



UNIVERSITY OF LEEDS

This is a repository copy of *Exposure to bioaerosols at open dumpsites: A case study of bioaerosols exposure from activities at Olusosun open dumpsite, Lagos Nigeria.*

White Rose Research Online URL for this paper:
<http://eprints.whiterose.ac.uk/147584/>

Version: Accepted Version

Article:

Akpeimeh, GF, Fletcher, LA and Evans, BE orcid.org/0000-0001-9815-3141 (2019)
Exposure to bioaerosols at open dumpsites: A case study of bioaerosols exposure from activities at Olusosun open dumpsite, Lagos Nigeria. *Waste Management*, 89. pp. 37-47.
ISSN 0956-053X

<https://doi.org/10.1016/j.wasman.2019.03.058>

© 2019. Published by Elsevier Ltd. This manuscript version is made available under the CC-BY-NC-ND 4.0 license <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

Reuse

This article is distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs (CC BY-NC-ND) licence. This licence only allows you to download this work and share it with others as long as you credit the authors, but you can't change the article in any way or use it commercially. More information and the full terms of the licence here: <https://creativecommons.org/licenses/>

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.



eprints@whiterose.ac.uk
<https://eprints.whiterose.ac.uk/>

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

3 G.F.Akpeimeh¹, L.A.Fletcher^{1a}, B.E.Evans¹

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

5 ^al.a.fletcher@leeds.ac.uk

6 **Abstract**

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

18 After a cross sectional health survey of 149 participants (waste workers, scavengers,
19 middlemen, food vendors and business owners), smokers reported higher symptoms of chronic
20 cough (21%) and chronic phlegm (15%) compared to non-smokers (chronic cough 15%,
21 chronic phlegm 13%) . Years of work > 5 years showed no statistically significant association
22 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;
23 p>0.05). At the 95th percentile, the concentration of gram-negative bacteria was the highest
24 (2188 CFU/m³), then total bacteria (2189 CFU/m³), total fungi (843 CFU/m³) and *Aspergillus*
25 *fumigatus* (441 CFU/m³) after ambient air sampling. A comparison of the data showed that the

26 activity-based sampling undertaken using body worn personal sampler showed higher
27 bioaerosols concentrations (10^4 - 10^6 CFU/m³), i.e. 2-3 logs higher than those recorded from
28 static ambient air sampling. Bioaerosol exposure was highest during scavenging activities
29 compared to waste sorting and site supervision . Particle size distributions showed that 41%,
30 46%, 76% and 63% of total bacteria, gram-negative bacteria, *Aspergillus fumigatus* and total
31 fungi respectively were of respirable sizes and would therefore be capable of penetrating deep
32 into the respiratory system, posing a greater human health risk. This study has shown that
33 exposure to bioaerosols can be associated with activities undertaken at open dumpsites and
34 may contribute to the high prevalence of the chronic respiratory symptoms, among the workers
35 in such environments.

36 **1. Introduction**

37 The rate of solid waste generation in developing countries has grown at a steady rate in recent
38 years, especially due to urbanization and the accompanying urban population growth. Sub-
39 Saharan Africa alone is estimated to generate 62 million tonnes per year of municipal solid
40 waste (MSW) with a corresponding annual rate of change of urban population of 2.27 percent
41 per year (UN-HABITAT 2009; Hoornweg and Bhada-Tata 2012b). Despite recording the
42 highest rate of urbanization in the world, most developing countries unfortunately do not have
43 the infrastructure to properly manage and treat their municipal solid waste. This has resulted in
44 waste management authorities resorting to open dumping as a cheap method for managing their
45 municipal solid waste (Srivastava et al., 2015). Hence, it is unsurprising that 17 of the world's
46 50 biggest dumpsites are located in the continent of Africa, of which 6 are in Nigeria (UNEP
47 2015). This form of waste treatment involves the uncontrolled dumping of waste MSW on open
48 land areas forming large waste hills with time. Microbial activities are central to the treatment
49 of biodegradable MSW and agitation activities, such as tipping, spreading and waste sorting
50 have been shown to aerosolise these microbial agents, including the pathogenic ones (Stagg et
51 al., 2010). Similarly, the analysis of the composition of MSW in sub-Saharan Africa have
52 shown to have high biodegradable (40-60%) and high moisture content (Ogwueleka 2009;
53 Hoornweg and Bhada-Tata 2012a). Furthermore, these characteristics in combination with the
54 hot and humid weather conditions in the region favours the growth of microorganisms
55 including pathogens that are eventually aerosolized during agitation activities at the dumpsite
56 (Odewabi et al., 2013; Epstein 2015). The individuals working on dumpsites such as
57 scavengers, waste workers and vendors are often exposed to elevated levels of these pathogenic
58 microorganisms majorly by inhalation as most have been noted to work in these conditions
59 without personal protective equipment (Odewabi et al., 2013). Workers exposure to organic
60 dust laden with bioaerosols have been reported from composting and landfills facilities

61 typically associated by high emission of organic dust during agitation activities, a condition
62 similar to open dumpsites (Ray et al., 2005; Schlosser et al., 2012). In addition to exposure by
63 inhalation, other exposure routes such as ingestion and the skin contact presents additional
64 exposure risk to the workers. These workers have been reported to be at risk of contracting
65 gastrointestinal diseases, blood infections such as HIV and hepatitis, physical symptoms like
66 impetigo and musculoskeletal symptoms (Thirarattanasunthon et al., 2012; Odewabi et al.,
67 2013).

68 Hitherto, respiratory health risk from exposure to bioaerosols at open dumpsite has received
69 limited attention from researchers compared to that associated with landfills and the
70 composting processes (Douwes et al., 2003; Heldal et al., 2015; Van Kampen et al., 2016).
71 Although activities such as tipping and spreading of waste may be common to landfills and
72 dumpsites, the latter has greater environmental and public health impact as there are little or no
73 controls over the safe handling, treatment and exposure limits to bioaerosols and particulate
74 matter (UNEP 2005; Hoornweg and Bhada-Tata 2012b). Moreover, there are currently very
75 limited literature on the exposure of dumpsite workers to bioaerosol emissions and the impacts
76 on their respiratory health in a single study. As such, this research aims to investigate the
77 degree of exposure to bioaerosols associated with working at open dumpsites and the potential
78 impact this might have on the respiratory health of the workers at Olusosun open dumpsite.

79 **2. Materials and Methods**

80 **2.1 Site description and waste characterization**

81 The open dumpsite used in this study was situated in Ojota, Lagos State Nigeria. Lagos State
82 has a population of 21 million with an annual growth of rate of 3.2% (LBS 2013). Of the three
83 principal dumpsites serving the urban population of Lagos i.e Ewu Elepe, Solous and Olusosun
84 dumpsites (LAWMA 2016), Olusosun is the biggest at 42.7 hectares (105.5 Acres), and is
85 located between 6°35'40.9"N and 3°22'38.4"E (Oyeku and Eludoyin 2010). Olusosun is
86 estimated to receive approximately 2,100,000 tonnes of MSW, construction and E-waste per
87 year and has received approximately 17,150,000 to 24,500,000 tonnes of waste already since
88 it became active in 1992 (D-Waste 2014). Olusosun dumpsite was chosen because it receives
89 about 40% of the total municipal solid waste deposits in Lagos and the dumpsite is surrounded
90 by sensitive receptors located less than 200 m from the boundary of the dumpsite (Olorunfemi
91 2011).

