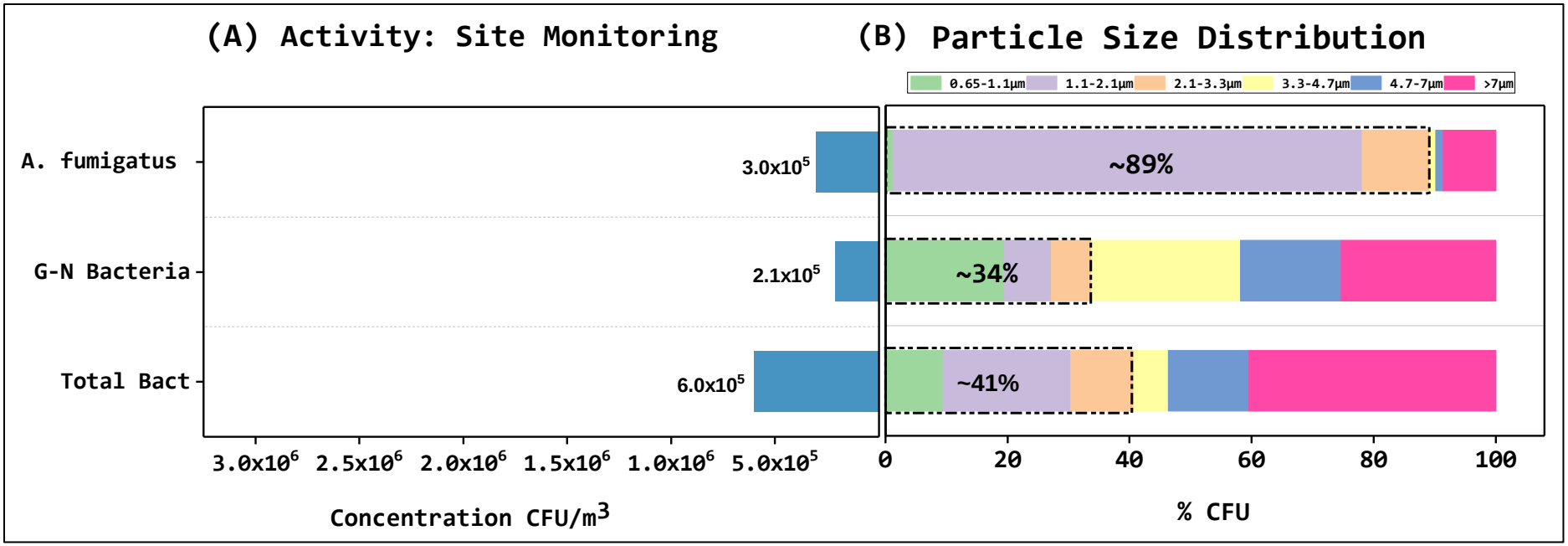

Figure 6.7: Bioaerosol concentration (A) and particle size distribution (B) emitted during Site monitoring activity at Olusosun dumpsite

Discussion of the findings

Bioaerosol particle size distribution in ambient air

6.4

6.4.1 The results of the air sampling at the dumpsite confirms that activities which result in agitation of the waste, are associated with a higher concentration of particulates in the air as well as an alteration in the distribution of the different particle sizes. The results suggest that proximity to the site is likely to be associated with a higher rate and an altered distribution of particulate deposition in the human respiratory tract (Haas *et al.*, 2013; Gao *et al.*, 2015). Brągoszewska *et al.*, (2017) and Ferguson *et al.*, (2017) observed that bioaerosols exist either as single cells or agglomerates depending on the season and the meteorological conditions at the time of sampling. Their existence in an aggregated form, they argued, are likely responsible for their settlement in the upper stages (aerodynamic diameter > 3.3 µm) of the Anderson sampler either as aggregates of cells, cells associated with water droplets or dust particles. Moreover, high relative humidity can further increase both the size and weight of the particle from absorption of ambient moisture. A phenomenon that favours large deposition within the upper stages of the Anderson sampler as observed in this study for total bacteria (~59%) and gram-negative bacteria (~54%) (Gao *et al.*, 2015; Liu *et al.*, 2015; Smets *et al.*, 2016). This is perhaps not surprising as the multiple regression carried out in this study showed that, of the three metrological factors tested, only relative humidity showed a statistically significant

6.4.2 association with the overall concentration of bioaerosols ($p < 0.01$), especially total bacteria [$F(3, 48) = 4.140$, $p < 0.05$, adj. $R^2 = 0.156$].

Patterns in bioaerosols particle size distribution from point source

In this study, as shown in Figure 6-1 and 6-2, the differences in the percentage of the total particles measured in each of the size ranges for total bacteria and gram-negative bacteria at the active operational area (point source) was not statistically significant ($p > 0.05$), indicating a relatively similar representation for all size ranges. However, as the particles travelled further away from the point source, a larger proportion of the particles measured were found to be in the larger size range (4.7-7 µm and >7 µm) which may indicate the presence of a larger number of aggregated cells as observed at the entrance, the dormant area and the boundary. This difference was shown in the progressive reduction in the proportion of particles with a size range of 0.65-1.1 µm compared to >7 µm, suggesting bacterial aggregation, which is a survival behaviour in response to the influence of meteorological factors (Amato *et al.*, 2015). This representation appears counter intuitive,

as the larger particle was expected to have settled out with distance, however, it could be that at the distance where the bioaerosols were measured, the particles had not reached settling velocities (Owen *et al.,* 1992). Brągoszewska *et al.,* (2017) observed that bacteria behaved in a similar way in their study, and attributing such to the influence of UV on the single bacterial cells. They further explained that the single bacterial cells made up the bulk of the bacterial particles with aerodynamic diameter <3.3 µm and they represented < 50% of the bacteria population. This finding is comparable to the results in this study, as the proportion of total bacteria and gram-negative bacteria with an aerodynamic diameter <3.3 µm were < 50% of the total number measured (Figure 6-1 and 6-2).

At the boundary of the dumpsite, the proportion of total bacteria and gram-negative bacteria that comprised of the particles with an aerodynamic diameter <3.3 µm were similar to those measured at the point source. For total bacteria, this proportion represented 40.8% at the point source and 37.1% at the boundary (difference: 3.68 percentage points). While for gram-negative bacteria, the portion represented 39.8% and 37.1% at the point source and the boundary respectively (difference: 2.68 percentage points). This result suggests that although there might have been increases in the number of aggregated cells forming larger class sizes and reduction effects through UV radiation from the sun, the proportion of bacteria particles within the respiratory size did not change much. This phenomenon is not surprising as the settling time for bioaerosols largely depend on the particle size, and particles with a diameter < 3 µm essentially do not settle (Tellier 2006). Hence, an associated a health risk from exposure to this class size of bacterial particles by the residents living beyond the boundary is likely, as this particle size would have travelled longer before settling.

The size distribution of total bacteria during the dry and wet season were measured in visit days 1 – 6 and 7 – 13 respectively, hence representing a seasonal variation in the particle size distribution at Olusosun (see Figure C-1). The proportion of particles of respirable size were observed to be relatively uniform and generally less than 50% for visit days 1-6 for all sampling locations except for visit day 5 at the boundary, which recorded this proportion to be up to 80.4%. The reason for this singular surge is not exactly clear, however, a higher concentration was also observed for the total fungi (74%) for the same sampling location and visit day (see Figure C-2). It is also interesting that the results of the sampling visits 7, 8 and 9 (recorded a marginal increase in the percentage

of respirable particles. This is not surprising as this period marked the beginning of the raining season for that year, typically characterised by frequent rains and lower atmospheric temperature. During the wet season, UV radiation, compared to the dry season gradually loses importance as a bactericidal factor, hence the potential increase in the number of single cells of respirable size and slower growth in microorganism preferring to form agglomerates (Brągoszewska *et al.,* 2017). Overall, the difference in the percentage point between the dry and wet season for all sampling locations is only marginal and may not be of much consequence to the exposure levels of particles of total bacteria of respirable size during the two seasons.

According to Figure 6-3 and 6-4, the differences in the size distribution for *Aspergillus fumigatus* and total fungi for all sampling locations were statistically significant ($p<0.05$). As for *Aspergillus fumigatus,* the size distribution was characterised by the predominance of fine particles (≤3.3 µm) compared to the larger size classes. A stepwise reduction in the proportion of particles with larger diameter (i.e. ≥ 3.3 µm) was observed as the particles travelled further away from the point source (i.e. active operational area) to the dormant area. This behaviour suggest that spores of *Aspergillus fumigatus* exist largely as single cells, a finding that is consistent with what was reported by Deacon *et al.,* 2009. They also postulated that mould spores may have an adaptation to minimise the odds of agglomeration in order to favour greater airborne travel distance. This behaviour is different from what was observed with total bacteria and gram-negative bacteria, where there appeared to be more agglomeration of bacterial particles as they travelled further away from the point source. This result goes some way to confirm that given a similar environmental condition, bacteria and mould behave differently to enable them to survive environmental stress (Jones and Harrison 2004). The diameter of *Aspergillus fumigatus* conidia is typically 2-3.5 µm, thereby placing them in the stages with pore size range 1.1-2.1 µm and 2.1-3.3 µm of the Anderson six stage sampler (Cole and Samson 1984; Webster and Weber 2007). It was then not surprising that these size ranges accounted for the majority of *Aspergillus fumigatus* collected within the dumpsite (Active area = 66%, Entrance= 41%, dormant 68%), thereby contributing to the overall proportion of particle of respirable size up to ~76% (see Figure 6-3). It is not uncommon to record large proportions of *A. fumigatus* of respirable range, as similar size ranges have previous been reported in high proportion from composting facilities and in outdoor air (Reinthaler *et al.*, 1997; Deacon *et al.*, 2009; Yamamoto *et al.*, 2012).

The size distribution for total fungi was similar to that of *A. fumigatus*, where a progressive reduction in the mean concentration of fungi particles >3.3 µm as they travelled further from the point source were observed (see Figure 6.4). At the boundary, the statistical analysis of the data showed that the mean concentration of particles of 1.1-2.1 µm was higher compared to those of 4.7-7 µm (p = 0.03). This can be explained by the fact that a large volume of green waste was tipped close to the boundary two days before the sampling visit day-3. This singular event was a one-off, yielding high concentrations of total fungi and was characterised by the presence of high levels of organic dust, hence the high percentage of coarse particles shown in Figure 6.4. With the proportion of total fungi with aerodynamic diameter < 3 µm at 63%, the exposure to single cell pathogenic mould such as *Aspergillus* spp. and *Penicillium* spp. commonly isolated in such environment are very likely (Nielsen *et al.*, 1995; Lis *et al.*, 2004; Webster and Weber 2007; Epstein 2015).

In a similar fashion to total bacteria, the size distribution of total fungi during the dry and wet seasons is depicted in visit days 1 – 6 and 7 – 13 respectively, as shown in Figure C-3. However, in this case, the data showed that particles of respirable size were greater than 50% on most sampling days irrespective of the season. High relative humidity and frequent rains typically characterize the wet seasons in Nigeria, consequently favouring short setting times and wet deposition of airborne particles (Jones and Harrison 2004). However, with adequate physical disturbance (or vibration) and threshold wind speed >0.5 m s^{-1}, spores of *Aspergillus fumigatus* and *Penicillium* spp. can be removed from attached surfaces (Pasanen *et al.*, 1991). In this study, a maximum and minimum wind speed was recorded as 4.2 and 1.2 m s^{-1} respectively. Coupled with the frequent agitation activities at the dumpsite, the data showing a large proportion of particles of respirable size was not a surprise, as the majority of fungi species do not have mucilaginous layers, which aids agglomeration during dispersion (Geagea *et al.*, 1997).

6.4.3

Bioaerosols exposure assessment

Bioaerosols emissions into ambient air at Olusosun dumpsite is primarily due to tipping, spreading and compacting of MSW brought to the dumpsite. However, due to the low-level of agitation associated with the scavenging, waste sorting and dumpsite monitoring activities, exposure to bioaerosol emitted from these activities is mainly due to the close interaction with the waste. Similar to the result of bioaerosols particle size distribution in ambient air (see section 6.5.2), the proportion of bioaerosols emitted during scavenging,

waste sorting and dumpsite monitoring that were of respirable size were was generally less than 50% for total bacteria and gram-negative bacteria and greater than 50% for *A. fumigatus* (See Figure 6.5, 6.6 and 6.7).

Particles of inhalable fraction (i.e. > 4.7 μm) deposited in the nasal area and upper respiratory tract can usually be removed by the action of the nasal and tracheobronchial escalators, which is a combined mucociliary function of trapping deposited bioaerosol particles in mucus and removal by the action of cilia (Mason and Nelson 2005). In other words, these particles are likely to be removed by the body's natural defences. However, this does not happen when particles of respirable fraction (< 2.2 μm) get down in to the pulmonary region. Here the risk of infection is higher and the chances of removal is significantly less, which results in a higher potential for negative health impacts. (Yoshida and Whitsett 2004; Thomas 2013).

Considering the tidal volume in humans (the expected volume of air displaced during normal breathing) is approximately 7 mL/kg or 500 ml for a healthy young adult (Quanjer *et al.*, 1993; Ricard 2003). The respiratory rate of an active adult was placed at 17 breaths per minute (Erden *et al.*, 2015), for an 11-hours (mean) daily working period, the workers on the dumpsite may be inhaling approximately 5.61 m^3 of air. According to the results of this study, this air may contain approximately 3.68×10^7 cfu m^{-3} total bacteria, 1.68×10^7 cfu m^{-3} of gram-negative bacteria and 3.78×10^5 cfu m^{-3} of *Aspergillus fumigatus* during scavenging. Waste sorters may have inhaled 2.69×10^6 cfu m^{-3} of total bacteria, 9.54×10^6 cfu m^{-3} of gram-negative bacteria and 5.05×10^5 cfu m^{-3} of *Aspergillus fumigatus* during waste sorting and the waste workers may have inhaled 3.37×10^6 cfu m^{-3} of total bacteria, 1.18×10^6 cfu m^{-3} gram-negative bacteria and 1.68×10^6 cfu m^{-3} of *Aspergillus fumigatus* when carrying out site monitoring. Wouters *et al.*, (2005) in their study of the tasks carried out during waste collection, waste transfer and waste composting, indicated that bioaerosol exposure levels were mainly determined by the task, the task regime and how intensively the waste is disturbed during the task. Thus, the fact that scavenging recoding the highest exposure concentration of total bacteria is not surprising, as the task is mostly carried out during tipping and waste spreading, which is generally characterised by high waste disturbance (see Table 5-7).

There are no international threshold limit values (TLV) for occupational exposure to bioaerosols. Similarly there are no national standards in the UK (whose sampling

guidelines where adopted for this study). Malmros *et al.,* (1992) have suggested a TLV of 5×10^3 -10^4 cfu m^{-3} for waste workers within an 8-hour working period in the Netherlands. Thus, in comparison to this suggested TLV the exposure concentrations reported from the different tasks assessed in this study presents a potential health risk to the population working at the dumpsite, as these limits were exceeded for all tasks assessed in this study. Table 6-1 describes the likely bioaerosol concentration of respirable size inhaled by the population during an 11-hour working period on the dumpsite, especially resulting from engagement in various activities at the dumpsite. However, these values are representative of the maximum concentrations measured during this study, typifying the worst-case scenario. Moreover, the fact that a culture-based approach was used for the microbial analysis in this study may be a limitation, as the proportion of culturable bioaerosols in outdoor air is estimated to be < 10% (Blomquist 1994; Swan *et al.,* 2003; Ibanga *et al.,* 2018), with the remainder being either viable non-culturable cells or dead but intact cells, with potential human health concerns (Pearson *et al.,* 2015). Thus, in reality the results might be an underestimation of the actual bioaerosol concentration inhaled by the population at the dumpsite, as there is a possibility of not detecting other microbial species that would normally been considered in a human health assessment (Eduarda and Heederik 1998). Occupational exposure to bioaerosols may trigger several health symptoms, such as respiratory symptoms, skin irritation, itchy eyes and gastrointestinal symptoms (Bünger *et al.,* 2000; Hambach *et al.,* 2012; HSE 2013). In this study, we recorded the prevalence of chronic cough and chronic expectoration of phlegm among the workers at 36% and 34.6% respectively (See section 4.3.1). An indication of respiratory exposure to pathogenic bioaerosols of respirable size that may have penetrated deep into the lungs.

Several inhalation studies have investigated the effect of bioaerosols particle size on deposition patterns in the lungs and the lethal dose required to initiate an infection (Bartrand *et al.,* 2008; Weir and Haas 2011; Darquenne 2012). Although there are several animal models to this effect, no human studies exist for investigating this relationship (Thomas 2013; Dabisch *et al.,* 2017). The use of mouse models to demonstrate infection from *Aspergillus fumigatus* have been reported in literature, and that perhaps is because mice display pathological consequences similar to humans (Kupfahl *et al.,* 2006; Dagenais and Keller 2009). Sheppard *et al.,* (2004) administered a dose of 2.4×10^3 cfu/mouse of *Aspergillus fumigatus* conidia to immunocompromised mice, which

resulted in lethal pulmonary infection in most of the mice, surviving between 5 to 12 days. The data in this study suggests that scavengers for instance, are exposed on a daily basis to 2.3 x 10^5 cfu of *Aspergillus fumigatus* of respirable size (See Table 6), particles capable of deposition both the bronchial and pulmonary regions of the lungs. Although the exposure concentration from all three activities considered in the study were 2-log higher than reported by Sheppard *et al.*, (2004), in reality, considering the complex nature of the structure and defence mechanism of the human respiratory system, it is unlikely that a similar dose will be lethal to humans compared to mice (Dagenais and Keller 2009; Wéry 2014a). Furthermore, the majority (74%) of the members of the sampled population in this study had been living/working on the dumpsite for at least 10 years, thereby suggesting that the reported symptomatic effects of the exposure maybe chronic rather than lethal. Nonetheless, prolonged exposure and neutropenia will certainly increase the risk of developing invasive aspergillosis by exposed workers especially, those who may be immunocompromised. The common types of invasive aspergillosis are the acute or chronic pulmonary aspergillosis and tracheobronchitis (Latgé 1999). The probability of acquiring invasive aspergillosis is worsen for patients with existing obstructive lung diseases, such as asthma, chronic bronchitis and COPD, as higher bronchial deposition is usually observed in such patients (Kim and Kang 1997). This exposure to *A. fumigatus* which may not only lead to tracheobronchitis, but also cause poor ventilation of subtended lungs regions, thereby reducing the efficacy of inhalable drugs administered during treatment (ibid). In this study, both the workers on the dumpsite and the residents close to the dumpsite have reported chronic cough, asthma, chronic phlegm, which are all symptom that have been observed in previous occupation studies to be associated with exposure to pathogenic agents from solid waste treatment processes (Pearson *et al.*, 2015).

Table 6-1: Bioaerosol concentration of respirable size (<3.3 µm) inhaled per day at Olusosun Dumpsite

Variable	[a]Active operational Area	[a]Entrance	[a]Dormant Area	[a]Boundary	[a]Scavengers	[a]Waste sorters	[a]Waste workers
Total number of total bacteria inhaled (cfu)	4.41×10^3	2.55×10^3	2.26×10^3	1.54×10^3	1.76×10^7	8.88×10^5	1.35×10^6
Total number of gram negative bacteria inhaled (cfu)	4.91×10^3	2.38×10^3	3.59×10^3	2.51×10^3	8.06×10^6	3.43×10^6	4.01×10^5
Total number of *Aspergillus fumigatus* inhaled (cfu)	1.21×10^3	3.57×10^2	1.63×10^2	1.10×10^2	3.29×10^5	3.79×10^5	1.51×10^6
Total number of fungi inhaled (cfu)	2.08×10^3	1.32×10^3	1.09×10^3	8.96×10^2	-	-	-

[a] Tidal Volume(ml) = 500, Respiratory rate = 17 breaths per minute, Working hours = 11 hours, Total volume of air inhaled (m^3) = 3.96

Endotoxin and β(1→3)-glucan

6.4.4 Although not measured in this study, endotoxin and β(1→3)-glucan are likely to be encountered in waste treatment practices that accepts municipal solid waste and agricultural waste, like open dumping, composting and landfilling (Smit *et al.,* 2008; Environment Agency 2010; Sykes 2011). Endotoxins are associated with gram-negative bacteria whether they are pathogenic or not, and workers exposure to such are well known causes of respiratory symptoms from non-allergic airway inflammation (Rylander 2002, 2006). β(1→3)-glucans on the other hand, are components of the cell wall of most moulds and are known to elicit both allergic and non-allergic inflammatory reaction in the lungs causing hypersensitivity pneumonitis, especially after repeated inhalation of mould in sufficiently high concentration (Fogelmark *et al.,* 1994; Schuyler *et al.,* 1994). Wouters *et al.,* (2005) reported workers exposure levels to endotoxins and β (1→3)-glucans along the waste management chain (waste collection, waste transfer, waste composting and biofuel power station) in the Netherlands. They observed that the endotoxin exposure levels exceeded on most occasions, the occupational exposure limit of 90 EU m^{-3} by the Dutch expert committee on occupational standard (DECOS 2010). Conversely, the dust levels were lower than the 10 mg m^{-3} occupational exposure limit on all occasions, thereby concluding that worker were still at the risk of developing adverse health effects from exposure to endotoxins even in the absence of high dust levels. This further suggests that a large proportion of the bacterial agents bearing the endotoxins would have been of respirable size, existed apart from the dust and might have been inhaled in such state that might cause an adverse health effect on the workers. In this study, the exposure concentration of gram negative bacteria and total fungi of respirable size probably inhaled daily by the residents living from ~50m from the boundary was 3.32×10^3 cfu and 9.04×10^2 cfu respectively (it is assumed that deposition to background levels may not have occurred at 50 m from the boundary, see section 5.7.1.2). The exposure to these microbial agents and repeated inhalation, potentially puts the residents located close to the boundary at the risk of inhaling endotoxins and β (1→3)-glucans, which invariably may contribute to the high prevalence of chronic cough (31.7%), chronic phlegm (28.9%) and asthma (8.2%) reported by this population.

Research Limitations

6.5 The results of the particle size distribution of bioaerosols in the ambient air around the Olusosun was measured at various locations and during a limited number of activities. It was not possible to determine the particle size distribution associated with specific major agitation activities such as spreading, compacting and tipping; as the routine for these activities were not made available during the ambient sampling. However, the results present an overview of the particle size distribution of bioaerosols at any given time at the dumpsite.

