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Exposure to Bioaerosols at Open Dumpsites: A Case study of bioaerosols exposure from activities at Olusosun Open Dumpsite, Lagos Nigeria.

G.F.Akpeimeh[1], L.A.Fletcher[1a], B.E.Evans[1]

[1]School of Civil Engineering, University of Leeds, Woodhouse Lane, Leeds, UK, LS2 9JT

[a]l.a.fletcher@leeds.ac.uk

Abstract

Activities associated with the open dumping of municipal solid waste has the potential to have greater impacts on the environment and public health compared to other forms of waste-to-land treatment of such wastes. However, there is a lack of quantitative data on the exposure to bioaerosols from open dumpsites, hence impeding the development of effective interventions that would reduce the risk of respiratory symptoms among scavengers and waste workers at such dumpsites. This study investigated exposure to bioaerosols at Olusosun open dumpsite, Lagos Nigeria using three methodologies; (1) Conducting a cross-sectional survey on the respiratory health of the population on the dumpsite, (2) Measuring bioaerosol concentrations in the ambient air by measuring four bioaerosols indicator groups (total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi) using a Anderson six stage impactor sampler, (3) Measuring activity related exposures to bioaerosols using an SKC button personal sampler.

After a cross sectional health survey of 149 participants (waste workers, scavengers, middlemen, food vendors and business owners), smokers reported higher symptoms of chronic cough (21%) and chronic phlegm (15%) compared to non-smokers (chronic cough 15%, chronic phlegm 13%) . Years of work > 5 years showed no statistically significant association with chronic phlegm (OR 1.2, 95% CI 0.4-3.4; $p>0.05$) or asthma (OR 1.8, 95% CI 0.6-5.2; $p>0.05$). At the 95th percentile, the concentration of gram-negative bacteria was the highest (2188 CFU/m^3), then total bacteria (2189 CFU/m^3), total fungi (843 CFU/m^3) and *Aspergillus fumigatus* (441 CFU/m^3) after ambient air sampling. A comparison of the data showed that the activity-based sampling undertaken using body worn personal sampler showed higher bioaerosols concentrations (10^4 -10^6 CFU/m^3), i.e. 2-3 logs higher than those recorded from static ambient air sampling. Bioaerosol exposure was highest during scavenging activities compared to waste sorting and site supervision . Particle size distributions showed that 41%, 46%, 76% and 63% of total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total fungi respectively were of respirable sizes and would therefore be capable of penetrating deep into the respiratory system, posing a greater human health risk. This study has shown that exposure to bioaerosols can be associated with activities undertaken at open dumpsites and may contribute to the high prevalence of the chronic respiratory symptoms, among the workers in such environments.

1. Introduction

The rate of solid waste generation in developing countries has grown at a steady rate in recent years, especially due to urbanization and the accompanying urban population growth. Sub-Saharan Africa alone is estimated to generate 62 million tonnes per year of municipal solid waste (MSW) with a corresponding annual rate of change of urban population of 2.27 percent per year (UN-HABITAT 2009; Hoornweg and Bhada-Tata 2012b). 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. This has resulted in waste management authorities resorting to open dumping as a cheap method for managing 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. 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 the pathogenic ones (Stagg *et al.,* 2010). Similarly, the analysis of the composition of MSW in sub-Saharan Africa have shown to have high biodegradable (40-60%) and high moisture content (Ogwueleka 2009; Hoornweg and Bhada-Tata 2012a). 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.,* 2013; Epstein 2015). The individuals working on dumpsites such as scavengers, waste workers and vendors are often exposed to elevated levels of these pathogenic microorganisms majorly by inhalation as most have been noted to work in these conditions without personal protective equipment (Odewabi *et al.,* 2013). Workers exposure to organic dust laden with bioaerosols have been reported from composting and landfills facilities typically associated by 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 the 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.,* 2013).

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.,* 2003; Heldal *et al.,* 2015; Van Kampen *et al.,* 2016). 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; Hoornweg and Bhada-Tata 2012b). 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 at Olusosun open dumpsite.

