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Public Health Risks Assessment of Bioaerosols from Different Locations in Bariga Metropolis of Shomolu Local Government Area, Lagos State, Nigeria

Ogah JO[1*]; Mba OO[2]; Okelola CA[3] and Kolawole RM[3]

[1]Department of Microbiology, Faculty of Science, University of Lagos, Akoka, Nigeria

[2]Department of Public Health, Faculty of Health Sciences, National Open University of Nigeria, Lagos

[3]Department of Cell Biology and Genetics, University of Lagos, Akoka, Nigeria

ORCID ID: 0009-0008-1462-2456

ABSTRACT

The increasing human populations and their daily activities have contributed to bioaerosols generation in Bariga, leading to air pollution with consequent public health threats to exposed individuals. This study aimed to assess public health risks associated with bioaerosols generated from outdoor activities in Bariga community, Shomolu Local Government Area of Lagos State. An analytical observational study design based on the measurement of meteorological parameters in the field and laboratory analysis of bioaerosol particles collected from the study population using a handheld Kestrel 3000 weather meter and standard microbiological procedures, respectively, was adopted. Four hundred (400) samples of bioaerosol particles obtained by the Taro Yamani formula at a 5% level of precision were analyzed. Passive air monitoring using Koch's sedimentation method was employed for total viable counts, while microbial isolates were identified using cultural, morphological, and biochemical characterization. The variation in environmental parameters obtained was largely dependent on time and seasons, with a consequent adverse effect on the presence and movement of bioaerosol particles in the atmosphere. Microbial populations varied in densely and less-densely populated study areas. The study identified Bariga as a high-risk area with CFU above 10^2 –10^4 CFU/m^3, thus capable of causing bioaerosols-related diseases. A total of twelve (12) bacterial and six (6) fungal genera were isolated, with Gram-positive bacteria having a prevalence rate of 87.02% and Gram-negative bacteria at 12.99%. The predominant fungi, on the other hand, were 87.94% mold and 12.06% yeast. One-way analysis of variance (ANOVA) at 0.05 significance level showed a significant correlation (F-ratio > F-critical value) (p=0.05) between exposure to bioaerosol particles and associated health risks in the exposed individuals. We recommend that Lagos State Government should intensify efforts to reduce the public health effect of bioaerosols through policies, structural planning, development, and education on environmentally friendly activities and personal hygiene.

Keywords: Bioaerosols; Meteorological Parameters; Microorganisms; Public Health; Bariga; COVID-19.

Corresponding Author's Email: jogah@unilag.edu.ng, hon.agumba1@gmail.com

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INTRODUCTION

The ubiquitous and diverse nature of microorganisms in an ecosystem could be beneficial and detrimental to the existence of plants and animals within the biosphere or community. The increasing human populations with their daily activities have greatly contributed to air pollution consisting of inorganic (particulate matter) and organic (bioaerosols). The generated bioaerosols could serve as a means of transmitting pathogens and thus pose a potential public health threat to the community. These pollutants have constituted an inevitable environmental issue in the world's developing countries, and it stands out among the array of global environmental hazards facing metropolitan cities such as Lagos [1]. Bioaerosols generated are suspensions of atmospheric particles of biological origin containing living and/or dead microorganisms, pollens, and their derivatives [2]. The concentration of different bioaerosols in the air varies from one location to another. The bioaerosols can be generated during sneezing, talking, laughing, and yawning [3]; pollens from plants or anthropogenic activities can influence the bioaerosol's particle size, composition, and concentration in the atmosphere [4]. Microbial spores suspended in the air could serve as a potential source of allergy and general health problems in different ways [5]. They can easily be transferred from one environment to another because of their small size (0.001-100 μm) and lightweight, which are dependent upon prevailing physicochemical properties of the atmosphere, such as temperature, humidity, solar radiation, wind, precipitation and atmospheric pressure, for transport and survival [6-9] as reported [5]. After the release of biological aerosols into the atmosphere, most of them combine with the ambient particulate matter for diffusion and transportation from one place to another over long distances [8]. The susceptibility to acquiring infections from inhaling bioaerosols is largely determined by the virulence of the biological agent, the pathogenicity of the agent, dosage and the host's immune response. The airs we breathe also contain a mixture of gaseous and particulate matter released from natural and anthropogenic sources [9].

Humans play a significant role as hosts to many microorganisms, some of which are normal flora of the body, while others are pathogens capable of causing infectious diseases in man. In developing countries like Nigeria, air pollution is mainly due to overpopulation and uncontrolled urbanization, coupled with rapid industrialization, disparity among residents and poor environmental sustainability management education [10]. The population density of bioaerosols suspended in the atmosphere in a particular environment is influenced by the human population and their interactions with such environment; for instance, human populations have been implicated in the spread of infectious diseases [11]. With the continuous growth of populations in Bariga, human mobility and interactions, production of biological aerosols becomes inevitable in a densely populated area (such as market squares, bus stops and other public gatherings) than in less densely populated area (such as residential and streets within the residential areas) thus increasing the presence of microorganisms putting forward an eco-epidemiological assumption that disease transmission at the population level could be caused by the mixing patterns of individuals within the environment [12]. Respiration and the shedding of microorganisms daily by the human populace as they interact with one another and their surrounding contribute to bioaerosols built-up in such environments [13, 14].

