ORIGINAL ARTICLE

Effects of bioaerosol polluted outdoor air on airways of residents: a cross sectional study

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Background: Bioaerosol pollution of workplace and home environments mainly affects airways and mucous membranes. The effect of environmental outdoor residential bioaerosol pollution, for example, livestock holdings, farming, and waste disposal plants, is unclear.
Aims: To investigate the perceived health of residents living in areas with measurable outdoor bioaerosol pollution (for example, spores of *Aspergillus fumigatus* and actinomycetes), and effects of accompanying odours.
Methods: In a cross sectional study, double blinded to ongoing microbial measurements, doctors collected 356 questionnaires from residents near a large scale composting site, and from unexposed controls in 1997. Self reported prevalence of health complaints during the past year, doctors' diagnoses, as well as residential odour annoyance were assessed. Microbiological pollution was measured simultaneously in residential outdoor air.
Results: Concentrations of $>10^5$ colony forming units of thermophilic actinomycetes, moulds, and total bacteria/m^3 air were measured 200 m from the site, dropping to near background concentrations within 300 m. Positive adjusted associations were observed for residency within 150–200 m from the site versus unexposed controls for self reported health complaints: "waking up due to coughing", odds ratio (OR) 6.59 (95% confidence interval (CI) 2.57 to 17.73); "coughing on rising or during the day", OR 3.18 (95% CI 1.24 to 8.36); "bronchitis", OR 3.59 (95% CI 1.40 to 9.4); and "excessive tiredness", OR 4.27 (95% CI 1.56 to 12.15). Reports of irritative airway complaints were associated with residency in the highest bioaerosol exposure, 150–200 m (versus residency >400–500 m) from the site, and period of residency more than five years, but not residential odour annoyance. Lifetime prevalence of self reported diseases did not differ with exposure.
Conclusions: Bioaerosol pollution of residential outdoor air can occur in concentrations found in occupational environments. For the first time residents exposed to bioaerosol pollution were shown to report irritative respiratory complaints similar to mucous membrane irritation independently of perceived odours.

Bioaerosols occur ubiquitously as inhalable mixtures of air and microorganisms, parts of microorganisms, or organic substances of microbial and plant origin.[1] In the outdoor air, exposure bioaerosols (for example, containing *Aspergillus fumigatus*) can occur from natural or anthropogenic sources.[2–4]

When evaluating health effects of bioaerosols (organic dusts), their composition, concentration, and measurement methods applied must be considered.[5] Individual susceptibility, for example, atopy, allergic sensitisation, or immunodeficiency, also plays an important role in the risk assessment. Health based threshold levels for microorganisms for outdoor, indoor, or workplace air have not been established.[4] It is, however, known that infectious, allergic, or toxic disturbances triggered by bioaerosols originate mostly in moulds, thermophilic actinomycetes, Gram negative bacteria, and viruses.[3 6–10]

Besides livestock breeding and farming, the increasing number of large scale composting facilities for sewage sludge, and yard and solid waste being established within the scope of modern disposal concepts can release bioaerosols. Health relevant moulds (*Aspergillus fumigatus*) and actinomycetes accumulated in compost material become airborne as vegetative cells or spores through movement of the material.[3 4] Workers on composting sites have higher rates of airway related mucous membrane complaints and diseases. In these workers, specific antibodies against actinomycetes, as well as airway inflammation (or mucous membrane irritation (MMI)) have been reported.[2 11 12] Severe cases of general disease, for example, hypersensitivity pneumonia or severe toxic reactions (toxic pneumonitis or organic dust toxic syndrome (ODTS)) were reported in workers and one private person following direct contact with compost.[3 13–15]

Worldwide several thousand of these often malodorous sites are operating. However, their health effects on nearby residents have not been investigated sufficiently. A study in residents living within 500 m of a site showed no clear evidence of health changes.[16] In a case report, an asthmatic, living 80 m from a composting site (52% of the year in the wind direction), was found to have an allergic bronchopulmonary aspergillosis (ABPA).[17]

There is an urgent need to evaluate pollution due to bioaerosols (organic dusts), which can also occur in indoor air,[18–22] as far as the general public health is concerned. This is particularly important as an increasing fraction of the general population in industrialised countries must be classified as a risk group (for example, atopics) in the context of bioaerosol pollution.[23]