2. Materials and Methods

2.1 Site description and waste characterization

The open dumpsite used in this study was situated in Ojota, Lagos State Nigeria. Lagos State has a population of 21 million with an annual growth of rate of 3.2% (LBS 2013). Of the three principal dumpsites serving the urban population of Lagos i.e Ewu Elepe, Solous and Olusosun dumpsites (LAWMA 2016), Olusosun is the biggest at 42.7 hectares (105.5 Acres), and is located between 6°35'40.9"N and 3°22'38.4"E (Oyeku and Eludoyin 2010). Olusosun is estimated to receive approximately 2,100,000 tonnes of MSW, construction and E-waste per year and has received approximately 17,150,000 to 24,500,000 tonnes 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 and the dumpsite is surrounded by sensitive receptors located less than 200 m from the boundary of the dumpsite (Olorunfemi 2011).

2.2 Control site

In order to be able to determine the impact of the open dumpsite on the concentration of bioaerosols it was necessary to identify a 'control' site at which the concentration of bioaerosols would not be impacted by activities at the open dumpsite. The two sampling points were located ~ 10.79 km away from Olusosun open dumpsite within 6°29'58.9"N 3°22'47.5"E and 6°29'45.3"N 3°22'45.0"E. Moreover, both locations and shared similar economic and demographic characteristics with Ojota, where Olusosun dumpsite is located. The median age of the sampled population at the control and Olusosun matched a national demographic characteristic: 70% of adult population in Nigeria are less than 30 years in age (Reed and Mberu 2014) and are both part of the planned Lagos Central Business District.

2.3 Respiratory Health Survey

A cross-sectional health survey was conducted across the Olusosun dumpsite between the 12th -20th January 2017. Sample size was calculated using the metrics as recommended by WHO (1991). Previous data on the prevalence of respiratory symptoms in landfill workers in India of 65%, was used to calculate the sample size (Ray *et al.,* 2004; 2005). With the confidence level at 95%, bound on error at 5%, and statistical power at 80%, the sample size was 145 ±4 to account for attrition.

Participants were classed into the five major occupational groups: Scavengers (those who ravage the waste pile with tongs for recyclable resources); Waste workers (staff of the Government agency in charge of the safe disposing of waste and maintenance at the dumpsite); Business Owners (those with kiosks rendering other side services to members of the local population); Middle Men (those who buy the recovered recyclable materials from the scavengers); Food vendors (people who sell food to the other members of the local population). Participants were selected at random and were required to have worked at the dumpsite for at least one year to be eligible. A written or verbal informed consent was sought from all participant before administering the questionnaires.

2.3.1 Operational definitions

These definitions were adapted from the operation guidelines of the European Community Respiratory Health Survey (ECRHS) II, and the 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 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 or 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.

2.4 Air sampling and sample analysis

Two different types of air sampling were undertaken; ambient static air sampling at points around the dumpsite and at the control site using a six stage Andersen sampler and activity-based personal sampling using a body worn SKC button sampler.

2.4.1 Ambient air sampling

In Figure 1a, the sampling points and their distances away from the active part of the dumpsite are shown on a map. The sampling locations were chosen based on the prevalent wind direction as shown in the wind rose and were located as close as possible to the point at which activity was undertaken (Environment Agency 2017). The wind rose shows the average wind direction in the area over the period of 30 years (WMO 2017). The active area was considered as the point source as activities such as tipping of waste, spreading, compacting and scavenging took place here most frequently. Air samples were collected one day a week, for 13 weeks from the 5th April to 28th August 2017. Due to the limited amount of equipment and manpower available to the researcher it was not possible to undertake concurrent sampling at all locations.