6.6 Chapter Summary

The result presented in this chapter show that a considerable proportion of the bioaerosols emitted primarily during the agitation activities carried out at the Olusosun open dumpsite were of respirable size. Up to 41% of total bacteria; ~46% for gram-negative bacteria, ~76% for *A. fumigatus* and ~ 63% for total fungi were of respirable size. The proportion of particles of respirable size associated with the three common activities at the dumpsite, showed that scavenging recorded the largest proportion for total bacteria (~48%) and gram-negative bacteria (~48%) while site monitoring recorded the largest proportion of *A.fumigatus* (~89%). Moreover, comparing the number of particles that are likely to be inhaled by the workers during an 11-hour work duration at the dumpsite, showed total bacteria and gram-negative bacteria from scavenging were 1-log higher than other activities at the dumpsite, unlike *A. fumigatus* which was the same log class irrespective of the activity. The exposure concentrations measured in this study were exceeding the 5×10^{3} -10^{4} cfu m^{-3} for waste workers within an 8-hour working period suggested by Malmros *et al.*, (1992). Particles of respirable size (<3.3 µm) remained comparable between the source point and the boundary for total bacteria (difference: 3.68 percentage points) and gram-negative bacteria (difference: 2.68 percentage points), however there appeared to be increased aggregation of cells forming particles of larger sizes as the particles travelled downwind. *A. fumigatus* and total fungi on the other hand showed no cell aggregation, rather a progressive reduction in the proportion of particles of larger size (> 3.3 µm) as the particles travelled downwind. This behaviour of the four indicator microorganisms observed in this study presents a possible health risk for both the workers and residents, as the proportion of bacterial particles of respirable size remains relatively unchanged downwind and fungi consisting majorly of single cells capable of depositing in the lower respiratory tract when inhaled.

Quantitative Microbial Risk Assessment

Chapter 7: Introduction

7.1 The previous chapters have presented analyses of data on worker exposure to contaminants arising from both the ambient air and during scavenging, waste sorting and site monitoring activities. However, exposure data alone is insufficient to adequately describe health risk. In this chapter, health risks will be estimated using quantitative microbial risk assessment (QMRA) based on the exposure data presented in the previous chapters (5 and 6). Estimates of health risks arising from exposure at open dumpsite are currently scarce in the literature (see Chapter 2). The direct observation of health impact is beyond the scope of this study and would present significant challenges, therefore QMRA is proposed as a method for generating indicative estimates of the health burdens associated with exposure. The QMRA in this study can be thought of as a three-stage process (see Figure 7-1), consistent with what was developed by Haas *et al.*, (2014). The first stage is hazard identification, where the pathogen, its source and its potential harm are identified. The next stage is a two-part process, which is exposure assessment and dose response model. The exposure doses are computed in the exposure assessment stage, and the results subsequently applied onto a dose response model to estimate the risk of infection. Moreover, data on the microbial exposure concentration from activities at the dumpsite were obtained from ambient sampling and air sampling during specific activities at the dumpsite. Details of the sampling processes can be found in sections 3.6 and 3.7. The third stage is the risk characterization. This step utilizes the result from steps one and two, to estimate the magnitude of the risk on the population over time.

Epstein (2015) proposes several exposure pathways for dumpsite workers, including inhalation, ingestion, eyes, and open skin wounds. However in this study, the focus is on inhalation and ingestion; these are presumed to be the most relevant routes because of the indicator microorganisms used in this study, the assumption of possible swallowing/ingestion of some of the pathogens deposited in the nasal and tracheobronchial region, and the availability of data in literature on dose-response models for risk estimation.

This chapter present the QMRA in four steps or parts; these are hazard identification (section 7.2.1), exposure assessment (section 7.2.2), dose-response assessment (section

7.2.3) and risk characterisation (section 7.2.4). As part of the exposure assessment, a stochastic model (Markov Chain Model) was applied to predict the transport and settlement of inhaled bioaerosols in the human respiratory system. The results from the modelling are presented in section 7.4, showing the risk estimates for each sample location, activities and a combined risk of both.

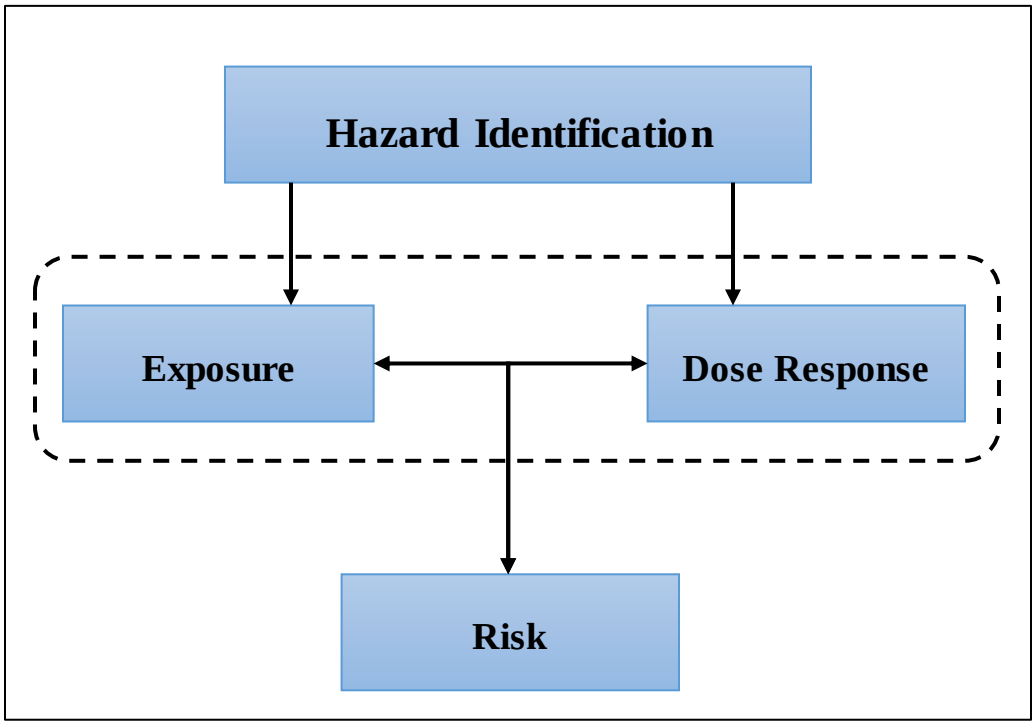

Figure 7-1 QMRA Frame work used in this study showing the three-stage process, adapted from Haas et al., (2014)

Hazard Identification

7.2 In this study, *Aspergillus fumigatus* and *E. coli* O157:H7 were selected as indicator pathogens capable of causing respiratory and gastrointestinal (GI) infections respectively. Although there are a wide range of pathogens that could be considered as indicator pathogens for respiratory and GI infection, *Aspergillus fumigatus* and *E.coli* were selected because they provide contrasting indicators of infection risk; the former in the lungs and the latter in the gastrointestinal tract (Rangel *et al.,* 2005; Hohl and Feldmesser 2007). Moreover, β-Poisson dose-response models, a method similar to the one used in this study, have previously been applied by Leleu *et al.,* (2013) to estimate risk of invasive aspergillosis from exposure to spores of *Aspergillus fumigatus* and by Brooks *et al.,* (2012) and Jahne *et al.,* (2015) for GI infections from ingesting aerosolised *E. coli* O157:H7.

7.3 ## Exposure assessment

The aim of the exposure assessment was to estimate the concentration and the exposure dose during the 11-hours working duration of the workers at the Olusosun dumpsite. The exposure assessment in this study can be broadly categorized as external and internal exposure dose assessment. Figure 7-2 shows the steps undertaken in assessing the

7.3.1 external and internal exposures doses in this study.

External exposure dose assessment

The external exposure dose assessment was designed to generate an estimate of the bioaerosol concentrations per cubic meter of air inhaled by the workers on the dumpsite from the ambient air and from specific activities engaged at the dumpsite. The exposure doses were estimated on the basis of the concentration of gram negative bacteria and *Aspergillus fumigatus* measured in the ambient air and during specific scavenging, waste sorting and site monitoring activities on the dumpsite. The dose estimate was based on a one-time exposure (cfu min^{-1}) and daily exposure (cfu day^{-1}) as shown in table 7-1.

Table 7-1: Concentration of bioaerosols of respirable size inhaled per day at Olusosun Dumpsite

Variable	[a]Active operational Area	[a]Entrance	[a]Dormant Area	[a]Boundary	[a]Scavengers	[a]Waste sorters	[a]Waste workers
Total bacteria inhaled (cfu)	4.41×10^3	2.55×10^3	2.26×10^3	1.54×10^3	1.76×10^7	8.88×10^5	1.35×10^6
Gram negative bacteria inhaled (cfu)	4.91×10^3	2.38×10^3	3.59×10^3	2.51×10^3	8.06×10^6	3.43×10^6	4.01×10^5
Aspergillus fumigatus inhaled (cfu)	1.21×10^3	3.57×10^2	1.63×10^2	1.10×10^2	3.29×10^5	3.79×10^5	1.51×10^6
Total Fungi inhaled (cfu)	2.08×10^3	1.32×10^3	1.09×10^3	8.96×10^2	-	-	-

[a] Tidal Volume(ml) = 500, Respiratory rate = 17 breaths per minute, Working hours = 11 hours, Total volume of air inhaled (m^3) = 3.96

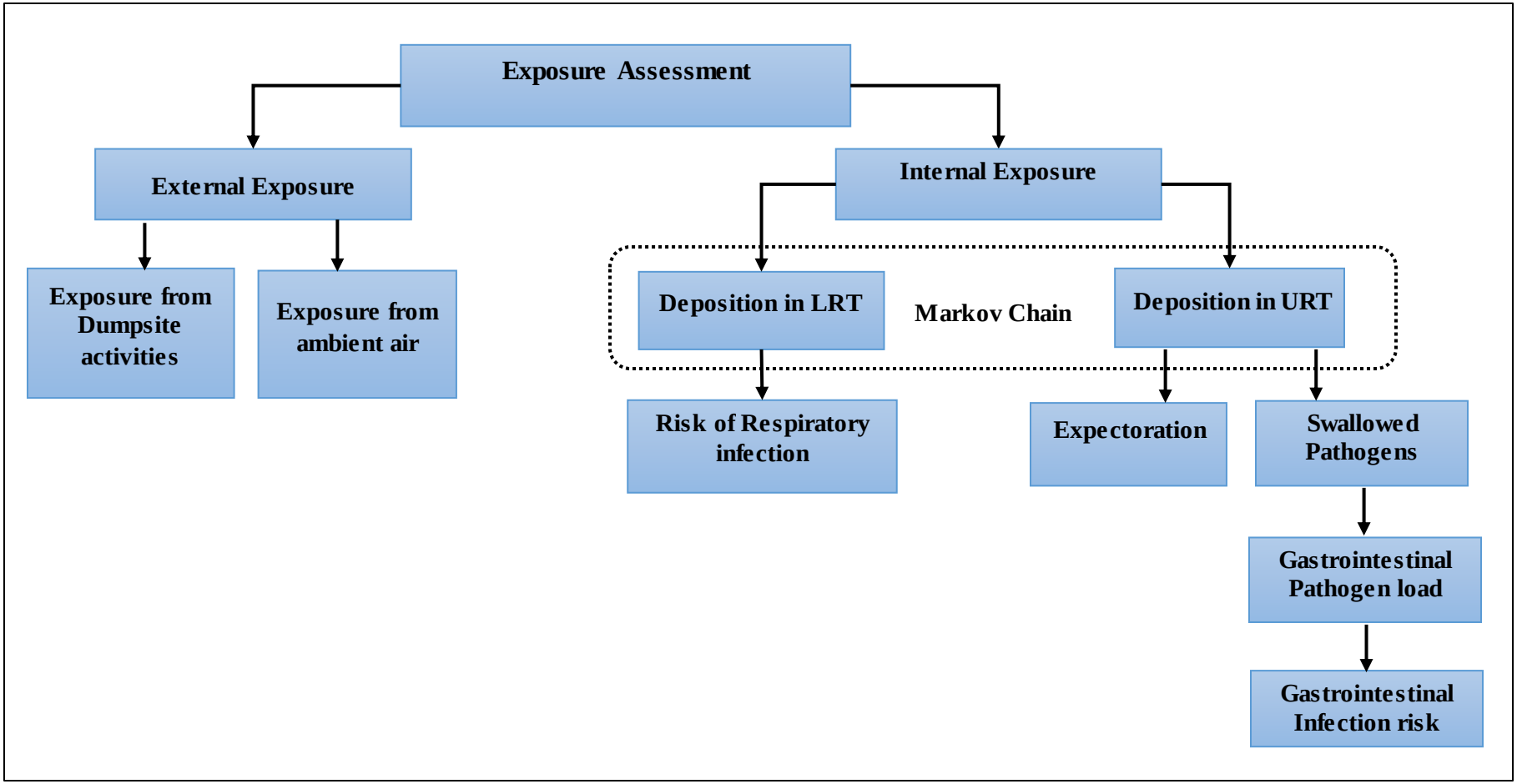

Figure 7-2 Schematics showing the stage considered including Markov Chain model stage for exposure assessment step of the QMRA process

Internal Exposure dose from inhalation of pathogenic spores

7.3.2 The internal exposure dose assessment was designed to generate an estimate of the effective dose of the bioaerosols inhaled by the workers. In other words, an estimate of the dose of viable pathogens capable of initiating an infection when deposited in either the lungs or the GI tract of the exposed worker. The effective infection dose is estimated on the basis of the concentration of viable pathogens in the inhaled air, the breathing rate and the fraction of pathogen transported and deposited in the respiratory tract or target organ for infection (Nicas and Sun 2006). Although modelling the full complexity of the workings of the respiratory system is computationally infeasible (Haber *et al.*, 2003), a simplified three-region model based on the respiratory system as a compartmentalized system (Morrow *et al.*, 1966), has been developed by Weir and Haas (2011) and was adopted in this study (see Table 7-2).

The respiratory model used in this study is built as a Markov chain model where each region consists of two primary states that a microorganism in the lung can be in; in the air, and deposition from air to tissue surface, based on flow through, deposition and survival of spores in the respiratory system (Figure 7-3). By modelling the transport of the pathogen through the respiratory system to deposition on the target tissue, especially in the alveolated region, it was possible to determine the effective dose (D_e), which in turn was used in computing the respiratory infection risk in the host. Because the target organ for *Aspergillus fumigatus* in this study was the pulmonary region of the lungs, effective dose (D_e) was determined by considering particles of sizes < 3.3 μm as the input data for the model. The Markov chain model was also adapted in this study to estimate the proportion of particles of *E.coli* that were either expectorated or swallowed by the exposed individual, thus computing the GI pathogen load and the risk of GI infection. The input data for the GI pathogen load of *E.coli* was a combination of larger size particles of gram-negative bacteria (> 3.3 μm) and the proportion of particles < 3.3 μm deposited in the tracheobronchial region as input data. Sections 7.3.3 and 7.3.5 describes the operation of the Markov Chain model and the computation of the GI pathogen load respectively in detail.

Table 7-2 Three-region Model of the respiratory system (Morrow *et al.*, 1966; Weir and Haas 2011)

Included anatomical structures	Region	Region name	Colour code on MC model
Nares, nasal cavity, oral cavity, nasopharynx, laryngopharynx, larynx	R_1	Nasopharynx	Green
Trachea, bronchi, first branches of bronchioles	R_2	Tracheobronchial	Yellow
Respiratory bronchioles, acinus, alveolar sacs	R_3	Pulmonary	Red

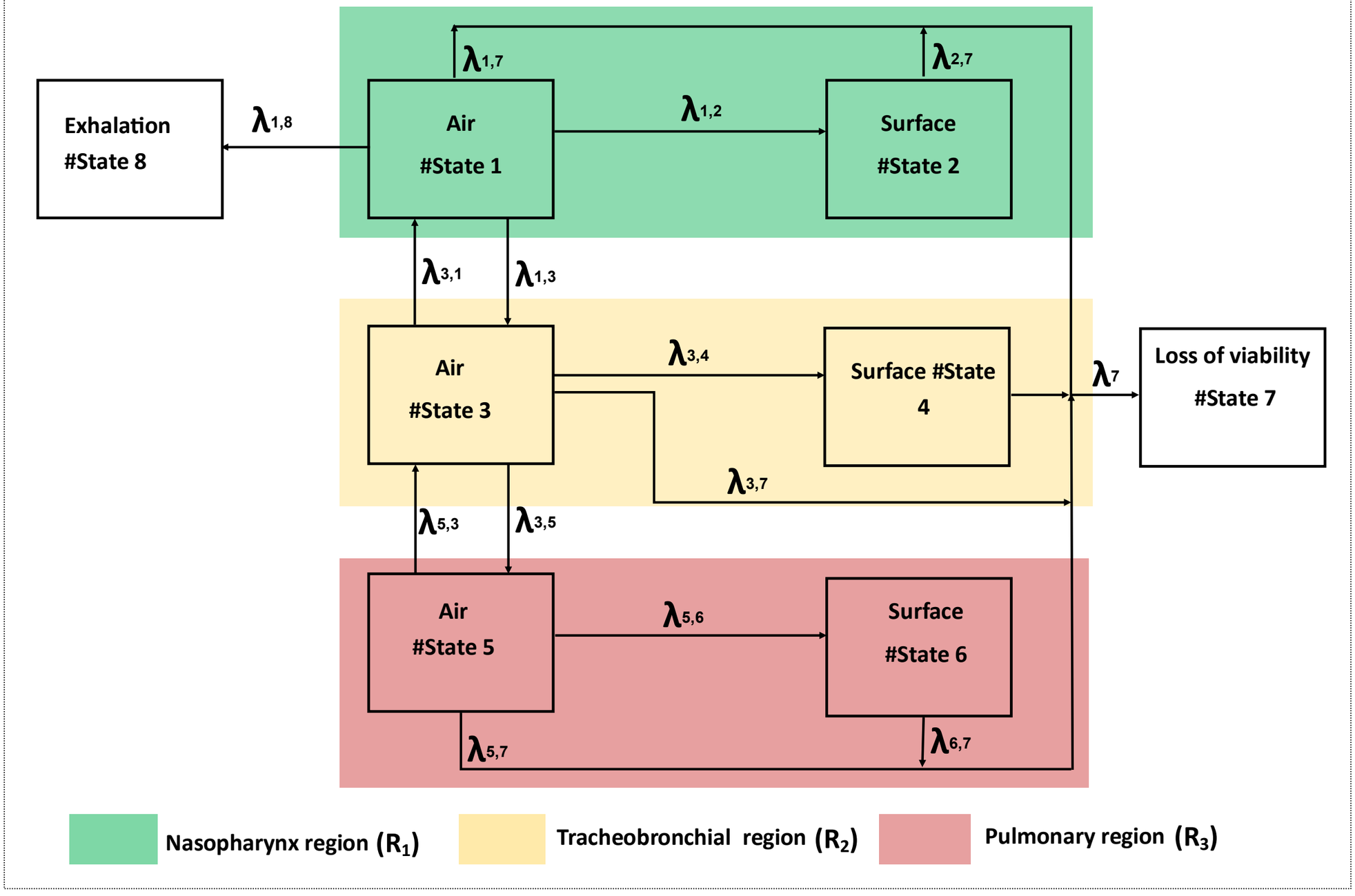

Figure 7-3 Schematics showing the connection between the eight states in the Markov chain model used for the exposure model

Markov Chain Model

7.3.3 A Markov chain model is a probabilistic tool that uses stochastic processes to model physical systems (Privault 2013). Figure 7-3 above shows the schematics of the Markov chain applied in this study where the physical element in each region is represented as 'states' and the loss rates from each associated state is signified as λ. The loss rate (λ) is the function that describes the rate of change of the pathogen from state *i* to state *j*, or pathogens being removed from state *i* to state *j*. This Markov chain model consists of 8 states. Described in order, the model starts from the lung region R_1 with the bulk fluid in state 1 (air) and deposition on the surface of the respiratory system in state 2 (deposition). As flow passes from R_1 to R_2 starting with the bulk fluid in state 3 (air) and deposition on surface of the respiratory system in state 4 (deposition). Then from R_2 to R_3 starting with the bulk fluid in state 5 (air) and deposition on the surface of the respiratory system in state 6 (deposition). Inactivation of the pathogen from natural causes is defined as state 7 (applicable to R_1, R_2 and R_3) and exhalation is state 8.

The next stage in the development of the Markov chain model was to develop the transition probability matrix. The Markov transition probability matrix (P) contains probabilities (*p*) that predict the transitioning of the pathogens from one state to another, either within the same region or to another region of the respiratory system. Consider an inhaled pathogen in state *i* (air). In the next time step Δt, the pathogen has an unconditional probability of remaining in the same state *i*, denoted as p_{ii} and an unconditional probability of transitioning to another state *j*, denoted as p_{ij}. The sum of p_{ij} (j = 1, 2…, 8) equals one. Equation 1 shows the first order transition probability matrix **P** for the system in Figure 7-3. The values of p_{ij} are entered with each row representing a state in the system. The zero entry, i.e. $p_{ij} = 0$, signifies that the pathogen cannot move between the two states in one-time step (1 min), e.g. P_{51}, P_{36}. For absorbing states such as states 7 and 8, $p_{ij} = 1$.

Furthermore, considering the Markov chain at time zero, a pathogen is introduced into the state *i*, and after $n \times \Delta t$ time steps, the probability that the introduced pathogen is in state *j* at $n \times \Delta t$ is the entry in *i*th row and *j*th column of **P** multiplied by itself *n*th times. The probability is designated p_{ij}^{n}, while the latter matrix is designated as $\mathbf{P}^{(n)}$, with *n* being the number of multiplications.

$$\mathbf{P} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & 0 & 0 & 0 & p_{17} & p_{18} \\ 0 & p_{22} & 0 & 0 & 0 & 0 & p_{27} & 0 \\ p_{31} & 0 & p_{33} & p_{34} & p_{35} & 0 & p_{37} & 0 \\ 0 & 0 & 0 & p_{44} & 0 & 0 & p_{47} & 0 \\ 0 & 0 & p_{53} & 0 & p_{55} & p_{56} & p_{57} & 0 \\ 0 & 0 & 0 & 0 & 0 & p_{66} & p_{67} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad \textbf{[1]}$$

Given the sum all the loses from state i (λ_i), the probability of remaining in state i or p_{ii} is the exponential survival probability in eq. 1 (Nicas and Sun 2006).

$$p_{ii} = \exp(-\lambda_i \cdot \Delta t) \quad \textbf{[2]}$$

Since the Markov chain model is based on a flow through the system, particles that are not deposited and have survived inactivation in a previous region (e.g. from R1 to R2) are assumed to have moved to the next region. Hence, the unconditional probability of the pathogen transitioning from state i to state j in Δt is the product of the probability that the pathogen in states i moves to j, i.e. (1- p_{ii}), and the ratio of the loss rates associated with transitioning from state i (λ_i) to state j(λ_{ij}), shown in eq. 3 (Weir and Haas 2011).

$$p_{ij} = \frac{\lambda_{ij}}{\lambda_i} \cdot [1 - p_{ii}] \quad \textbf{[3]}$$

Where $\lambda_i > 0$. If $\lambda_i = 0$, state i is an absorbing state and $p_{ij} = 0$ for $i \neq j$

The loss rate associated with inhaled spores moving deeper into the respiratory system from a region of higher R_x air volume to lower R_y, is generalised in eq. 4 (Weir and Haas 2011).

$$\lambda_{xy} = \frac{Q + B}{V_{R_x}} \quad \textbf{[4]}$$

Where V_{R_x} = the volume of the higher region (cm^3), λ_{xy} = the loss of a spore in the higher region transitioning from region x to region y, Q= the volumetric flow rate of the inhaled air and B = the volumetric flow rate of exhaled air. Both Q and B are assumed to be constant throughout the lungs (i.e. inflow is equal to outflow) and has the value of 125 $cm^3\ min^{-1}$ (Weibel *et al.*, 1963).