Potential health effects on the community caused by bioaerosols depend on the pathogenicity or immunogenic potential of specific microorganisms and/or their metabolites, as well as other environmental conditions that can influence their survival in the air, the behaviour of the bio-aerosol particles and immunogenic status of the host [15]. The short-term and long-term exposure to air polluted with bioaerosols by members of the community increases their chances of contracting bioaerosols-related infections or reactions such as acute respiratory diseases, skin reactions, cough, watery eyes, difficulty in breathing and predisposing factors to pneumonia, influenza, measles, asthma, allergies, tuberculosis, cardiovascular diseases and gastrointestinal illness as long term effects [5, 16, 17, 18]. Many countries of the world, including Nigeria, has not recovered from the economic recession due to airborne bioaerosol disease such as COVID-19. Findings revealed that Nigeria's Gross Domestic Products (GDP) fell by 23% during the lockdown, especially in the food chain, with a GDP of 11%, which was primarily due to restrictions of movement that prevented food from the North to the South leading to hunger and poverty on households at 9% [19]. In Nigeria, there is no official data on economic loss due to bioaerosols-originated infections. However, the current fight against COVID-19, which is a bioaerosols-related disease, was estimated to cost the country over N45b [20]. Thus, the influx of migrating population from rural to urban areas with

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increasing settlement in Bariga can lead to public health threats.

Despite these challenges, there was no previous study on the increasing emerging and re-emerging airborne-related infectious diseases and how there are influenced by the increasing human population, environmental factors and their implications in the study area. The aim of this study was, therefore, to assess public health risks associated with bioaerosols generated from outdoor activities in different locations in the Bariga metropolis of Shomolu Local Government Area of Lagos State, Nigeria.

METHODOLOGY

The Study Area

The study area was Bariga, a district and suburb in Lagos State, South-West, Nigeria, formerly under Shomolu Local Government Development Area (LCDA) (Figure 1). The coordinates of Bariga LCDA are 6°32′6.0″N 3°23′41.0″E with a population of 391,200 people, according to [21]. Due to the high cost of rent in Lagos Island and some parts of the Mainland, with the increasing population of rural-urban migration, low and middle-income earners patronize places like Bariga, where rent is relatively affordable, thus contributing to a high level of aerosols generation with subsequent health hazards on the community.

Figure 1: The Map of Lagos State showing red shaded study area (Bariga-Shomolu)

Study design, sampling size and study population

Multi-stage sampling technique was adopted in the study, namely: observational study design and cluster sampling methods. The amount of airborne biological aerosol particles was observed based on the frequency of anthropogenic activities that contributed to the abundance of bioaerosols in the atmosphere and which emanated from human population indices: densely populated and less-densely populated parts of the study area. The sampling units, therefore, were aerosol particles collected from bus stops, markets, residential areas and streets in the study area.

In the second stage sampling technique, four hundred (400) samples of bioaerosols from the atmosphere were randomly collected from twenty (20) clusters using random cluster sampling technique from different locations (Table 1). The sample size of approximately four hundred (400) was determined using the Yamani formula [22]. The observation was made from selected clusters to represent the sample populations; this was based on the variables, which were the frequency of anthropogenic activities resulting in the production of biological aerosols in the study area. Thus samples were taken from densely populated clusters (markets and bus stops) and less-densely populated clusters (residential areas and streets) for microbial population density enumeration (bacteria and fungi) and the likely effects it will have on the populace. This is because the more densely the populations of people engaging in different activities, the higher the probability of biological aerosol generation compared to the less densely populations. Table 1 indicates the sampling frame where samples were taken from the clusters.

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Table 1: The sampling frame where bioaerosols samples were collected in the study area

S/No	Densely populated clusters	Less-densely populated clusters
1.	Bariga Market – BM	Olanrewaju Street - OL
2.	Ilaje Bus Stop - IL	Ifelodun Street - IF
3.	New Garage - NG	Community Road - CR
4.	Odo-Eran Market - OE	Temple Residential Area - TEM
5.	Igbo-Igunnu Spare-Parts Market - IG	Adeboye Residential Street - AD
6.	Odunsi Bus Stop - OD	Olalere Street - OLA
7.	Evening Market - EM	Lawal Street - LW
8.	Murtala Bus Stop - MB	Abeokuta Residential Area - AB
9.	Bariga Bus Station - BS	Evans Adelaja Area - EA
10.	Kajola Bus Stop – KB	Oshinfolarin Street – OS

Methods of Data Collection

Total viable counts for bacteria and fungi (CFU/m^3), temperature (^oC), humidity (%), precipitation (%), wind (km/hr), atmospheric pressure (mBar), and sunlight (Ultraviolet radiation) were primary data obtained from direct observations using quantitative measurement: microbial enumeration and their probable identity, environmental factors and secondary data obtained from review of risks assessment or health effects of biological aerosols from different articles and journals.

Microbiological analyses of bioaerosol particles

The isolation, enumeration and probable identification of microbial isolates followed microbiological standard procedures, including isolation of pure culture, cultural characterization, cellular morphology (Gram staining and fungi staining) and biochemical characterization: catalase, oxidase, starch hydrolysis, coagulase, carbohydrate fermentation, gas production, hydrogen sulphide production, indole, citrate utilization, motility, hemolysis and bile esculin tests according to [23, 24, 25]. Thus, passive air monitoring, otherwise known as Koch's sedimentation method or settling plate technique [26, 28], was adopted for this study. The exposure of nutrient plates to air allowed viable biological particles to sediments out of the air onto the nutrient plate's surface over the period of exposure. The bioaerosols were collected in duplicate plates using a random cluster sampling technique from designated study locations (Table 1). Ninety millimetres (90 mm) diameter Petri dishes containing nutrient agar (CM0003 Oxoid, UK) and potato dextrose-chloramphenicol agar (M096 Himedia Lab, India) for the isolation of bacteria and fungi, respectively, were exposed to the air above the shoulder level for one h; at 10 mins interval, the exposed nutrient plates were removed and covered with lids until one h was completed. The inoculated plates were transported to the Laboratory of the Department of Microbiology, University of Lagos, Nigeria, for incubation at 35 ± 2°C (bacteria) for 24 h and 28 ± 2°C (fungi) for four days along with control plates. The developed colonies were counted in duplicates, and the mean values were taken to determine the colony forming units per cubic meter (CFU/m^3) of the isolates and were further estimated according to Polish standard PN89/2-04088/08 [26, 27].