During sampling, air was pumped through the Anderson 6 stage sampler at the rate of 28.3 L min^{-1} with a sampling time of 2.45 mins to avoid overloading of the petri dishes containing the selective media for the bioaerosols (Reinthaler *et al.,* 1997). Samples were stored in sterile sealed bags and were taken to the laboratory for further analysis. It is important to note that at the time of sampling, site activities at Olusosun were at their peak. The microorganism, agar type, growth inhibitants, incubation temperature and duration for the different bioaerosols are shown in the Table S1. After incubation, the number of colony forming units on each plate were counted, summed and subjected to positive-hole correction according to Macher (1989) and based on the volume of air sampled, were expressed as cfu/m^3. This method, including bioaerosol quantification and enumeration, followed the protocol outlined in the Technical Guidance Note (M9) for monitoring of bioaerosols at regulated facilities by Environment Agency (2017) (England and Wales). Hence, the study was designed not to identify all mesophilic bacteria and fungi at the dumpsite but to align with emission standards from UK facilities, since Nigeria does not have any of such.

2.4.2 Activity-based air sampling

Activity-based air sampling was carried out in order to measure bioaerosol exposure from specific activities engaged in by members of the population at the dumpsite. Three volunteers were recruited who were involved in scavenging, waste sorting and site supervision on the sampling days. They were required to spend most of their active time within 70 m from the active area of the dumpsite as exposure from these activities at this distance was assumed to be the highest compared to the other three sampling locations. The personal air sampler (Button Aerosol Sampler, SKC Inc., PA USA) was mounted vertically on the volunteers as close to the breathing zone as was practically possible. Sampling involved drawing sampled air at a flow rate of 4 L/min through a stainless cassette containing a 0.8 µm pore size gelatin filter while they went about their normal activities (Figure S1). The sampler captured air around the breathing zone for 30 mins for the three activities measured. After each sampling episode, the filters were removed from the sampler, dissolved in a sterile 30 ml vial of extraction fluid (0.01% Tween 80 in distilled water), and stored at 4 ^{o}C for transport back to the laboratory within 24 h. Serial dilution were performed on all the raw samples with sterile buffered fluid (0.01% Tween 80 in distilled water) down to 10^{-4} using standard aseptic techniques.. Subsequently, 10 µl of the samples were plated out onto the appropriate selective media and incubated as shown in Table S1. The bioaerosol density (c/m^3) in the raw sample from the activity-based sampling was calculated using the following equation (Herigstad *et al.,* 2001):

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

Where *TC:* total colony count, *VP*: Plated volume, *DF*: Dilution factor, *BV*: Volume of the raw sample.

2.5 Statistical analysis

a) ***Qualitative health Survey***: Epi info™ 7 developed 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 predictor variables such as chronic cough, chronic phlegm, wheezing and asthma was analysed using a logistic regression statistic model. Covariates such as age, sex, smoking status, 'years at study area', 'use of nose mask' were adjusted for.

b) ***Air sampling***: 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 bioaerosol concentrations for the entrance, 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, a Krustal-Wallis test was conducted to determine the difference in means across the sampling points at the dumpsite. Generally, the 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).

3. Results and Discussion

3.1 Ambient air sampling

The result of the one-way ANOVA conducted to determine if the difference in concentration of total bacteria and gram- negative bacteria across the four sampling locations were significant showed no statistically significant difference in their mean concentration, irrespective of the sampling location (total bacteria: $F = 1.144$, $p > 0.05$, gram-negative bacteria: $F= 2.463$, $p > 0.05$). Furthermore, running a Kruskal-Wallis one-way ANOVA on total fungi and *Aspergillus fumigatus*, total fungi indicated no statistically significant differences in mean concentration across the all sampling locations (χ^2 (3) = 5.799, p = 0.122). *Aspergillus fumigatus* however, showed a significant difference between the means of the concentration at the active area and every other sampled location (χ^2 (3) =14.725, p = 0.002), suggesting a steep drop in the concentration of *Aspergillus fumigatus* as it travels beyond 50 m from the active area.