92 **2.2 Control site**

93 In order to be able to determine the impact of the open dumpsite on the concentration of
94 bioaerosols it was necessary to identify a 'control' site at which the concentration of
95 bioaerosols would not be impacted by activities at the open dumpsite. The two sampling points
96 were located ~ 10.79 km away from Olusosun open dumpsite within 6°29'58.9"N 3°22'47.5"E
97 and 6°29'45.3"N 3°22'45.0"E. Moreover, both locations and shared similar economic and
98 demographic characteristics with Ojota, where Olusosun dumpsite is located. The median age
99 of the sampled population at the control and Olusosun matched a national demographic
100 characteristic: 70% of adult population in Nigeria are less than 30 years in age (Reed and Mberu
101 2014) and are both part of the planned Lagos Central Business District.

102 **2.3 Respiratory Health Survey**

103 A cross-sectional health survey was conducted across the Olusosun dumpsite between the 12th
104 -20th January 2017. Sample size was calculated using the metrics as recommended by WHO
105 (1991). Previous data on the prevalence of respiratory symptoms in landfill workers in India of
106 65%, was used to calculate the sample size (Ray et al., 2004; 2005). With the confidence level
107 at 95%, bound on error at 5%, and statistical power at 80%, the sample size was 145 ±4 to
108 account for attrition.

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

118 **2.3.1 Operational definitions**

119 These definitions were adapted from the operation guidelines of the European Community
120 Respiratory Health Survey (ECRHS) II, and the American Thoracic Society Division of Lung
121 Disease questionnaire (ATS-DLD-78A) (Ferris 1978; ECRHS 2002; Birring 2011; Shaikh et
122 al., 2012; Gibson et al., 2016). **Chronic cough** was defined as a consistent cough as much as
123 4 to 6 times a day, 4 or more days a week or a cough first thing morning or both for at least 3
124 months. **Chronic Phlegm** was defined as expectoration of sputum for as much as twice a day
125 for at least 4 days a week or expectoration of sputum first thing in the morning or both for at
126 least 3 months. **Chronic wheezing** was defined as wheezing in a dusty environment that would

127 have triggered 2 or more episodes of shortness of breath. **Asthma** was classified as at least two
128 reported asthma attacks or shortness of breath with wheezing in the past two months with
129 normal breathing between episodes of shortness of breath or a diagnosed asthmatic by a
130 physician.

131 **2.4 Air sampling and sample analysis**

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

135 **2.4.1 Ambient air sampling**

136 In Figure 1a, the sampling points and their distances away from the active part of the dumpsite
137 are shown on a map. The sampling locations were chosen based on the prevalent wind direction
138 as shown in the wind rose and were located as close as possible to the point at which activity
139 was undertaken (Environment Agency 2017). The wind rose shows the average wind direction
140 in the area over the period of 30 years (WMO 2017). The active area was considered as the
141 point source as activities such as tipping of waste, spreading, compacting and scavenging took
142 place here most frequently. Air samples were collected one day a week, for 13 weeks from the
143 5th April to 28th August 2017. Due to the limited amount of equipment and manpower available
144 to the researcher it was not possible to undertake concurrent sampling at all locations.

145 During sampling, air was pumped through the Anderson 6 stage sampler at the rate of 28.3 L
146 min⁻¹ with a sampling time of 2.45 mins to avoid overloading of the petri dishes containing the
147 selective media for the bioaerosols (Reinthal et al., 1997). Samples were stored in sterile
148 sealed bags and were taken to the laboratory for further analysis. It is important to note that at
149 the time of sampling, site activities at Olusosun were at their peak. The microorganism, agar
150 type, growth inhibitors, incubation temperature and duration for the different bioaerosols are

151 shown in the Table S1. After incubation, the number of colony forming units on each plate
152 were counted, summed and subjected to positive-hole correction according to Macher (1989)
153 and based on the volume of air sampled, were expressed as cfu/m³. This method, including
154 bioaerosol quantification and enumeration, followed the protocol outlined in the Technical
155 Guidance Note (M9) for monitoring of bioaerosols at regulated facilities by Environment
156 Agency (2017) (England and Wales). Hence, the study was designed not to identify all
157 mesophilic bacteria and fungi at the dumpsite but to align with emission standards from UK
158 facilities, since Nigeria does not have any of such.

159 **2.4.2 Activity-based air sampling**

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

176 in Table S1. The bioaerosol density (c/m^3) in the raw sample from the activity-based sampling
177 was calculated using the following equation (Herigstad et al., 2001):

$$178 \quad \text{Density (CFU } m^{-3}) = \frac{TC}{VP} \times DF \times BV$$

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

180 **2.5 Statistical analysis**

181 a) **Qualitative health Survey:** Epi info™ 7 developed by the Centre for Disease Control and
182 Prevention (CDC), USA., was used for preliminary data processing which were later
183 transferred to Microsoft Excel for further processing. The relationship between predictor
184 variables such as chronic cough, chronic phlegm, wheezing and asthma was analysed using a
185 logistic regression statistic model. Covariates such as age, sex, smoking status, ‘years at study
186 area’, ‘use of nose mask’ were adjusted for.

187 b) **Air sampling:** The test for normality was assessed by Kolmogorov-Smirnov test and
188 nonparametric statistical tests were applied to the data set that violated the rule. The differences
189 between the bioaerosol concentrations for the entrance, active area, dormant area and the
190 boundary were assessed using the one-way ANOVA/Wetch ANOVA of normality. The
191 homogeneity of variance was assessed by Levene’s test of homogeneity of variance. If violated
192 by any of the variables, a Krustal-Wallis test was conducted to determine the difference in
193 means across the sampling points at the dumpsite. Generally, the statistical analysis was carried
194 out using IBM SPSS Statistics 22 for Windows (Version 22.0. Armonk, NY: IBM Corp., USA),
195 Microsoft Excel and graphs generated using Origin (2015b, Origin Lab Corp., Northampton,
196 MA, USA).

197 **3. Results and Discussion**

198 **3.1 Ambient air sampling**

199 The result of the one-way ANOVA conducted to determine if the difference in concentration
200 of total bacteria and gram- negative bacteria across the four sampling locations were significant
201 showed no statistically significant difference in their mean concentration, irrespective of the
202 sampling location (total bacteria: $F = 1.144$, $p > 0.05$, gram-negative bacteria: $F = 2.463$, $p >$
203 0.05). Furthermore, running a Kruskal-Wallis one-way ANOVA on total fungi and *Aspergillus*
204 *fumigatus*, total fungi indicated no statistically significant differences in mean concentration
205 across the all sampling locations ($\chi^2 (3) = 5.799$, $p = 0.122$). *Aspergillus fumigatus* however,
206 showed a significant difference between the means of the concentration at the active area and
207 every other sampled location ($\chi^2 (3) = 14.725$, $p = 0.002$), suggesting a steep drop in the
208 concentration of *Aspergillus fumigatus* as it travels beyond 50 m from the active area.