Measurement of environmental factors affecting the survival or dispersion of microbes in bioaerosols

Since environmental factors or parameters play an important role in the survival, growth and dispersal of released bioaerosols [29], they were measured at every sampling location with handheld Kestrel (3000) weather meter and Galaxy A01 Samsung Global Positioning System (GPS); the values for Humidity, Atmospheric temperature, Pressure, Sunlight or Ultraviolet-radiation, Wind and Precipitation were recorded (Table 2A, 2B).

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Table 2A: Environmental factors affecting the survival or dispersal of microbial cells suspended in the bioaerosol particles in the densely populated study area

Environmental Parameters at 95% confidence		Temperature (°C)	Humidity (%)	UV-radiation	Atmospheric pressure (mBar)	Precipitation (%)	Wind (mph)
S/N	*Locations*						
1.	Bariga Bus-station	29.2±1.46	41.0±2.05	06.0±0.3	1012.0±50.6	00.0±0.0	0.8±0.04
2.	Bariga Market	29.9±1.50	36.1±1.80	08.0±0.4	1009.0±50.5	00.0±0.0	1.0±0.05
3.	Evening Market	30.8±1.54	69.4±4.82	11.0±0.6	1010.0±50.5	20.0±1.0	0.6±0.03
4.	Igbo-Igunnu Spares-Part Market	33.0±1.65	29.4±1.47	11.0±0.6	1010.0±50.5	10.0±0.5	1.2±0.06
5.	Ilaje Bus stop	31.9±1.60	74.4±3.72	11.0±0.6	1012.0±50.6	40.0±2.0	0.8±0.04
6.	Kajola Bus stop	29.3±1.47	68.8±3.44	04.0±0.2	1010.0±50.5	25.0±1.25	0.5±0.03
7.	Murtala Bus stop	30.5±1.53	70.3±3.52	09.0±0.5	1011.0±50.6	10.0±0.5	1.5±0.08
8.	New Garage	32.1±1.61	71.7±3.59	11.0±0.6	1012.0±50.6	70.0±3.5	1.3±0.07
9.	Odo-Eran market	32.1±1.61	71.5±3.58	04.0±0.2	1009.0±50.5	30.0±1.5	2.6±0.13
10.	Odunsi Bus stop	28.2±1.41	36.6±1.83	05.0±0.3	1012.0±50.6	10.0±0.5	0.7±0.04

The meteorological parameters obtained in the tables both in densely and less-densely populated study areas showed a relatively significant rise in temperature as the ultraviolet radiation (sunlight) rises. The rising and falling of environmental factors witnessed in this study were majorly due to variations in time and season when the parameters were measured.

Table 2B: Environmental factors affecting the survival or dispersal of microbial cells suspended in the bioaerosol particles in the less-densely populated study area

Environmental Parameters at 95% confidence		Temperature (°C)	Humidity (%)	UV-radiation	Atmospheric pressure (mBar)	Precipitation (%)	Wind (mph)
SN	*Locations*						
1.	Abeokuta Street	29.5±1.48	79.0±3.95	05.0±0.25	1011.0±50.6	50.0±2.5	0.5±0.03
2.	Adeboye Street	30.2±1.51	62.8±3.14	11.0±0.55	1013.0±50.7	00.0±0.0	1.0±0.05
3.	Community road	28.8±1.44	73.2±3.66	02.0±0.10	1010.0±50.5	06.0±0.3	4.0±0.20
4.	Evans-Adelaja	32.2±1.61	80.0±4.00	11.0±0.55	1008.0±50.4	10.0±0.5	0.6±0.03
5.	Ifelodun Street	32.6±1.63	69.5±3.48	02.0±0.10	1010.0±50.5	50.0±2.5	2.3±0.13
6.	Lawal Street	29.1±1.46	75.6±3.75	07.0±0.35	1010.0±50.5	06.0±0.3	1.5±0.08
7.	Olalere Street	34.8±1.74	29.5±1.48	11.0±0.55	1009.0±50.5	10.0±0.5	1.2±0.06
8.	Olanrewaju Street	29.7±1.49	80.2±4.01	06.0±0.33	1012.0±50.6	60.0±3.0	0.6±0.03
9.	Oshinfolarin Street	32.7±1.64	59.0±2.95	11.0±0.55	1010.0±50.5	00.0±0.0	0.9±0.05
10.	Temple Area	32.4±1.62	36.5±1.83	08.0±0.40	1011.0±50.6	00.0±0.0	0.8±0.04

Public health risks assessment of bioaerosols and its economic implications

Public health risks assessment of bioaerosols was evaluated based on Occupational Safety and Health Administration recommendation [6, 30] and empirical knowledge on the pathogenicity of microbial isolates, their potential adverse health effects on the exposed population and their economic implications on the community. The economic implication involved the direct and indirect costs of the treatment of diseases caused by these identified infectious agents.

Exposure duration to pollutants of anthropogenic origin as a risk factor and ways to mitigate them

Pollutants of anthropogenic origin are pollutants that emanate from human activities that affect the ecosystem; some of these activities cause environmental pollution; for example, combustion of fossil fuel, waste disposal, urbanization, industrialization, agricultural activities, deforestation, construction, etc. [31, 32] Short-term and long-term exposure to these pollutants can cause acute and chronic respiratory diseases; it is important that careful evaluation of the findings to

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establish the relationship between duration of exposure to bioaerosols and health hazards as hypothesized was done using relevant statistical tools and empirical methods. Thus the findings were then reviewed based on the findings of other researchers, and necessary solutions were proffered to reduce their effects.

Data Analysis

The primary data obtained in this study from direct observation or measurement of samples in duplicates were sorted, processed, analyzed, presented and interpreted using mean, tables, charts, One-way analysis of variance (ANOVA) and F-distribution calculator [33].