The dumpsites entrance recorded a median concentration of 1.312×10^3 cfu/m^3 (231-1.849×10^3 cfu/m^3) and 1.144×10^3 cfu/m^3 (786-2.043×10^3 cfu/m^3) for total bacteria and gram-negative bacteria respectively, a 1-2 log higher concentration compared to *Aspergillus fumigatus* and total fungi (Table 1). The reason for this disparity is unclear, however it is possible that the use open-back waste trucks (1 in 4 waste trucks on dumpsite is open-back) and the extended waiting time at the entrance before tipping (mean: 2 hours), would likely contribute to bioaerosols concentration at that sampling location, as bioaerosols can also be emitted during the transport of waste to tipping point (Schlosser *et al.,* 2016). The weather conditions were favourable for most days, except for visit day 9, which started with a light shower but ended just before sampling begun at the entrance location. For the dormant area, the form of activities observed to take place here were mostly sorting and loading of recovered recycled materials into trucks; moreover, scavenging was also observed to sparsely take place as well. Bioaerosols sampling result shows the concentration of bacteria were > 10^3 cfu/m^3 except for total bacteria on visit day 6 (884 cfu/m^3) and gram-negative on visit day 9 (939 cfu/m^3). Total fungi on the other hand had concentration < 10^3 cfu/m^3 for the entire sampling visit (See Figure 2 M-P). The boundary was the closest sampling location to the nearest sensitive receptor. Bioaerosols concentration up to 1.63×10^3 cfu/m^3 and 2.26×10^3 cfu/m^3 for total bacteria and gram-negative bacteria respectively were measured at this location even though *aspergillus fumigatus* and total fungi were < 10^2 cfu/m^3 and 10^3 cfu/m^3 respectively.

Described in Table S2 are the meteorological conditions monitored during the sampling operation. The mean air temperature at the site varied from a low of 27°C up to a high of 35.7 °C over the entire period. The relative humidity ranged between 64.3 – 88% with average wind speed of 1.2 (minimum) and 4.2 (maximum) during the same period. . Assessing the relationship between meteorological factors and bioaerosol concentrations across the dumpsite, the coefficient of Person's product moment correlation indicated that there was a statistically significant positive correlation between the concentration of gram-negative bacteria taken at the dormant area and atmospheric temperature ($r = 0.649$ $n= 13$, $p < 0.05$). Wind speed on the other hand showed a 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. Relative humidity showed no statistically significant correlation with the concentration of bioaerosols with respect to the sampling locations. However, upon conducting a multiple regression to further explain the overall change in the concentration of bioaerosols across the dumpsite in response to the independent variables (meteorological factors), the result indicated that, of the three independent variables tested, only relative humidity added statistically significantly to the prediction ($p< 0.01$) and that total bacteria concentration [$F(3, 48) = 4.140$, $p< 0.05$, adj. $R^2 = 0.156$] was the most affected by the independent variable.

In general, the results of the bioaerosol sampling shows a progressive decline in concentration with distance, from the source point, downwind (see Figure 2). However, the one-way ANOVA indicated no statistically significant difference in mean concentrations for the sampling points across the dumpsite for total bacteria ($p>0.05$) and gram-negative bacteria ($p>0.05$). This is surprising given that some of the sampling points were located a considerable distance from the active area (see Figure 1a). 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 or further bioaerosol emission from other sampling locations or both (Ogden *et al.,* 1969; Giner *et al.,* 1999). Moreover, although the prevailing wind direction was identified prior to sampling, during sampling it may be that the wind direction was variable and there may have been swirling locally. 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. Gram-negative bacteria particularly have been observed to be in high prevalence at open dumpsites located in these regions, hence their higher concentrations in this study is not a surprise (Odeyemi 2012). The steep decline in the concentration of *Aspergillus fumigatus* observed between the sampling location at the active area (50 m from active point; Median: 283 CFU/m^3), the dormant area (531 m; median: 43 CFU/m^3) and the boundary (788 m; 51 CFU/m^3) showed an 80-81% reduction in concentration downwind. 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 point at the landfill and the property boundary.