The loss rate associated with spores transitioning from lower regions to the higher regions of the respiratory system via exhalation, is expressed in eq. 5

$$\lambda_{yx} = \frac{B}{V_{R_y}} \quad \textbf{[5]}$$

Where V_{R_y} = the volume of the lower region, λ_{yx} = the loss of a spore in the lower region transitioning from region y to region x.

Bulk transport or phagocytosis is the main mechanism of loss of pathogens in the human body, including the respiratory system (Clarke *et al.*, 2010). In addition to phagocytosis, deposition can occur on the respiratory system surface. The resuspension of the deposited pathogens is prevented by mucociliary escalators, and are eventually expectorated within 12 h (Koblinger 1985). The loss due to deposition are accounted for by impaction, sedimentation and diffusion (Weir and Haas 2011). For sedimentation, the rate is determined by the terminal settling velocity of the particle (v_{ts}) and is expressed in eq. 6

$$v_{ts} = 0.0018 \cdot d_{\mathrm{p}}^2 \cdot \left[1 + \frac{0.166}{d_{\mathrm{p}}}\right] \quad \textbf{[6]}$$

Where d_{p} is the particle size and hold accurate for particle up to 50 μm in diameter.

Therefore, the loss of spore from deposition accounting for sedimentation, impaction and diffusion can be estimated in eq. 7

$$\lambda_{deposition} = \frac{v_{ts}}{d_{R_x}} + DI_{R_x} \quad \textbf{[7]}$$

Where: DI_{R_x} = diffusion deposition rate in associated region, d_{R_x} = diameter of the associated region. The estimated values of the loss rates in the Markov chain model and the physiological parameters for humans used in the computation can be seen in Table 7-3, 4.

Table 7-3 Loss rate mechanisms, equations and estimated loss values

Loss rate	Description of loss mechanism	Equation	Loss rate values (min^{-1})	References
$\lambda_{1,3}$	Bulk transport from R_1 to R_2	$\frac{Q+B}{V_{R_1}}$	2.789	Weir and Haas (2011)
$\lambda_{1,2}$	Deposition to R_1 surface	$\frac{v_{ts}}{d_{R_1}} + DI_{R_1}$	1.126	Heyder *et al.*, (1986)
$\Lambda_{3,5}$	Bulk transport from R_2 to R_3	$\frac{Q+B}{V_{R_2}}$	2.252	Weir and Haas (2011)
$\lambda_{3,1}$	Bulk transport from R_2 to R_1	$\frac{B}{V_{R_2}}$	0.0765	Weir and Haas (2011)
$\lambda_{3,4}$	Deposition to R_2 Surface	$\frac{v_{ts}}{d_{R_2}} + DI_{R_2}$	0.0765	Heyder *et al.*, (1986)
$\lambda_{5,3}$	Bulk transport from R_3 to R_2	$\frac{B}{V_{R_3}}$	6.713×10^{-4}	Weir and Haas (2011)
$\lambda_{5,6}$	Deposition to R_3 surface	$\frac{v_{ts}}{d_{R_3}} + DI_{R_3}$	1.43×10^{-3}	Heyder *et al.*, (1986)
λ_7	Loss of viability/inactivation	4.641×10^{-7}	4.641×10^{-7} [a]	Sinclair *et al.*, (2008)
λ_8	Exhalation from respiratory system	$\frac{B}{V_{R_1}}$	0.011	Weir and Haas (2011)

[a] Inactivation of spores is assumed constant and is associated with spores of *Bacillus anthracis*.

Table 7-4 Physiological parameters for humans used as

Physiological dimension	Human
Region 1 Volume	89.63 cm^3
Region 2 Volume	111.025 cm^3
Region 3 Volume	1633.99 cm^3
Region 1 Mean Diameter	3.4 cm
Region 2 Mean Diameter	1.47 cm
Region 3 Mean Diameter	0.18 cm
Inhalation flow rate	125 $cm^3\ min^{-1}$

parameters in the Markov Chain (Weibel et al., 1963)

Effective dose from inhalation

7.3.4 Once the probabilities of the transition matrix P (eq. 1) were assigned, the estimate of the viable pathogens in any given state at time Δt is the product of the sum total of the probabilities associated with that state in each time step as seen in eq. 8

$$E[D_i] = N_i \cdot \sum_{n=1}^{\infty} p_{ij}^n \quad [8]$$

Where *n* is the number of multiplications associated with the time step in the model, *Ni* = initial pathogen load either transitioned or remaining in the same state.

Subsequently, the initial pathogen load for the next state or region in turn equals the effective dose *E* [D_e] of the previous state or region. For example, in order to compute the effective dose of the particle deposited in the surface at state 6, let's consider *E* [D_1] which denote viable pathogens in state 1 (Air), *E* [D_3] denotes viable pathogens in state 3 (Air), *E* [D_5] denotes viable pathogens in state 5 (Air) and *E* [D_6] denotes viable pathogens to state 6 (Respiratory surface), the doses are quantified as follows:

$$E\ [D_1] = N_1 \times (p_{11}^n + p_{13}^n) \quad \textbf{[9]}$$

$$N_2 = N_1 \times p_{12}^n \quad \textbf{[10]}$$

$$E[D_2] = N_2 \times p_{22}^n \quad \textbf{[11]}$$

$$E\ [D_3] = E[D_1] \times (p_{33}^n + p_{35}^n) \quad \textbf{[12]}$$

$$E\ [D_5] = E[D_3] \times (p_{55}^n) \quad \textbf{[13]}$$

$$N_6 = E[D_3] \times p_{56}^n \quad \textbf{[14]}$$

$$E\ [D_6] = N_6 \times p_{66}^n \quad \textbf{[15]}$$

7.3.5 Effective dose from swallowing of pathogens

The effective internal swallowed dose (d_i) was calculated from considering two major sources:

1. Estimated internal dose from particles with an aerodynamic diameter < 3.3 µm , may be deposited in the Nasopharynx region of the respiratory system, i.e. $E\,[D_2]$.
2. Exposure concentration of viable pathogens > 3.3 µm in diameter that may deposited in the Nasopharynx region of the respiratory system, E_c. For gram-negative bacteria of this size range, it was assumed that all inhaled pathogen particles were deposited in the upper respiratory track or Nasopharynx region of the respiratory system.

The sum total of inhaled dose (d_i) of viable gram-negative deposited in Nasopharynx region can be estimated in eq. 16

$$d_i = E\,[D_2] + E_c \qquad \textbf{[16]}$$

Where $E_c = ec \cdot \lambda_7$, ec being the initial exposure concentrations per day of particles with aerodynamic diameter > 3.3 µm.

Entrapped particles (or pathogens) on the surface of the respiratory system are prevented from resuspension by the actions of the mucociliary escalators, and they are eventually removed by expectoration or swallowed, with the later increasing the gastrointestinal (GI) pathogen load (Koblinger 1985; Pillai 2007). The ingestion rate *ag*, is placed between 10-50% of the inhaled pathogen (Medema *et al.*, 2004; Brooks *et al.*, 2005). Pathogen ingestion is accounted for by multiplying eq. 16 with ingestion rate *ag*, as shown in eq. 17:

$$d_{sw} = d_i \cdot ag \qquad \textbf{[17]}$$

The effective gastrointestinal pathogen dose is expressed in the eq. 18:

$$E[d_{sw}] = d_{sw} - (d_{sw} \cdot \lambda_s) \qquad \textbf{[18]}$$

Where d_{sw} is the ingested pathogen load; ag = ingestion rate (%); $E[d_{sw}]$ = effective gastrointestinal pathogen dose; λ_s (min^{-1}) is the rate of inactivation of *E. coli* from stomach acid (Lindqvist and Barmark 2014).

The estimated values of the loss rates in the Markov chain model and the swallow of *E. coli* used in the computation of the GI load can be seen in Table 7-5.

Table 7-5 Loss rate mechanisms, equations and estimated loss values for swallow of E.coli

Loss rate	Description of loss mechanism	Equation	Loss rate values (min^{-1})	References
$\lambda_{1,2}$	Deposition to R_1 surface	$\frac{v_{ts}}{d_{R_1}} + DI_{R_1}$	1.126	Heyder *et al.*, (1986)
λ_7	Loss of viability/ inactivation	4.641×10^{-7} [a]	4.641×10^{-7} [a]	Sinclair *et al.*, (2008)
λ_s	Inactivation of *E.coli* from stomach acid	4.166×10^{-4} [b]	4.166×10^{-4} [b]	Lindqvist and Barmark (2014)

[a] Inactivation of spores is assumed constant and is associated with spores of *Bacillus anthracis*.
[b] Inactivation of *E.coli* in lactic acid and is assumed to mimic acid inactivation in the gastro-intestinal tract.

7.4 Dose-response (D-R) Assessment

The aim of the dose-response assessment was to establish mathematically the relationship between the inhaled pathogen dose and the probability of infection in exposed workers at Olusosun dumpsite. The beta-Poisson D-R model by Haas *et al.*, (1999) was used to estimate risk of infection from exposure to both respiratory and GI pathogens as described in eq. 19:

$$P_i = 1 - \left[1 + \left({}^{d_e}/_{\beta}\right)\right]^{-\alpha} \qquad \textbf{[19]}$$

Where P_i is the probability of infection, d_e is the effective infective dose (either as $E\,[D_6]$ or $E[d_{sw}]$ for respiratory or gastrointestinal respectively), α and β are the slope parameters related to the pathogen, and their values can be found in Table 7-6.

The beta-Poisson dose-response model was used in this study because the model has been widely used from inhalation and ingestion of *Aspergillus fumigatus* and *E.coli* respectively (Teunis *et al.*, 2008; Leleu *et al.*, 2013; Dungan 2014). In the review of the literature in where QMRA was reported (Section 2.3.3), the dose-response model commonly used for infection estimation from both bacteria and virus were β-Poisson and

the exponential model, however beta-Poisson D-R model was only used for bacterial and fungal pathogens.

Table 7-6 Slop parameters used in the beta-Poisson D-R model and assumptions

Pathogen	D-R Model	Parameter	Conditions of development	References
A. fumigatus	β-Poisson	$\alpha = 1.1$, $\beta = 20$	Developed from animal model of immunosuppressed mice.	Leleu *et al.*, (2013)
E.coli	β-Poisson	$\alpha = 0.248$, $\beta = 48.8$	Developed from fitting data from 8 out breaks from *E. coli* O157:H7	Teunis *et al.*, (2008); Jahne *et al.*, (2015)

7.5 Risk characterization

The risk characterization combined the dose-response results and exposure information to estimate the magnitude of the risk on the exposed workers. The infection probability was calculated based on a one-time, daily and annual exposure duration. The daily estimate is based on an 11-hour average daily work duration of the workers on the dumpsite (Table 4.1). Pathogen to indicator ratio (P:I) ranging from conservative 1: 1000 to a least conservative 1: 10,000 for the ratio of *E. coli* O157:H7 to gram-negative bacteria was used to calculate the infection risk from exposure to gram-negative bacteria. Brooks et al., (2005) have used similar ratios in modelling of infection risks from aerosolized *Salmonella* spp. and coxsackievirus A21 from the spreading liquid biosolids. Risk combination using the inclusion-exclusion principle estimated the overall risk estimate in different scenarios combining several risk estimates.

7.5.1 Combining Risk

The mathematical principle of inclusion-exclusion was used to calculate the overall expected infection risk ($E[R]$) in any particular scenario. This assumes that infection can occur only once, as described in eq. 20,21 and 22 for two, three and four risk combination respectively (Nicas and Sun 2006):

$$E[R] = |R_A| + |R_B| - |R_A R_B| \quad \textbf{[20]}$$

OR

$$E[R] = |R_A| + |R_B| + |R_C| - |R_A R_B| - |R_A R_C| - |R_B R_C| + |R_A R_B R_C| \quad \textbf{[21]}$$

OR

$$E[R] = |R_A| + |R_B| + |R_C| + |R_D| - |R_A R_B| - |R_A R_C| - |R_A R_D|$$
$$-|R_B R_C| - |R_B R_D| - |R_C R_D| + |R_A R_B R_C| + |R_A R_B R_D|$$
$$+|R_A R_C R_D| + |R_B R_C R_D| - |R_A R_B R_C R_D| \quad \textbf{[22]}$$

$E[R]$ = Overall expected risk, R_A, R_B, R_C, R_D are the risk variables

7.6 Data analysis and model testing

The Markov chain model was developed as a steady state model. A one-minute time-step was used, as the model was expected to estimate pathogen deposition in human lungs based on the number of breaths taken per minute. The model was developed in MS Excel 2013 (Microsoft Inc.) and later replicated in R-project (by the R Foundation) and the copy of the code can be found in Figure D-1. The Monte Carlo simulation for β- Poisson dose-response model was run on Minitab 18 statistical software. Data generated from the models were processed in MS Excel 2013 (Microsoft Inc.).

A Monte Carlo simulation is a mathematical technique that was used to account for the natural variability in the model parameters and to reduce the level of uncertainty in the model results (Soller *et al.,* 2010). The technique works by sampling values at random from the probability distribution of the input data, in this case, the bioaerosols exposure data (Kottegoda and Rosso 2008). Thus, it was important that, prior to running the Monte Carlo simulation, a goodness-of-fit test was conducted to determine the kind of distribution best fits the input data for this study. A one-sample Kolmogorov-Smirnov (K-S) test was carried on the bioaerosol exposure data to determine the distribution of best-fit for gram-negative bacteria and *Aspergillus fumigatus* (Sunger and Haas 2015). The data for gram-negative bacteria was fit to a normal distribution (p = 0.59) and *Aspergillus fumigatus* fit to an exponential distribution (p= 0.49). Randomised data were subsequently generated based on the result of the one-sample K-S test for *Aspergillus*

fumigatus ($E[D_6]$) and *E. coli* O157:H7 ($E[d_{sw}]$) and were used to run the Monte Carlo simulation for β- Poisson dose-response model. The Monte Carlo simulation was run for 10,000 iterations and the median was considered to present the most likely scenario for estimating the infection risk.

Results

7.7 Infection risk from exposure during activities at the dumpsite

7.7.1 Table 7-7 shows the daily and annual risk of GI infection from inhalation and subsequent swallow of bioaerosols containing *E.coli* O157:H7 at 10-50% pathogen ingestion and P:I = $1:10^3$, $1:10^4$. Scavenging was the activity that presented the highest risk of GI infection for P:I = $1:10^3$ and $1: 10^4$ (range: 5.03×10^{-1}-6.63×10^{-1} and 2.10×10^{-1}-4.20×10^{-1}) compared to waste sorting and site monitoring. The risk of GI infection associated with waste sorting was ranked as high as scavenging, as the difference was only marginal. Furthermore, the range of values were two-threefold higher than what was recorded for site monitoring (1.89×10^{-1}-3.96×10^{-1} and 3.04×10^{-2}-1.18×10^{-1}).

Table 7-8 describes the daily and annual risk of respiratory infection from inhaling spores of *Aspergillus fumigatus* during activities at the dumpsite. The predicted risk of infection from all three activities were similar with only marginal differences between them. The annual risk of infection was predicted to be between 7.93-8.25×10^{-1} for all three activities, indicating a high chance of acquiring invasive aspergillosis due the activities at the dumpsite. After one year, the risk estimates from exposure to *Aspergillus fumigatus* would have increased by 0.182, 0.179 and 0.154 points due to scavenging, waste sorting and site supervision respectively at Olusosun dumpsite.

Figure 7-4 shows an eleven-hour risk of GI and respiratory infection from inhalation of *E.coli* O157:H7 (P:I=$1:10^3$, *ag* = 50%) and *Aspergillus fumigatus* respectively. Comparatively, the risk levels for both *E.coli* O157:H7 and *Aspergillus fumigatus* for all three activities were within 6.0-7.0×10^{-1} except for site supervision with risk value of 3.96×10^{-1}.

Table 7-7 Risk of infection (median) from inhalation-ingestion exposure to E.coli O157:H7 during activities at Olusosun dumpsite

Exposure Activity	Risk of infection for 10-50% (low-high) ingestion rate (*ag*)			
	1:1000‡		1:10000‡	
	11 h	1 year*	11 h	1 year*
Scavenging	5.03×10^{-1}-6.63×10^{-1}	8.79×10^{-1}-9.19×10^{-1}	2.10×10^{-1}-4.20×10^{-1}	7.86×10^{-1}-8.56×10^{-1}
Waste sorting	4.54×10^{-1}-6.27×10^{-1}	8.66×10^{-1}-9.11×10^{-1}	1.63×10^{-1}-3.65×10^{-1}	7.62×10^{-1}-8.40×10^{-1}
Site monitoring/ supervision	1.89×10^{-1}-3.96×10^{-1}	7.76×10^{-1}-8.49×10^{-1}	3.04×10^{-2}-1.18×10^{-1}	6.05×10^{-1}-7.34×10^{-1}

*Annual risk of infection based on exposure for 6 days a week for 52 weeks.
‡ Pathogen – indicator ratio (P:I) at $1:10^3$ and $1:10^4$

Table 7-8. Risk of infection (median) from inhalation of spores of Aspergillus fumigatus during activities at the Olusosun dumpsite

Exposure Activity	Risk of infection	
	11 h	1 year*
Scavenging	6.11×10^{-1}	7.93×10^{-1}
Waste sorting	6.17×10^{-1}	7.96×10^{-1}
Site monitoring/ supervision	6.71×10^{-1}	8.25×10^{-1}

*Annual risk of infection based on exposure for 6 days a week for 52 weeks.

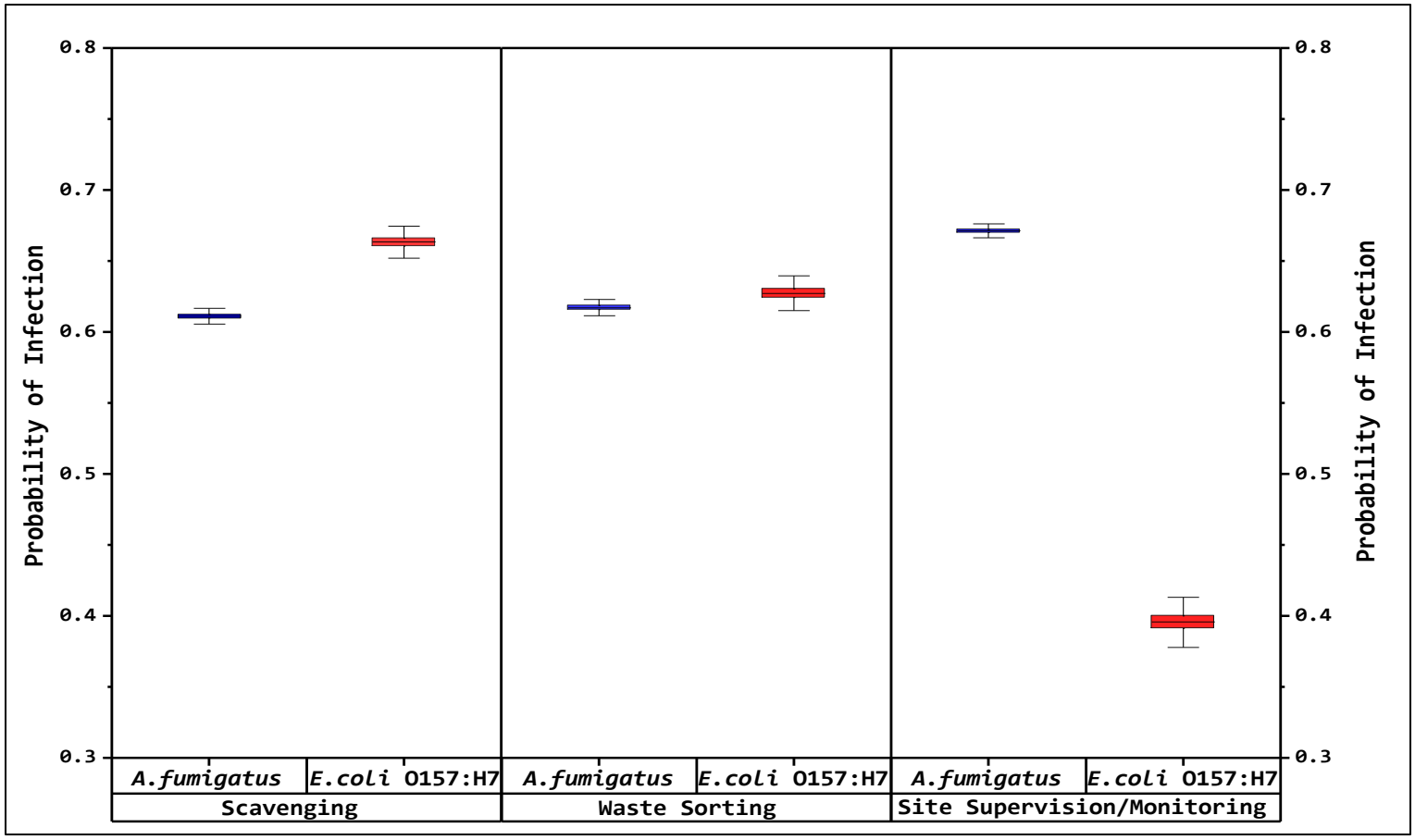

Figure 7-4: Eleven-hour risk of infection from bioaerosol containing Aspergillus fumigatus and E. coli O157:H7 (P:I = 1:103, ag 50%) during scavenging, waste sorting and site supervision. Boxplots indicates upper/ lower quartiles and median: Whiskers indicates 95th

Infection risk from exposure at locations on dumpsite

7.7.2 Table 7-9 summarizes the daily and annual risk of GI infection from inhalation (subsequent swallow) of bioaerosols containing E.coli O157:H7 at 10-50% pathogen ingestion rate and P:I of $1:10^3$ and $1: 10^4$ from the four sampling locations at Olusosun dumpsite. The predicted risk of GI infection was highest at the active area for P:I = $1:10^3$ and $1: 10^4$ (range: 3.23×10^{-3}- 1.56×10^{-2} and 3.25×10^{-4}-1.62×10^{-3}). These values were two time higher than the risk from exposures to E.coli O157:H7 at the boundary of the dumpsite (1.82×10^{-3} - 8.82×10^{-3} and 2.09×10^{-4}-8.94×10^{-4}). The risk of infection after a year of exposure for P:I = $1:10^3$, $1:10^4$ was estimated to have increased exponentially as seen in Table 7-3.