RESULTS

This study showed variation in environmental parameters (Table 2A, 2B) at a p=0.05 significance level, which was largely dependent on time and seasons with subsequent adverse effects on the presence and movement of biological aerosol droplets suspended in the study area. The data obtained in this study showed that there was variation in the microbial concentration, with densely populated areas having the highest microbial populations than less densely populated areas. The highest bacterial populations within the exposed period of 1h were recorded in Bariga Market (BM), which ranged from $4.40x10^5$ to ND and lowest in New Garage (NG) from $2.83x10^4$ to $2.46x10^4$ (Table S1, Figure 2A), while fungal populations in the same category showed Bariga Market (BM) with highest populations ranging from $2.04x10^4$ to $3.93x10^2$ and lowest in Odo-Eran Market (OE) with $0.00x10^1$ to $1.57x10^3$ (Table S2, Figure 2B). The less-densely populated study areas, on the other hand, showed the highest bacterial populations in the Temple area (TEM), ranging from $8.33x10^4$ to $4.87x10^4$ cfu/m^3 and lowest in Olanrewaju Street (OL) from $1.18x10^4$ to $6.94x10^3$ (Table S3, Figure 3A) while the highest fungal population was observed in Temple area (TEM) $3.14x10^4$ to $8.64x10^3$ and lowest in Abeokuta Street (AB) from $0.0x10^1$ to $2.75x10^3$ (Table S1, S2, S4 - https://getjournal.org/wp-content/uploads/2023/05/Supplementary-Table-GJOBOH-2022-031.pdf and Figure 3B). Tables 3A and 3B show the microbial prevalence rate, while Table 4 shows public health risk assessment values compared to a recommended threshold.

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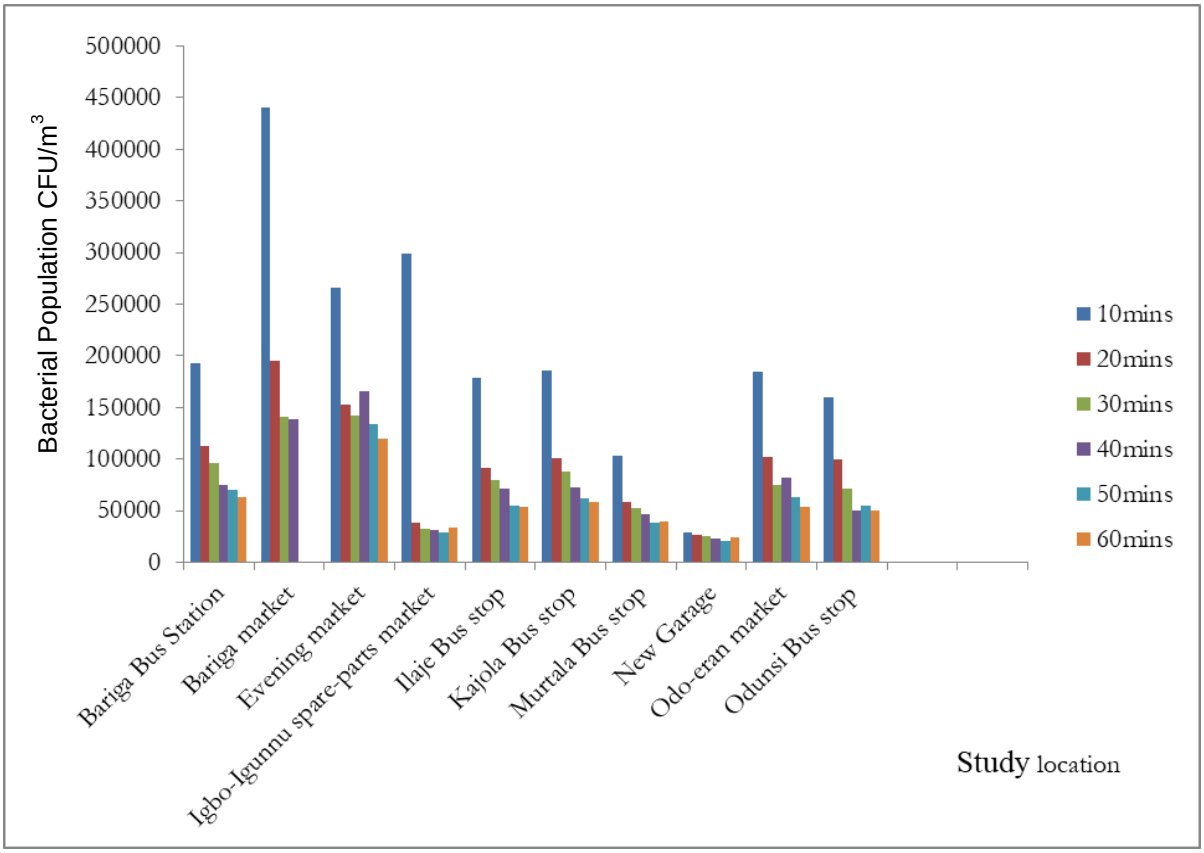

Figure 2A: Bacterial populations suspended in bio-aerosol particles in densely populated study area per hour