The mean bioaerosol concentration at the control site was generally 1-log lower than the concentrations observed at Olusosun dumpsite (Table 3), supporting the fact that the Olusosun dumpsite was a major source of bioaerosols within the study area. In general, the bacteria concentration at the Olusosun dumpsite was typically 1-log higher than the fungi concentration. This is not surprising as Xu and Yao (2013) also reported that there are usually higher viable bacteria concentrations when compared to viable fungi concentrations when using an Anderson impactor for air sampling. When the concentration of bioaerosols at all the sampling points were added together, the 95th percentile of concentration 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) were 2-3 log lower than reported in literature where similar activities such as tipping, spreading and compaction takes place (Kalwasińska *et al.,* 2014; Sangkham *et al.,* 2014). The main explanation for such differences probably relates to the sampling locations on-site and the sampling method employed. In this study using the Anderson six stage impactor, the closest sampling location to the active area was 50 m downwind; compared to other studies where sampling was either carried out at the working area or up 20 m away (Breza-Boruta 2012; Schlosser *et al.,* 2016).

Assessing bioaerosols emissions at Olusosun dumpsite against the expected limits set in the UK by the Environment Agency (2017), the concentration limits of total bacteria and gram-negative bacteria were exceeded on most visits to the sampling site during ambient air sampling (Figure 2, Table 2). Although the *Aspergillus fumigatus* and total fungi concentrations never exceeded the expected limits, the set limits were based on an 8-hour time weighted average estimation of exposure (HSE 2014). In this study however, the median daily exposure duration for participants at Olusosun dumpsite was 11 hours, indicating longer exposures, hence greater chances of inhaling more bioaerosols that could potentially cause related respiratory health problems to the population.

3.2 Activity–based air sampling

The result of the activity-based air sampling shows that the scavengers and workers alike were exposed to concentrations 2 -3log higher than the mean bioaerosol concentration measured during the static ambient air sampling (Table 3). The activity-based sampling using the personal body worn sampler allowed a picture to be obtained of the exposure of workers to bioaerosols as a result of engaging in multiple activities typical of those at a dumpsite. Activity such as scavenging typically involves material collection and sorting with material collection being most prevalent during tipping and spreading of the waste while sorting tends to take place further away from the active area (Afon 2012).

Table 2 shows the concentration of total bacteria, gram-negative bacteria and *Aspergillus fumigatus* during site supervision, waste sorting and scavenging activities compared to the control and ambient air sampling. Although Schlosser *et al.,* (2016) alluded to the fact that the use of different equipment for bioaerosol sampling will yield different result, but the use of a combination of different sampling methods in this study produces a better validation of the results (Sandelowski 2000). Unlike several other studies where bioaerosol exposure measurements at landfills and dumpsites were restricted to static measurements from impaction and/or sedimentation, this study combined personal sampling and static sampling, consequently providing a robust dataset for the study. Furthermore, using bioaerosol data from static sampling only is problematic since the participants are usually not stationed at the same spots throughout the day's activities (Małecka-Adamowicz *et al.,* 2007; Schlosser *et al.,* 2016; Frączek *et al.,* 2017).

In Figure S2, exposure to bioaerosols from the various activities are compared to ambient air sampling and the result indicated higher exposure to total bacteria and gram-negative bacteria from scavenging up to 10^6 CFU/m^3. Exposure to *Aspergillus fumigatus* on other hand was found to be high when undertaking site-supervision activities (3×10^5 CFU/m^3) with lower exposure from sorting (9×10^4 CFU/m^3) compared to scavenging (Table 3). This unusual spike in *Aspergillus fumigatus* during site monitoring may not be unrelated to the property of the waste (waste rich in fungi) tipped at the dumpsite at the time of sampling. Bioaerosols exposure from scavenging and sorting activities accounted for the highest exposure levels at the dumpsite, levels comparable to or higher than other forms waste-to-land treatment of municipal solid waste such as landfilling and open windrow composing reported in some literature (Lis *et al.,* 2004; Odeyemi 2012; Wéry 2014b; Breza-Boruta 2016).

