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ORIGINAL PAPER

Spatio-temporal characterisation of bioaerosols at diverse outdoor land-use sites in an urban environment

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Abstract The land-use configuration has huge impact on emission sources and also a major influencing factor, which ultimately determine the microbial count, composition and seasonal dynamics of bioaerosols at respective site. Despite this, very few studies compare bioaerosols exposure at different land-use sites. The aim of the present study was to measure and compare the aerosolised bacterial and fungal counts across seasons using active Anderson cascade impactor at different land-use configurations in an urban metropolitan. The counts of aerosolised bacteria and fungi were estimated across five seasons of a tropical climate. A mixed-effect model showed that the season and land-use configuration have a bearing on microbial counts. Season and land use interact in a complex manner to produce bioaerosol count variability. Meteorological parameter (temperature and relative humidity) had a significant effect on microbial counts at all land-use configurations, but they could not fully explain variations of microbial counts in the mixed model.

Keywords Bioaerosol · Aerosolised Bacteria · Aerosolised Fungi · Land-use configuration · Season

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1 Introduction

Bioaerosols are ubiquitous and potential pollution contributors; their counts range between 10^4 and 10^8 cells per m^3 of air (Bowers et al. 2011). Bioaerosols transported from a source site to other places through wind (Nasir et al. 2012) and form a substantiate fraction of the $PM_{2.5}$. This fraction can penetrate deep into the respiratory system and requires regular monitoring and remediation (Bowers et al. 2011).

Aerosolised microbes are derived from various sources (outdoors or indoors). The quantification and composition of bioaerosols depend on the type and strength of the sources, factors affecting aerosolisation, viability and the settling rate of microbes (Balyan et al. 2017), and these factors majorly depend on land-use configuration of a place.

Land use is permanent or cyclic human intervention on the environment to satisfy human needs. It includes human use of 'land cover', along with the social, economic, political or cultural 'function' of the land (Bičík et al. 2015). Land use is characterised by the arrangements, inputs and activities people undertake in a certain land cover type to produce, change or maintain it (Kempka and Browne 2005). A 'microenvironment' created by land use involves the properties of a specific location, interacting collectively in a complex manner (Balyan et al. 2017). Microenvironments, thus, could be expected to play a crucial role in bioaerosol generation, propagation, aerosolisation, resuspension, controlling diffusion, transportation and intermolecular interactions. However, there are still critical gaps in the understanding of how land use may influence bioaerosol counts. Thus, the study hypothesises that land-use configurations influence bioaerosol count and composition owing to changes in factors defining microenvironments.

2 Materials and methods

Aerosolised bacterial and fungal counts were measured in three different land-use sites within the campus of the University of Delhi (a vegetated site, a residential site and a commercial site) selected on the basis of relative human presence and activities. The vegetated site represented a natural environment with low human interference, whereas the residential and commercial sites had a high human presence with various human activities. The vegetated site was a 2.5 km^2 ridge dominated by indigenous tree. The residential site was inhabited by approximately 2000 residents. The colony has large, open areas, with one central urban green space (park), open dumping enclosure and covered sewage lines. The commercial site was a market, mainly dominated by shops and it lies on a busy road.

Bioaerosol monitoring was conducted weekly using an active Andersen Cascade Impactor (Six Stages), across all the seasons in one season cycle (May 2016 to April 2017): winter, spring, pre-monsoon, monsoon and post-monsoon. The activities were allowed to continue unimpeded as samples were being taken so that the observed culturable count would remain near the usual one.

Blood agar and Chloramphenicol Rose Bengal Potato Dextrose agar were used for sampling the aerosolised bacteria and fungi, respectively. Petri plates were incubated at a temperature of 37 $\pm$ 2 °C (for bacteria) and 28 $\pm$ 2 °C (for fungi), and the number of colony-forming units were counted after 48 and 72 h of growth, respectively (Zimbro 2003).

The spatio-temporal variability was analysed by calculating mean microbial count trends of seasonal variation at each site. Since data were unbalanced and had a significant homogeneity of variance, mixed-model analysis was used to analyse the effects of season and land-use configurations (Garson 2012). Season and site were used as the fixed effects variables in the mixed model. The temperature and relative humidity were entered again, along with the season, to determine whether the effects of the season are mediated via temperature and relative humidity.

3 Results and discussion

3.1 Spatial variation of microbial counts in outdoor environments

The highest bacterial and fungal counts were observed at the commercial site and the vegetated site, respectively, in the studied season cycle. The bacterial count was maximum at the commercial site followed by the residential site, and it was at its lowest at the vegetated site. The land use was found to significantly influence the aerosolised bacterial counts ($p < 0.01$) (Table 1).