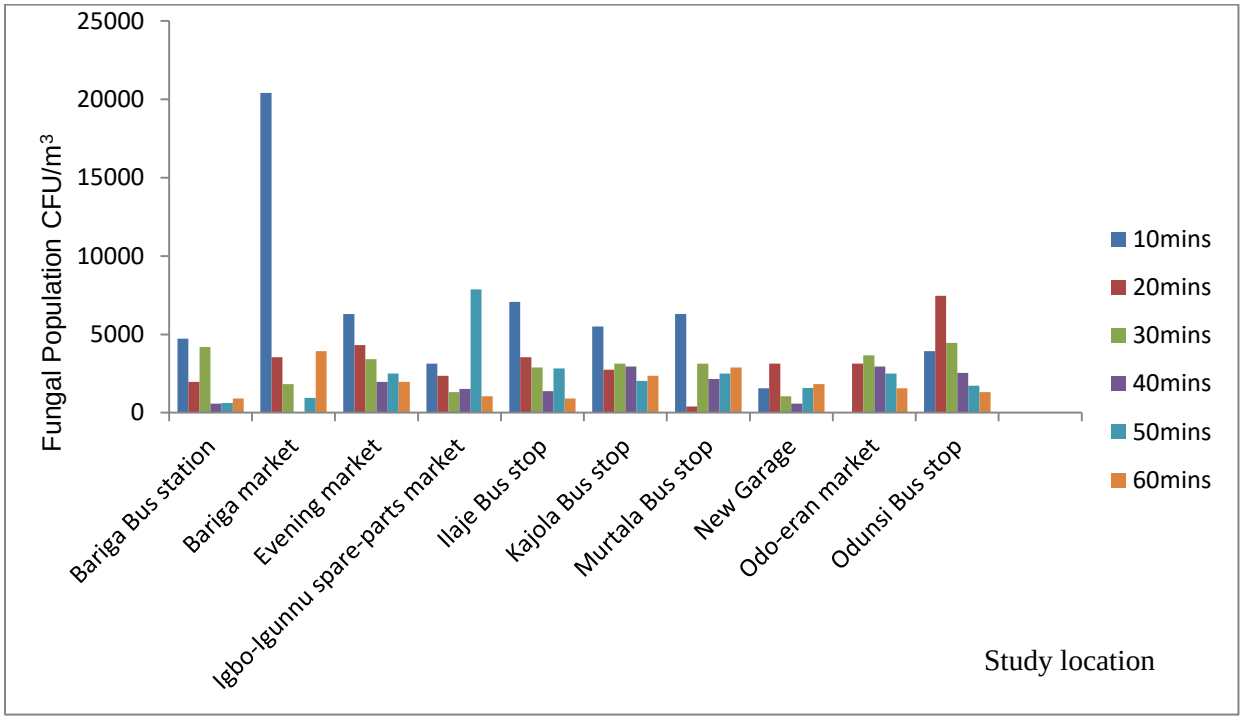

Figure 2B: Fungal populations suspended in bio-aerosol particles in densely populated study area per hour

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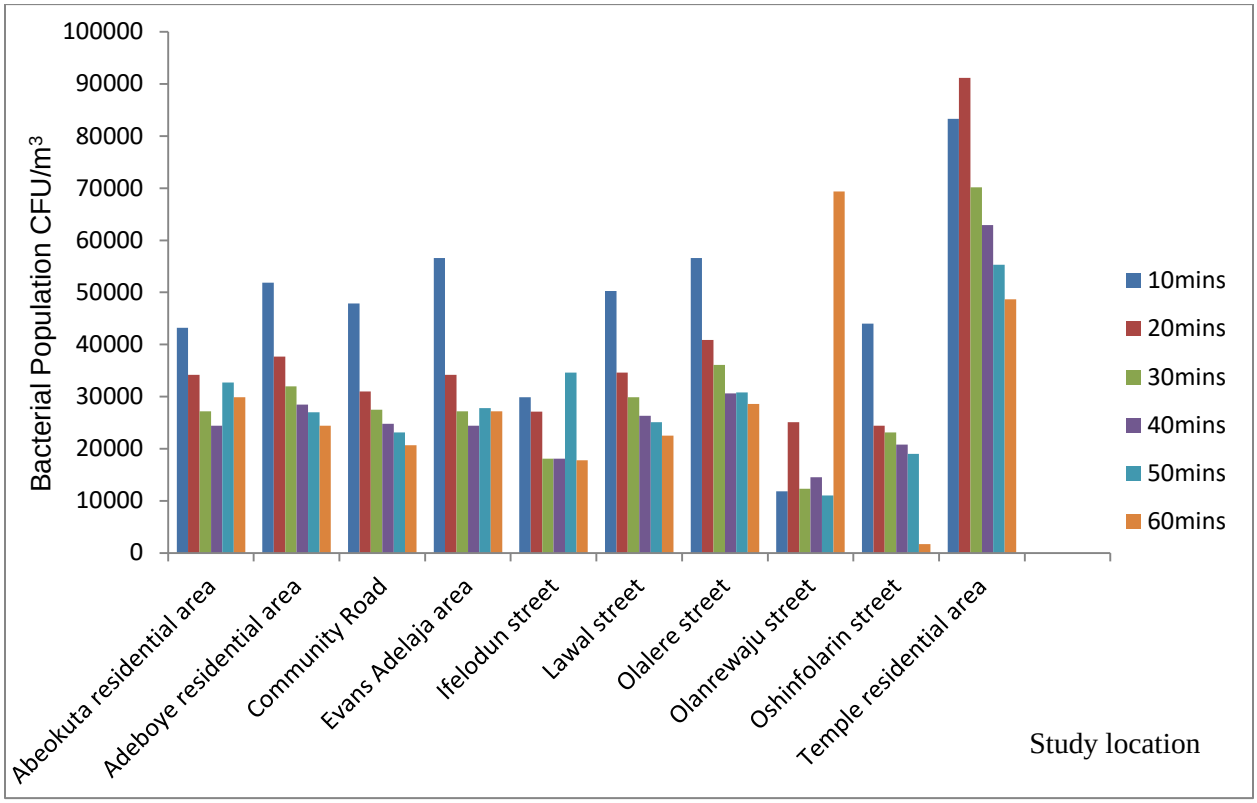

Figure 3A: Bacterial populations suspended in bio-aerosol particles in the less-densely populated study area