Described in Table 7-10 is the daily and annual risk of respiratory infection from inhalation of spores of Aspergillus fumigatus at the four sampling locations at Olusosun dumpsite. The active area of the dumpsite recorded the higher risk (3.01×10^{-1}) compared to the boundary with lowest risk estimates (1.01×10^{-1}). In other words, at the active area the chances of in infection after a day's work on the dumpsite was 3 in 10 exposures while at the dumpsite boundary the chance was 1 in 10 exposures. Table 7-10 also shows that the risk of respiratory infection after a year would have increases twofold, threefold, threefold and fivefold at the active area, entrance, dormant area and boundary respectively.

Figure 7-5 shows an eleven-hour risk of GI and respiratory infection from inhalation of E.coli O157:H7 (P:I=$1:10^3$, ag = 50%) and Aspergillus fumigatus respectively. The risk of infection from *Aspergillus fumigatus* was highest at the active area (4.22×10^{-1} at 95^{th} percentile) and lowest at the boundary (2.47×10^{-1} at 95^{th} percentile). Risk of infection from E.coli O157:H7 were relatively uniform across the four sampling locations, with the boundary recording the highest risk (1.91×10^{-2} at 95^{th} percentile) and entrance the lowest (1.59×10^{-2} at 95^{th} percentile). Comparatively, the likelihood of the population at the dumpsite developing a respiratory infection was higher compared to GI infection.

Figure 7-6 shows an 11-hour cumulative (sum) risk from inhaling bioaerosols containing *Aspergillus fumigatus* and *E.coli* O157:H7 (P:I= $1:10^3$, ag = 50%) at the dumpsite. Overall, the likelihood of getting infected from inhaling *Aspergillus fumigatus* was 16 times higher (median: 7.9×10^{-1}) than for *E.coli* O157:H7 **(**median: 4.82×10^{-2}**).** This risk value is considered at the inherent risk from bioaerosol inhalation at the dumpsite without engagement in activities at the dumpsite.

Table 7-9: Risk of infection (median) from inhalation-ingestion exposure to E.coli O157:H7 at the four sampling location at Olusosun dumpsite

	Risk of infection for 10-50% ingestion rate			
	1:1000‡		1:10000‡	
Variable	11 h	1 year*	11 h	1 year*
Risk associated with active involvement at sampling location (Breathing rate = 17 breathe per min)				
Active Area	3.23×10^{-3}- 1.56×10^{-2}	3.32×10^{-1}-5.32×10^{-1}	3.25×10^{-4}-1.62×10^{-3}	8.16×10^{-2}- 2.41×10^{-1}
Entrance	1.85×10^{-3}- 9.09×10^{-3}	2.58×10^{-1}-4.68×10^{-1}	1.87×10^{-4}-9.27×10^{-4}	5.12×10^{-2}-1.75×10^{-1}
Dormant Area	2.06×10^{-3}- 1.01×10^{-2}	2.72×10^{-1}- 4.81×10^{-1}	2.09×10^{-4}-1.04×10^{-4}	5.64×10^{-2}-1.87×10^{-1}
Boundary	1.82×10^{-3} - 8.82×10^{-3}	2.56×10^{-1}-4.64×10^{-1}	2.09×10^{-4}-8.94×10^{-4}	5.01×10^{-2}-1.71×10^{-1}
Combined Risk	8.93×10^{-3} - 4.29×10^{-2}	7.32×10^{-1}-9.31×10^{-1}	9.32×10^{-4} -4.47×10^{-3}	2.19×10^{-1}-5.78×10^{-1}
Risk associated with passive involvement at the sampling location (Breathing rate = 12 breathe per min)				
Active Area	2.28×10^{-3}- 1.11×10^{-2}	2.86×10^{-1}- 4.90×10^{-1}	2.29×10^{-4}- 1.14×10^{-3}	6.09×10^{-2}- 1.99×10^{-1}
Entrance	1.31×10^{-3}- 6.46×10^{-3}	2.15×10^{-1}- 4.24×10^{-1}	1.31×10^{-4}- 6.57×10^{-4}	3.71×10^{-2}- 1.39×10^{-1}
Dormant Area	1.45×10^{-3}- 7.19×10^{-3}	2.27×10^{-1}- 4.43×10^{-1}	1.46×10^{-4}- 7.32×10^{-4}	4.11×10^{-2}- 1.49×10^{-1}
Boundary	1.15×10^{-3}- 5.73×10^{-3}	1.99×10^{-1}- 4.09×10^{-1}	1.46×10^{-4}- 5.72×10^{-4}	3.31×10^{-2}- 1.25×10^{-1}
Combined Risk	6.19×10^{-3}- 3.05×10^{-2}	-	6.52×10^{-4}- 3.11×10^{-3}	-
One-time exposure (min^{-1})	1.39×10^{-5}- 6.97×10^{-5}	-	1.40×10^{-6}- 7.00×10^{-6}	-

*Annual risk of infection based on exposure for 6 days per week for 52 weeks.
‡ Pathogen – indicator ratio at $1:10^3$ and $1:10^4$

Table 7-10: Risk of infection (median) from inhalation of spores of Aspergillus fumigatus at the four sampling locations

Variable	Risk of infection	
	11 h	1 year*
Risk associated with active involvement at sampling location (Breathing rate = 17 breathe per min)		
Active Area	3.01×10^{-1}	6.27×10^{-1}
Entrance	2.04×10^{-1}	5.71×10^{-1}
Dormant Area	1.72×10^{-1}	5.50×10^{-1}
Boundary	1.01×10^{-1}	4.96×10^{-1}
Combined risk	5.9×10^{-1}	9.64×10^{-1}
Risk associated with passive involvement at the sampling location (Breathing rate = 12 breathe per min)		
Active Area	2.75×10^{-1}	6.12×10^{-1}
Entrance	1.77×10^{-1}	5.54×10^{-1}
Dormant Area	1.48×10^{-1}	5.34×10^{-1}
Boundary	8.12×10^{-2}	4.77×10^{-1}
Combined risk	5.33×10^{-1}	9.58×10^{-1}
One-time exposure (min^{-1})	1.4×10^{-5}	-

*Annual risk of infection based on exposure for 6 days per week for 52 weeks.

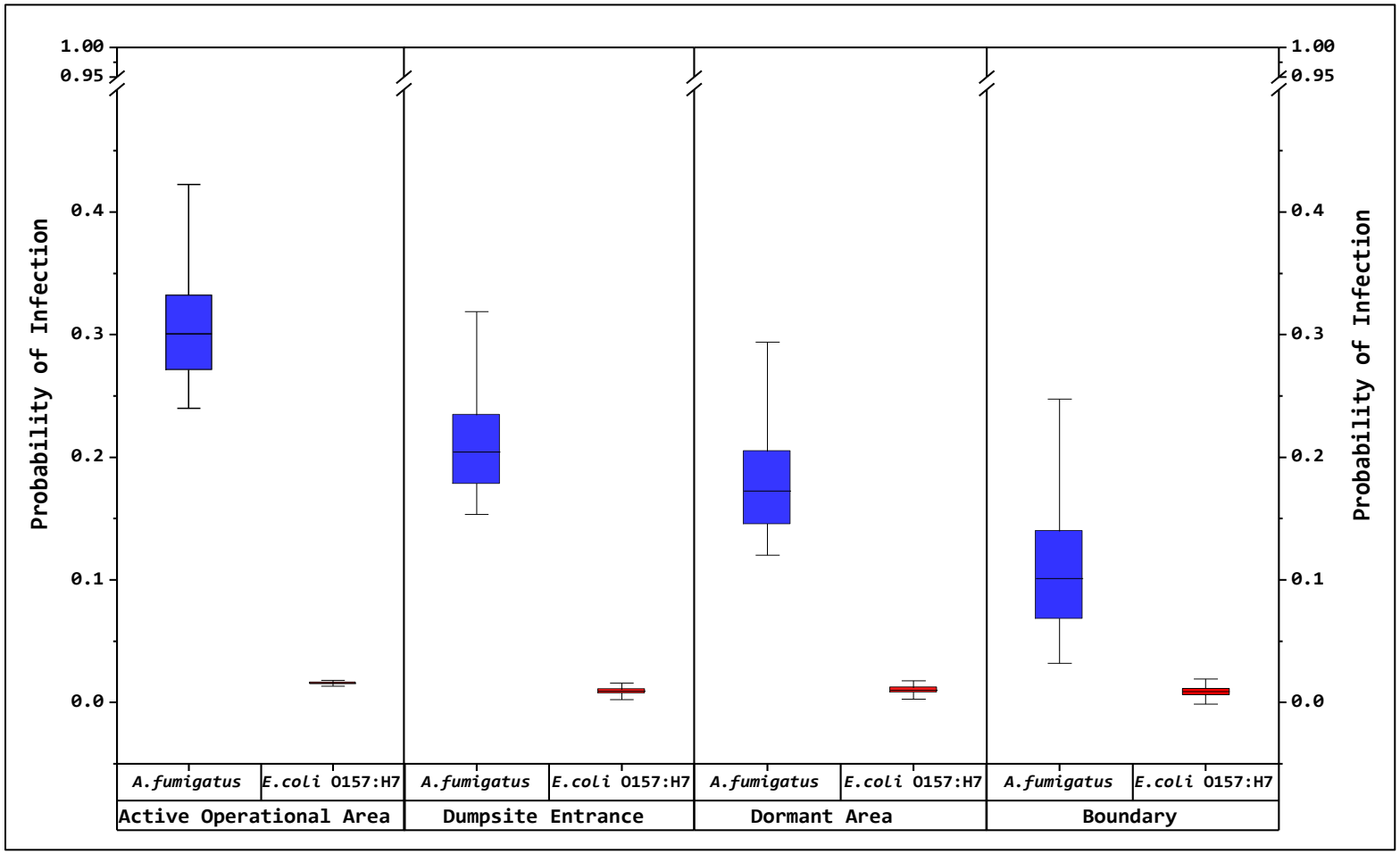

Figure 7-5: Eleven-hour risk of infection from bioaerosol containing Aspergillus fumigatus and E. coli O157:H7 from the four sampling locations at Olusosun dumpsite. Boxplots indicates upper/ lower quartiles and median; Whiskers indicates 95th percentiles.

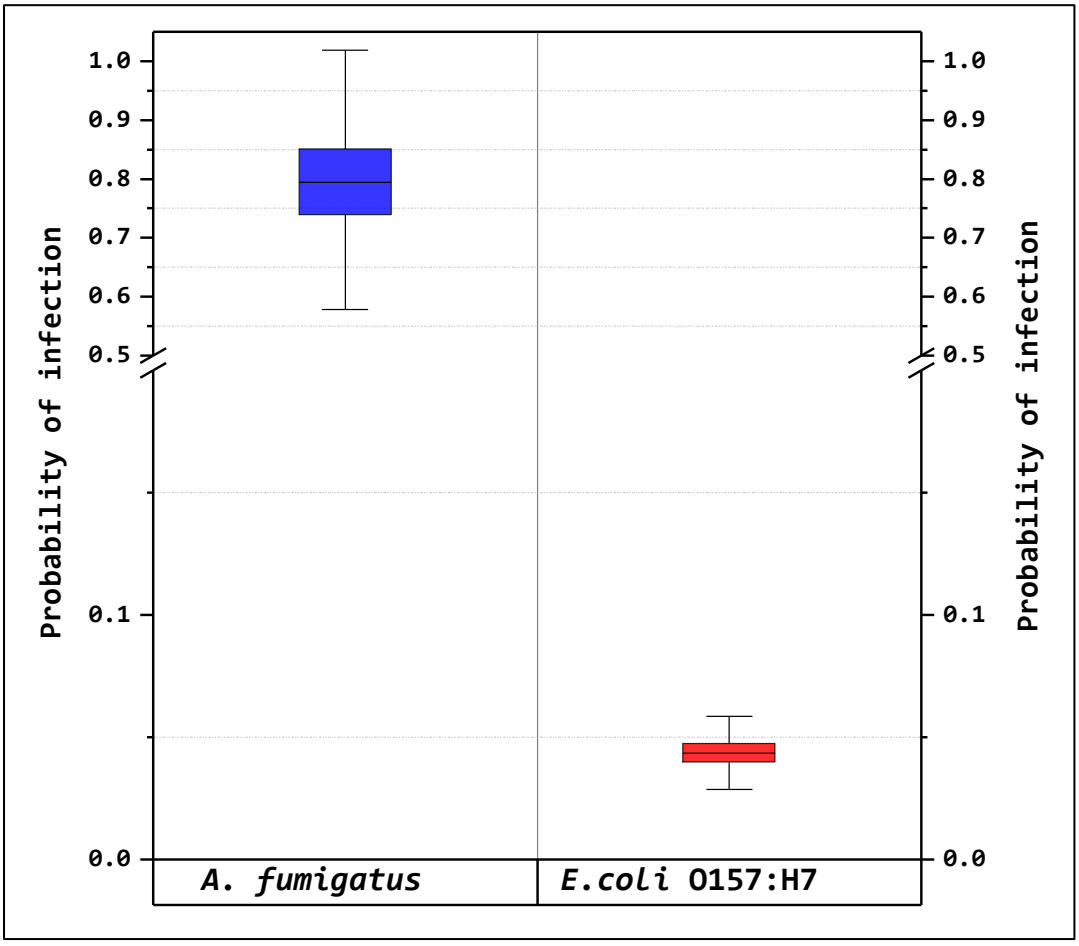

Figure 7-6: Cumulative risk of infection from bioaerosol containing Aspergillus fumigatus and E. coli O157:H7 (P:I= 1:103 , ag = 50%) from the four sampling locations at Olusosun dumpsite. Boxplots indicates upper/ lower quartiles and median; Whiskers

Discussion of Findings

Risk of infection inherent to dumpsite location *(Aspergillus fumigatus)*

7.8

7.8.1 The results of the QMRA have shown the potential health impact of the poor microbial air quality at Olusosun dumpsite. The risk from the one-time exposure (1.4×10^{-5}) to *Aspergillus fumigatus* increased by 5-log (combined risk: 5.33×10^{-1}) after 11 hours of exposure from passive activities (e.g. Middlemen, visitors and small business owners) at the dumpsite (Table 7-10). This implies that overall, there is at least a 53.3% chance of an individual involved in passive activities at the dumpsite to develop a respiratory ailment from inhalation of the spores of *Aspergillus fumigatus* from merely being present at Olusosun dumpsite for 11 hours. *Aspergillus fumigatus* is one of the common moulds present in the ambient air at compositing sites and landfill sites (Persoons *et al.,* 2010; Schlosser *et al.,* 2016). Though the respiratory pathologies associated with the inhalation of its spores have been thoroughly investigated, the probable estimate of the risk of infection from inhalation of the spores have received limited attention. In this study, the result of the D-R model suggest that, based on the levels of spores of *Aspergillus fumigatus* in the air samples, the risk to the individuals actively working on the dumpsite per day might be between 1.01×10^{-1} to 3.01×10^{-1}, which 1.24 times higher overall compared to those who are not involved in activities at the dumpsite (Table 7-10).

The differences between the two infection risk estimates (passive and active workers) was marginal, suggesting that the aetiology of the infection would be the same once the pathogen is inhaled whether or not people are active or passive at the dumpsite.

Figure 7-5 shows a trend that suggest an overall reduction in risk levels with distance from the active area to the boundary. Although the risk magnitude remained the same across locations i.e. 10^{-1}, the result otherwise suggests that workers working at the active area may be at greater risk of infection from *Aspergillus fumigatus* than those located further away.

The combined risk indicates adjusted overall expected risk for Olusosun open dumpsite, taking into account the risk levels inherent to each sampling location (Table 7-10). Because the waste workers and food vendors spend their time moving from one part of the dumpsite to the other during the day (11-hour exposure), the minimum expected infection risk for these group of workers is the combined risk of 5.90×10^{-1} (Annual risk = 9.58×10^{-1}). In other words, on the one-time pathogen exposure, for every 10 times

during the day they are exposed at the dumpsite, they will likely be infected 6 times from inhaling spore of *Aspergillus fumigatus*. Owners of small businesses and middlemen are usually stationed at the dormant area and the boundary, which are 'relatively' lower risk compared to the active area where scavenging is predominant. However, by combining the inherent risk from each activity with their associated locations, the chances of infection increases to the range of 66-78% (see Table D-2). Take the dormant area as an example; the result of the combined risk for waste sorting (which is the predominant activity) estimates that the chances of infection at 68% and 90% as daily and annual infection risk respectively, which is a 5 and 4 percentage points increase, assuming the individual was not engaged in waste sorting at the dormant area. The trend suggests that that the kind of the activity undertaken at the dumpsite can play a great role in heightening the risk of infections of the workers irrespective of the location they take place.

7.8.2 Risk of GI infection inherent to dumpsite location (*E.coli* O157:H7)

The risk of GI infection from an 11-hour exposure to bioaerosols containing *E.coli* O157:H7 at the active area was only 1-log greater than the boundary for P: I = 1:10^3 and 1: 10^4 (Table 7-9). The decrease in bioaerosol concentration with distance (Section 5.7.1.2), may explain the decrease in GI infection risk from the result of the QMRA. A similar trend was observed by Dungan (2014), where the decrease in GI infection risk from enteric pathogen during land application of dairy wastewater was associated with the decrease in the concentration with distance, owing to primarily to wind dilution. There are currently no guidelines for the acceptable risk threshold from exposure to aerosolized enteric bacteria in occupational environments, however, the range 10^{-6}-10^{-4} (conservative to a less-conservative) have been commonly cited in literature for GI infection risk, and have been adopted in this study for comparison purposes (Regli *et al.*, 1991; Dungan 2014). Considering the result of the QMRA, only the estimates of GI infection risk for P: I = 1:10^4 were within acceptable limit (upper boundary). For individuals involved in passive activities at the entrance (1.31×10^{-4}- 6.57×10^{-4}) dormant area (1.46×10^{-4}-7.32×10^{-4}) and the boundary (1.46×10^{-4}- 5.72×10^{-4}) would do so within acceptable GI infection risk threshold. Furthermore, only individuals involved in active activities at the entrance (1.87×10^{-4}-9.27×10^{-4}) and the boundary (2.09×10^{-4}-8.94×10^{-4}) would do so within acceptable GI infection-risk threshold. Furthermore, the data for P: I = 1:10^3 showing the an 11-hour combined risk for all four sampling locations indicates that workers who are physically active (lifting, climbing the waste hill, pulling etc.; breathing rate=17 breath per min) at the dumpsite will be have a risk range of $8.93\times10^{-3} – 4.29\times10^{-}$

^{2}, while the infection risk for those who are passively active (breathing rate=12 breath per minute) will range from 6.19×10^{-3}-3.05×10^{-2} (Table 7-9). Interestingly, the differences in the risk estimates for the two levels of activities is only marginal, thereby indicating that, not engaging in physical activities does not necessarily decrease the magnitude of the risk. Jahne *et al.,* (2015) reported a GI infection risk from *E.coli* O157:H7 aerosolized during manure application to be 10^{-3}-10^{-2} for an 8-hour exposure, values comparable to the prediction in this study. Although ranked as a medium-risk scenario, they however cautioned that that the risk level could easily escalate to high should there be any outbreak of *E.coli* O157:H7 from the sources feeding the point of exposure. A similar threshold (5×10^{-3}) was also reported by Seto *et al.,* (2007) and Brooks *et al.,* (2012) to have caused the *E.coli* O157:H7 outbreak in 2006, with 205 reported illnesses and 5 death in the United States.

7.8.3 Risk of infection inherent to activities at dumpsite (*Aspergillus fumigatus*)

The annual respiratory infection risk inherent to activities like scavenging, waste sorting and site supervision are as high as 10^{-1} (Table 7-8). The result further indicates that by engaging in these activities in the active area (infection risk = 3.01×10^{-1}), the risk of infection increases by 3.11×10^{-1}, 3.16×10^{-1} and 3.70×10^{-1} points for scavenging, waste sorting and site monitoring respectively. The annual risk of respiratory infection from exposure to *Aspergillus fumigatus* during scavenging, waste sorting and site monitoring ranged from 7.93×10^{-1}-8.25×10^{-1}. For such estimates, it can be assumed based on a one-time exposure, for every 10 times the workers are exposed during the year to this dose at the dumpsite, they will likely become infected 8 times, especially those with suppressed immune systems. By implication, the workers are likely to be infected several times in a year from the inhaling conidia of *Aspergillus fumigatus*. The risk estimates are very high considering that, the workers are exposed 6 days per week and may be exposed to other pathogenic agents that may take a toll on their immune systems.

For healthy individuals, the inhaled spores are either removed by the mucociliary clearance mechanism or killed by the alveolar macrophages. Those that evade macrophage killings may germinate in the bronchioles or alveolar spaces; and at this point are targeted by infiltrating neutrophils capable of destroying their hyphae (Dagenais and Keller 2009). The risk associated with developing any form of invasive aspergillosis is primarily the breakdown or dysfunction of the hosts defence system and the survival ability of pathogen in the target growth environment of the hosts (Schaffner *et al.,* 1982).

Moreover, the combination of smoking and exposure to other aerosolized environmental pollutants can impair mucociliary clearance even in healthy individuals, thereby increasing the chances of deposition and possible growth of inhaled spores *Aspergillus fumigatus* (Wolff 1986; Xavier *et al.,* 2013). In this study, 41% of the participants were smokers and 89% had never used nose masks for nasal protection during work at the dumpsite. With conditions such as stated above, the estimates of the annual risk of respiratory infection may be consistent with the reality of the respiratory health risk associated with working in environments such as Olusosun dumpsite.