3.3 Particle size distribution

To further evaluate the potential degree of exposure to bioaerosols at Olusosun dumpsite, the size distribution of bioaerosols were analysed and related to typical tidal volumes inhaled by humans. During sampling using the six stage Andersen sampler, bioaerosols are deposited out onto six separate agar plates located in the six stages of the sampler. The six stages of the sampler are designed to mimic the human respiratory system with collection of progressively smaller particles from stages 1 (top, upper respiratory tract) to stage 6 (bottom, lower respiratory tract and alveoli) (Jensen *et al.,* 1992; Tisch Environmental Inc. 2018). Particles of inhalable fraction with aerodynamic diameter >4.7 µm are deposited in stages 1 and 2, representing deposition in the nasal area. Stages 3 and 4 (thoracic fraction with aerodynamic diameter 2.1 - 4.7 µm) represents bronchial deposition, while deposition in the alveoli is represented in stages 5 and 6 (respirable fraction with aerodynamic diameter < 2.1 µm) (Andersen 1958; HSE 2003, 2014).

Figure 3(a)-(d) shows the percentage size distribution of bioaerosols as deposited on the different stages of the Anderson 6 stage sampler measured at the four sampling locations across the dumpsite. Taking into account all the bioaerosol collected from the 13 visit days, ~41% of the total bacteria (ambient air: $1.9\text{-}3\times10^2$ CFU/m^3; Scavenging: 1.2×10^6 CFU/m^3; Site supervision : 6.0×10^5 CFU/m^3; Sorting: 4.8×10^5 CFU/m^3) were sized at < 2.1 µm aerodynamic diameter. Gram-negative bacteria on the other hand were slightly higher with ~ 46% of the gram-negative bacteria at Olusosun dumpsite being < 2.1 µm aerodynamic diameter. The data for total fungi which also includes *Aspergillus fumigatus* indicates that ~76% of all the fungi collected at Olusosun dumpsite were in the < 2.1 µm size range.

The aerodynamic diameter of bioaerosols is key to their dispersion, potential risk from inhalation and disposition in either the tracheal, bronchial or the alveolar regions of the lungs Brągoszewska *et al.,* (2017) and Ferguson *et al.,* (2017) had observed that bioaerosol 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 particulate matter. Moreover, high relative humidity can further increase both the size and weight of the particle from absorption of ambient moisture, a phenomenon that favours higher deposition at upper stages of the Anderson sampler (Total Bacteria: ~59%; Gram-negative bacteria: ~54%) or dry deposition, giving a low reading for bioaerosol in the ambient air as observed in this study (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 association with the concentration of bioaerosols ($p< 0.01$), especially total bacteria ($F(3, 48) = 4.140$, $p< 0.05$, adj. $R^2 = 0.156$). The results shown in Figure 3 suggests a higher percentage of fungi (Aspergillus fumigatus ~76%; and total fungi ~63%) were within respirable fraction compared to bacteria (Total bacteria ~41%; gram-negative bacteria ~43%). Moreover, as observed by Deacon *et al.,* (2009), the recovery of Aspergillus fumigatus is usually highest within instruments pore size range of 3.3 -1.1 µm as they are typically 2-3.5 µm in diameter. Particles of inhalable fraction 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). However, this does not happen when particles of respirable fraction get down in to the pulmonary region where there is much more potential for health problems if deposited down there, especially those who are immunocompromised (Yoshida and Whitsett 2004; Thomas 2013).

The tidal volume, which is 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). With a respiratory rate of 12 breaths per minute (Cretikos *et al.,* 2008; Erden *et al.,* 2015), the scavengers, waste sorters and waste workers working 11-hours (median) at Olusosun dumpsite, will inhale approximately 3.96 m^3 of air containing approximately 4.8×10^5 CFU/m^3 total bacteria, 1.4 $\times10^6$ CFU/m^3 of gram-negative bacteria and 5.2×10^4 CFU/m^3 of *Aspergillus fumigatus* during scavenging; 9.6×10^4 CFU/m^3 of total bacteria, 8×10^5 CFU/m^3 of gram-negative bacteria and 6.93×10^4 CFU/m^3 of *Aspergillus fumigatus* during waste sorting; 2.4 $\times10^5$ CFU/m^3 of total bacteria, 9.7×10^4 CFU/m^3 gram-negative bacteria and 2.3 $\times10^4$ CFU/m^3 of *Aspergillus fumigatus* when carrying out site supervision , Table S3.