This cross sectional study aimed to relate self reported health to measurable bioaerosol pollution in the residential outdoor air. Prevalence of perceived complaints and self

Abbreviations: ABPA, allergic bronchopulmonary aspergillosis; CFU, colony forming units; CI, confidence interval; ISAAC, International Study on Allergy and Asthma in Childhood; MMI, mucous membrane irritation; N, north; ND, not detected; NW, northwest; ODTS, organic dust toxic syndrome; OR, odds ratio; WHO, World Health Organisation; SS, sample size; SE, southeast; WNW, west-northwest

reported doctors' diagnoses of residents living very close (150–200 m) to a composting site were compared to those in the same neighbourhood living further away (>400–500 m), and to a corresponding unexposed control group without a residential source of bioaerosols. Measurements of viable airborne microorganisms in residential air were performed during the ongoing epidemiological study and were known neither to interviewers nor to the study subjects at that time. Reports of annoying residential odours were also assessed, as they are known to be of relevance to reported health.[24–26]

METHODS

Assessment of exposure to cultivable microorganisms in the outdoor air of the residential area

The aim of the measurements was to assess location specific "worst case" conditions with regard to released bioaerosols into the neighbourhood. This concerned periods of intense microorganism releasing work activity, previously defined meteorological conditions at the time of measurement, as well as topographical aspects. Because of the ubiquity of the microorganisms under research, especially the thermophilic organisms, comparative quantitative measurements of background concentrations were taken upwind of the site.

The concentrations of three fractions of culturable microorganisms were determined in three repeated measurements. These were collected with filter based samplers (MD 8 Sartorius, Goettingen, Germany, flow rate 8 m^{-3} h^{-1}, collection time 10 min) 1.5 m above ground level, with subsequent indirect plating method after filtration and precipitation on gelatine filters[27 28]:

- Total bacteria (R2A agar (oxoid), 25°C)
- Moulds (dichrorane-glycerine-(DG18)–(oxoid), 25°C)
- Thermophilic and thermotolerant actinomycetes (glycerine-arginine-agar, 50°C).[29]

As results of single microbial measurements are known to vary considerably, results of the three consecutive measurements are given as maximum and minimum concentrations in table 2 and not mean values.

Epidemiological investigation

Study population

A team of doctors, process engineers, microbiologists, and meteorologists selected a composting site which had been in operation for five years and had lead to distress in the neighbouring residents due to odour annoyance and fear of allergies and infection. Considering topographical and meteorological (for example, wind direction) as well as technical aspects (site not completely closed off, processing of yard trimmings and organic waste, a turnover of approximately 12 500 Mg per year), discharge of bioaerosols from the site into the neighbouring residential area was presumed prior to the study. Other sources of bioaerosol exposure (sewage plants, etc) did not exist in the proximity of the residential area. Together with the local health authority, an unexposed control area was selected in the same governmental district. Criteria for the selection were: similarity of population pattern, residential area (size of households, road traffic, petrol stations, and industrial sites) and the lack of sources of microorganisms in the residential outdoor air.

The residential area next to the composting plant was located at a distance from 150 to 500 m downwind. All persons living there (n = 310) and 411 unexposed inhabitants in the control area were invited to participate in the study. Addresses were collected from the municipal registration of address office.

Questionnaires concerning perceived health and odour annoyance

An environmental health questionnaire was used for the assessment of self reported health: complaints and symptoms as well as lifetime prevalence of doctors' diagnoses. The questionnaire was developed with items validated and applied in several national and international studies, for example,

Table 1 Characteristics of 356 participants of the cross sectional study: unexposed controls and residents of a neighbourhood with bioaerosol pollution in outdoor air classified according to the distance between home and emitting composting site