7.8.4 Risk of GI infection inherent to activities at dumpsite (*E.coli* O157:H7)

Workers engagements in activities at the dumpsite, depending on the kind of activity, are at a high risk of GI infection, i.e. risk estimates higher than the inherent risk associated with the location where the activity took place. The risk of GI infection from scavenging at the active area (5.03×10^{-1}-6.63×10^{-1}) for example, is two-threefold greater than the inherent at the active area (3.23×10^{-3}- 1.56×10^{-2}) for the same exposure duration (Table 7-7 and 7-9). A similar trend was also observed for the category of P:I = 10^4 where risk levels were higher by three-four orders of magnitude for scavenging, waste sorting and site supervision compared to the inherent risk levels at the active area where the sampling took place. Furthermore, the combined risk showed an even higher risk estimate overall than if the inherent risk for the locations and activity were measured as stand-alone (Table D-2). Combining the risk of active area and scavenging increased the overall adjusted risk by 2-3 order of magnitude to 5.05×10^{-1}-6.68×10^{-1} for P:I=10^3 and 3-4 order of magnitude to 2.10×10^{-1}-4.21×10^{-1} for P:I=10^4. The proximity of these activities to the exposure source and the reduced effect of dilution during these activities might explain the high-risk values in the dose-response model. Occupational risk studies accounting for enteric bacterial risk is very limited. Some notable exceptions are healthcare workers, wastewater treatment plant personnel and in concentrated animal feeding operations (CAFOs) (Medema *et al.,* 2004; Bobo and Dubberke 2010; Brooks *et al.,* 2012). Notably, Medema *et al.,* (2004) had reported the predicted annual risk from a wastewater treatment plant to be as high as 2×10^{-1} from a one-time exposure to enteric pathogens. Tanner *et al.,* (2008) on the otherhand, simulated annual risk range of 2×10^{-2} (use of protective equipement) to 3×10^{-1} (no use of protective equiptment) during CAFOs. Brooks *et al.,* (2012) reported similar risk values to Tanner *et al.,* (2008), ranging from 1×10^{-2} to 5×10^{-1}, values comparable what is predicted in this study (Table 7-7).

As it currently stands, inhalation transmission of enteric bacterial pathogens is assumed to be less than 6% of all diarrhoea cases worldwide (WHO 2006). This is assumed because as yet there are no epidemiological or clinical studies that have demonstrated this transmission route in humans (Brooks *et al.,* 2012). In most cases, the environment where the inhalation-ingestion route of exposure exist, there also exist the faecal-oral route (from fomite, waterborne or foodborne). Because the detection procedure for the former has been established overtime, it is common to ignore inhalation-ingestion route of transmission. However, there are mounting evidence from animal trials that inhalation-ingestion route of transmission exist and can pose a high risk of GI infection in a population exposed to aerosolized enteric bacteria (Clemmer *et al.*, 1960; Fedorka-Cray *et al.,* 1995; Darlowa *et al.,* 2009).

7.9 Research constraints

In carrying out this research, there were sources of uncertainty inherent to the simulation such as the sample collection, effective dose dose-response model and the population type. These uncertainties are explained below:

- The method of sample collection was a potential source of uncertainty in the risk calculation as the enteric bacteria *E.coli* O157:H7 was not originally isolated in the air samples at the dumpsite. However, one of the approaches used to address this was to assume a pathogen-indicator ratio in the exposure dose. This approach has been applied by Brooks *et al.,* (2005) representing the risk estimate as a range of values of the pathogen doses and this was adopted in this study.
- The limitation that the exposure dose relied only on cultured bioaerosols (leaving out the uncultivatable viable fraction) increased the uncertainty, as the predicted risk in this study could be an underestimation of the actual risk posed by the dumpsite.
- Because the inactivation rates vary by microbial specie and the environment, applying the same inactivation rates for both indicator microorganisms as used in this study, increased the uncertainty in the model. However, the use of a Monte Carlo simulation to estimate the natural variability of the indicator organisms as they are inhaled mitigates this uncertainty to some extent.
- In computing the risk combination for locations and activities, the results presented for locations such as the dormant area and the boundary could be an overestimation of the actual risk because the bioaerosol exposure from activities were only measured at the active area and not at the other three locations.

- Because there is still no respective epidemiological-based evidence from exposure from aerosolized enteric bacteria on public health, generating accurate risk estimates would require an understanding of the viability and infectivity of the pathogen in a range of environmental conditions and the susceptibility across representative populations. Regarding *Aspergillus fumigatus*, the model parameter used in the dose responds model did not take into account the susceptibility of the sub-population, as it assumed that the individual was already immunocompromised, thereby increasing the uncertainty in the risk estimates for exposure to spores of *Aspergillus fumigatus* (Leleu *et al.*, 2013).
- The effects of the all the limitations in this study can cascade through the model, widening the 'cone of uncertainty' through the various steps of the modelling process. At the end, such an effect results in a high level of uncertainty in the estimates, even though the researcher is reasonably confident about the observed levels of contaminants in the air.

Summary of chapter

7.10 The QMRA risk simulation presented here involved the first application of a stochastic model to predict the transport of bioaerosols in the human respiratory system (Markov Chain Model), and to estimate the risk of infection specific to dumpsite workers from the settlement of those pathogens in the respiratory and gastrointestinal tracks. The overarching trends suggest the following:

- That the infection risk from inhaling contaminated air containing spores of *Aspergillus fumigatus* at all locations were of the same magnitude (10^{-1}) irrespective of whether the individual was involved in activities in the dumpsite or not.
- The combined risk of exposure from activities and ambient exposure to *Aspergillus fumigatus* increases the daily chances infection. At the risk of infection ranged between 73-78%, while at the boundary the range was 66-70% for all activities associated with the locations.
- The daily estimates of the risk of infection from ingestion of *E.coli* O157:H7 ranged from 10^{-3}-10^{-2} for the conservative and 10^{-4}-10^{-3} for the least conservative pathogen to indicator ratio and classified as a medium-high and low-medium risk respectively.
- The probable outcome from ingesting inhaled *E.coli* O157:H7 during scavenging, waste sorting and site monitoring was high (10^{-1}), with similar magnitude comparable to the annual infection risk.
- Overall, the trends in the risk estimates suggest that the activities at the dumpsite may contribute more to the likelihood of workers developing either respiratory infection or GI infection than anything else.

General Discussion

Chapter 8: Introduction

8.1 In a bid to balance the high global rate of urbanization with the rate of municipal solid waste generation that results from urbanisation, the sustainable development goal (SDG) 11.6 aims to reduce the per capita environmental impact of cities by paying attention to air quality and municipal solid waste management (UN-Habitat 2018). In general, the rates of urbanisation are highest in the least developed countries (with particularly high rates experienced in low and middle income countries in sub-Saharan Africa) (Moore *et al.*, 2003); in most cases MSW facilities are absent or of poor quality. These countries therefore have the highest need and lowest capacity to implement effective MSW management. As a result, it means that government authorities in these countries resort to open dumping as a cheap method for managing MSW or they do not have any realistic strategy at all so illegal and informal dumping just happens anyway.

Because tipping, spreading and compacting of waste are common practices at dumpsites, they result in the waste pile being agitated, favouring aerosolization of the microorganisms and dust (including pathogens) attached to the surface of the waste. Thus, exposing the dumpsite workers and residents near the dumpsite to these pathogenic agents via inhalation (Schlosser *et al.*, 2016). It is not a surprising that the negative health and environmental impacts of illegal and informal dumping are high; this is reflected in the fact that global indices for health effects and environmental hazards are highest in the poorest countries (Moore *et al.*, 2003). Studies on occupational health risks experienced by landfill and dumpsite workers suggest that the predominant exposure route is inhalation (Heldal *et al.*, 2003; Ray *et al.*, 2004; Odewabi *et al.*, 2013a) and the current study confirms this view. Despite the awareness of the prevalence of respiratory symptoms caused by workers exposure to bioaerosols during MSW treatment processes, there is very limited information in the literature on exposure from developing countries, especially sub-Saharan Africa. Thus, the primary aim of this research was to investigate the potential respiratory health risk posed to dumpsite scavengers, waste workers and residents living close to open dumpsites from exposure to bioaerosols emitted at dumpsites.

8.2 Respiratory health conditions of dumpsite workers and residents close to dumpsites

Before carrying out this research, it was necessary to understand the kind of interaction that existed between the population on and around the dumpsite with the activities happening on Olusosun dumpsite. The findings in this study shows that both the individuals working on the dumpsite and those residing close to the dumpsite were exposed to emissions originating from the dumpsite. Evidence from the prevalence of respiratory symptoms and conditions as reported by the exposed population further confirms this. Chronic cough and Asthma were commonly reported symptoms amongst the study population. While these particularly affected smokers the overall prevalence ranged between 32-38% and 2-8.2% for chronic cough and asthma respectively. The prevalence of chronic cough was however, higher than the national average of 10% (Song *et al.*, 2015). Chronic cough is a known precursor to developing COPD and environmental factors rank high among the plausible causes of chronic cough and other respiratory symptoms (Zhang *et al.*, 2002; de Marco *et al.*, 2007; Ternesten-Hasséus *et al.*, 2011). Thus the high prevalence of reported chronic cough may be an indicator of a worsening respiratory condition in the population. Moreover, the daily duration of exposure to contaminated air was associated with an estimated odds ratio of 1.2 with chronic cough when comparing workers on the dumpsite to the control. Thus, the finding suggests that the 11-hours daily time weighted average (TWA) the workers may be spending at the dumpsite could increase their chances of developing chronic cough. An 8-hour TWA (or lower) has been recommended by HSE (2018) as a safe limit when working in highly dusty occupational environment, conditions that can be applicable to Olusosun dumpsite. It is therefore recommended that the workers reduce their hours of work to the 8-hour TWA (or lower), as a these changes may reduce the prevalence of chronic cough in the population.

The prevalence of asthma on the other hand was observed to be lower than the national average of 10.2% (Musa and Aliyu 2014). Owing to the highly dusty environment at Olusosun dumpsite, it could be assumed that individuals diagnosed with atopy might not want to work in such environment knowing it may lead to hypersensitivity from environmental triggers; hence, the overall low report of asthma. It was not clear from the

findings of this study if the reported asthma were atopic or occupational causes. However, both atopic and non-atopic asthma can be aggravated by environmental exposure, especially from an environment high on respirable particles like Olusosun dumpsite (Eduard *et al.,* 2004). This is further supported by findings in this study as the prevalence of asthma were not associated with lifestyle (smoking) but more from probable inhalation of aetiological agents from the air in the environment, largely from Olusosun dumpsite. It is therefore recommended that residents, especially those located downwind of the dumpsite should move to at least 250 m away from the boundary of the dumpsite, because at this distance, it is believed that bioaerosols and other aerosolized particles would have settled to background concentration.

8.3 Bioaerosol exposure and infection risk from ambient air

The finding in this study has shown beyond doubt that bioaerosols are emitted during operational activities at Olusosun dumpsite. The maximum ambient concentration of bacteria and fungi for this study were well within magnitude of 10^3 cfu m^{-3}, a result that is comparable to ambient concentration of bacteria and fungi reported on landfill sites across the globe. For example in Poland, Kalwasińska *et al.,* (2014) reported 1.9×10^3 cfu m^{-3} and 2.07×10^3 cfu m^{-3} for bacteria and fungi concentration respectively. Sangkham *et al.,* (2014) reported 1.29×10^4 cfu m^{-3} for fungi in Thailand while Huang *et al.,* (2002) reported concentrations of 3.76×10^3 cfu m^{-3} and 6.0×10^3 cfu m^{-3} in Taiwan for bacteria and fungi respectively. The results shows that the concentration of total bacteria and gram-negative bacteria were twofold and eightfold higher respectively than recommended background level of 1000 cfu m^{-3} (Total bacteria) and 300 cfu m^{-3} (gram-negative bacteria) by the UK and Wales Environment Agency (Pearson *et al.,* 2015). The differences between the concentration of bacteria and fungi measured at the active operational area (major source of bioaerosols) and the other three sampling locations, was not significant. Implying that bioaerosol particles (bacteria and fungi) in the air at the dumpsite may not have settled out quickly as they travelled from the active operational area downwind, even at a distance of 788 m (i.e. boundary). The probable consequence is that they may settle out at distances further from the dumpsite, in areas where people reside, thus exposing them to air contaminated with bioaerosols. Furthermore, both the dumpsite workers and the residents are exposed to these aetiological agents on a daily basis. This may also explain the high prevalence of respiratory disease among the workers and population living near the dumpsite as described in Section 8.2.

The effect of seasonal changes on ambient bioaerosol concentration observed in this study was minimal. There were no significant differences observed between bioaerosols concentration measured in the dry season and wet season. The result suggests that the daily average bioaerosol concentration depended largely on the presence of agitation-related activities that takes place at the dumpsite and might remain the same throughout the year, thus unaffected by seasonal cycle.

The probably risk of infection was calculated based on the proportion of bioaerosols that were of respirable size (<3.3 µm) to which workers were exposed. The study shows that the proportion of total bacteria and gram-negative bacteria of respirable size had not change much with distance, as the bioaerosol particles travelled between the active area (point source) and the boundary. For total bacteria, this proportion represented 40.8% at the active area and 37.1% at the boundary. While the respirable proportion for gram-negative bacteria represented 39.8% at the active area and 37.1% at the boundary. The implication of this result is that, given the same bioaerosol concentration at active area and boundary, the risk of infection from bacteria were of similar magnitude at both locations. For instance, the risks of GI infection from exposure to *E.coli* O157:H7 (gram-negative bacteria) at P:I=10^3 (11-hours exposure) ranged between 3.23×10^{-3}- 1.56×10^{-2} and 1.82×10^{-3} - 8.82×10^{-3} at the active area and boundary respectively. This risk was only 1-log higher for the upper bound of the risk estimate for the active area. That is not a lot of difference. The annual infection risk on the other hand was of the same magnitude for active area (3.32×10^{-1}-5.32×10^{-1}) and boundary (2.56×10^{-1}-4.64×10^{-1}). This level of GI infection risk at the boundary when assessed on a one-time pathogen exposure means that, for every 10 times a worker is exposed to the dose at the active area and the boundary, they will likely become infected 3-5 at both locations, especially those with suppressed immune systems. Moreover, the result can also be applied to the residents near the boundary of the dumpsite, as some of them were located as close as 50 m to the boundary.

The pattern of particle size distribution for total fungi showed a stepwise increase in the proportion of fungal particles that were of respirable size as the particles travelled from the active area downwind. This proportion represented more than 50% of the overall concentration for fungi to which workers were exposed. Thus, higher chances of inhaling more particles capable penetrate deep into the lower region of the lungs to cause infection. Inhalation of *Aspergillus fumigatus* for instance, increases the chance of the workers developing aspergillosis, especially the immunocompromised. The findings in this study

shows that the risk of infection from inhaling spores of *Aspergillus fumigatus* by the workers was 5.9×10^{-1} following 11-hours of exposure. Thus, for every ten times a worker is exposed to spores of *Aspergillus fumigatus*, they will become infected six times. These risk values are very high for an 11-hour exposure. At the boundary, the risk of respiratory infection from *Aspergillus fumigatus* for passively active people was 8.12×10^{-2}. This group of people would include the business owners, middlemen and residents near the dumpsite. For every 100 time they are exposed to spores of *Aspergillus fumigatus* while working at the boundary during the 11 hours working period, they are likely to be infected 8 times, especially the immunosuppressed individuals.

8.4 Bioaerosol exposure and infection risk from activities

Exposure to bioaerosols is influenced by the activities that workers undertake. The most significant working practices are scavenging, waste sorting and dumpsite monitoring. Of the three practices assessed, scavenging recorded the highest exposure concentration to bacteria, while site monitoring recorded the highest exposure to *Aspergillus fumigatus*. Overall, the workers engaged in these activities were exposed to bioaerosol concentration in the magnitude of 10^4 -10^6 cfu m^{-3}, i.e. 2-3 log higher than exposure from ambient air. These values in comparison to the 8-hour occupational threshold limit of 5×10^3 -10^4 cfu m^{-3} suggested by Malmros *et al.*, (1992) and BAuA (2018) for Denmark and Germany, the workers at the dumpsite were exposed to magnitude that were 1-2 log higher. The implication of this finding is that the workers are exposed to unsafe concentrations that will make them more susceptible to infection with time (if not already) from undertaking these activities.

The estimates of respiratory infection risks from inhaling particles of *Aspergillus fumigatus* ranged between 6.11×10^{-1}-6.71×10^{-1} for an 11 hrs exposure during all three activities. Annual estimates recorded similar magnitude, ranging from 7.96×10^{-1} - 8.25×10^{-1}. These risk estimates were higher than was recorded in healthcare setting where invasive *Aspergillus* infections were reported between 2-26% and 1-15% of immunocompromised patients of hematopoietic stem cell transplants and solid-organ transplants (Vonberg and Gastmeier 2006). Unfortunately, clinical diagnosis of aspergillosis among the workers was beyond the scope of this study. However, the high-risk estimates are largely bases on the high exposure counts of *A. fumigatus* recorded in air of the dumpsite and may indicate plausible infection crises soon to happen to the workers.

Dumpsite workers were also at risk of developing gastrointestinal infection (GI) due to the activities they undertook. The risk of GI from *E.coli O157:H7* was in the magnitude of 10^{-1} for all three activities, values similar to the risk of *Aspergillus* infections. These risk estimates are very high, especially considering that, these activities are the main source of livelihood for the workers engaged in them, and that most of those working there in the first year (i.e. at the time of the interview), might still be working there for the next 5 years.

8.5 Exposure risks of sensitive receptors near Olusosun dumpsite

Olusosun dumpsite is surrounded by several sensitive receptors (SR), most of which are located downwind of the dumpsite. SR's are classed as neighboring homes, public spaces and other occupied buildings near the dumpsite that might be affected by the activities at the dumpsite (AfOR 2009; Environment Agency 2017). Factors (other than meteorological factors) that can contribute to high exposure risk levels of sensitive receptors are their distance from the dumpsite, the duration of exposure and the likely presence of vulnerable individuals i.e. individuals who are susceptible to or unable to cope with the adverse effect of environmental exposures (Wisner *et al.*, 2002; Kovats *et al.*, 2003).

In this study, the SRs were identified based on the factors earlier stated, and their risk levels were ranked accordingly (Table D-3). Table 8.1 shows the description of the sensitive receptors considered, i.e. Hospitals, residential homes, schools, parks and event/worship centres. Figure 8.1 highlights the location of the sensitive receptors on a map, in relation to their distances from the boundary of the dumpsite. As assessed, the closest hospital (H1) to the dumpsite was 900 m east of the dumpsite. This location was well out of the 250 m recommended safe distance away from the boundary of the dumpsite, thus placing it in low risk category (UNEP 2005). The sensitive receptors categorised as Medium-High and High risk were all located south-west, the predominant wind direction over the dumpsite. Locations S1 and S2 are a nursery and primary school respectively. The results show that, 5 days in a week for at least 8 hours per day (except for public holidays and school breaks), a large population of children are exposed to either pathogens or other aetiological agents that are capable of causing infection when inhaled. Due to the nature of the activities that takes place in locations E, R1 and R2, children, pregnant women, the sick and elderly are likely be found at one time the other in these buildings. Their very presence at these locations puts them at risk of inhaling bioaerosols

or other aetiological agents. It is therefore recommended that vulnerable individuals (children, pregnant women, elderly and sick) in the buildings categorised as high risk be moved to safer locations where exposure risk from the dumpsite is low. This will mean relocating the schools, homes and event/worship centres to location at least 250 m from the boundary of the dumpsite from all directions.

Table 8-1 Sensitive receptors and the exposure risk categories based on distance from dumpsite boundary, susceptibility of individuals and duration of exposure

Sensitive receptor	Description	Distance from boundary	Cardinal direction	Coordinate	Vulnerable	One-time Exposure duration per day	Exposure Risk computation	Risk Category
S1	School	25 m	SW	6°35'35.1"N, 3°22'30.7"E	Children	8 hours	17.4	High
S2	School	185 m	SW	6°35'28.7"N, 3°22'29.7"E	Children	8 hours	15.3	M-High
S3	School	730 m	NW	6°36'00.5"N, 3°22'34.0"E	Children	8 hours	9	Low
E	Place of Worship	63.6 m	SW	6°35'29.3"N, 3°22'34.0"E	Elderly, Children, Pregnant women	6 hours	27.6	High
R1	Accommodation	36 m	SW	6°35'43.0"N, 3°22'28.0"E	Elderly, Children, Sick, Pregnant women	10 hours	64	High
R 2	Accommodation	133 m	SW	6°35'30.8"N, 3°22'28.2"E	Elderly, Children, Sick, Pregnant women	10 hours	58	High
H1	Hospital	900 m	East	6°35'51.2"N, 3°23'16.8"E	Sick	>10 hours	8	Low
H2	Hospital	1350 m	West		Sick	>10 hours	8	Low
P	Recreational Park	180 m	SE	6°35'36.1"N, 3°22'54.8"E	Children	4-5 hours	6	Low

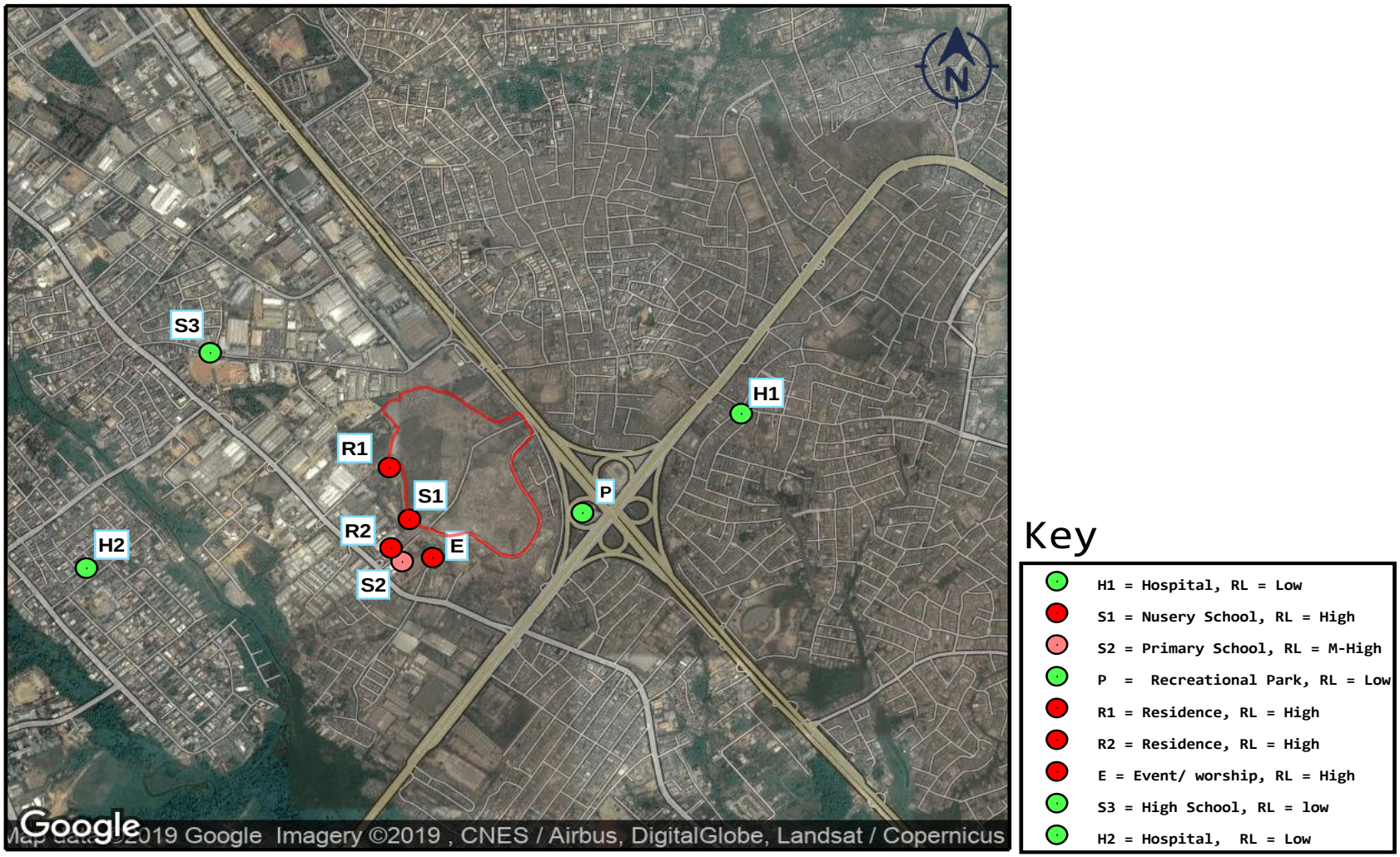

Plate 8-1: Sensitive receptors around Olusosun dumpsite showing exposure risk levels based on Nearness to dumpsite, Exposure duration and Availability of vulnerable people.