Several inhalation studies have investigated the effect of bioaerosols particle size on bioaerosol lungs deposition and the lethal dose required to initiate an infection. Although there are several animal models to this effect, no human studies exist investigating this relationship (Thomas 2013; Dabisch *et al.,* 2017). The use of mouse models to demonstrate infection from *Aspergillus fumigatus* have been widely reported in literature, and that perhaps is because mice displays pathological consequences similar to humans (Kupfahl *et al.,* 2006; Dagenais and Keller 2009). Sheppard *et al.,* (2004) administered a dose of 2.4 $\times10^3$ CFU/mouse of *Aspergillus fumigatus* conidia to immunocompromised mice, resulting in a lethal pulmonary infection in most of the mice, surviving between 5 to 12 days. The exposure to *Aspergillus fumigatus* in this research (from scavenging, waste sorting and site supervision) however, was up to 2.74 x 10^5 CFU/day , a 2-log higher than reported by Sheppard *et al.,* (2004). However, 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, however, a prolong exposure and neutropenia to will increase the risk of developing invasive aspergillosis by the exposed workers especially, the immunocompromised (Dagenais and Keller 2009; Wéry 2014a). Gram negative bacteria have also been reported to be a potent pro-inflammatory stimulus in the human lungs due to flagellin release from their flagella (Liaudet *et al.,* 2003).

3.4 Respiratory symptom from workers

Summarised in Table 4 is the socio-demographic description of the participants in the cross sectional health survey. Of the 149 participants, 130(87%) and 19(13%) were males and females respectively. The result also shows that participants spent 11 hours daily (median) at the dumpsite and recorded a median "year at work" as 5. Moreover, the median age of the participants was 30 years, and the smoker and non-smoker population was 61(41%) and 84(56%) respectively.

As shown in Figure 4 (A), smokers reported higher symptoms of chronic cough (21%) and chronic phlegm (15%) compared to non-smokers (chronic cough 15%, chronic phlegm 13%). This was however different with chronic wheezing and asthma, as non-smokers recorded higher prevalence (chronic wheezing 4%, asthma 1.3) when compared to smokers (chronic wheezing 3.5%, asthma 0.7%). Figure 4 (B) further shows reported symptoms among the non-smoker population in relation to how long the members have been at the study location. The occurrence of chronic cough (10%) and chronic phlegm (10%) were the highest for members of the population that have been at the study location in the first 5 years. Chronic phlegm was also noticed to be consistently reported to varying degree by non-smokers, irrespective of the years spent working at the dumpsite. Generally, the reported chronic respiratory symptoms were observed to have reduced as the years of spent at the dumpsite increased.

The result of the logistic regression showed a weak association between the independent variable 'Use of Nose Mask' and occurrence of chronic cough ($p > 0.05$). Another independent variable was 'Years of work' which showed no statistically significant association with chronic cough, chronic phlegm and asthma, for participants with years of work > 5 years (Table 5).

The prevalence of respiratory symptoms among the sampled population is not surprising since previous researches have also reported similar respiratory symptoms among waste workers and dumpsite scavengers. Athanasiou *et al.,* (2010) and Garrido *et al.,* (2015) for instance reported high prevalence of asthma and COPD symptoms among solid waste workers in municipality of Keratsini, Greece and city of Hamburg, Germany, respectively. Black *et al.,* (2019) also reported that 70% of the 1278 informal waste workers surveyed in their study at the dumpsite in Nuwakot district Nepal, reported one form of respiratory symptoms or other. Moreover, 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, India have been reported by Ray *et al.,* (2009). Although the study did not report the possible exposure concentration, the observed biomarkers from the body of the female rag pickers were evidence indicating a heightened immune system, which would suggest that they have been exposed to bacteria, endotoxins and viruses through inhalation.

Figure 6A shows that chronic cough and chronic phlegm recording a higher prevalence among smokers was not surprising, since chronic respiratory symptoms are most of the time associated with smoking (Abramson *et al.,* 2002; Frank *et al.,* 2006; Garrido *et al.,* 2015). The differences in percentage points in the prevalence of the reported respiratory symptom between smokers and non-smokers was marginal (chronic cough – 6%, Chronic phlegm- 2%, chronic wheezing-0.5% and asthma-0.6%) and suggests that the reported respiratory symptoms were largely of occupational origin than life style. This further supports growing evidence that chronic cough and chronic phlegm are risk factors for chronic obstructive pulmonary disease (COPD) and that reported cases of COPD among non-smokers are on the rise in developing countries (Salvi and Barnes, 2009; de Marco et al., 2007).