	Study population		Unexposed controls		Residents of a neighbourhood with bioaerosol pollution of outdoor air							
					Total		Classified					
Distance from the emitting site	–		–		150–500 m		150–200 m		>200–400 m		>400–500 m	
Bioaerosol pollution in residential air	–		Not measured		Up to >10^5 CFU* m^{-3}		Up to >10^5 CFU m^{-3}		Up to <10^5 CFU m^{-3}		Near background	
Participants	n=356		n=142		n=214		n=82		n=76		n=56	
	SS†	Yes [%]	SS	Yes [%]	SS	Yes [%]	SS	Yes [%]	SS	Yes [%]	SS	Yes [%]
Female	356	56.7	142	52.8	214	59.3	82	59.8	76	60.5	56	57.1
Age >50 years	356	43.0	142	36.6	214	47.2	82	46.3	76	50.0	56	44.6
Duration of present residency >5 years	350	71.7	137	70.8	213	72.3	82	73.2	75	76.0	56	66.1
Odour annoyance in the residential area	344	59.3	132	25.8	212	80.2	82	95.1	74	75.7	56	64.3
Type of odour annoyance, disgusting	199	7.5	37	0.0	162	9.3	74	5.4	52	17.3	36	5.6
Separate collection of organic household waste	348	55.5	136	75.0	212	42.9	82	32.9	75	45.3	55	54.5
Composting in own garden	350	67.4	137	65.7	213	68.5	82	76.8	75	61.3	56	66.1
Occupation at a composting site	337	0.6	136	0.0	201	1.0	76	1.3	71	1.4	54	0.0
Smoking status (smoker and non-smoker <5 years)	324	26.5	132	25.0	192	27.6	73	17.8	69	39.1	50	26.0
Environmental tobacco smoke (at home/in the workplace)	283	39.6	111	39.6	172	39.5	65	41.5	63	38.1	44	38.6
Use of inhalers at home	343	9.9	140	7.1	203	11.8	78	10.3	73	6.8	52	21.2
Bedroom equipment‡	355	97.5	142	99.3	213	96.2	81	90.1	76	100	56	100
Exposure in the workplace§	349	22.3	136	28.7	213	18.3	82	23.2	75	16.0	56	14.3
Home <50 m from busy street	356	30.6	142	17.6	214	39.3	82	39.0	76	35.5	56	44.6

*CFU, colony forming units.
†SS, sample size.
‡Bedroom furnishings include one of the following: carpet, furs, eiderdown, horsehair or innerspring mattress, furniture made of chipboard.
§Vapours, gases, dusts, heat, cold, dampness.

Table 2 Concentrations of culturable microorganisms [minimum/maximum]* in residential air neighbouring a bioaerosol releasing composting site

Sample points (by distance and direction to composting site†)	Total bacteria [CFU‡ m^{-3} air]		Moulds [CFU m^{-3} air]		Thermophilic actinomycetes [CFU m^{-3} air]	
	Min	Max	Min	Max	Min	Max
Upwind						
500 m SE§	8.4×10^2	1.8×10^3	1.9×10^3	3.6×10^3	[ND]¶	[ND]
Downwind						
200 m NW**	2.2×10^4	5.1×10^5	7.7×10^3	1.3×10^5	2.3×10^4	5.5×10^5
250 m WNW††	3.9×10^4	1.7×10^5	1.3×10^4	4.6×10^4	1.9×10^4	1.1×10^5
300 m N‡‡	4.4×10^3	8.3×10^4	4.3×10^3	1.7×10^4	2.8×10^3	6.0×10^4
320 m NW	6.8×10^3	5.9×10^4	3.9×10^3	1.9×10^4	1.3×10^3	5.0×10^4
550 m N	8.3×10^2	4.3×10^3	2.3×10^3	4.1×10^3	<5	9.9×10^2
Sampling conditions						
Samplers	Filter based MD 8 Sartorius, (Goettingen, Germany), flow rate 8 $m^{-3}h^{-1}$					
Collection time	10 min at 1.5 m above ground level with subsequent indirect plating method after filtration and precipitation on gelatine filters					
Detection limit	40 CFU					
Date and time	07.08.1997; 00:00–02:15§§					

*Minimum (Min) and maximum (Max) values of three repeated measurements. †"Kompostwerk Langes Feld", Kassel, Germany. ‡CFU, colony forming units. §SE, southeast. ¶ND, not detected. **NW, northwest. ††WNW, west-northwest. ‡‡N, north. §§Although there was a cold air flow from the composting site towards the studied neighbouring residential area "worst case" conditions.

ISAAC.[23] It was designed in particular to record health impairments and diseases of the respiratory tract from air pollution.