8.6 Applicability of results

The findings in study have provided a new insight into the occupational risks associated with open dumping by quantifying these risks. This study has further provided a broader understanding of the probable causes of respiratory and gastrointestinal infections experienced by dumpsite workers and residents located near dumpsites. This was achieved by relating the risk of infection to the bioaerosol concentrations the workers are exposed to on the dumpsite. It should however be noted that the results in this study brings with it some level of uncertainties and limitations clearly stated in previous chapters, hence generalisation of the result presented should be undertaken with caution.

Although the workers at the dumpsite seemed healthy and were actively involved in the dumpsite activities, the results of the questionnaire showed that some the workers were suffering from chronic respiratory symptoms conditions that were of occupational origin, a finding that agrees with literature (Ray *et al.,* 2004; Ray *et al.,* 2005). Notably, the exposure time was a factor that greatly influenced the risk of infection from exposure to bioaerosols capable of causing the respiratory symptoms reported by the workers. Furthermore, because of the high level of bioaerosols and dust emitted at Olusosun, it is recommended that the workers adhere to the daily exposure duration of 8-hour TWA or less where possible, as recommended by the HSE (2018).

It was also observed that workers generally did not use personal protective equipment (PPE), especially respiratory protective equipment (RPE) reportedly because they were expensive and they could not afford them. This is actually a reflection of the economic status of the workers, as most of the recycled materials are sold to intermediaries are at cheap rates; barely enough for their daily upkeep let alone afford a personal protective equipment. To this end, intervention by the authorities is necessary to protect the health of the workers. PPE's and RPE's should be subsidised for the workers, and the workers monitored for effective usage of the PPE's. Compulsory respiratory health checks (however rudimental) of the workers should be carried out on a regular basis, as this will help the authorities keep the on top of the health conditions of the workers at the dumpsite.

Scavengers composed of the highest proportion of the population of workers in Olusosun dumpsite (61%). Due to the nature of their activities, they are exposed the most to bioaerosols resulting to highest risk of infection from *E.coli* O157:H7. It is therefore recommended that by

systematically reducing the number of scavengers picking at the dumpsite, it is possible to reduce the overall health impact on population at the dumpsite. If the city's authority implement programmes/schemes to reduce the amount of recyclables reaching the dumpsite to the barest minimum, the population of scavengers on the dumpsite will consequently reduce. The UK's waste hierarchy for example, is core of the waste directive (Directive 2008/98/EC) which prioritizes waste prevention, then re-use, then recycling, then recovery and last of all, disposal (e.g. landfill). Another example is described by Asim *et al.*, (2012), where informal recyclers are integral part of the mainstream of Lahore city's waste management system. They go door-to-door collecting household recyclable waste, and then taken to waste transfer points across the city where itinerant buyers buy the waste at higher value than they would at the dumpsite. Moreover, the use of local expertise or approach (like above), to proffer sustainable low-cost solutions to solid waste management problems will directly or indirectly impact positively to the social-economic status of the people in that society (Zurbrügg *et al.*, 2012). One of the benefit of such schemes/solution is that the informal workers will earn more money and will reduce exposure of the workers to infection and disease, thus improving their overall health.

Conclusion and Recommendation

Chapter 9: Conclusions

9.1 This study investigated bioaerosol emissions from a municipal solid waste dumpsite in Lagos Nigeria, and the associated respiratory health problem facing the workers and residents located near the dumpsite from exposure to bioaerosols. Having presented the result of the observations in the previous chapters, the key conclusions of this study are arranged under four themes and are presented below:

Respiratory health condition of workers and residents near Olusosun dumpsite

- It was discovered that cough was the most prevalent respiratory symptom reported by the dumpsite workers and residents near the dumpsite. The prevalence of chronic cough and chronic phlegm were significantly higher in both study groups, compared to the control. Asthma on the other hand showed a significantly higher prevalence only among residents residing close to the dumpsite. The result of the findings also showed that the overall prevalence of chronic cough was significantly higher compared to the national prevalence in Nigeria, while asthma was not.
- The study also showed that the daily exposure duration of the workers to aerosolised pollutants from the dumpsite was associated with an estimated odds ratio of 1.2 (95% CI 1-1.4) for chronic cough when compared to the controls. This implies that the longer the exposures to aerosolised pollutants from the dumpsite the higher the odds of the worker developing of chronic cough.
- Smoking was associated with higher rates of chronic cough and chronic phlegm among the workers on the dumpsite. Conversely, higher rates of chronic cough and chronic phlegm were associated with non-smokers who were residents, suggesting that there may be other possible pollutant sources in the neighboring area responsible for these high rates.
- For every instance a resident interacted or visited Olusosun dumpsite, the estimated odds ratio for chronic cough, chronic phlegm and asthma was 3.8 (95 % CI 1.6, 8.4), 4 (95% CI 1.1, 14.4) and 6.8 (95% CI 1.3, 33) respectively when compared to the controls. Thus, the residents may be exposed to higher concentrations of pollutants at

the dumpsite when they visit and this could exacerbate their exiting respiratory conditions.

Bioaerosol concentration in ambient air and emission from activities at Olusosun dumpsite

- Based on the measured results, the concentration of bacteria and fungi in the ambient air at the dumpsite were well within the magnitude of 10^3 cfu m^{-3}.
- From the data, the concentration of bioaerosols were the highest in the active operational area and decreased with increasingdistance downwind of the point source. No significant differences in concentration across the four sampling points for total bacteria, gram-negative bacteria and the total bacteria were observed. However, the trend observed for *Aspergillus fumigatus* showed the concentration was observed to have decreased up to 80-81% between the source point and the boundary.
- The data from the study indicated that the effect of seasonal changes on the concentration of bioaerosols was minimal, as no significant differences were observed in the concentrations between the dry season and the wet season.
- Of the three significant activities undertaken by the workers at the dumpsite, scavenging exposed the workers to more bacteria, compared to the other two, while site monitoring recorded the highest exposure to *Aspergillus fumigatus*. Bioaerosol exposure concentrations from all three activities ranged between 10^4 - 10^6 cfu m^{-3}, which was 2-3 log higher in magnitude than the ambient air concentration. These activities required the workers undertaking the task close to the point sources of bioaerosol, thus the high exposure concentration recorded in this study.
- Overall, ambient concentrations of bacteria exceeded the occupational exposure limits for UK Environment Agency, however the fungi concentration was below the expected exposure limit. Exposure from all three activities assessed in this study (scavenging, waste sorting and site monitoring) exceeded the acceptable exposure limits by the UK Environment Agency standard by 2-4 log in magnitude. Exposure concentrations of this magnitude are hazardous to the health of the workers at the dumpsite

Particle size distribution of bioaerosols at Olusosun dumpsite

- The data from this study show that a considerable proportion of the bioaerosols measured were of an aerodynamic diameter considered to be respirable.
- In the ambient air, up to 41% of total bacteria; 46% of gram-negative bacteria, 76% of *A. fumigatus* and 63% of total fungi were of respirable size. The concentration of bioaerosols of respirable size measured during the three common activities at the dumpsite, showed that scavenging had the largest proportion for total bacteria (~48%) and gram-negative bacteria (~48%) while site monitoring recorded the largest proportion for *A. fumigatus* (~89%).
- The proportion of bioaerosols of respirable size (<3.3 µm) remained similar between the source point and the boundary for total bacteria (difference: 3.68 percentage points) and gram-negative bacteria (difference: 2.68 percentage points), however there appeared to be increased aggregation of cells, forming particles of larger sizes as the particles travelled downwind. *A. fumigatus* and total fungi on the other hand showed no cell aggregation, rather a progressive reduction in the proportion of particles of larger size (> 3.3 µm) as the particles travelled downwind.
- Bioaerosols concentrations measured during the scavenging, waste sorting and site monitoring exceeded the 5×10^3 -10^4 cfu m^{-3} exposure limit for waste workers within an 8-hour working period suggested by Malmros *et al.,* (1992). Thus raising concerns regarding health risk for the workers undertaking those activities at the dumpsite.

Risk of infection of workers from inhaling air containing *Aspergillus fumigatus* and *E. coli* O157:H7

- The risk of infection from spores of *Aspergillus fumigatus* was high in this study. The infection risk estimates for all locations were of the same magnitude (10^{-1}) irrespective of whether the individual was involved in activities at the dumpsite or not.
- The combined risk from undertaking activities and inhaling ambient air contaminated with *Aspergillus fumigatus* increases the daily chances infection, placing the risk of infection between 73-78% at the active area and 66-70% at the boundary for all activities associated with those locations.

- The risk of infection from ingestion of *E. coli* O157:H7 because of inhaling contaminated ambient air was classified as a medium-high and low-medium risk range. The daily estimates of the risk of infection from ranged from 10^{-3}-10^{-2} for the conservative and 10^{-4}-10^{-3} for the least conservative pathogen to indicator ratio.
- The probable outcome from ingesting inhaled *E. coli* O157:H7 during scavenging, waste sorting and site monitoring was high (10^{-1}).
- Overall, the trends in the risk estimates suggest that the activities at the dumpsite may contribute more to the likelihood of workers developing either respiratory infection or GI infection than anything else.

9.2 Recommendations for future research

This research has produced some significant contributions to the body of knowledge on exposures to bioaerosols arising from dumpsites and the associated health risks, and has generated valuable insights to the key factors that contribute to the severity of the health conditions. Nonetheless, some knowledge gaps were identified that will require further research to provide a better understanding of the health risks associated with exposure to bioaerosols. These are presented in this section.

- The respiratory health study aspect in this research was based largely on a subjective inquiry without a complementary objective clinical measure. Spirometry and haematological profiling could have provided a better understanding of the lung functions in response to inhaled bioaerosols and particulate matter and to the detection inhaled particulate matter in the blood.
- Bioaerosols sampling at the sensitive receptor is an important part of the protocol required by the UK Environment Agency (2017) Technical Guidance Note M9 guidelines for bioaerosol monitoring in waste facilities. Unfortunately, this was not carried out in this study; as a result, there is no clear measure of the concentration of bioaerosols the residents near the dumpsite were exposed to.
- Information from this study indicated at there was a high prevalence of respiratory disease as well as a high level of exposure to bioaerosols. However, it was unclear what species of bioaerosols were predominant in the air at the dumpsite and could be associated to the some of the respiratory symptoms reported by the workers and

residents. Thus, it becomes imperative to employ a next generation sequencing and quantitative polymerase chain reaction (qPCR) to determine the microbial community in such environment.

- Because of the limited number of sampling equipment, the air-sampling regime in this study could not take place at all the sampling locations concurrently. This may have given room for the influence of meteorological factors in the sample bioaerosol concentrations collected.
- The air sampling aspect of the research spanned 13 weeks. This duration may be too short for studies like this, as such may require longitudinal studies to make affirmative conclusions on the findings.
- A major challenge in the dose-response modelling is the lack of data in the literature on dose response models for fungal infections. Unfortunately, the dose response model in this study for exposures to *Aspergillus fumigatus* assumed an immunocompromised condition of the patient, which was not at best, fitting for this study, since it appeared that most of the workers were not immunocompromised at the time of the study. In future, dose-response models developed should take into account the immunity status of the individuals.
- The interaction of the waste workers with the community around the dumpsite and tracing of the possible spread of pathogens through surface contact could be looked into for further study.

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APPENDIX A: DATASET FOR CHAPTER 4

Table A-1 Metrics used in calculating population-sampling size (WHO 1991)

	Variables	Values
Parameters considered when calculating Statistical power	Total population	1528
	p-value	0.05
	Effect size (d)	0.50
	Statistical power	0.90
	Statistical Test	One tailed t-test for two independent sample mean
Result	Standard deviation	3.316
	Number of groups	3
	Individual sample size	88
	Attrition/ mission data	20 per group
	Minimum sample size	108 per group

Table A-2. Socio demographic characteristics of On-dumpsite participants

Variable	Category	Scavengers [a] *n*	Food Vendors [a] *n*	Waste workers [a] *n*	Middle Men [b] *n*	Small Business [b] *n*	Overall (N)
Sample Size	Frequency	91(61%)	3(2%)	24(16%)	17(11%)	14(10%)	149(100%)
Age	Median	32.1	25.6	32.9	34.4	29.2	30
Gender	Female	15 (16%)	0 (0%)	2 (8%)	1 (6%)	1(7%)	19(13%)
	Male	76 (84%)	3 (100%)	22 (92%)	16 (96%)	14(93%)	130(87%)
Level of education	No Formal education	13(14%)	1(33%)	2(8%)	2(12%)	3(20%)	21(14%)
	Primary	37(41%)	0(0%)	4(17%)	3(18%)	3(20%)	47(32%)
	Secondary	38(42%)	2(67%)	11(50%)	9(53%)	7 (47%)	67(46%)
	Tertiary	3(3%)	0(0%)	6(25%)	3(18%)	2(13%)	14(8%)
Hours of work/ day	Mean (SD)	10.2(2.6)	9.7(1.5)	11(2.1)	10.8(2.4)	12.8(2.7)	11 hours
days per week	Median						6 days
Years of work	1-5yrs	42	1	10	7	10	70(47%)
	6-10yrs	27	2	5	4	2	40(27%)
	11-15yrs	10	0	2	2	3	17(11.4%)
	16-20yrs	9	0	4	4	0	19(12.8%)
	21+	3	0	0	0	0	3 (2%)
	Median						5
Smoking Status	Ever Smoked	37(42%)	0(%)	12(52%)	8(47%)	4(29)	61(41%)
	Non-smoker	51(58%)	3(100%)	11(48%)	9 (53%)	10 (71%)	84(56%)
Use of nose mask	NO	83 (91%)	2(67%)	18(75%)	16(94%)	15(100%)	133(89%)
	YES	8(9%)	1(33%)	6(38%)	1(6%)	0	16(11%)
Eating at active points.	On	74(81%)	1 (33%)	12(50%)	9(53%)	8(57%)	104(70%)
	Away	17(19%)	2 (67%)	12(50%)	8(47%)	6(43%)	45(30%)
Respirators	< 6 months	8 (8.8%)	1 (33%)	5 (21%)	1(5.8%)	0	15 (10%)
Safety gloves	< 6 months	28 (31%)	1 (31%)	16 (67%)	5 (29.4%)	0	50 (34%)
Safety googles	< 6 months	1 (1.1%)	1 (31%)	1 (4.2%)	1 (5.8%)	0	4 (3%)
Safety Shoes	< 6 months	51 (56%)	2 (67%)	14 (58%)	7 (41%)	0	74(50%)
Protective clothing	< 6 months	0	0	4 (17%)	0	0	4 (3%)

[a] Active workers on dumpsite
[b] Passive workers on dumpsite

Table A-3: Socio-demographic characteristics of sampled population located close-to-dumpsite

Variable	Category	Residents	Business Owners	Workers	Overall
Sample size	Frequency	43(29.7%)	40(27.5%)	62(42.7%)	145(100%)
Age	Median	34.6	34.7	34.1	32
Gender	Female	18(42%)	18(20%)	19(31%)	45(31%)
	Male	25(58%)	32(80%)	43(69%)	100(69%)
Level of education	No Formal	1(2%)	2(5%)	2(3%)	5(3%)
	Primary	2(5%)	9(23%)	6(10%)	17(12%)
	Secondary	26(60%)	22(56%)	23(37%)	71(49%)
	Tertiary	14(33%)	6(15%)	31(50%)	51(35%)
Year at location	1-5 years	16(11%)	22(15.2%)	40(27.5%)	78 (54%)
	6-10 years	12(8.2%)	10(6.8%)	6 (4.1%)	28(19.4%)
	11-15 years	3(2%)	2(1.4%)	3(2%)	8(5.5%)
	16 -20 years	6(4.1%)	10(6.8%)	8(5.5%)	16(11.1%)
	21+	6(4.1%)	3(2%)	5(3.4%)	14(9.7%)
Hours at location per day	Mean (SD)				12(3.3)
Smoking Status	Smokers	8(19%)	9(22%)	17(29%)	34(23%)
	Non-smokers	35(81%)	31(78%)	42(71%)	108(76%)
Cigarette per day	Mean (SD)	3.8(2.0)	6.7(3.0)	8.2(9.4)	6.8(7.1)

Table A-4. Respiratory health condition and symptoms of sampled population close to dumpsite (Expanded)

Reported Symptom			N (%)	95%CI
Cough			76(52.4%)	43.9-60.7
	Cough as much as 4 to 6 time a day		66(45.5%)	37.2-53.9
	Cough first thing in the morning		69(47.9%)	39.5-56.3
	Chronic Cough		46(31.7%)	24.2-39.9
Phlegm			55(37.9%)	30.0-46.3
	Phlegm as much as twice a day, 4 or more days a week		42(28.9%)	21.7-37.1
	Phlegm first thing in the morning		43(29.9%)	22.3-37.8
	Chronic Phlegm		42(28.9%)	21.7-37.0
Wheezing				
	When cold		22(15.7%)	9.7-22.0
	Occasionally in a dusty enviro		26(17.9%)	12.0-25.1
	Wheezing that causes short breath		18(12.4)	7.5-18.9
Bronchitis			9 (6.21%)	2.8-11.4
	Bronchitis confirmed by a Doctor		7 (4.8%)	1.9-9.69
Asthma			14 (9.6%)	5.3-15.6
	Asthma confirmed by a Doctor		12 (8.2%)	4.3-14.0
	Asthma attacks when close to OOWD		10(6.9%)	3.4-12.3
		Jan/Feb	4(2.7)	0.76-6.9
		Mar/Apr	2(1.4)	0.17-4.8
		May/Jun	3(2.1)	0.43-5.9
		Jul/Aug	2(1.4)	0.17-4.8
		Sep/Oct	2(1.4)	0.17-4.8
Sneezing/Runny Nose			72(49.6)	41.2-58.1
	Nose problem with itchy eyes		65(44.8)	36.5-53.3
	Month of Occurrence	Jan/Feb	7(4.8)	1.9-9.6
		Mar/Apr	5(3.4)	1.1-7.86
		May/Jun	16(11.0)	6.4-17.3
		Sep/Oct	32(22.0)	15.6-29.7
		Nov/Dec	3(2.0)	0.43-5.9
Overall Chest Symptoms	What happed when you were away from OOWD for 1 week	Stayed the same	63(43.5)	35.3-51.9
		Got worse	3 (2.1)	0.4-5.9
	What happed the days when you were present here compare to days were not	Improved	46(31.7)	24.2-39.9
		Stayed the same	55(37.93)	30.0-46.4
		Got worse	4(2.7)	0.8-6.9