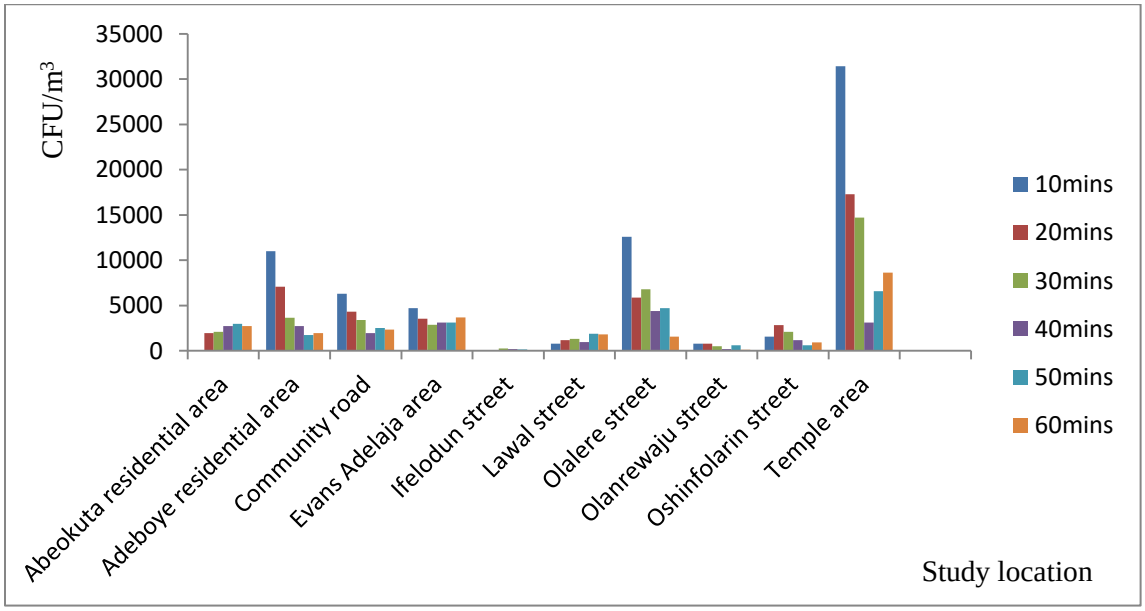

Figure 3B: Fungal populations suspended in bio-aerosol particles in less-densely populated study area per hour

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Table 3A: Prevalence rate of Bacterial Genera in the study population

S/No	Bacteria Genera	Frequency	Percentage (%)	Prevalence rate (%)
1.	*Staphylococcus*	32	41.56	8.18
2.	*Bacillus*	26	33.77	6.65
3.	*Micrococcus*	06	7.79	1.53
4.	*Pseudomonas*	04	5.19	1.02
5.	*Actinomycetes*	02	2.60	0.51
6.	*Streptococcus*	01	1.30	0.26
7.	*Shigella*	01	1.30	0.26
8.	*Serratia*	01	1.30	0.26
9.	*Enterobacter*	01	1.30	0.26
10.	*Escherichia*	01	1.30	0.26
11.	*Salmonella*	01	1.30	0.26
12.	*Yersinia*	01	1.30	0.26
	Total	**77**	**100**	

Table 3B: Prevalence rate of fungal genera in the study population

S/No	Fungi Genera	Frequency	Percentage (%)	Prevalence rate (%)
1.	*Aspergillus*	21	36.21	5.37
2.	*Fusarium*	16	27.59	4.09
3.	*Saccharomyces*	07	12.07	1.79
4.	*Neurospora*	05	8.62	1.28
5.	*Rhizopus*	05	8.62	1.28
6.	*Mucor*	04	6.90	1.02
	Total	**58**	**100**	

These tables state the prevalence rate of bacteria and fungi in the studied population.

Table 4: Public health risks or hazard assessment of bioaerosols on the study population

Study location	Mean total Bacteria CFU/m^3	Mean total Fungi CFU/m^3	Guideline CFU/m^3	Remarks
L1-Bariga Bus Station	2.88 x 10^5	5.50 x10^3	<1.0 x 10^2	Low
			10^2–1.0 x 10^3	Intermediate
			>1.0 x 10^3	High
L2-Bariga Market	4.97 x 10^5	7.86 x 10^3	*For houses*	
			<2.0 x 10^2	Low
			<1.0 x 10^3	Intermediate
			<1.0 x 10^4	High
L3-Evening Market	4.57 x 10^5	9.59 x 10^3	>1.0 x 10^3	Indicates contamination
			>1.06 x 10^2fungi/g of dust	Indicates contamination
L4-Igbo-Igunnu	1.12 x 10^5	4.72 x 10^3		
			<8.0 x 10^2	Normal
L5-Ilaje Bus Stop	2.47 x 10^5	8.02 x 10^3	<3.0 x 10^2	Common fungi are accepted
			<1.5 x 10^2	Mixedfungi other than pathogenic is accepted
L6-Kajola Bus Stop	2.67 x 10^5	9.43 x 10^3	<7.5 x 10^2	Total airborne bacteria and fungi are accepted if species are not infective or allergenic
L7-Murtala Bus Stop	1.65 x 10^5	1.04 x 10^4		
L8-New Garage	8.33 x 10^4	6.83 x 10^3		
L9-Odo-Eran Market	2.63 x 10^5	8.80 x 10^3		
L10-Odunsi Bus Stop	2.33 x 10^5	9.82 x 10^3	>1.04 x 10^2	Total fungi is a threat to health
			>5.0 x 10^2	One species of potentially pathogenic nature is a threat to health
L11-Abeokuta Street	1.05 x 10^5	8.80 x 10^3		
L12-Adeboye Street	1.03 x 10^5	1.12 x 10^4		
L13-Community Road	8.86 x 10^4	9.98 x 10^3		
L14-Evan Adelaja	1.01 x 10^5	1.18 x 10^4		
L15-Ifelodun Street	8.17 x 10^4	7.86 x 10^2		
L16-Lawal Street	9.57 x 10^4	5.27 x 10^3		
L17-Olalere Street	1.16 x 10^5	1.66 x 10^4		
L18-Olanrewaju Street	4.24 x 10^4	1.57 x 10^3		
L19-Oshinfolarin Street	7.39 x 10^4	4.56 x 10^3		
L20-Temple Area	2.16 x 10^5	3.46 x 10^4		

This remark was made based on guidelines adopted from Kim, K.-H.et al. (2017). Airborne bioaerosols and their impact on human health, J. Environ. Sci. (2017), https://doi.org/10.1016/j.jes.2017.08.027