Prevalence of respiratory (12 items), eye related (two items), and general (eight items) health complaints, as well as current intake of medicine during the past 12 months were recorded (table 1). Subjects were also asked to state lifetime prevalence of diseases found by their own doctors in 18 categories. Interviewing doctors checked allergic conditions and current medicine intake by inspecting documents stating allergies and medicine supply during the study related house call.

Lifestyle factors and individual exposure to microorganisms from household sources (contact with compost, organic waste collection in the home,[30] inhalers, soft furnishings) were determined (see table 1). Further questions concerned the occurrence and quality of annoying odours in the residential area.

Epidemiological survey

The survey was carried out after consultation with the state data protection officer. It took place on all seven days of one week in July 1997, not during school holidays. A press conference, information by mail, and public event had previously taken place. The selected sample was mailed the questionnaire accompanied by additional information stating, for example, that their participation was voluntary. They were then phoned up to three times in order to arrange appointments for the doctor supported medical history interviews. These interviews took place in their homes and lasted for about an hour per person.

Statistical analysis

Using the LOGISTIC procedure of the SAS/STAT software, version 8.0, a logistic regression modelling approach was employed to analyse the health data of the 356 respondents studied. The model associated odds ratios (OR) and the corresponding 95% confidence intervals (CI) were determined. A p value of 0.05 or less was judged relevant. First a core model in which residents living at different distances (150–200 m, >200–400 m, >400–500 m) from the site were compared to unexposed controls living in the residential area without an adjoining compost site. The model included age, odour annoyance, and period of residence in the current home >5 years as fixed covariables. Additional confounders were gender, composting in own garden, collection of organic waste in the home, distance of home from a busy street <50 m, smoking, and exposure to passive smoke.

In a second stage the model was calculated for those 214 residents living near the composting site only. Those living in the two distance groups nearest to the site (150–200 m, >200–400 m) were compared to those living at >400–500 m. Fixed covariables were age, odour annoyance, and period of residence in the current home >5 years.

RESULTS

Exposure to culturable microorganisms in the outdoor air of the residential area

In the outdoor air of the residential area 200 m from the plant, concentrations of up to $>10^5$ CFU m^{-3} air were recorded for total bacteria, moulds, and thermophilic actinomycetes. Even 320 m from the site differences in concentrations of total bacteria and moulds which were 100 times background levels (10^3–10^4 CFU m^{-3} air) were detected. Furthermore, the site characteristic thermophilic actinomycetes which were not found in upwind—background measurements—were still detectable 550 m downwind from the site at a concentration of $<10^3$ CFU m^{-3} air.[27]

These high concentrations of culturable microorganisms close to the plant came down quickly to near background concentrations within 550 m from the plant (table 2). Based on this observation, the exposed population was divided into three groups, dependent on the linear distance of the respective home from the site (150–200 m, >200–400 m, >400–500 m).

Epidemiological investigation

Study population

A total of 356 people took part in the study (see table 1). The response rate in the residential area with bioaerosol pollution was 69%. Selection bias due to low participation rate (35%) in the unexposed group would be characterised by stronger weighing of health concerned subjects perceiving health impairment.

More females and subjects >50 years took part in the exposed group. As stated above an adjustment was made for both parameters in the core model.

In the neighbourhood of the site, residential odour annoyance was reported by 80%, increasing to 95% in residents living 150–200 m from the site. When asked to characterise this odour annoyance, 10% described it as "disgusting". None of the unexposed controls reporting odours from other possible environmental sources stated this kind of odour annoyance. This underlines the specific odour annoyance of the exposed group.