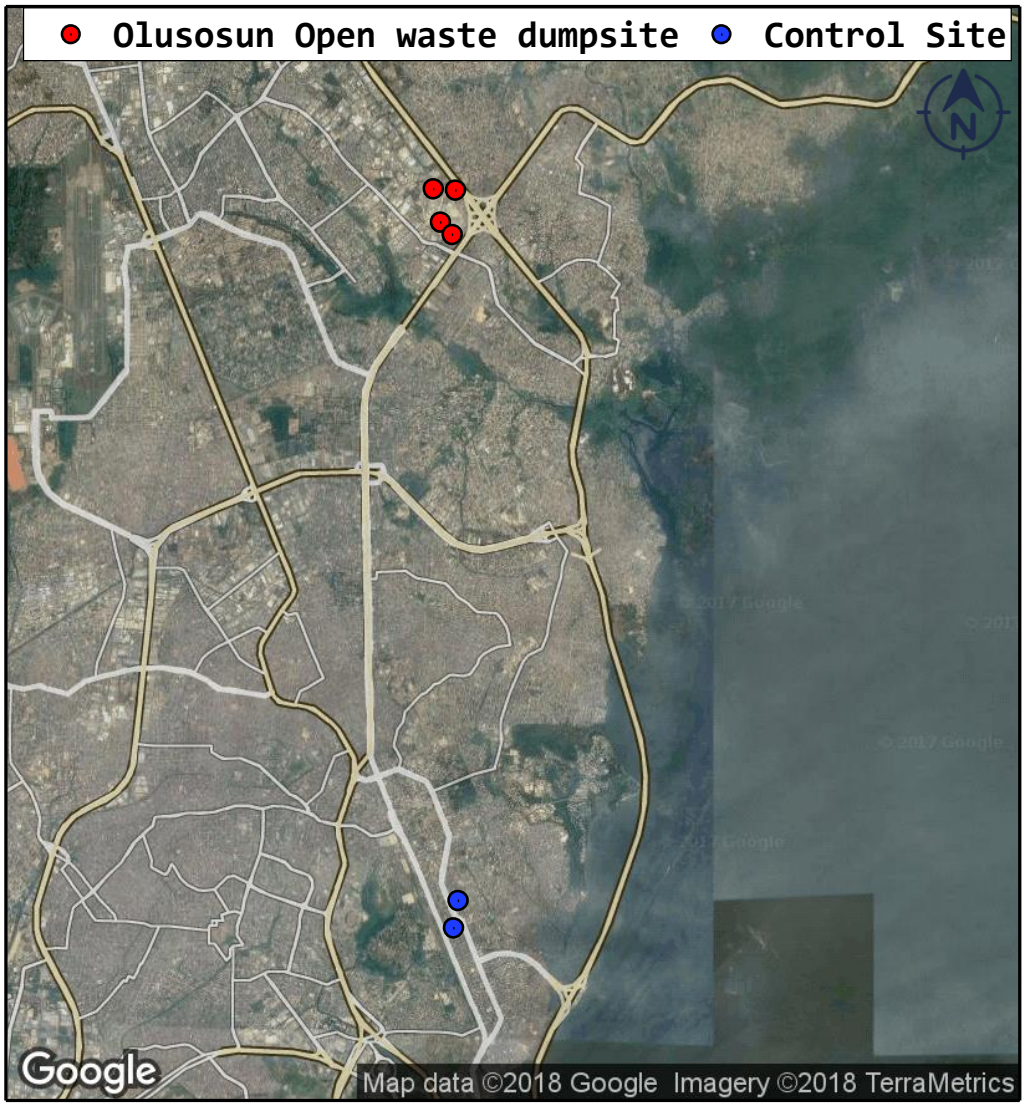
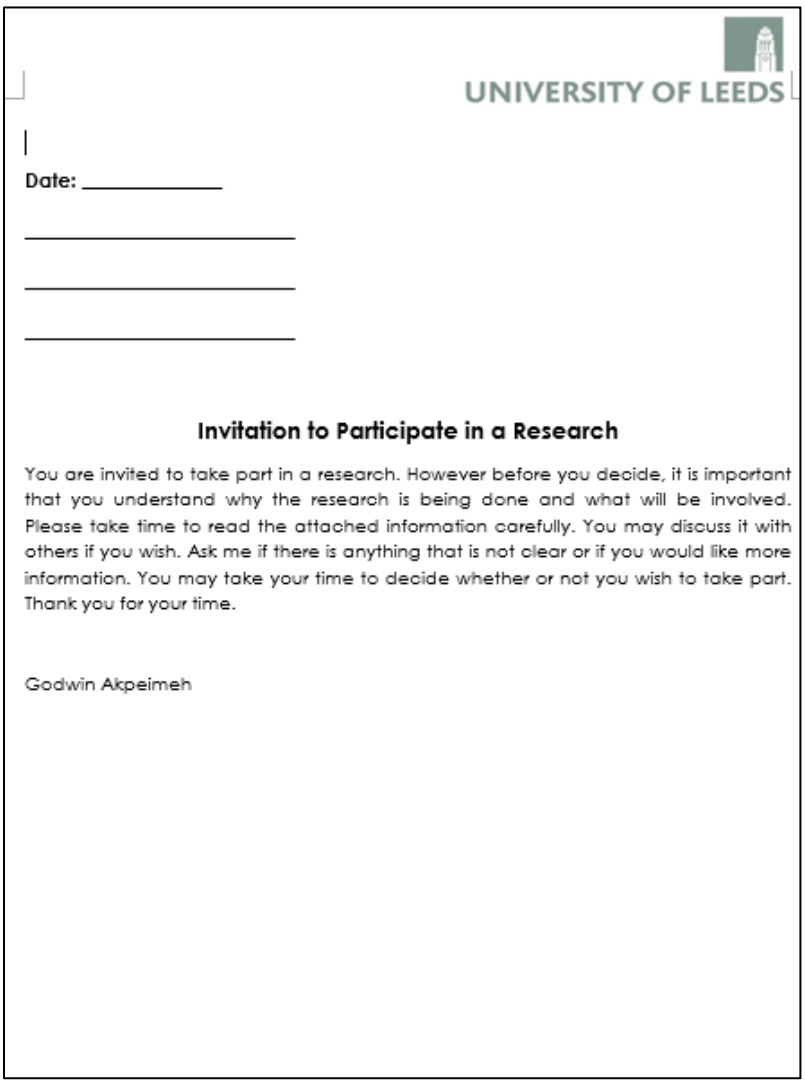


Plate A-1: Map showing the sampling locations at the control and Olusosun Dumpsite



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Date: _____

_____

_____

_____

Invitation to Participate in a Research

You are invited to take part in a research. However before you decide, it is important that you understand why the research is being done and what will be involved. Please take time to read the attached information carefully. You may discuss it with others if you wish. Ask me if there is anything that is not clear or if you would like more information. You may take your time to decide whether or not you wish to take part. Thank you for your time.

Godwin Akpeimeh

Plate A-2: The consent form for participants

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PARTICIPANTS BIO-DATA				
NO	**Questions and Filters**	**Responses**		**Skip To**
S 1	Do you agree to participate in this survey?	YES NO	1 2	→CONTINUE → END and thank respondent
S 2	Are you any of the following _____ in this area?	Business owner Resident Worker Waste Worker Scavenger Other (specify)_____	1 2 3 4 5 99	→ CONTINUE, use **CTS** Q → CONTINUE, use **CTS** Q → CONTINUE, use **CTS** Q → CONTINUE, use **OS** Q → CONTINUE, Use **OS** Q
S 3	How many years have you been _____ (Answer in S2)?	_____ Years		
S 4	What is your highest level of education:	Primary Education Secondary Education Tertiary Education No formal Education		
S 5	Name of Area of interview: Address of interview Location:			**Unique Area ID**
S 6	Time started: _____	Time Ended:_____		
S 7	**Participants ID Code:**	**Gender** Male Female		**Age in Years**
S 8	**A. Interviewer**	**B. Team Leader**		**C. Data Entry**
	Name:	Name:		Name:
	Time:	Time:		Time:
	Date :	Date :		Date :

Plate A-3: Interview Questionnaire for On-site respondents

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QUESTIONNAIRE FOR ON-SITE PARTICIPANTS				
NO	**Question and filters**	**Responses**		**Skip To**
A. Interaction with Olusosun Open Waste Dumpsite (OOWD)				
Q 1	How long how you been Scavenging or working at OOWD?	_____Years	98	
Q 2	What time of the day do you begin and end scavenging/work each day.	Begin: ☐☐☐☐	98	
		End: ☐☐☐☐	98	
Q 3	How many days in a week do you Scavenge or work at this location?	No of Days_____		
B. Sanitation Behaviour (Ingestion of food)				***(For Scavengers and Waste Workers)***
Q 4	How many times do you eat food when you are at the dumpsite?	Breakfast	1	
		Lunch	2	
		Dinner	3	
		Other (specify)	4	
Q 5	How do you obtain the food you eat at dumpsite?	Buy from dumpsite vendors	1	→ CONTINUE
		Bring from home	2	→ Q 7
Q 6	How many times in a day do you buy your food from dumpsite food vendor?	1 meal	1	
		2 meals	2	
		3 meals	3	
Q 7	Do you eat your meals on or away from the active points on the dumpsite?	On	1	
		Away	2	
Q 8	How do you eat your food?	Use of bare hands	1	→ CONTINUE
		Spoons/ forks	2	→ Sect C
Q 9	Before you eat with your bare hands, do you do any of the following?	Wash hands with only water	1	
		Wash hands with water and soap	2	
		Do not wash hands	3	
		Wash sometimes	4	
C. WASTE CHARACTERISTICS AND SCAVENGER EXPOSURES				***(For scavengers)***
Q 8	What are the main items you recover from scavenging?	Bottles	1	

Plate A-3: Interview Questionnaire for On-site respondents *(cont'd)*

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QUESTIONNAIRE FOR CLOSE-TO-SITE (CTS) PARTICIPANTS				
A. Interaction with Olusosun Open Dumpsite (OOWD)				
NO	**Question and filters**	**Responses**		**Skip To**
Q 1	How long how you been in this location either residing/ working/ running a business in this area?	_____Years	98	
Q 2	What time of the day do you arrive and leave your business/work each day.	Arrival: _____ Departure: _____	98 98	
Q 3	How many days in a week do you run your business/come work?	Number of Days_____		
Q 4	Does your business involve interacting with the scavengers at OOWD?	YES NO	1 2	
B. MULTIPLE RESPIRATORY SYMPTOMS				
B 1.1 Cough				
Q 5	Do you usually have cough?	YES NO	1 2	→CONTINUE → Q 7
Q 6	Do you usually have cough as much as 4 to 6 times a day, 4 or more days out of the week?	YES NO	1 2	
Q 7	Do you usually cough at all on getting up or first thing in the morning?	YES NO	1 2	
Q 8	Do you usually cough at all during the rest of the day or at night?	YES NO	1 2	
NOTE: If **YES** to **ANY** of above (Q 5, 6, 7 or 8), continue to Q 9, 10. If **NO** to **ALL** SKIP to Q 12				
Q 9	Do you usually cough like this on most days for 3 conservative months or more during the year?	YES NO Does Not apply	1 2 99	→ CONTINUE → CONTINUE → Q 11
Q 10	For how many years have you had this cough?	_____ Does Not apply	 99	
B 1.2 Phlegm				
Q 11	Do you usually bring up phlegm from your chest? (*Exclude phlegm form Nose. Count swallowed phlegm*)	YES NO	1 2	→ CONTINUE → Q 13

Plate A-4: Interview Questionnaire for respondent's close-to-dumpsite

Chi-square goodness of fit test comparing reported respiratory symptoms at Olusosun dumpsite to control

Cough

	Observed N	Expected N	Residual
1.00 Yes	75	53.1	21.9
2.00 No	74	95.9	-21.9
Total	149		

Test Statistics

			Cough
Chi-Square			14.021[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

Chronic Cough

	Observed N	Expected N	Residual
1.00 Yes	56	9.6	46.4
2.00 No	93	139.4	-46.4
Total	149		

Test Statistics

	Chronic Cough
Chi-Square	239.743[a]
df	1
Asymp. Sig.	.000

Chronic_Plgm

	Observed N	Expected N	Residual
1.00 Yes	52	5.0	47.0
2.00 No	97	144.0	-47.0
Total	149		

Test Statistics

			Chronic_Plgm
Chi-Square			461.460[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

Phlegm

	Observed N	Expected N	Residual
1.00 Yes	73	55.9	17.1
2.00 No	76	93.1	-17.1
Total	149		

Test Statistics

			Phlegm
Chi-Square			8.398[a]
df			1
Asymp. Sig.			.004
Monte Carlo Sig.	Sig.		.005[b]
	95% Confidence Interval	Lower Bound	.003
		Upper Bound	.007

Whez

	Observed N	Expected N	Residual
1.00 Yes	29	14.9	14.1
2.00 No	120	134.1	-14.1
Total	149		

Test Statistics

			Whez
Chi-Square			14.826[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.001[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

Broc

	Observed N	Expected N	Residual
1.00 Yes	16	8.6	7.4
2.00 No	133	140.4	-7.4
Total	149		

Test Statistics

			Broc
Chi-Square			6.651[a]
df			1
Asymp. Sig.			.010
Monte Carlo Sig.	Sig.		.011[b]
	95% Confidence Interval	Lower Bound	.008
		Upper Bound	.014

The difference in prevalence of asthma on dumpsite compared to national average

Asth_SB

	Observed N	Expected N	Residual
1.00 Yes	3	15.2	-12.2
2.00 No	146	133.8	12.2
Total	149		

Test Statistics

			Asth_SB
Chi-Square			10.902[a]
df			1
Asymp. Sig.			.001
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

Asth_SB

	Observed N	Expected N	Residual
1.00 Yes	3	6.3	-3.3
2.00 No	146	142.7	3.3
Total	149		

Test Statistics

			Asth_SB
Chi-Square			1.771[a]
df			1
Asymp. Sig.			.183
Monte Carlo Sig.	Sig.		.225[b]
	95% Confidence Interval	Lower Bound	.213
		Upper Bound	.237

Chi-square goodness-of-fit test comparing reported respiratory symptoms among residents close-to-Olusosun dumpsite to control

Cough_CTSP

	Observed N	Expected N	Residual
1.00 Yes	76	52.2	23.8
2.00 No	69	92.8	-23.8
Total	145		

Test Statistics

			Cough_CTSP
Chi-Square			16.955[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

CP_CPSP

	Observed N	Expected N	Residual
1.00 Yes	42	3.6	38.4
2.00 No	103	141.4	-38.4
Total	145		

Test Statistics

			CP_CPSP
Chi-Square			416.662[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

Broc_CTSP

	Observed N	Expected N	Residual
1.00 Yes	7	8.4	-1.4
2.00 No	138	136.6	1.4
Total	145		

Test Statistics

			Broc_CTSP
Chi-Square			.251[a]
df			1
Asymp. Sig.			.616
Monte Carlo Sig.	Sig.		.721[b]
	95% Confidence Interval	Lower Bound	.708
		Upper Bound	.733

Asth_SB_CTSP

	Observed N	Expected N	Residual
1.00 Yes	18	6.1	11.9
2.00 No	127	138.9	-11.9
Total	145		

Test Statistics

			Asth_SB_CTSP
Chi-Square			24.313[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

Whez_CTSP

	Observed N	Expected N	Residual
1.00 Yes	26	14.5	11.5
2.00 No	119	130.5	-11.5
Total	145		

Test Statistics

			Whez_CTSP
Chi-Square			10.134[a]
df			1
Asymp. Sig.			.001
Monte Carlo Sig.	Sig.		.002[b]
	95% Confidence Interval	Lower Bound	.001
		Upper Bound	.003

Asth_CTSP

	Observed N	Expected N	Residual
1.00 Yes	18	6.1	11.9
2.00 No	127	138.9	-11.9
Total	145		

Test Statistics

			Asth_CTSP
Chi-Square			24.313[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

CC_CTSP

	Observed N	Expected N	Residual
1.00 Yes	46	9.7	36.3
2.00 No	99	135.3	-36.3
Total	145		

Test Statistics

			CC_CTSP
Chi-Square			145.255[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

Cough_CTSP

	Observed N	Expected N	Residual
1.00 Yes	76	9.7	66.3
2.00 No	69	135.3	-66.3
Total	145		

Test Statistics

			Cough_CTSP
Chi-Square			484.737[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

Sneez_RN

	Observed N	Expected N	Residual
1.00 Yes	72	3.6	68.4
2.00 No	73	141.4	-68.4
Total	145		

Test Statistics

			Sneez_RN
Chi-Square			1322.763[a]
df			1
Asymp. Sig.			.000
Monte Carlo Sig.	Sig.		.000[b]
	95% Confidence Interval	Lower Bound	.000
		Upper Bound	.001

Plgm_CTSP

	Observed N	Expected N	Residual
1.00 Yes	55	54.4	.6
2.00 No	90	90.6	-.6
Total	145		

Test Statistics

			Plgm_CTSP
Chi-Square			.011[a]
df			1
Asymp. Sig.			.915
Monte Carlo Sig.	Sig.		.931[b]
	95% Confidence Interval	Lower Bound	.924
		Upper Bound	.938

The difference in prevalence of asthma among residents close to dumpsite compared to national average

Asth_SB_CTSP

	Observed N	Expected N	Residual
1.00 Yes	18	14.8	3.2
2.00 No	127	130.2	-3.2
Total	145		

Test Statistics

			Asth_SB_CTSP
Chi-Square			.776[a]
df			1
Asymp. Sig.			.378
Monte Carlo Sig.	Sig.		.415[b]
	95% Confidence Interval	Lower Bound	.401
		Upper Bound	.428

APPENDIX B: DATASET FOR CHAPTER 5

Table B-1: Correlation between Meteorological factors and Bioaerosol concentration at specific sampling locations

		GBp3	AFp3	AFp4	Temp	Wind	RH
T B (Boundary)	Pearson Correlation				0.624*		
	Sig. (2-tailed)				0.023		
	N				13		
GNB (Dormant Area)	Pearson Correlation	1	.568*	.139	.604*	-.254	-.338
	Sig. (2-tailed)		.043	.651	.029	.403	.259
	N	13	13	13	13	13	13
AF (Dormant Area)	Pearson Correlation	.568*	1	.043	.439	-.616*	-.260
	Sig. (2-tailed)	.043		.890	.134	.025	.391
	N	13	13	13	13	13	13
AF (Boundary)	Pearson Correlation	.139	.043	1	.179	.571*	.164
	Sig. (2-tailed)	.651	.890		.558	.042	.592
	N	13	13	13	13	13	13
Temp	Pearson Correlation	.649*	.439	.179	1	-.409	-.479
	Sig. (2-tailed)	.016	.134	.558		.166	.098
	N	13	13	13	13	13	13
W/Speed	Pearson Correlation	-.254	-.570*	.571*	-.409	1	.615*
	Sig. (2-tailed)	.403	.042	.042	.166		.025
	N	13	13	13	13	13	13
RH	Pearson Correlation	-.338	-.260	.164	-.479	.615*	1
	Sig. (2-tailed)	.259	.391	.592	.098	.025	
	N	13	13	13	13	13	13

* Correlation is significant at the 0.05 level (2-tailed).

Correlations

		TB003	GB003	AF003	TF003	Temp003	Wnd003	RH003
TB003	Pearson Correlation	1	.625**	.371**	.347*	.227	-.080	-.384**
	Sig. (2-tailed)		.000	.007	.012	.105	.575	.005
	N	52	52	52	52	52	52	52
GB003	Pearson Correlation	.625**	1	.409**	.251	.242	.140	-.238
	Sig. (2-tailed)	.000		.003	.073	.084	.323	.089
	N	52	52	52	52	52	52	52
AF003	Pearson Correlation	.371**	.409**	1	.695**	.031	.013	-.003
	Sig. (2-tailed)	.007	.003		.000	.827	.928	.985
	N	52	52	52	52	52	52	52
TF003	Pearson Correlation	.347*	.251	.695**	1	.177	-.143	-.094
	Sig. (2-tailed)	.012	.073	.000		.210	.313	.507
	N	52	52	52	52	52	52	52
Temp003	Pearson Correlation	.227	.242	.031	.177	1	-.087	-.270
	Sig. (2-tailed)	.105	.084	.827	.210		.539	.053
	N	52	52	52	52	52	52	52
Wnd003	Pearson Correlation	-.080	.140	.013	-.143	-.087	1	.186
	Sig. (2-tailed)	.575	.323	.928	.313	.539		.187
	N	52	52	52	52	52	52	52
RH003	Pearson Correlation	-.384**	-.238	-.003	-.094	-.270	.186	1
	Sig. (2-tailed)	.005	.089	.985	.507	.053	.187	
	N	52	52	52	52	52	52	52

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

*. Correlation is significant at the 0.05 level (2-tailed).

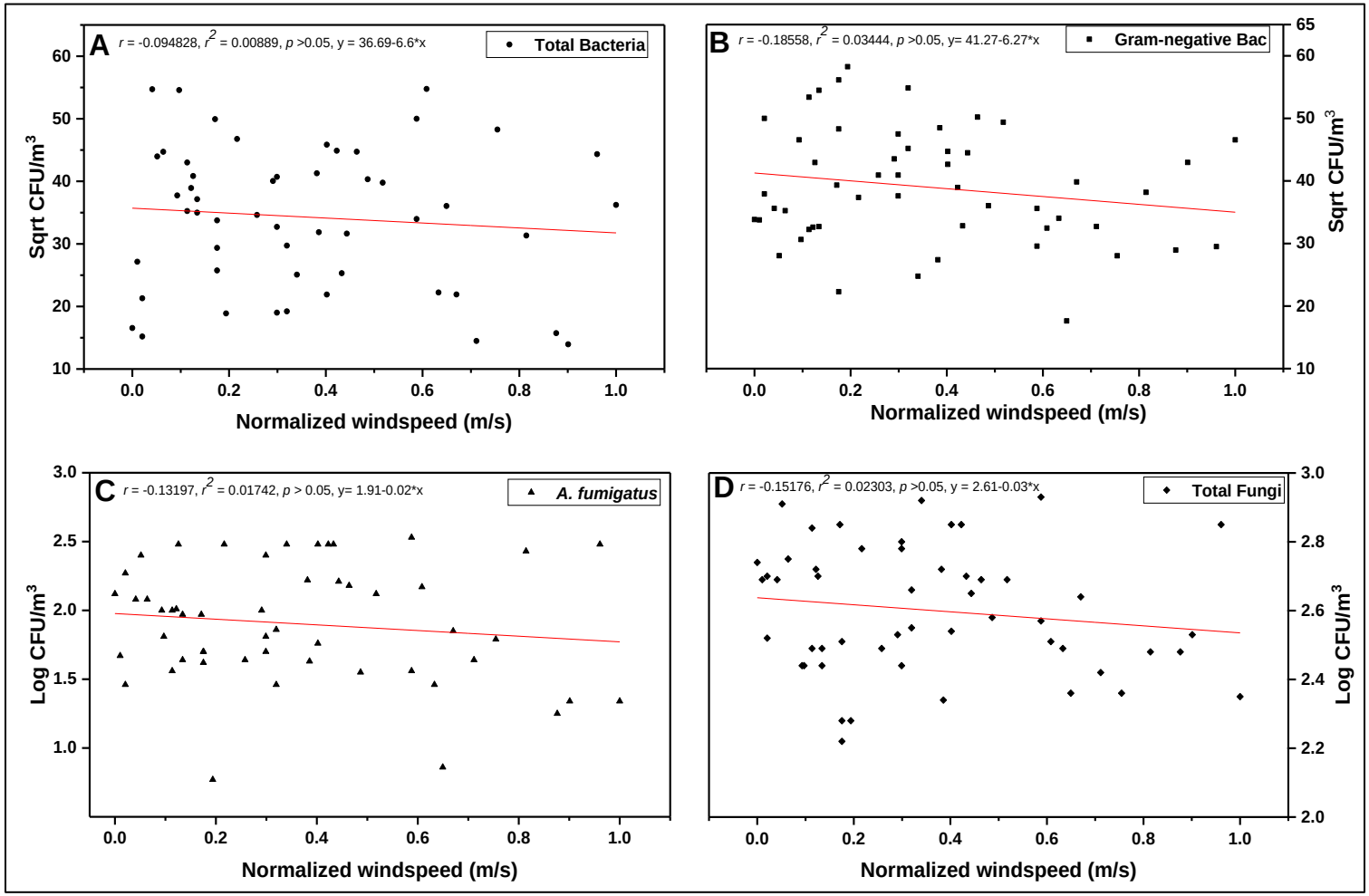

Figure B-1: Bioaerosol correlation with wind speed at dumpsite (A) Total Bacteria (B) Gram-negative Bacteria (C) A. fumigatus (D) Total Fungi.