Humans release millions of microbes along with organic droplets in the air while talking, sneezing, coughing and shedding skin cells. These organic droplets provide protection to microbes and enhance their survival in the air. Further, human activity and persistent vehicular traffic prevent aerosolised microbes from settling down and cause settled microbes to be resuspended (Heo et al. 2017).

Fungal counts showed an overall different pattern (Table 1), being highest at the vegetated site, followed by the commercial and the residential sites. The high fungal count at vegetated site could be due to decomposing leaf litter and organic waste material. This organic litter acted as a host for various types of pathogenic and saprobic fungi (Womack et al. 2015).

Table 1 Fixed effects of land use on microbial counts (CFU/m^3)

Land-use configuration	Bacterial counts		Fungal counts	
	Mean ± SD	*p* value	Mean ± SD	*p* value
Vegetated site	6257.41 ± 549	< 0.01	8648.48 ± 824	< 0.01
Residential site	11,261.21 ± 962		3781.49 ± 297	
Commercial site	12,894.62 ± 1057		6842.18 ± 624	

The land use had a significant influence on aerosolised fungal counts ($p < 0.01$) (Table 1).

3.2 Seasonal trend of bioaerosols

Site-specific seasonal trends were observed amongst the different land-use sites (Fig. 1a, b). A dip in the bioaerosol count was observed in the pre-monsoon season at all sites. However, this dip was more pronounced at the residential and commercial sites. Seasonal trends were also quite similar in the residential and commercial sites (i.e. those with high human occupancy), whereas a different trend was observed at the vegetated site as their microenvironment was markedly different due to different land-use practices. In terms of the temporal difference in the aerosolised microbial counts, results of the fixed effects analysis in the mixed modelling depicted a statistically significant effect of the seasons on microbial counts at all three land-use configuration sites (Fig. 1a, b).

The low bioaerosol counts during pre-monsoon season might be due to (a) heat waves—Delhi is a tropical city, and it experiences heat waves known as *loo*, which blow from western India along with high temperature and low humidity, produce a condition of *heat stress* (De Rensis and Scaramuzzi 2003). The *urban heat island effect* at the concretised commercial site and residential site further accentuated the effect of heat waves. High temperature and low relative humidity produce changes at the nucleic acid, protein and phospholipid membrane levels of microbes, inhibiting their growth and propagation (Arnfield 2003). (b) Outdoor human activities and movement were low during pre-monsoon season because of high intensity of solar radiations and heat waves during sampling time. The heat waves and commensurate decrease in human movements, and activities at outdoor (Horanont et al. 2013) might have antagonised microbial growth, aerosolisation and resuspension.

A rise in microbial counts was observed during monsoon and post-monsoon seasons, due to moderate temperatures and high relative humidity. Generally, warm and humid conditions permit optimum microbial growth. A moderate temperature with less severe solar radiation also increases outdoor human activity during monsoon season, compared to pre-monsoon season, though these activities come to a standstill when the rainfall begins (Horanont et al. 2013). However, rainfall causes the release of fungal spores by splash tap and puff mechanisms (Burge 2004).

A pattern of increase in bacterial and fungal counts was noted from the pre-monsoon to the post-monsoon and the winter seasons (Fig. 1a, b). This may arguably be attributed to the fact that a rise in outdoor human footfall and activities was observed at the residential and commercial sites during the post-monsoon and winter seasons compared to pre-monsoon season. Maximum temperature and solar radiation occurred during the sampling times of the day, producing comfortable outdoor conditions compared to the chilly weather in the mornings and evenings (Adams et al. 2015).

In this study, the vegetated site exhibited high fungal concentrations throughout the seasonal cycle, especially during spring and the monsoon seasons. These two seasons had moderate temperature and high relative humidity owing to frequent rainfall during monsoon months and western disturbances during spring. A rise in the vegetative biomass during spring season may also have functioned as a host for plant pathogenic and saprobic fungi. The wet and humid environment during spring and the monsoon season promoted sporulation of mesophilic fungi, whereas dry spores were released under decreasing humidity during pre-monsoon season (Meredith 1973; Fernando et al. 2000). The decomposing organic matter at the vegetated site also provided a substrate for fungal growth.