209 The dumpsites entrance recorded a median concentration of 1.312×10^3 cfu/m³ ($231-1.849 \times 10^3$
210 cfu/m³) and 1.144×10^3 cfu/m³ ($786-2.043 \times 10^3$ cfu/m³) for total bacteria and gram-negative
211 bacteria respectively, a 1-2 log higher concentration compared to *Aspergillus fumigatus* and
212 total fungi (Table 1). The reason for this disparity is unclear, however it is possible that the use
213 open-back waste trucks (1 in 4 waste trucks on dumpsite is open-back) and the extended
214 waiting time at the entrance before tipping (mean: 2 hours), would likely contribute to
215 bioaerosols concentration at that sampling location, as bioaerosols can also be emitted during
216 the transport of waste to tipping point (Schlosser et al., 2016). The weather conditions were
217 favourable for most days, except for visit day 9, which started with a light shower but ended
218 just before sampling begun at the entrance location. For the dormant area, the form of activities
219 observed to take place here were mostly sorting and loading of recovered recycled materials
220 into trucks; moreover, scavenging was also observed to sparsely take place as well. Bioaerosols
221 sampling result shows the concentration of bacteria were $> 10^3$ cfu/m³ except for total bacteria

222 on visit day 6 (884 cfu/m³) and gram-negative on visit day 9 (939 cfu/m³). Total fungi on the
223 other hand had concentration < 10³ cfu/m³ for the entire sampling visit (See Figure 2 M-P).
224 The boundary was the closest sampling location to the nearest sensitive receptor. Bioaerosols
225 concentration up to 1.63×10³ cfu/m³ and 2.26×10³ cfu/m³ for total bacteria and gram-negative
226 bacteria respectively were measured at this location even though aspergillus fumigatus and
227 total fungi were < 10² cfu/m³ and 10³ cfu/m³ respectively.

228 Described in Table S2 are the meteorological conditions monitored during the sampling
229 operation. The mean air temperature at the site varied from a low of 27°C up to a high of
230 35.7 °C over the entire period. The relative humidity ranged between 64.3 – 88% with average
231 wind speed of 1.2 (minimum) and 4.2 (maximum) during the same period. . Assessing the
232 relationship between meteorological factors and bioaerosol concentrations across the dumpsite,
233 the coefficient of Person's product moment correlation indicated that there was a statistically
234 significant positive correlation between the concentration of gram-negative bacteria taken at
235 the dormant area and atmospheric temperature ($r = 0.649$ $n= 13$, $p < 0.05$). Wind speed on the
236 other hand showed a positive and negative correlation with the concentration of Aspergillus
237 fumigatus at the boundary ($r = 0.571$, $n = 13$, $p < 0.05$) and dormant area ($r = -0.57$, $n= 13$, $p <$
238 0.05) respectively. Relative humidity showed no statistically significant correlation with the
239 concentration of bioaerosols with respect to the sampling locations. However, upon conducting
240 a multiple regression to further explain the overall change in the concentration of bioaerosols
241 across the dumpsite in response to the independent variables (meteorological factors), the result
242 indicated that, of the three independent variables tested, only relative humidity added
243 statistically significantly to the prediction ($p < 0.01$) and that total bacteria concentration [$F(3,$
244 $48) = 4.140$, $p < 0.05$, $\text{adj. } R^2 = 0.156$] was the most affected by the independent variable.

245 In general, the results of the bioaerosol sampling shows a progressive decline in concentration
246 with distance, from the source point, downwind (see Figure 2). However, the one-way ANOVA

247 indicated no statistically significant difference in mean concentrations for the sampling points
248 across the dumpsite for total bacteria ($p>0.05$) and gram-negative bacteria ($p>0.05$). This is
249 surprising given that some of the sampling points were located a considerable distance from
250 the active area (see Figure 1a). The result suggests a ‘fairly-uniform’ concentration for total
251 bacteria and gram-negative bacteria across the dumpsite, which may be due to either
252 meteorological factors or further bioaerosol emission from other sampling locations or both
253 (Ogden et al., 1969; Giner et al., 1999). Moreover, although the prevailing wind direction was
254 identified prior to sampling, during sampling it may be that the wind direction was variable
255 and there may have been swirling locally. This could mean that some sampling locations may
256 have been influenced by emission from other places and that would not have happened if the
257 prevailing wind direction was maintained throughout the sampling period. Gram-negative
258 bacteria particularly have been observed to be in high prevalence at open dumpsites located in
259 these regions, hence their higher concentrations in this study is not a surprise (Odeyemi 2012).
260 The steep decline in the concentration of *Aspergillus fumigatus* observed between the sampling
261 location at the active area (50 m from active point; Median: 283 CFU/m³), the dormant area
262 (531 m; median: 43 CFU/m³) and the boundary (788 m; 51 CFU/m³) showed an 80-81%
263 reduction in concentration downwind. This behaviour of *Aspergillus fumigatus* was similar to
264 what was observed by Schlosser et al., (2016) where the decline was up to 77% between the
265 tipping point at the landfill and the property boundary.

266 The mean bioaerosol concentration at the control site was generally 1-log lower than the
267 concentrations observed at Olusosun dumpsite (Table 3), supporting the fact that the Olusosun
268 dumpsite was a major source of bioaerosols within the study area. In general, the bacteria
269 concentration at the Olusosun dumpsite was typically 1-log higher than the fungi concentration.
270 This is not surprising as Xu and Yao (2013) also reported that there are usually higher viable
271 bacteria concentrations when compared to viable fungi concentrations when using an Anderson

272 impactor for air sampling. When the concentration of bioaerosols at all the sampling points
273 were added together, the 95th percentile of concentration of total bacteria (2189 CFU/m³), gram
274 negative bacteria (2352 CFU/m³), *Aspergillus fumigatus* (300 CFU/m³) and total fungi (824
275 CFU/m³) were 2-3 log lower than reported in literature where similar activities such as tipping,
276 spreading and compaction takes place (Kalwasińska et al., 2014; Sangkham et al., 2014). The
277 main explanation for such differences probably relates to the sampling locations on-site and
278 the sampling method employed. In this study using the Anderson six stage impactor, the closest
279 sampling location to the active area was 50 m downwind; compared to other studies where
280 sampling was either carried out at the working area or up 20 m away (Breza-Boruta 2012;
281 Schlosser et al., 2016).

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

291 **3.2 Activity-based air sampling**

292 The result of the activity-based air sampling shows that the scavengers and workers alike were
293 exposed to concentrations 2 -3log higher than the mean bioaerosol concentration measured
294 during the static ambient air sampling (Table 3). The activity-based sampling using the
295 personal body worn sampler allowed a picture to be obtained of the exposure of workers to
296 bioaerosols as a result of engaging in multiple activities typical of those at a dumpsite. Activity

297 such as scavenging typically involves material collection and sorting with material collection
298 being most prevalent during tipping and spreading of the waste while sorting tends to take
299 place further away from the active area (Afon 2012).

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

312 In Figure S2, exposure to bioaerosols from the various activities are compared to ambient air
313 sampling and the result indicated higher exposure to total bacteria and gram-negative bacteria
314 from scavenging up to 10^6 CFU/m³. Exposure to *Aspergillus fumigatus* on other hand was
315 found to be high when undertaking site-supervision activities (3×10^5 CFU/m³) with lower
316 exposure from sorting (9×10^4 CFU/m³) compared to scavenging (Table 3). This unusual spike
317 in *Aspergillus fumigatus* during site monitoring may not be unrelated to the property of the
318 waste (waste rich in fungi) tipped at the dumpsite at the time of sampling. Bioaerosols exposure
319 from scavenging and sorting activities accounted for the highest exposure levels at the dumpsite,
320 levels comparable to or higher than other forms waste-to-land treatment of municipal solid

321 waste such as landfilling and open windrow composting reported in some literature (Lis et al.,
322 2004; Odeyemi 2012; Wéry 2014b; Breza-Boruta 2016).