DISCUSSION

As a result of daily anthropogenic activities in the Bariga metropolis of Shomolu, Lagos, Nigeria, microorganisms are released in the form of bioaerosol droplet nuclei, which float in the atmosphere. People are exposed to these bioaerosols being carried about by wind and other environmental factors through the exchange of gases (respiration), contaminated air containing pathogens is inhaled and equally released via talking, coughing, sneezing, yawning and laughing. The exposed individuals, especially the vulnerable ones, may come down with one form of infection or another, thus causing public health threats. Some of these environmental factors have been observed to be relatively less densely populated than less densely populated study areas, thus affecting the microbial distribution and leading to a high population of microorganisms in densely populated areas than in less densely populated study areas. This assertion was corroborated by Samaranayakea et al. [34], who stated that

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aerosols could be transported or suspended in the air for considerable periods of time depending on the humidity, airflow, and temperature of the environment into which they are expelled. Górny [35] also observed that microclimate parameters such as temperature and relative humidity of the air, together with ultraviolet radiation, oxygen and other physical factors, contribute to the influx of airborne microorganisms. These environmental factors also influence the survival of airborne microbes and affect their ability to colonize surfaces after deposition. As the ultraviolet radiation rises over time, there is a corresponding gradual rise in temperature. This rise in temperature between 28.2-34.8^{o}C, as observed in this study, favoured the survival and viability of mesophiles which are generally known to be human pathogens and capable of surviving at body temperature (37^{o}C). Humidity and precipitation support the growth of microorganisms, as bacterial cells are composed mainly of water. Though the high the precipitation, the less the microbial population is due to the fact that rainfall washes the microorganisms from the atmosphere unto open surfaces. The total microbial population densities varied from location to location depending on the human population densities. It was observed that mean microbial colonies increase with the increase in exposure period with a decline in CFU/m^3 when estimated with Polish standard PN89/2-04088/08. The high microbial population recorded in densely populated areas is attributable to the influx of people and their daily activities that resulted in the generation of bioaerosols leading to high microbial contamination above the standard limits of 0 – 1.0 x 10^3 CFU/m^3 [15]. Bariga market recorded high microbial populations. Market squares and bus terminals are heterogeneous settings where several activities are taking place daily. Human, animal, vehicular movement and unhygienic environmental practices become the order of the day with the resultant generation of one form of aerosols or another, thus polluting the air and exposing the market and bus patrons to the danger of respiratory diseases, skin diseases, systemic diseases and allergic reactions. This study is in line with Adams et al. [14], who affirmed that the population density of microorganisms in bioaerosol suspended in the atmosphere in a particular environment is influenced by human populations and their interactions with such environment. On the other hand, the high microbial populations witnessed at Temple residential area compared to others in the same categories could be a result of the poor environmental sanitation and lack of personal hygiene practised by the residents. The place was observed to be more of a 'ghetto' settlement inhabited by low-income earners that lacked the will and capacity to practice environmental hygiene compared to the Olanrewaju residential area, where the residents were middle-income earners and educated. Thus the level of environmental and personal hygiene was relatively acceptable compared to other study locations within the populations. This study shows that the predominant bacteria isolated were Gram-positive bacteria (87.02%), with the genus, *Staphylococcus* having (41.56%) population frequency and the least prevalence rate (1.79%). The high occurrence of Gram-positive bacteria and moulds in this study may be due to their ubiquitous nature, ability to survive longer in the air, colonization of the skin and other body orifices, presence of thick layers of peptidoglycan in their cell wall (20 – 80 nm), possession of spores by some genus *Bacillus* and mold, presence of small protective molecules such as sugars, amino acids, alcohols and betaine, expression of heat shock proteins [36]; whereas least occurrence of Gram-negative bacteria which are majorly enteric bacteria recorded in this study could be due to their inability to survive outside their natural habitat (human body) and the presence of a thin layer of peptidoglycan in their cell wall (2 – 3 nm) surrounded by an outer membrane containing lipopolysaccharide [37]. This observation is in conformity with earlier findings [1, 6, 26, 38] which isolated some predominant bacterial genera of *Staphylococcus, Bacillus, Streptococcus, Escherichia, Micrococcus, Pseudomonas, Serratia, Salmonella, Shigella* and fungal genera of *Aspergillus, Fusarium, Rhizopus,* and *Saccharomyces*. Some of the bioaerosols in this study are capable of causing infections in exposed individuals to contaminated air; for instance, *Staphylococcus* sp is a potential cause of sepsis, infective endocarditis, osteomyelitis, skin and soft tissue infections [39]; *Bacillus* sp has also been implicated in previous studies as a potential cause of abscesses, bacteremia, wound and burn infections, ear infections, endocarditis, meningitis, ophthalmitis, osteomyelitis, peritonitis, respiratory, urinary tract infections and food poisoning [40]. *Micrococcus* spp. are capable of causing opportunistic infections in immuno-compromised HIV patients [41], *Actinomyces* which causes Actinomycosis [42, 43], *Streptococcus* has been identified in previous studies to be responsible for Strep throat infection, scarlet fever, impetigo, cellulitis, streptococcal toxic shock syndrome and rheumatic fever [44]. *Pseudomonas, Shigella, Serratia, Enterobacter, Escherichia, Salmonella* and *Yersinia* are Gram-negative, enteric bacteria