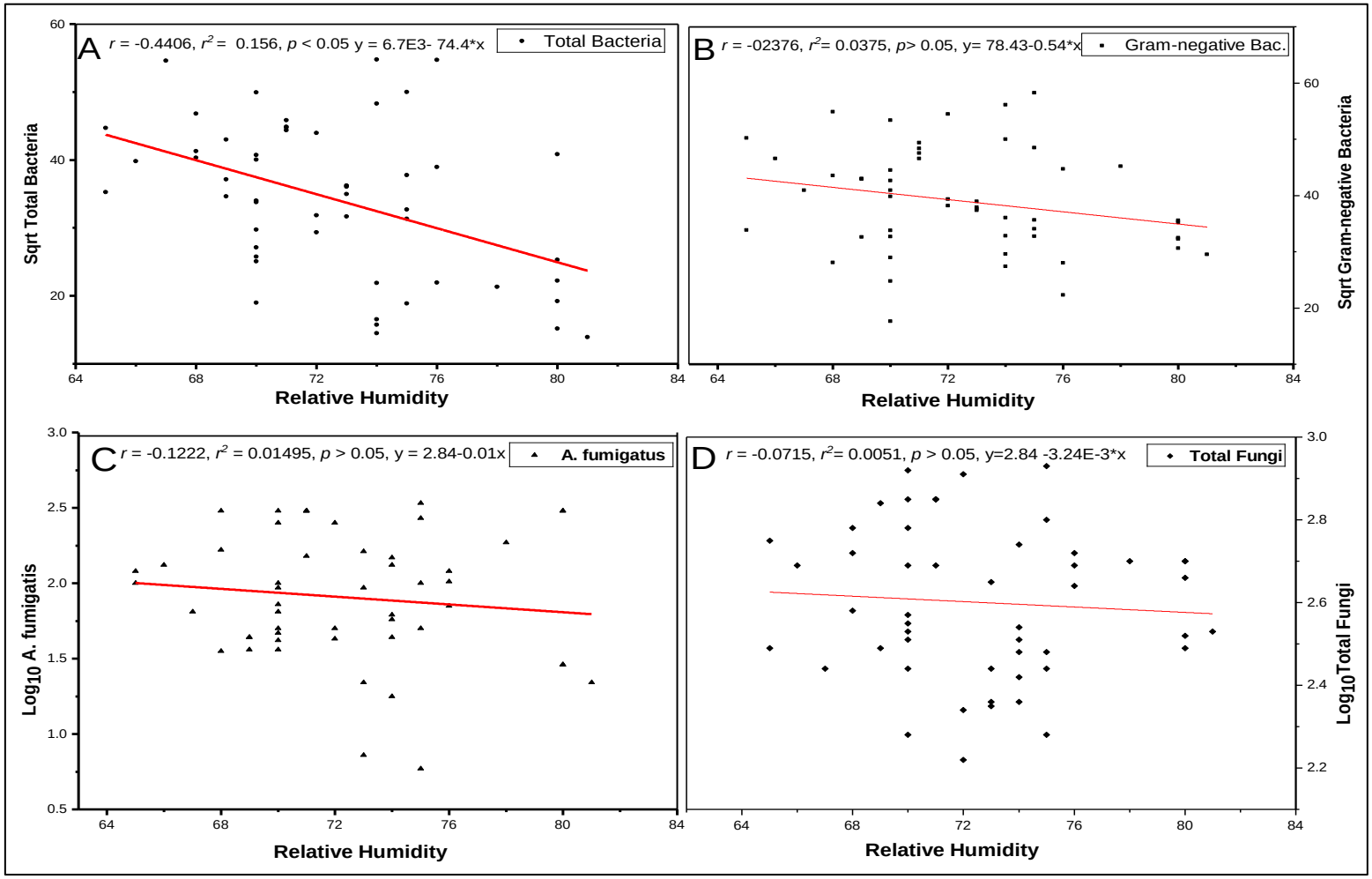

Figure B-2: Linear Pearson correlation between Relative Humidity and (A) Total bacteria (B) Gram-negative Bacteria (C) Aspergillus fumigatus (D) Total Fungi

Table B-3: Mean ambient bioaerosol concentration (cfu m^{-3}) for visit 1-4 (25th April – 22nd May 2017)

Sampling days/Date		Sampling locations	Total Bacteria		Gram negative Bacteria		Aspergillus fumigatus		Total Fungi	
			Concentration	SD	Concentration	SD	Concentration	SD	Concentration	SD
Visit 1	25.04.17	Active Area	2015.31	622.99	2439.3	1450.9	428.2	137.4	848.7	112.4
		Entrance	1657.83	187.40	1679.1	1584.1	134.4	17.5	597.8	50.8
		Dormant Area	1300.00	401.44	1411.9	2352.9	54.0	11.6	842.8	40.8
		Boundary	1009.14	1569.96	1168.5	5308.7	58.1	92.4	326.9	144.1
Visit 2	05.05.17	Active Area	628.98	96.61	2187.6	145.8	479.4	78.3	834.5	25.8
		Entrance	356.89	118.27	1268.6	114.9	5.9	8.3	189.1	34.1
		Dormant Area	1139.58	27.48	1587.8	566.4	41.2	41.6	189.6	168.2
		Boundary	737.34	129.93	838.6	15.0	47.1	0.0	485.3	81.6
Visit 3	12.05.17	Active Area	1603.81	332.47	1980.2	713.9	101.0	81.6	340.4	73.4
		Entrance	1849.72	107.08	1063.7	262.1	36.1	30.6	684.4	366.1
		Dormant Area	1059.00	117.28	1820.2	807.7	93.8	30.6	703.8	628.2
		Boundary	1009.14	297.79	2257.2	197.8	50.6	18.1	339.7	16470.4
Visit 4	22.05.17	Active Area	2994.35	298.83	2175.0	246.9	120.1	89.9	490.5	74.0
		Entrance	1015.55	276.85	1547.0	282.8	42.4	20.0	219.8	90.9
		Dormant Area	1052.00	10356.24	2520.9	1094.4	120.9	51.0	556.9	143.9
		Boundary	1627.56	132.93	1561.5	471.7	35.3	30.0	378.1	334.8

Table B-3: Mean ambient bioaerosol concentration (cfu m^{-3}) for visit 5-8 (2^{nd} - 23^{rd} June 2017) *(continued)*

Sampling days /Date		Sampling locations	Total Bacteria		Gram negative Bacteria		*Aspergillus fumigatus*		Total Fungi	
			Concentration	SD	Concentration	SD	Concentration	SD	Concentration	SD
Visit 5	02.06.17	Active Area	1583.62	748.56	2168.5	76.5	130.5	62.2	495.4	188.7
		Entrance	1515.83	1362.51	786.0	40.8	101.7	103.0	525.7	353.9
		Dormant Area	1379.53	15.30	1844.7	1537.9	43.3	40.8	311.5	71.4
		Boundary	1009.00	2040.70	1675.9	430.4	64.9	51.0	275.5	0.0
Visit 6	09.06.17	Active Area	2188.65	419.15	2095.8	173.4	363.5	0.0	599.3	37.7
		Entrance	1242.52	74.45	1144.4	294.7	101.0	61.2	311.5	10.2
		Dormant Area	884.11	50.99	1070.2	399.8	72.1	0.0	355.5	31.6
		Boundary	663.45	30.60	310.8	92.8	50.5	30.6	325.2	154.0
Visit 7	16.06.17	Active Area	2331.27	336.06	2054.0	1100.6	61.8	62.5	230.6	201.1
		Entrance	454.06	12.49	2043.3	133.7	186.4	63.7	498.2	102.4
		Dormant Area	1100.34	149.92	1299.5	1185.6	17.7	25.0	301.2	176.2
		Boundary	480.57	199.89	2054.0	1100.6	70.7	75.0	436.4	139.9
Visit 8	23.06.17	Active Area	274.0	40.8	2175.0	559.9	130.5	103.0	554.6	166.2
		Entrance	1668.7	1262.6	1053.6	1388.0	95.2	1142.2	419.6	595.6
		Dormant Area	1100.3	114.2	1242.5	1120.8	28.9	20.4	459.4	47.9
		Boundary	194.7	71.4	871.1	738.4	47.3	10.2	342.5	11.2

Table B-3: Mean ambient bioaerosol concentration (cfu m^{-3}) for visit 5-8 (7^{th} July – 4^{th} August 2017) *(continued)*

Sampling Days/Date		Sampling Location	Total Bacteria		Gram negative Bacteria		*Aspergillus fumigatus*		Total Fungi	
			Concentration	SD	Concentration	SD			Concentration	SD
Visit 9	07.07.17	Active Area	641.1	162.2	2321.3	341.6	282.9	1031.1	626.8	65.3
		Entrance	230.8	40.8	1039.9	350.8	28.9	20.4	327.4	30.6
		Dormant Area	1139.6	145.8	938.9	208.0	28.9	20.4	312.3	72.4
		Boundary	209.9	154.0	1078.1	9.2	43.3	61.2	261.8	19.4
Visit 10	14.07.17	Active Area	982.2	212.1	2352.4	958.7	441.3	85.7	820.8	258.0
		Entrance	1312.5	79.5	1517.3	356.9	21.6	30.6	225.0	30.6
		Dormant Area	1300.2	64.2	1396.1	185.6	7.2	10.2	231.5	41.8
		Boundary	1001.7	551.7	1438.7	94.8	50.6	41.8	444.2	10.2
Visit 11	21.07.17	Active Area	1934.1	212.1	2187.7	164.2	470.9	11.2	817.8	104.0
		Entrance	1424.2	205.0	1158.9	43.9	101.0	20.4	274.0	20.4
		Dormant Area	1225.2	421.2	1414.9	318.2	93.8	10.2	274.0	0.0
		Boundary	861.8	125.4	1458.1	128.5	50.5	30.6	165.9	71.4
Visit 12	28.07.17	Active Area	2000.4	769.0	2168.5	76.5	152.2	113.2	495.4	188.7
		Entrance	1704.8	175.4	786.8	41.8	166.6	31.6	525.7	353.9
		Dormant Area	1199.3	221.3	1845.4	1538.9	43.3	40.8	310.8	72.4
		Boundary	361.3	82.6	1675.9	430.4	64.9	51.0	275.5	0.0
Visit 13	04.08.17	Active Area	2102.8	711.8	2335.0	585.4	362.7	41.8	1116.3	169.3
		Entrance	1154.5	96.9	1140.1	223.3	36.1	10.2	369.9	11.2
		Dormant Area	1070.9	82.6	1070.9	125.4	50.5	10.2	625.2	227.4
		Boundary	479.6	62.2	751.4	136.7	57.7	40.8	346.9	19.4

Table B-5: Climatic data for Lagos during the study period in 2017 (Lavoyageur 2017; WMO 2018)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average high (°C)	34	34	33	33	32	29	27	27	28	30	32	33
Average Low (°C)	23	24	24	25	24	23	23	23	23	23	24	24
Mean Precipitation (mm)	4	23	88	150	156	182	173	147	183	179	29	7
Humidity (%)	79.3	77.3	78.7	81.3	83.6	89.4	88.4	85.3	84.9	86	83.3	89.4

APPENDIX C: DATASET FOR CHAPTER 6

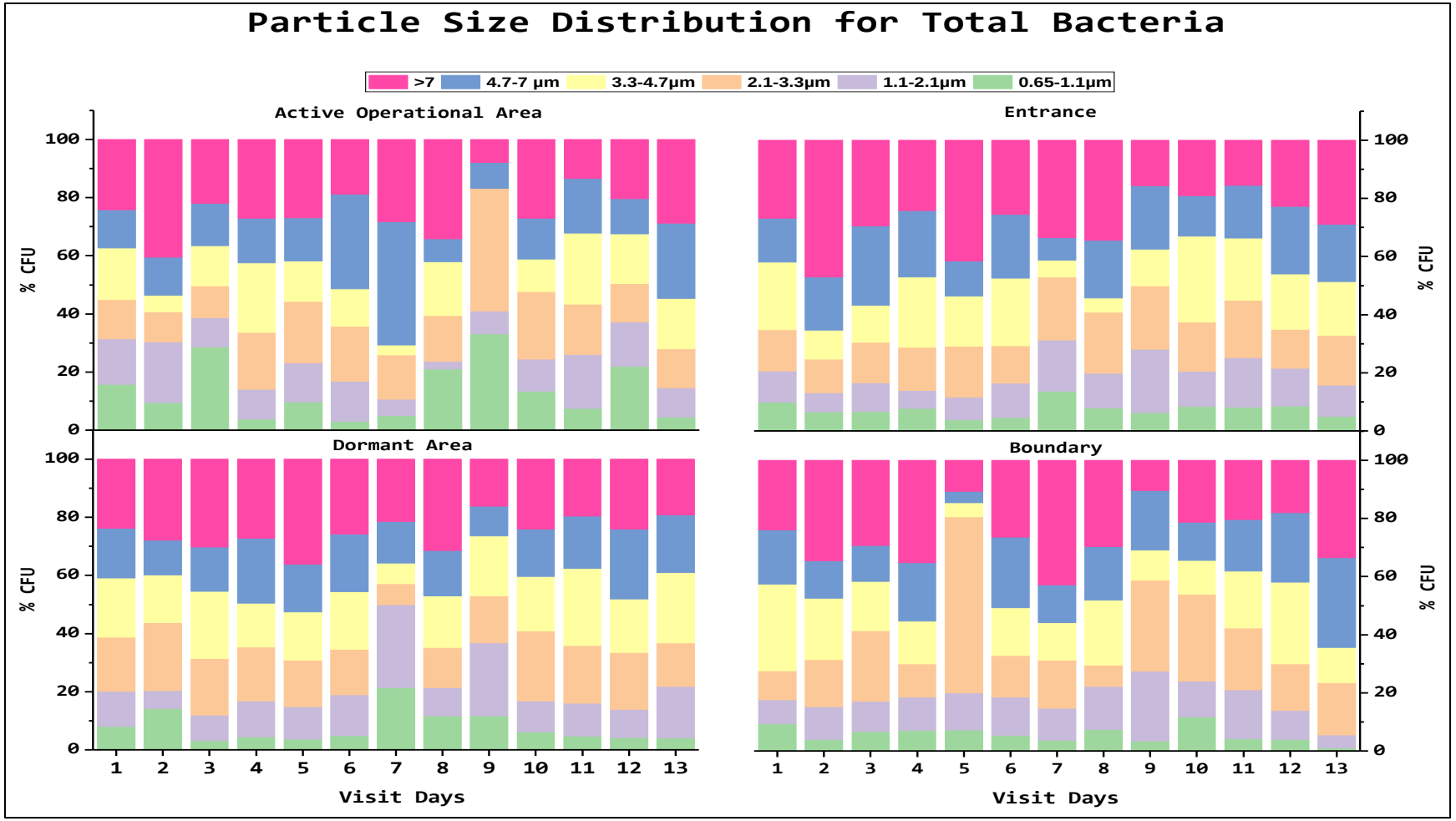

Figure C-1 Particle size distribution of Total bacteria at the four sampling location for 13 visit days

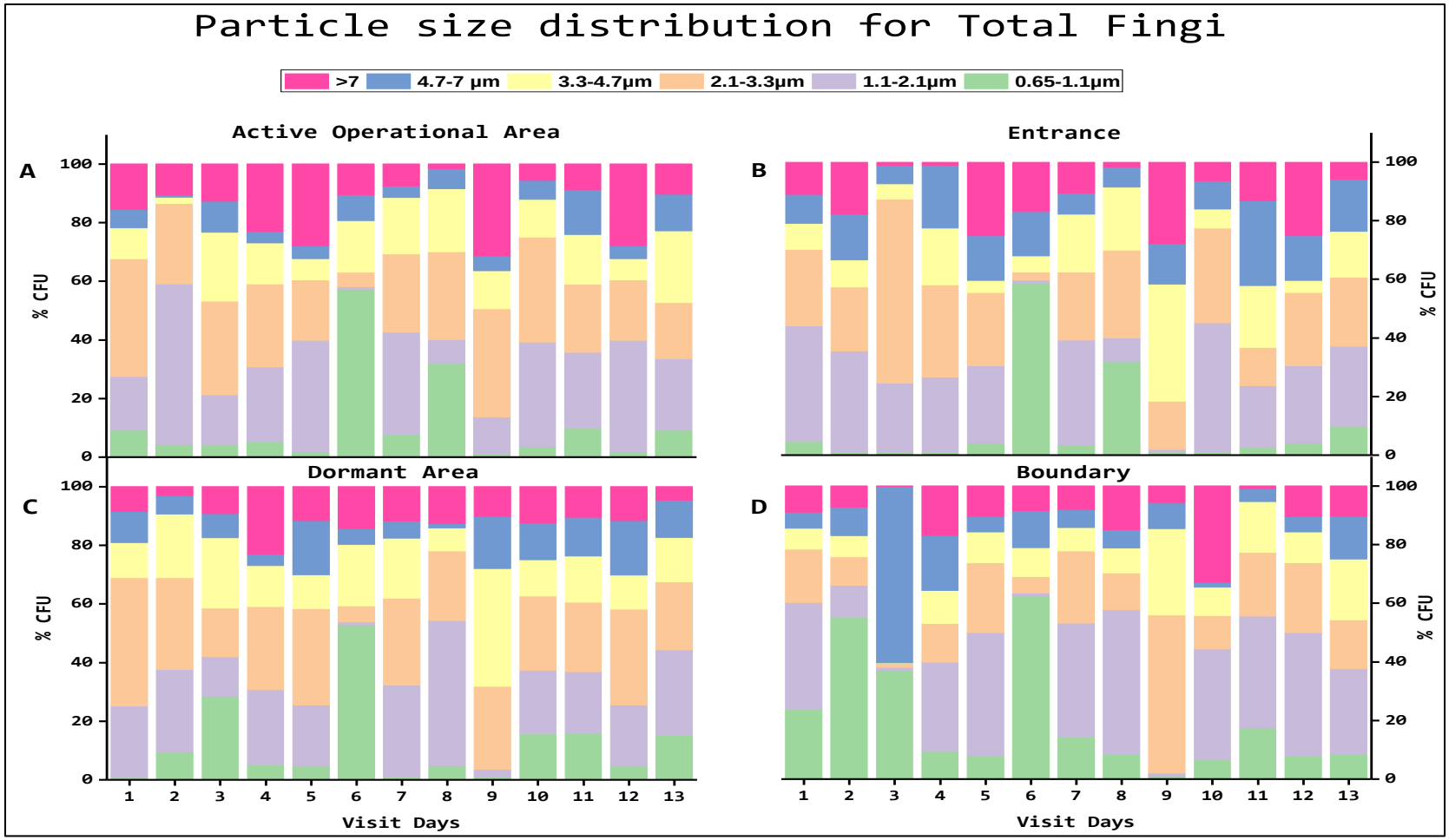

Figure C-2 Particle size distribution of Total Fungi at the four sampling location for 13 visit days

APPENDIX D: DATA SET FOR CHAPTER 7 AND 8

Table D-1: Inertial impaction and diffusion deposition rates from Sinclair et al., (2008) for a 1 µm diameter particles, measured from a human lung cast, adapted from (Weir and Haas 2011)

Aerodynamic Diameter of Particles (µm)	Location of deposition	Rate of deposition due to inertial impaction and diffusion (min^{-1})	Associated inertial and diffusion deposition rate symbol
1	Nasal Cavity	0.0022	DI_{R_1}
	Larynx	0.0000	$\sum DI_{R_2}$
	Main Bronchi	0.0000	
	Bronchioles	0.0038	DI_{R3}

Table D-2: Combined risk calculations for the four dumpsite location and activities

Activity	Active		Entrance [a]		Dormant [a]		Boundary [a]	
	11 h	1 yr.	11 h	1 yr.	11 h	1 yr.	11 h	1 yr.
Aspergillus fumigatus								
Scavenging	7.28×10^{-1}	9.19×10^{-1}	-	-	-	-	-	-
Waste sorting	7.32×10^{-1}	9.24×10^{-1}	-	-	6.83×10^{-1}	9.05×10^{-1}	6.56×10^{-1}	8.07×10^{-1}
Site monitoring	7.77×10^{-1}	8.77×10^{-1}	-	-	7.28×10^{-1}	9.18×10^{-1}	7.04×10^{-1}	8.34×10^{-1}
E.coli O157:H7 (P:I = 10^3)								
Scavenging	5.05×10^{-1}-6.68×10^{-1}	9.19×10^{-1}-9.62×10^{-1}	-	-	-	-	-	-
Waste sorting	4.54×10^{-1}-6.33×10^{-1}	9.10×10^{-1}-9.58×10^{-1}	-	-	4.55×10^{-1}-6.31×10^{-1}	9.03×10^{-1}-9.54×10^{-1}	-	-
Site monitoring	1.92×10^{-1}-4.05×10^{-1}	8.50×10^{-1}-9.29×10^{-1}	-	-	1.91×10^{-1}-4.02×10^{-1}	8.39×10^{-1}-9.22×10^{-1}	1.91×10^{-1}-4.01×10^{-1}	8.33×10^{-1}-9.19×10^{-1}
E.coli O157:H7 (P:I = 10^4)								
Scavenging	2.10×10^{-1}-4.21×10^{-1}	8.03×10^{-1}-8.91×10^{-1}	-	-	-	-	-	-
Waste sorting	1.63×10^{-1}-3.66×10^{-1}	7.81×10^{-1} -8.78×10^{-1}	-	-	1.63×10^{-1}-3.66×10^{-1}	7.75×10^{-1}-8.69×10^{-1}	1.63×10^{-1}-3.66×10^{-1}	7.74×10^{-1}-8.67×10^{-1}
Site monitoring	3.07×10^{-2}-1.19×10^{-1}	6.37×10^{-1}-7.98×10^{-1}	-	-	3.06×10^{-2}-1.18×10^{-1}	6.27×10^{-1}-7.84×10^{-1}	3.06×10^{-2}-1.19×10^{-1}	6.25×10^{-1}-7.79×10^{-1}

[a] Empty spaces means activities didn't take place in the sampling location

Figure D-1: The R code for the Markov Chain Model

Table D-3: Likert table showing Risk factors and Risk Category for Locations near Olusosun Open dumpsite

Distance from boundary	Likert rating (A)	Susceptible people	Likert rating (B)	Duration of stay at location	Likert rating (C)	Risk range‡	Category	Colour code
0-100	4	Sick	4	≥ 9 hours	4	≥17	High	Red
101-150	3	Children	3	8 hours	3	$15 \leq x < 17$	Medium-High	Amber
151-200	2	Pregnant women	2	7 hours	2	$10 \leq x < 15$	Medium	Yellow
201-250	1	Elderly	1	6 hours	1	< 10	Low	Green

‡ Risk values calculated based this equation $(A \cap B) \cdot C$