323 **3.3 Particle size distribution**

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

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

345 The aerodynamic diameter of bioaerosols is key to their dispersion, potential risk from
346 inhalation and disposition in either the tracheal, bronchial or the alveolar regions of the lungs
347 Brągoszewska et al., (2017) and Ferguson et al., (2017) had observed that bioaerosol exist
348 either as single cells or agglomerates depending on the season and the meteorological
349 conditions at the time of sampling. Their existence in an aggregated form, they argued, are
350 likely responsible for their settlement in the upper stages (aerodynamic diameter $> 3.3 \mu\text{m}$) of
351 the Anderson sampler either as aggregates of cells, cells associated with water droplets or
352 particulate matter. Moreover, high relative humidity can further increase both the size and
353 weight of the particle from absorption of ambient moisture, a phenomenon that favours higher
354 deposition at upper stages of the Anderson sampler (Total Bacteria: $\sim 59\%$; Gram-negative
355 bacteria: $\sim 54\%$) or dry deposition, giving a low reading for bioaerosol in the ambient air as
356 observed in this study (Liu et al., 2015; Smets et al., 2016). This is perhaps not surprising as
357 the multiple regression carried out in this study showed that, of the three metrological factors
358 tested, only relative humidity showed a statistically significant association with the
359 concentration of bioaerosols ($p < 0.01$), especially total bacteria ($F(3, 48) = 4.140$, $p < 0.05$, adj.
360 $R^2 = 0.156$). The results shown in Figure 3 suggests a higher percentage of fungi (*Aspergillus*
361 *fumigatus* $\sim 76\%$; and total fungi $\sim 63\%$) were within respirable fraction compared to bacteria
362 (Total bacteria $\sim 41\%$; gram-negative bacteria $\sim 43\%$). Moreover, as observed by Deacon et al.,
363 (2009), the recovery of *Aspergillus fumigatus* is usually highest within instruments pore size
364 range of $3.3 - 1.1 \mu\text{m}$ as they are typically $2 - 3.5 \mu\text{m}$ in diameter. Particles of inhalable fraction
365 deposited in the nasal area and upper respiratory tract can usually be removed by the action of
366 the nasal and tracheobronchial escalators, which is a combined mucociliary function of
367 trapping deposited bioaerosol particles in mucus and removal by the action of cilia (Mason and
368 Nelson 2005). However, this does not happen when particles of respirable fraction get down in
369 to the pulmonary region where there is much more potential for health problems if deposited

370 down there, especially those who are immunocompromised (Yoshida and Whitsett 2004;
371 Thomas 2013).

372 The tidal volume, which is the expected volume of air displaced during normal breathing, is
373 approximately 7 mL/kg or 500 ml for a healthy young adult (Quanjer et al., 1993; Ricard 2003).
374 With a respiratory rate of 12 breaths per minute (Cretikos et al., 2008; Erden et al., 2015), the
375 scavengers, waste sorters and waste workers working 11-hours (median) at Olusosun dumpsite,
376 will inhale approximately 3.96 m³ of air containing approximately 4.8×10⁵ CFU/m³ total
377 bacteria, 1.4 ×10⁶ CFU/m³ of gram-negative bacteria and 5.2×10⁴ CFU/m³ of *Aspergillus*
378 *fumigatus* during scavenging; 9.6×10⁴ CFU/m³ of total bacteria, 8×10⁵ CFU/m³ of gram-
379 negative bacteria and 6.93×10⁴ CFU/m³ of *Aspergillus fumigatus* during waste sorting; 2.4
380 ×10⁵ CFU/m³ of total bacteria, 9.7×10⁴ CFU/m³ gram-negative bacteria and 2.3 ×10⁴ CFU/m³
381 of *Aspergillus fumigatus* when carrying out site supervision , Table S3.

382 Several inhalation studies have investigated the effect of bioaerosols particle size on bioaerosol
383 lungs deposition and the lethal dose required to initiate an infection. Although there are several
384 animal models to this effect, no human studies exist investigating this relationship (Thomas
385 2013; Dabisch et al., 2017). The use of mouse models to demonstrate infection from
386 *Aspergillus fumigatus* have been widely reported in literature, and that perhaps is because mice
387 displays pathological consequences similar to humans (Kupfahl et al., 2006; Dagenais and
388 Keller 2009). Sheppard et al., (2004) administered a dose of 2.4 ×10³ CFU/mouse of
389 *Aspergillus fumigatus* conidia to immunocompromised mice, resulting in a lethal pulmonary
390 infection in most of the mice, surviving between 5 to 12 days. The exposure to *Aspergillus*
391 *fumigatus* in this research (from scavenging, waste sorting and site supervision) however, was
392 up to 2.74 x 10⁵ CFU/day , a 2-log higher than reported by Sheppard et al., (2004). However,
393 considering the complex nature of the structure and defence mechanism of the human
394 respiratory system, it is unlikely that a similar dose will be lethal to humans, however, a prolong

395 exposure and neutropenia to will increase the risk of developing invasive aspergillosis by the
396 exposed workers especially, the immunocompromised (Dagenais and Keller 2009; Wéry
397 2014a). Gram negative bacteria have also been reported to be a potent pro-inflammatory
398 stimulus in the human lungs due to flagellin release from their flagella (Liaudet et al., 2003).

399 **3.4 Respiratory symptom from workers**

400 Summarised in Table 4 is the socio-demographic description of the participants in the cross
401 sectional health survey. Of the 149 participants, 130(87%) and 19(13%) were males and
402 females respectively. The result also shows that participants spent 11 hours daily (median) at
403 the dumpsite and recorded a median “year at work” as 5. Moreover, the median age of the
404 participants was 30 years, and the smoker and non-smoker population was 61(41%) and
405 84(56%) respectively.

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

417 The result of the logistic regression showed a weak association between the independent
418 variable ‘Use of Nose Mask’ and occurrence of chronic cough ($p > 0.05$). Another independent

419 variable was 'Years of work' which showed no statistically significant association with chronic
420 cough, chronic phlegm and asthma, for participants with years of work > 5 years (Table 5).

421 The prevalence of respiratory symptoms among the sampled population is not surprising since
422 previous researches have also reported similar respiratory symptoms among waste workers and
423 dumpsite scavengers. Athanasiou et al., (2010) and Garrido et al., (2015) for instance reported
424 high prevalence of asthma and COPD symptoms among solid waste workers in municipality
425 of Keratsini, Greece and city of Hamburg, Germany, respectively. Black et al., (2019) also
426 reported that 70% of the 1278 informal waste workers surveyed in their study at the dumpsite
427 in Nuwakot district Nepal, reported one form of respiratory symptoms or other. Moreover,
428 increased alveolar macrophages, neutrophils, eosinophils and lymphocytes in the sputum
429 samples of examined female rag pickers (female scavengers) working on a waste dumpsite in
430 Kolkata, India have been reported by Ray et al., (2009). Although the study did not report the
431 possible exposure concentration, the observed biomarkers from the body of the female rag
432 pickers were evidence indicating a heightened immune system, which would suggest that they
433 have been exposed to bacteria, endotoxins and viruses through inhalation.