Table 3 Prevalence of reported health complaints in residents in the neighbourhood of a composting site stratified according to the distance between home and composting site respectively, increasing concentration of bioaerosol exposure in residential air and unexposed controls

	Study population	Unexposed controls	Residents in the neighbourhood of a composting site with bioaerosol pollution of outdoor air							
			Total		Classified					
Distance of home from composting site	–	–	150–500 m		150–200 m		>200–400 m		>400–500 m	
Bioaerosol pollution in residential air	–	Not measured	Up to $>10^5$ CFU* m^{-3}		Up to $>10^5$ CFU m^{-3}		Up to $<10^5$ CFU m^{-3}		Near	
Participants	n=356	n=142	n=214		n=82		n=76		n=56	
Reported health complaints†	SS‡	SS	Yes [%]	SS	Yes [%]	SS	Yes [%]	SS	Yes [%]	SS	Yes [%]
Respiratory tract											
Frequency of colds >5×/year	352	142	6.3	210	11.4	81	21.0	73	2.7	56	8.9
Hay fever	355	142	16.2	213	19.7	81	18.5	76	19.7	56	21.4
Sinusitis	354	141	14.2	213	17.4	82	26.8	75	10.7	56	12.5
Bronchitis	355	142	26.8	213	33.3	81	54.3	76	17.1	56	25.0
Pneumonia	348	139	1.4	209	3.3	80	6.3	75	1.3	54	1.9
Shortness of breath at rest	343	137	5.1	206	18.4	82	24.4	68	20.6	56	7.1
Shortness of breath following exertion	344	136	16.2	208	31.3	82	43.9	70	30.0	56	14.3
Waking up with chest tightness	338	135	11.9	203	22.2	79	26.6	69	26.1	55	10.9
Waking up due to shortness of breath	341	136	3.7	205	9.3	82	7.3	67	13.4	56	7.1
Waking up due to coughing	343	138	25.4	205	41.5	82	57.3	67	31.3	56	30.4
Wheezing	349	139	15.8	210	28.1	79	38.0	76	23.7	55	20.0
Cough on rising/during the day§	355	142	19.0	213	35.2	82	47.6	75	28.0	56	26.8
Eyes and general health											
Itching eyes >10×/year	340	131	20.6	209	40.2	80	47.5	74	40.5	55	29.1
Smarting eyes >10×/year	344	136	15.4	208	35.6	80	43.8	74	40.5	54	16.7
Loss of appetite	347	140	5.0	207	10.1	76	10.5	76	10.5	55	9.1
Nausea or vomiting >5×/year	343	136	5.9	207	16.9	81	23.5	73	16.4	53	7.5
Diarrhoea >5× year	349	138	3.6	211	9.5	81	21.0	76	2.6	54	1.9
Excessive tiredness >5×/year	341	138	13.0	203	40.4	76	53.9	76	36.8	51	25.5
Shivering	353	140	13.6	213	19.7	82	29.3	75	20.0	56	5.4
Fever >5×/year	356	142	1.4	214	2.3	82	2.4	76	3.9	56	0.0
Joint trouble >10×/year	346	136	19.1	210	37.1	80	41.3	75	36.0	55	32.7
Muscular complaints >10×/year	339	135	11.1	204	25.0	77	26.0	72	26.4	55	21.8
Current intake of medicine/vitamins	355	142	41.5	213	56.8	82	54.9	76	59.2	55	56.4

*CFU, colony forming units.
†Frequency or occurrence in the past 12 months. If not otherwise stated, rates are for a single occurrence.
‡SS, sample size.
§Criteria of the World Health Organisation for chronic bronchitis.

Regarding exposure to airborne microorganisms from domestic sources, residents near the composting site reported less separate collection of organic household waste. This rate was lowest in those living closest to the site. From this observation, as well as from reports on composting in own gardens, there was no indication of a higher exposure of the residents in the neighbourhood of the site to bioaerosols from domestic waste sources.

Smoking status and exposure to environmental tobacco smoke, occupational exposure, personal use of inhalers, as well bedroom equipment, also gave no indication of a higher burden on the airways of the exposed group. The same applied to the statements on mould or dampness in homes (9% in unexposed controls, 3% in exposed).

Differences were observed for the proximity of the home to a busy street (<50 m), which indicated a higher exposure to car traffic related pollutants close to the site. For this reason an adjustment was made in the logistic regression.

Health effects in a residential area with bioaerosol pollution

Residents living in the neighbourhood of the composting site reported health complaints, medicine intake, and 11 of the 18 self reported illnesses ever diagnosed by a doctor more frequently than unexposed controls without a neighbouring composting site. Stratification showed the highest prevalence of complaints in those living closest to the site who were respectively exposed to the highest concentration of bioaerosols measured. Nevertheless, the exposed group living furthest away from the site at a distance of >400–500 m still reported higher rates of health complaints (but not self perceived diseases) compared to unexposed controls (table 3).