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responsible for gastrointestinal diseases in infants, adults and the elderly with characteristics of abdominal cramps and diarrhoea, nausea and vomiting, gastroenteritis, fever, and other clinical infections such as neonatal meningitis and pneumonia [45-47]. Moulds and *Bacillus* are generally spore-producing organisms which can withstand unfavourable environmental conditions; their spores can easily be carried about from one place to another by the wind until they come in contact with a suitable medium that supports their growth. The presence of these spores in the study area is a public health threat, thus exposing individuals, especially those with underlying diseases such as asthma and respiratory diseases, to inhaling contaminated air leading to allergic reactions and severe respiratory infections. Some *Aspergillus* species have been implicated in causing mycoses in humans, allergic sinusitis, and systemic and respiratory diseases in exposed hosts [1, 45, 48]. *Fusarium* spp. is known to cause superficial, locally invasive, diffuse infections and keratomycosis in humans [49]. *Saccharomyces* sp can cause opportunistic infections on exposed hosts [52]; *Neurospora* sp is a non-human pathogen useful as an experimental model in genetics [48]. *Rhizopus* sp and *Mucor* are known for causing Mucormycosis [51]. The predominance of bioaerosols in the study area and their ability to survive harsh conditions of the atmosphere other than their physiochemical properties might be due to the presence of dust in the air, which supports their existence in spore form [16]. This is in conformity with the World Health Organization, which postulated that exposure to microbial agents of aerosol origin increases the risks of rare health conditions. The variation and prevalence of bacterial and fungal genera in the air, as observed here, are due to differences in stability and viability in the air. Gorny [35] asserted that air as a biotope does not support the survival of biological agents, but he further stated that several studies showed that numerous fine particles of biological origin were able to maintain their viability and immunological reactivity in the air much longer than bigger organisms. This also explains why the bacterial population is high in this study, considering their size, which is between 0.5 - 2.0 µm, than fungi, whose individual cell size can vary widely from 2 – 3 µm to 20 – 50 µm in length.

The potential health hazards associated with frequent exposure to bioaerosols in the study population were shown to be very high in all locations. According to Occupational Safety and Health Administration [30] and other regulatory bodies provided a guideline for microbial load threshold between 10^2 – 10^4 CFU/m^3 (low – high risk); though this value varies from country to country. In Nigeria, for instance, there is no official data from environmental and health regulatory bodies on biological aerosols threshold; the data obtained in this study were interpreted based on standards/guidelines for bioaerosols proposed by different governmental and private organizations; based on European literature databases on residential indoor air quality as reported by Kumar et al. [5]. This study showed mean microbial load of 7.86 x 10^2 – 4.97 x 10^5CFU/m^3. Hence it can be deduced that there is a high public health risk of frequent exposure to biological aerosols in the Bariga community. Therefore, adequate hazard mitigation should be employed to reduce the risk, thus promoting healthy living.

A significant correlation (p=0.05) between bioaerosols exposure duration and the likelihood of developing the onset of diseases in the susceptible, exposed host was observed. This is supported by Franchitti et al. [52], who reported a statistically significant correlation between bioaerosols exposure and the onset of health effects on humans. The economic implication of pathogens of bioaerosols origin has been estimated: the cost of treatment of infections or diseases ($10 - 720,167.22) per episode or annum, low productivity and deaths [53]. It can be challenging to treat some of these pathogens because of their multi drugs resistance, thus putting their hosts in grave danger and other life-threatening situations. Preventive measures to curb the pandemic emanating from bioaerosols include quarantine, preparation of health facilities, isolating infectious cases, and tracing contacts involving public health resources, human resources and implementation costs. It also involves health system expenditures to provide health facilities for infectious cases and the arrangement of consumables such as antibiotics, medical supplies, and personal protective equipment [56]. In Nigeria, there is no official data on economic loss from bioaerosol-originated infections. However, the current fight against COVID-19 (bio-aerosol borne) disease was reported to cost the country over N45b [25]. Bioaerosols-related infectious diseases have been reported to be responsible for economic losses, including medical expenditures of about US$21 billion globally, economic productivity losses, environmental degradation and material losses [20]. This cost is significantly high in this era of economic recessions, which can create global implications of bioaerosols-related pandemic impact on the health system and simultaneously the growth prospects of the whole countries [8]. The health risk of outbreaks of infectious diseases,

the fear and worry that accompany them, low productivity due to illness and absenteeism from work and school lead to various economic risks, thus increasing poverty within the community and the nation at large.

CONCLUSION

This study has shown a significant relationship between the frequencies of exposure to bioaerosols and associated public health risks on the exposed individuals. The statistical analysis one-way analysis of variance (ANOVA) at 0.05 significance level between exposure to bioaerosols and subsequent health hazards on the general public. The variation in environmental parameters is largely dependent on time and seasons, with subsequent adverse effects on the presence and movement of biological aerosol droplets suspended in the atmosphere. The study also revealed that the study area is a high-risk area (10^2 – 10^4CFU/m^3) for biological aerosol-related infections or diseases. Hence, the prevalence of genera, *Staphylococcus, Bacillus, Micrococcus, Pseudomonas, Actinomycetes, Streptococcus, Shigella, Serratia, Enterobacter, Escherichia, Salmonella, Yersinia, Aspergillus, Fusarium, Saccharomyces, Neurospora, Rhizopus* and *Mucor* is an indication of microbial contamination. The knowledge of the presence of biological agents and adaptation of lifestyles by the residents in the study area can help in environmental and public health sustainability, thus reducing bioaerosols-related pollution. It is therefore recommended that adequate proactive, preventive and control measures such as structural and aesthetic modification in line with urban plans should be put in place to reduce the survival, distribution, colonization and establishment of bioaerosols in the Bariga community, thus promoting the health of the residents. Lagos State Government should also intensify efforts to reduce the public health effect of bioaerosols through policies, structural planning, development, and education on environmentally friendly activities and personal hygiene.

ABBREVIATIONS

ASHRAE - The American Society of Heating, Refrigerating, and Air-Conditioning Engineers.
CFU - Colony-forming Unit
COVID-19 - *Coronavirus disease*
GDP - Gross Domestic Product
GPS - Global Positioning System
LCDA - Local Council Development Area
ND – Not Determined
OECD - The Organization for Economic Cooperation and Development
OSHA - Occupational Safety and Health Administration
TNTC - Too Numerous to Count
UK - United Kingdom
WHO - World Health Organization

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