434 Figure 6A shows that chronic cough and chronic phlegm recording a higher prevalence among
435 smokers was not surprising, since chronic respiratory symptoms are most of the time associated
436 with smoking (Abramson et al., 2002; Frank et al., 2006; Garrido et al., 2015). The differences
437 in percentage points in the prevalence of the reported respiratory symptom between smokers
438 and non-smokers was marginal (chronic cough – 6%, Chronic phlegm- 2%, chronic wheezing-
439 0.5% and asthma-0.6%) and suggests that the reported respiratory symptoms were largely of
440 occupational origin than life style. This further supports growing evidence that chronic cough
441 and chronic phlegm are risk factors for chronic obstructive pulmonary disease (COPD) and
442 that reported cases of COPD among non-smokers are on the rise in developing countries (Salvi
443 and Barnes, 2009; de Marco et al., 2007).

444 It was expected that the non-use of a nose mask would greatly increase the odds of developing
445 these outcomes; however, the model was not sensitive enough to measure this. This perhaps is
446 because 87% of the respondents admitted not to have used a nose mask while working at the
447 dumpsite, and the few that did (13%), used them only occasionally when they had access to
448 PPE. This result should not be viewed as undermining the need to provide appropriate safety
449 interventions, as such interventions have been recommended by researchers to reducing the
450 risk of acquiring work related respiratory health problems (Lavoie et al., 2006; Kuijter et al.,
451 2010). It was also observed that all the respiratory health outcomes were not associated with
452 'Years of work' > 5 years ($p > 0.05$) (Table 5). In their study of the respiratory health of brick
453 kiln workers, Shaikh et al., (2012) observed a similar result, however only for workers with
454 'years of work' > 10 years. The median 'years of work' at Olusosun dumpsite was 5 years and
455 this represented 46% of the participants (Table 4). By implication, the majority of the
456 participants who had reported to suffer chronic respiratory symptoms, would have contracted
457 either chronic phlegm or asthma within the first 5 years of working at Olusosun open dumpsite.
458 In a different report of a 5-year follow-up study of compost workers, Büniger et al., (2007)
459 observed a doubling of the number of workers with chronic bronchitis (RR 1.41; 95% CI 1.3-
460 1.5) over the study period. Van Kampen et al., (2016) also observed an increase relative risk of
461 cough (RR 1.28; 95% CI 1.2-1.5) and phlegm (RR 1.32; 95% CI 1.2-1.5) and among compost
462 workers working for at least 5 years at the composting facility irrespective how long their years
463 of work was. They however, reported COPD as having no significant association with years of
464 work. This study has demonstrated that working at dumpsites such as Olusosun may increase
465 the odds of contracting chronic respiratory symptoms. This perhaps is primarily due to the
466 limited use of PPE by the population, limited control over activities on the dumpsite and longer
467 exposure hours, rather than longer years of work in such environments. In undertaking this
468 study, there were some limitations which were largely due to limited resources and lack of

469 health records. Firstly, there was no morbidity record for the workers at the dumpsite making
470 it difficult to compare the number of those who would have left the dumpsite due to ill health
471 from exposure, with those currently working at the dumpsite within the same period. This may
472 result in the underestimation of the extent of the respiratory health problems suffered by the
473 workers in Olusosun dumpsite. Secondly, the findings for this study were largely based on a
474 subjective inquiry without a complementary objective clinical measure. Spirometry and
475 haematological profiling could not be carried out to assess the lungs functions and detect
476 inhaled PM in the blood. The third limitation was that only the areas downwind of the
477 dumpsite (selection based on the predominant wind direction across the dumpsite) was selected
478 for sample group near the dumpsite. This may present a bias in the data, as there was regular
479 swirling in the local wind during the survey activity, hence a possible exclusion of an important
480 exposed group. Other cofounding factors such as vehicular emissions and industrial emissions
481 at the study locations were not considered and consequently adjusted for in this study. Lastly,
482 the probable underestimation of the actual bioaerosol exposure concentration due to
483 uncultivable and non-viable fraction of airborne microorganisms; a weakness inherent in the
484 use of the impaction sampling technique (HSE 2003; Persoons et al., 2010).

485 **4. Conclusion**

486 This study has demonstrated that open waste dumpsites are a major source of bioaerosols that
487 can contribute adversely to the respiratory health of the waste workers, scavengers and others
488 that are working at the dumpsite. Bioaerosols concentrations at Olusosun open dumpsite were
489 2-3 log higher when compared to the control site. The results from the activity-based air
490 sampling suggests that exposure to bioaerosol at Olusosun open dumpsite may also depend on
491 the activities engaged in at the dumpsite. Scavenging recorded the highest level of bioaerosols
492 exposure when compare to waste sorting, site supervision and the sampled ambient air. Gram-
493 negative bacteria represented the highest bioaerosol concentration in Olusosun dumpsite. The

494 particle size distribution for *Aspergillus fumigatus* and total fungi showed a greater portion
495 approximately 76% and 63% respectively were sizes < 3.3 μm . These particle sizes are
496 respirable and can be deposited at the lower respiratory tracts. Observed also was the
497 prevalence of chronic respiratory symptoms such as chronic cough and chronic phlegm, with
498 earlier showing equally prevalence in both smokers and non-smokers and the later, more
499 prevalent among the non-smoker population. Further clinical investigation into the respiratory
500 health of the workers at the Olusosun dumpsite is necessary to determine the lungs function in
501 responds to exposure to the bioaerosols.

502 **5. Supplementary data**

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

504 **Acknowledgment**

505 The study was carried out as part of a PhD studentship funded by the Niger Delta Development
506 Commission, Nigeria. The authors thank, Dr Stella Smith, Moses Bamidele, Prof. Bakare
507 Adekunle, Sunday Asindi and Maria Omogbe for their excellent technical assistance.