It was expected that the non-use of a nose mask would greatly increase the odds of developing these outcomes; however, the model was not sensitive enough to measure this. This perhaps is because 87% of the respondents admitted not to have used a nose mask while working at the dumpsite, and the few that did (13%), used them only occasionally when they had access to PPE. This result should not be viewed as undermining the need to provide appropriate safety interventions, as such interventions have been recommended by researchers to reducing the risk of acquiring work related respiratory health problems (Lavoie *et al.,* 2006; Kuijer *et al.,* 2010). It was also observed that all the respiratory health outcomes were not associated with 'Years of work' > 5 years (p > 0.05) (Table 5). In their study of the respiratory health of brick kiln workers, Shaikh *et al.,* (2012) observed a similar result, however only for workers with 'years of work' > 10 years. The median 'years of work' at Olusosun dumpsite was 5 years and this represented 46% of the participants (Table 4). By implication, the majority of the participants who had reported to suffer chronic respiratory symptoms, would have contracted either chronic phlegm or asthma 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 doubling of the number of workers with chronic bronchitis (RR 1.41; 95% CI 1.3-1.5) over the study period. Van Kampen *et al.,* (2016)also observed an increase relative risk of cough (RR 1.28; 95% CI 1.2-1.5) and phlegm (RR 1.32; 95% CI 1.2-1.5) and 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 years of work. This study has demonstrated that working at dumpsites such as Olusosun may increase the odds of contracting chronic respiratory symptoms. This perhaps is primarily due to the limited use of PPE by the population, limited control over activities on the dumpsite and longer exposure hours, rather than longer years of work in such environments. In undertaking this study, there were some limitations which were largely due to limited resources and lack of health records. Firstly, there was no morbidity record for the workers at the dumpsite 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. This may result in the underestimation of the extent of the respiratory health problems suffered by the workers in Olusosun dumpsite. Secondly, the findings for 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 lungs functions and detect inhaled PM in the blood. The third limitation was that only the areas downwind of the dumpsite (selection based on the predominant wind direction across the dumpsite) was selected for 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 an important exposed group. Other cofounding factors such as vehicular emissions and industrial emissions at the study locations were not considered and consequently adjusted for in this study. Lastly, the probable underestimation of the actual bioaerosol exposure concentration due to 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).

4. Conclusion

This study has demonstrated that open waste dumpsites are a major source of bioaerosols that can contribute adversely to the respiratory health of the waste workers, scavengers and others that are working at the dumpsite. Bioaerosols concentrations at Olusosun open dumpsite were 2-3 log higher when compared to the control site. The results from the activity-based air sampling suggests that exposure to bioaerosol at Olusosun open dumpsite may also depend on the activities engaged in at the dumpsite. Scavenging recorded the highest level of bioaerosols exposure when compare to waste sorting, site supervision and the sampled ambient air. Gram-negative bacteria represented the highest bioaerosol concentration in Olusosun dumpsite. The particle size distribution for *Aspergillus fumigatus* and total fungi showed a greater portion approximately 76% and 63% respectively were sizes < 3.3 µm. These particle sizes are respirable and can be deposited at the lower respiratory tracts. Observed also was the prevalence of chronic respiratory symptoms such as chronic cough and chronic phlegm, with earlier showing equally prevalence in both smokers and non-smokers and the later, more prevalent among the non-smoker population. Further clinical investigation into the respiratory health of the workers at the Olusosun dumpsite is necessary to determine the lungs function in responds to exposure to the bioaerosols.

5. Supplementary data

Supplementary data associated with this article is available at https://doi.org/10.5518/449

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Ethics approval

Ethical approval was obtained from the Engineering Faculty Research Ethics Committee, University of Leeds, UK.

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