In the core model the unexposed residents without an adjacent composting site were compared with exposed residents in the neighbourhood of the site. For this the exposed group was stratified according to distance between home and composting site, and nine confounders were taken into consideration. Adjusted associations were found between close residency to the site (150–200 m)—highest concentration of airborne microorganisms (up to $>10^5$ CFU m^{-3} residential air)—and three of 12 airway related complaints, as well as excessive tiredness and intake of medicine (table 4). For those living further away from the site (>200–400 m), these associations were not observed.

In this core model, duration of present residency (>5 years), respectively duration of exposure was positively associated with "waking up due to coughing" (OR 2.29; 95% CI 1.13 to 4.79) and "bronchitis" (OR 2.37; 95% CI 1.65 to 5.06) during the past 12 months.

In a second step only those living in the neighbourhood of the composting site were studied. This allowed the effects of the bioaerosols (measured concentrations and duration of exposure) and the possible bias due to the specific, in part disgusting, residential odour annoyance near the composting site to be analysed more precisely. This comparison of the most highly exposed (up to $>10^5$ CFU m^{-3} residential air) with the least exposed (near background concentrations of airborne

Table 4 Health effects* of bioaerosol pollution in residential outdoor air highly exposed (>10^5 CFU† m^{-3} air) in the neighbourhood of a composting site compared to unexposed controls without a neighbouring composting site

	Residents with bioaerosol pollution of up to >10^5 CFU m^{-3} residential air living 150–200 m from the composting site		
Reported health complaints‡	SS§	OR¶	95%CI**
Bronchitis	262	3.59	1.40 to 9.47
Waking up due to coughing	255	6.59	2.57 to 17.73
Coughing on rising or during the day††	263	3.18	1.24 to 8.36
Excessive tiredness	251	4.27	1.56 to 12.15
Current medication intake	263	2.64	1.08 to 6.60

*Only the significant positive associations from table 3 are listed.
†CFU, colony forming units.
‡Frequency of occurrence in the past 12 months; if not otherwise stated, rates are for a single occurrence.
§SS, sample size.
¶OR, adjusted odds ratio comparing the group nearest to the composting site (150–220 m) with the control group in a residential area without a neighbouring composting site adjusted for residential odour annoyance, duration present residency >5 years, composting in own garden, separate collection of organic household waste, distance of home to busy road <50 m, age, gender, smoking, and passive smoke exposure.
**CI, confidence interval.
††Criteria of the World Health Organisation for chronic bronchitis.

Table 5 Health effects* of highest (>10^5 CFU† m^{-3} air) versus near background concentrations of outdoor bioaerosol, pollution, duration of present residency, and odour annoyance in a residential area with a neighbouring composting site

		Bioaerosol pollution in residential air‡ up to >10^5 CFU m^{-3} air		Duration of present residency >5 years		Odour annoyance in the residential area	
Reported health complaints§	SS¶	OR**	95% CI††	OR	95% CI	OR	95% CI
Respiratory tract							
Frequency of colds >5×/year	209	1.94	0.65 to 6.78	**4.72**	**1.19 to 31.83**	3.09	0.50 to 60.14
Bronchitis	210	**3.02**	**1.35 to 7.06**	**2.91**	**1.29 to 7.03**	1.86	0.71 to 5.54
Waking up due to coughing	202	**2.70**	**1.23 to 6.10**	**2.51**	**1.19 to 5.53**	1.95	0.81 to 5.08
Wheezing	207	1.96	0.84 to 4.82	**2.95**	**1.22 to 7.99**	1.97	0.72 to 6.35
Shortness of breath at rest	203	**3.99**	**1.31 to 15.19**	1.50	0.56 to 4.49	1.97	0.59 to 9.02
Coughing on rising or during the day‡‡	210	**2.67**	**1.17 to 6.10**	1.51	0.69 to 3.29	1.51	0.61 to 3.75
Shortness of breath after exertion	205	**4.23**	**1.74 to 11.34**	2.03	0.90 to 4.91	2.15	0.79 to 6.90
Eyes and general health							
Itching eyes >10×/year	206	1.35	0.61 to 3.05	**2.85**	**1.31 to 6.50**	**4.97**	**1.89 to 15.67**
Smarting eyes >10×/year	205	**2.44**	**1.02 to 6.22**	**2.42**	**1.06 to 5.86**	**10.40**	**2.87 to 66.96**
Nausea or vomiting >5×/year	204	2.65	0.87 to 9.97	**4.10**	**1.28 to 18.44**	§§	§§
Excessive tiredness >5×/year	200	**2.80**	**1.22 to 6.72**	1.83	0.84 to 4.11	§§	§§
Shivering	210	**4.63**	**1.44 to 20.85**	**3.67**	**1.32 to 12.20**	§§	§§
Joint trouble >10×/year	207	1.27	0.54 to 3.07	1.52	0.65 to 3.71	**4.30**	**1.55 to 14.17**
Muscular complaints >10×/year	201	1.17	0.47 to 2.99	1.39	0.55 to 3.86	**2.99**	**1.02 to 11.03**