508 **Ethics approval**

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

511

512

513 **References**

- 514 ABRAMSON, M., M. MATHESON, C. WHARTON and M. SIM. 2002. Prevalence of respiratory
515 symptoms related to chronic obstructive pulmonary disease and asthma among
516 middle aged and older adults. *Respirology*, **7**(4), pp.325-331.
- 517 AFON, A. O. 2012. A survey of operational characteristics, socio-economic and health effects
518 of scavenging activity in Lagos, Nigeria. *Waste Management & Research*, **30**(7),
519 pp.664-671.
- 520 AGARWAL, S. 2017. Seasonal variability in size-segregated airborne bacterial particles and
521 their characterization at different source-sites. *Environmental Science and Pollution
522 Research*, **24**(15), pp.13519-13527.
- 523 ANDERSEN, A. A. 1958. New sampler for the collection, sizing, and enumeration of viable
524 airborne particles. *Journal of Bacteriology*, **76**(5), p471.
- 525 ATHANASIOU, M., G. MAKRYNOS and G. DOUNIAS. 2010. Respiratory health of municipal
526 solid waste workers. *Occupational medicine*, **60**(8), pp.618-623.
- 527 BIRRING, S. S. 2011. Controversies in the evaluation and management of chronic cough.
528 *American journal of respiratory and critical care medicine*, **183**(6), pp.708-715.
- 529 BLACK, M., J. KARKI, A. LEE, P. MAKAI, Y. BARAL, E. KRITSOTAKIS, A. BERNIER and A. F.
530 HECKMANN. 2019. The health risks of informal waste workers in the Kathmandu
531 Valley: a cross-sectional survey. *Public health*, **166**, pp.10-18.
- 532 BRĄGOSZEWSKA, E., A. MAINKA and J. S. PASTUSZKA. 2017. Concentration and Size
533 Distribution of Culturable Bacteria in Ambient Air during Spring and Winter in
534 Gliwice: A Typical Urban Area. *Atmosphere*, **8**(12), p239.
- 535 BREZA-BORUTA, B. 2012. Bioaerosols of the municipal waste landfill site as a source of
536 microbiological air pollution and health hazard. *Ecological Chemistry and
537 Engineering. A*, **19**(8), pp.851-862.
- 538 BREZA-BORUTA, B. 2016. The assessment of airborne bacterial and fungal contamination
539 emitted by a municipal landfill site in Northern Poland. *Atmospheric Pollution
540 Research*, **7**(6), pp.1043-1052.
- 541 BÜNGER, J., B. SCHAPPLER-SCHEELE, R. HILGERS and E. HALLIER. 2007. A 5-year follow-up
542 study on respiratory disorders and lung function in workers exposed to organic dust
543 from composting plants. *International archives of occupational and environmental
544 health*, **80**(4), pp.306-312.
- 545 BURKOWSKA, A., M. SWIONTEK-BRZEZINSKA and A. KALWASIŃSKA. 2011. Impact of the
546 municipal landfill site on microbiological contamination of air. *Contemporary
547 Problems of Management and Environmental Protection*, **9**, pp.71-7.
- 548 CRETIKOS, M. A., R. BELLOMO, K. HILLMAN, J. CHEN, S. FINFER and A. FLABOURIS. 2008.
549 Respiratory rate: the neglected vital sign. *Medical Journal of Australia*, **188**(11),
550 p657.
- 551 D-WASTE. 2014. *Waste Atlas 2014 Report: The World's 50 Biggest Dumpsites* [online].
552 [Accessed 29/07/2018]. Available from: <http://www.d-waste.com/>.
- 553 DABISCH, P., Z. XU, J. BOYDSTON, J. SOLOMON, J. BOHANNON, J. YEAGER, J. TAYLOR, R.
554 REEDER, P. SAYRE and J. SEIDEL. 2017. Quantification of regional aerosol deposition
555 patterns as a function of aerodynamic particle size in rhesus macaques using PET/CT
556 imaging. *Inhalation toxicology*, **29**(11), pp.506-515.
- 557 DAGENAIS, T. R. and N. P. KELLER. 2009. Pathogenesis of *Aspergillus fumigatus* in invasive
558 aspergillosis. *Clinical microbiology reviews*, **22**(3), pp.447-465.

559 DEACON, L., L. PANKHURST, G. DREW, E. T. HAYES, S. JACKSON, P. LONGHURST, J.
560 LONGHURST, J. LIU, S. POLLARD and S. TYRREL. 2009. Particle size distribution of
561 airborne *Aspergillus fumigatus* spores emitted from compost using membrane
562 filtration. *Atmospheric Environment*, **43**(35), pp.5698-5701.

563 DOUWES, J., P. THORNE, N. PEARCE and D. HEEDERIK. 2003. Bioaerosol health effects and
564 exposure assessment: progress and prospects. *Annals of Occupational Hygiene*,
565 **47**(3), pp.187-200.

566 ECRHS. 2002. The European Community Respiratory Health Survey II. *European Respiratory*
567 *Journal*, **20**(5), pp.1071-1079.

568 ENVIRONMENT AGENCY. 2017. *Technical Guidance Note M9. Environmental Monitoring of*
569 *Bioaerosols at regulated facilities* 1ed. United Kingdom: Environment Agency.

570 EPSTEIN, E. 2015. *Disposal and Management of Solid Waste: Pathogens and Diseases*. 6000
571 Broken Sound Parkway NW, Suite 300: CRC Press, Taylor & Francis Group.

572 ERDEN, F., A. Z. ALKAR and A. E. CETIN. 2015. Contact-free measurement of respiratory rate
573 using infrared and vibration sensors. *Infrared Physics & Technology*, **73**, pp.88-94.

574 FERGUSON, R. M. W., CHARLOTTE E. NEATH, ALEX J. DUMBRELL, CORINNE WHITBY and I.
575 COLBECK. 2017. Novel insights into the size distribution of bacterial bioaerosols at
576 composting sites. *In: The Aerosol Society Focus Meeting 10-Bioaerosols, 8 June, 2017,*
577 *University of Bristol, UK.* The Aeorosl Society.

578 FERRIS, B. G. 1978. Epidemiology Standardization Project-American Thoracic Society. *Am*
579 *Rev Respir Dis*, **118**, pp.1-120.

580 FRAŃCZEK, K., J. KOZDRÓJ, R. GÓRNY, M. CYPROWSKI and M. GOŁOFIT-SZYMCZAK. 2017.
581 Fungal air contamination in distinct sites within a municipal landfill area.
582 *International Journal of Environmental Science and Technology*, **14**(12), pp.2637-
583 2648.

584 FRANK, P., J. MORRIS, M. HAZELL, M. LINEHAN and T. FRANK. 2006. Smoking, respiratory
585 symptoms and likely asthma in young people: evidence from postal questionnaire
586 surveys in the Wythenshawe Community Asthma Project (WYCAP). *BMC pulmonary*
587 *medicine*, **6**(1), p10.

588 GARRIDO, M. V., C. BITTNER, V. HARTH and A. M. PREISSER. 2015. Health status and health-
589 related quality of life of municipal waste collection workers—a cross-sectional survey.
590 *Journal of Occupational Medicine and Toxicology*, **10**(1), p22.

591 GIBSON, P., G. WANG, L. MCGARVEY, A. E. VERTIGAN, K. W. ALTMAN, S. S. BIRRING, T. M.
592 ADAMS, A. F. BARKER, F. BLACKHALL and D. C. BOLSER. 2016. Treatment of
593 unexplained chronic cough: CHEST guideline and expert panel report. *Chest*, **149**(1),
594 pp.27-44.

595 GINER, M. M., J. S. C. GARCÍA and J. G. SELLÉS. 1999. Aerobiology of *Artemisia* airborne
596 pollen in Murcia (SE Spain) and its relationship with weather variables: annual and
597 intradiurnal variations for three different species. Wind vectors as a tool in
598 determining pollen origin. *International Journal of Biometeorology*, **43**(2), pp.51-63.

599 GLADDING, T. L. and C. L. GWYTHYER. 2017. A study of the potential release of bioaerosols
600 from containers as a result of reduced frequency residual waste collections. *Science*
601 *of the Total Environment*, **576**, pp.481-489.

602 GREEDY, D. and J. THRANE. 2012. Closed for business- A look at the closure of open dumps.
603 *Waste Management World* **9**(6).

604 HELDAL, K. K., L. MADSO and W. EDUARD. 2015. Airway inflammation among compost
605 workers exposed to actinomycetes spores. *Annals of Agricultural and Environmental*
606 *Medicine*, **22**(2).

607 HERIGSTAD, B., M. HAMILTON and J. HEERSINK. 2001. How to optimize the drop plate
608 method for enumerating bacteria. *Journal of microbiological methods*, **44**(2), pp.121-
609 129.