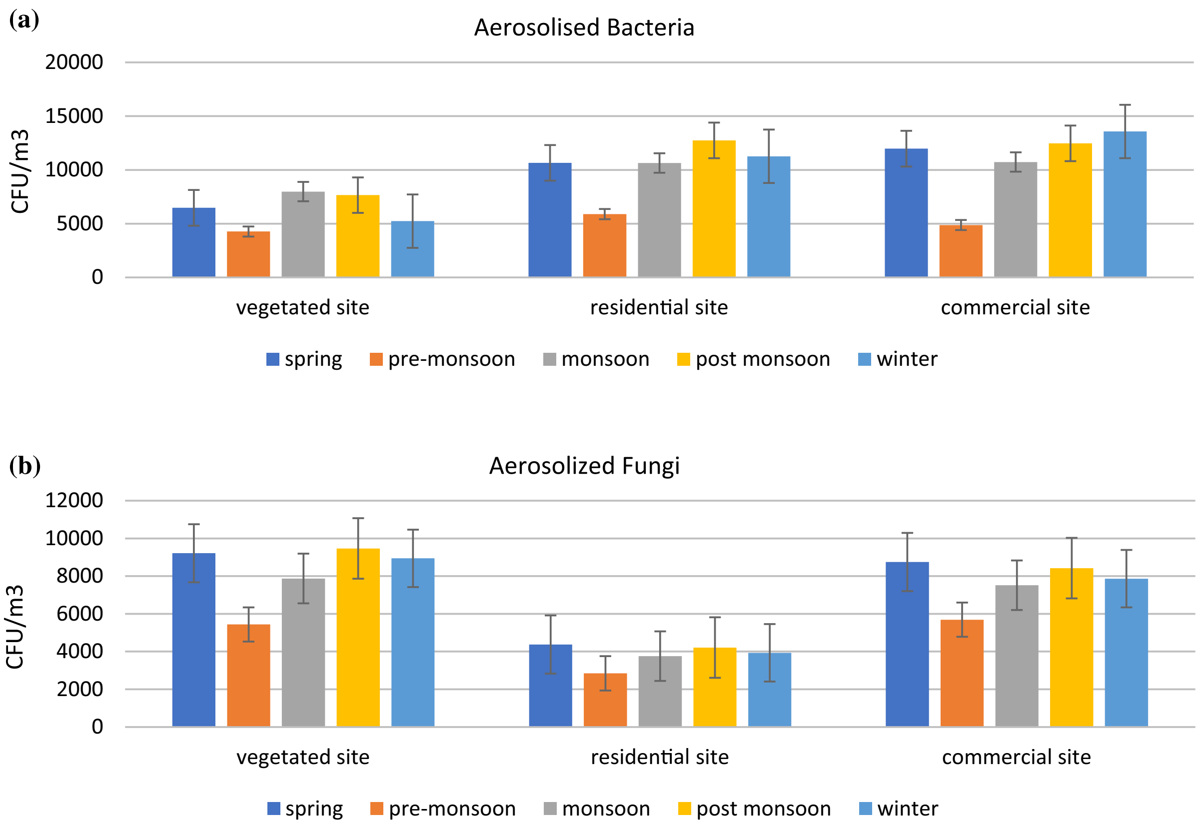

Fig. 1 Spatio-temporal trend of mean **a** bacterial count and **b** fungal count. *Season fixed effect: p value* < 0.01

Table 2 Effects of temperature with season on bacterial and fungal counts at three sampling sites

Land-use configuration	Bacteria			Fungi		
	Temperature Estimate	RH Estimate	Season *p* value	Temperature Estimate	RH Estimate	Season *p* value
Vegetated site	− 0.76	0.77	< 0.05	− 3.23**	2.84**	< 0.05
Residential site	− 1.42	2.43*		− 1.95**	1.44**	
Commercial site	− 0.26	0.07		− 1.53	1.00	

**p value* < 0.05

***p value* < 0.01

3.3 Effects of the meteorological parameters on microbial counts

Meteorological parameters are important factors affecting bioaerosol counts. Statistically significant effects of temperature and relative humidity on both bacterial and fungal counts were found at the residential and commercial sites (data not presented). The parameters were combined with the season in the mixed model to determine whether the effects of a season's weather on microbial counts were mediated by temperature and relative humidity or not (Table 2).

The influence of season remained significant on microbial counts when considered alongside the meteorological parameters (Table 2). The season retaining its significant effect in the model indicates the potential involvement of other unknown season-dependent factors, which could be either natural or anthropogenic, affecting the microbial counts at a site.

4 Conclusion

The study unequivocally concluded that land-use pattern has a significant bearing on bioaerosol counts. Study also concluded that the variation in the count is affected by meteorological parameters and site-specific activities. Thus, the net result of bioaerosol count may be a complex sum total of land-use pattern, seasonality, weather parameters and human activities including traffic movement. However, the apportionment of contributing factors will require further studies in specific microenvironments and also in controlled experimental conditions.

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