610 HOORNWEG, D. and P. BHADA-TATA. 2012a. What a waste: a global review of solid waste
611 management.

612 HOORNWEG, D. and P. BHADA-TATA. 2012b. *What a waste: a global review of solid waste*
613 *management*. Urban Development Series, Urban Development and Local
614 Government Unit, WB, Washington, DC 20433 USA: World Bank.

615 HSE. 2003. *Occupational and environmental exposure to bioaerosols from compost and*
616 *potential health effects - a critical review of published data* [online]. [Accessed
617 23/03/2018]. Available from: <http://www.hse.gov.uk/research/rrpdf/rr130.pdf>.

618 HSE. 2014. *General methods for sampling and gravimetric analysis of respirable thoracic and*
619 *inhalable aerosols* [online]. [Accessed]. Available from:
620 <http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-4.pdf>.

621 JENSEN, P. A., W. F. TODD, G. N. DAVIS and P. V. SCARPINO. 1992. Evaluation of eight
622 bioaerosol samplers challenged with aerosols of free bacteria. *American Industrial*
623 *Hygiene Association Journal*, **53**(10), pp.660-667.

624 KALWASIŃSKA, A., A. BURKOWSKA and M. SWIONTEK BRZEZINSKA. 2014. Exposure of
625 Workers of Municipal Landfill Site to Bacterial and Fungal Aerosol. *CLEAN—Soil, Air,*
626 *Water*, **42**(10), pp.1337-1343.

627 KUIJER, P., J. K. SLUITER and M. H. FRINGS - DRESEN. 2010. Health and safety in waste
628 collection: Towards evidence - based worker health surveillance. *American journal*
629 *of industrial medicine*, **53**(10), pp.1040-1064.

630 KUPFAHL, C., T. HEINEKAMP, G. GEGINAT, T. RUPPERT, A. HÄRTL, H. HOF and A. A.
631 BRAKHAGE. 2006. Deletion of the gliP gene of *Aspergillus fumigatus* results in loss of
632 gliotoxin production but has no effect on virulence of the fungus in a low - dose
633 mouse infection model. *Molecular microbiology*, **62**(1), pp.292-302.

634 LAVOIE, J., C. J. DUNKERLEY, T. KOSATSKY and A. DUFRESNE. 2006. Exposure to aerosolized
635 bacteria and fungi among collectors of commercial, mixed residential, recyclable and
636 compostable waste. *Science of the total environment*, **370**(1), pp.23-28.

637 LAWMA. 2016. *Landfill Operations* [online]. [Accessed 30th August 2016]. Available from:
638 http://www.lawma.gov.ng/lawma_landfill.html.

639 LAWMA. 2017. *Statistics of Refuse Deposited at Various Landfill Sites for 2014-2016*. In: P. R.
640 A. S. DEPARTMENT (Ed.).

641 LBS. 2013. *Household Survey 2013*. Lagos Welfare and Service Delivery Survey, Lagos
642 Nigeria: Lagos Bureau of Statistics.

643 LIAO, C.-M. and W.-C. LUO. 2005. Use of temporal/seasonal-and size-dependent bioaerosol
644 data to characterize the contribution of outdoor fungi to residential exposures.
645 *Science of the Total Environment*, **347**(1-3), pp.78-97.

646 LIAUDET, L., C. SZABO, O. V. EVGENOV, K. G. MURTHY, P. PACHER, L. VIRÁG, J. G. MABLEY, A.
647 MARTON, F. G. SORIANO and M. Y. KIROV. 2003. Flagellin from gram-negative
648 bacteria is a potent mediator of acute pulmonary inflammation in sepsis. *Shock*,
649 **19**(2), pp.131-137.

- 650 LIS, D. O., K. ULFIG, A. WLAZŁO and J. S. PASTUSZKA. 2004. Microbial air quality in offices at
651 municipal landfills. *Journal of occupational and environmental hygiene*, **1**(2), pp.62-
652 68.
- 653 LIU, Z., B. HU, L. WANG, F. WU, W. GAO and Y. WANG. 2015. Seasonal and diurnal variation
654 in particulate matter (PM 10 and PM 2.5) at an urban site of Beijing: analyses from a
655 9-year study. *Environmental Science and Pollution Research*, **22**(1), pp.627-642.
- 656 MACHER, J. M. 1989. Positive-hole correction of multiple-jet impactors for collecting viable
657 microorganisms. *American Industrial Hygiene Association Journal*, **50**(11), pp.561-
658 568.
- 659 MAŁECKA-ADAMOWICZ, M., J. KACZANOWSKA and W. DONDESKI. 2007. The Impact of a
660 Landfill Site in Żółtwin--Wypaleniska on the Microbiological Quality of the Air. *Polish*
661 *Journal of Environmental Studies*, **16**(1).
- 662 MASON, C. M. and S. NELSON. 2005. Pulmonary host defenses and factors predisposing to
663 lung infection. *Clinics in chest medicine*, **26**(1), pp.11-17.
- 664 MOORE, M., P. GOULD and B. S. KEARY. 2003. Global urbanization and impact on health.
665 *International journal of hygiene and environmental health*, **206**(4), pp.269-278.
- 666 ODEWABI, A. O., O. A. OGUNDAHUNSI, A. A. ODEWABI, K. S. ORITOGUN and M. EKOR. 2013.
667 Adenosine deaminase activity and immunoglobulin levels as potential systemic
668 biomarkers of occupational hazards and health status in municipal solid waste
669 management workers. *Environmental toxicology and pharmacology*, **35**(1), pp.1-12.
- 670 ODEYEMI, A. 2012. Antibigram Status of Bacterial Isolates from Air Around Dumpsite of
671 Ekiti State Destitute Centre at Ilokun, Ado-Ekiti, Nigeria. *Journal of Microbiology*
672 *Research*, **2**(2), pp.12-18.
- 673 OGDEN, E. C., J. V. HAYES, RAYNOR and G. S. 1969. Diurnal patterns of pollen emission in
674 Ambrosia, Phleum, Zea, and Ricinus. *American Journal of Botany*, **56**(1), pp.16-21.
- 675 OGWUELEKA, T. 2009. Municipal solid waste characteristics and management in Nigeria.
676 *Journal of Environmental Health Science & Engineering*, **6**(3), pp.173-180.
- 677 OLORUNFEMI, F. 2011. Landfill development and current practices in Lagos metropolis,
678 Nigeria. *Journal of Geography and Regional Planning*, **4**(12), p656.
- 679 OYEKU, O. and A. ELUDOYIN. 2010. Heavy metal contamination of groundwater resources in
680 a Nigerian urban settlement. *African Journal of Environmental Science and*
681 *Technology*, **4**(4).
- 682 PERSOONS, R., S. PARAT, M. STOKLOV, A. PERDRIX and A. MAITRE. 2010. Critical working
683 tasks and determinants of exposure to bioaerosols and MVOC at composting
684 facilities. *International journal of hygiene and environmental health*, **213**(5), pp.338-
685 347.
- 686 QUANJER, P. H., G. TAMMELING, J. COTES, O. PEDERSEN, R. PESLIN and J. YERNAULT. 1993.
687 Lung volumes and forced ventilatory flows. **6**(16), pp.5-40.
- 688 RAY, M., G. MUKHERJEE, S. ROYCHOWDHURY and T. LAHIRI. 2004. Respiratory and general
689 health impairments of ragpickers in India: a study in Delhi. *International Archives of*
690 *Occupational and Environmental Health*, **77**(8), pp.595-598.
- 691 RAY, M. R., S. ROYCHOWDHURY, G. MUKHERJEE, S. ROY and T. LAHIRI. 2005. Respiratory and
692 general health impairments of workers employed in a municipal solid waste disposal
693 at an open landfill site in Delhi. *International Journal of Hygiene and Environmental*
694 *Health*, **208**(4), pp.255-262.
- 695 RAY, M. R., S. ROYCHOWDHURY, S. MUKHERJEE, S. SIDDIQUE, M. BANERJEE, A. AKOLKAR, B.
696 SENGUPTA and T. LAHIRI. 2009. Airway Inflammation and Upregulation of. BETA. 2

697 Mac-1 Integrin Expression on Circulating Leukocytes of Female Ragpickers in India.
698 *Journal of occupational health*, **51**(3), pp.232-238.

699 REED, H. E. and B. U. MBERU. 2014. Capitalizing on Nigeria's demographic dividend: reaping
700 the benefits and diminishing the burdens. *Etude de la population africaine = African*
701 *population studies*, **27**(2), pp.319-330.

702 REINTHALER, F. F., E. MARTH, U. EIBEL, U. ENAYAT, O. FEENSTRA, H. FRIEDL, M. KÖCK, F. P.
703 PICHLER-SEMMELOCK, G. PRIDNIG and R. SCHLACHER. 1997. The assessment of
704 airborne microorganisms in large-scale composting facilities and their immediate
705 surroundings. *Aerobiologia*, **13**(3), pp.167-175.

706 RICARD, J.-D. 2003. *Are we really reducing tidal volume—And should we?* : Am Thoracic Soc.

707 SANDELOWSKI, M. 2000. Focus on research methods combining qualitative and quantitative
708 sampling, data collection, and analysis techniques. *Research in nursing & health*, **23**,
709 pp.246-255.

710 SANGKHAM, S., P. SAKUNKOO and C. ARUNLERTAREE. 2014. Concentrations of airborne
711 fungi from dumping landfill a case study with a Khon Kaen municipality site, Khon
712 Kaen Province. *Journal for Public Health Research-วารสาร วิจัย สาธารณสุข ศาสตร มหาวิทาลัย ขอนแก่น*,
713 **7**(2).

714 SCHLOSSER, O., A. HUYARD, D. RYBACKI and Z. DO QUANG. 2012. Protection of the vehicle
715 cab environment against bacteria, fungi and endotoxins in composting facilities.
716 *Waste management*, **32**(6), pp.1106-1115.

717 SCHLOSSER, O., S. ROBERT and C. DEBEAUPUIS. 2016. *Aspergillus fumigatus* and mesophilic
718 moulds in air in the surrounding environment downwind of non-hazardous waste
719 landfill sites. *International journal of hygiene and environmental health*, **219**(3),
720 pp.239-251.

721 SHAIKH, S., A. A. NAFEEES, V. KHETPAL, A. A. JAMALI, A. M. ARAIN and A. YOUSUF. 2012.
722 Respiratory symptoms and illnesses among brick kiln workers: a cross sectional study
723 from rural districts of Pakistan. *BMC Public Health*, **12**(1), p999.

724 SHEPPARD, D. C., G. RIEG, L. Y. CHIANG, S. G. FILLER, J. E. EDWARDS and A. S. IBRAHIM.
725 2004. Novel inhalational murine model of invasive pulmonary aspergillosis.
726 *Antimicrobial agents and chemotherapy*, **48**(5), pp.1908-1911.

727 SMETS, W., S. MORETTI, S. DENYS and S. LEBEER. 2016. Airborne bacteria in the
728 atmosphere: presence, purpose, and potential. *Atmospheric Environment*, **139**,
729 pp.214-221.

730 SRIVASTAVA, V., S. A. ISMAIL, P. SINGH and R. P. SINGH. 2015. Urban solid waste
731 management in the developing world with emphasis on India: challenges and
732 opportunities. *Reviews in Environmental Science and Bio/Technology*, **14**(2), pp.317-
733 337.

734 STAGG, S., A. BOWRY, A. KELSEY and B. CROOK. 2010. Bioaerosol emissions from waste
735 composting and the potential for workers' exposure. *Health and Safety Executive*
736 *Research report*, **786**.

737 THIRARATTANASUNTHON, P., W. SIRIWONG, M. ROBSON and M. BORJAN. 2012. Health risk
738 reduction behaviors model for scavengers exposed to solid waste in municipal dump
739 sites in Nakhon Ratchasima Province, Thailand. *Risk management and healthcare*
740 *policy*, **5**, p97.

741 THOMAS, R. J. 2013. Particle size and pathogenicity in the respiratory tract. *Virulence*, **4**(8),
742 pp.847-858.

- 743 TISCH ENVIRONMENTAL INC. 2018. *Viable Andersen Cascade Impactors* [online]. [Accessed
744 28th March]. Available from: www.tisch-env.com.
- 745 UN-HABITAT. 2009. *Global Report on Human settlements*. Planning Sustainable Cities,
746 (GRHS/09/FS1). Nairobi Kenya: United Nations Human Settlements Programme (UN-
747 HABITAT).
- 748 UNEP. 2005. *Closing an open dumpsite and shifting from open dumping to controlled*
749 *dumping and to sanitary landfilling In: U. N. E. PROGRAMME (Ed.) Nairobi Kenya:*
750 *UNEP Division of Technology, Industry and Economics (DTIE).*
- 751 UNEP. 2015. DTI /1957/JA. *Global Waste Management Outlook*. GWMO, United Nations
752 Environment Programme.
- 753 VAN KAMPEN, V., F. HOFFMEYER, A. DECKERT, B. KENDZIA, S. CASJENS, H. NEUMANN, M.
754 BUXTRUP, E. WILLER, C. FELTEN and R. SCHÖNEICH. 2016. Effects of bioaerosol
755 exposure on respiratory health in compost workers: a 13-year follow-up study.
756 *Occup Environ Med*, **73**, pp.829-837.
- 757 WÉRY, N. 2014a. Bioaerosols from composting facilities—a review. *Frontiers in cellular and*
758 *infection microbiology*, **4**, p42.
- 759 WÉRY, N. 2014b. Bioaerosols from composting facilities—a review. *Frontiers in cellular and*
760 *infection microbiology*, **4**.
- 761 WHO. 1991. *Sample size determination in health studies: a practical manual*. *Epidemiology*
762 *and Statistics*. Geneva World Health Organization.
- 763 WMO. 2017. *World Weather Information Service* [online]. [Accessed 10th March]. Available
764 from: <http://worldweather.wmo.int/en/city.html?cityId=258>.
- 765 XU, Z. and M. YAO. 2013. Monitoring of bioaerosol inhalation risks in different environments
766 using a six-stage Andersen sampler and the PCR-DGGE method. *Environmental*
767 *monitoring and assessment*, **185**(5), pp.3993-4003.
- 768 YOSHIDA, M. and J. WHITSETT. 2004. Interactions between pulmonary surfactant and
769 alveolar macrophages in the pathogenesis of lung disease. *Cellular and molecular*
770 *biology (Noisy-le-Grand, France)*, **50**, pp.OL639-48.

771

772