*Only the significantly increased complaints from table 3 are listed and printed in bold type.
†CFU, colony forming units.
‡Distance of home to the emitting site 150–200 m.
§Frequency or occurrence in the past 12 months. If not otherwise stated, rates are for a single occurrence.
¶SS, sample size.
**OR, odds ratio of those living the stated distance from site compared to those living >400 m from the site adjusted for odour annoyance in the residential area, period of residence in the present home >5 years, and age.
††CI, confidence interval.
‡‡Criteria of the World Health Organisation for chronic bronchitis.
§§Due to the small number of subjects of this complaint reliable odds ratio could not be determined.

microorganisms) population of the same neighbourhood was positively associated with eight items of reported health (table 5).

"Shortness of breath" ("following exertion" and "while at rest") was most strongly associated with residential exposure to highest concentrations (>10^5 CFU m^{-3}) bioaerosols. Frequency of perceived bronchitis in the past 12 months and two symptoms associated with cough all had positive adjusted OR above 2.5. Sore eyes as well as diarrhoea, excessive tiredness, and shivering were also positively associated with the close proximity of home to the composting site (table 5).

Duration of present residency (>5 years), defining those individuals exposed to residential bioaerosol since the commencement of operations at the site, was positively associated with an increased frequency of one third of the airway complaints, eye complaints, as well as nausea or vomiting and shivering. Specific odour annoyance did not confound any of the airway related complaints in the neighbourhood of the composting site (table 5).

In this analysis, distance of the home from the site, and duration of residency, as well as residential odour annoyance were not associated with increased reporting of lifetime prevalence of 18 self reported doctor diagnosed illnesses.

DISCUSSION

Concentrations of culturable airborne microorganisms, including moulds, measured in the residential air during the study (table 2) at 150 to 320 m from the composting site were 100–1000 times higher than those concentrations generally reported as natural background concentrations. Background concentrations for total bacteria and moulds are given as <10^3

CFU m^{-3} air and $<10^2$ CFU m^{-3} air for actinomycetes.[2] As a result of this, and particularly because of the detection of site typical actinomycetes, a distance dependent influence of the composting site on the residential air could be demonstrated up to 550 m (table 2). In a study conducted in Islip, New York,[16] the bioaerosol related influence of a large scale composting site on a residential area 500 m away could not be excluded. However, this study has methodological shortcomings as far as exposure measurements and health effects are concerned. In other studies, the bioaerosol pollution due to sites could only be demonstrated up to a distance of 200 m.[4]

The highest concentrations of total bacteria and actinomycetes ($>10^5$ CFU m^{-3} air) measured, were within the range of those reported in occupational studies of composting sites.[2 11] For total bacteria, the measured concentrations of 10^4 or 5×10^3 CFU m^{-3} air also exceeded occupational threshold levels recommended in Denmark and Sweden.[31] Health effects have been observed in the studies on workplace or indoor environment in association with concentration levels recorded here for total bacteria and moulds (*Aspergillus fumigatus*).[11 22]

These microbiological measurements were performed under meteorological conditions which occur on 50% of the days in a year. Desired "worst case" conditions were not achieved completely during these measurements. Considering this the exposure to airborne culturable microorganisms in the residential area could at times have been even higher. The additional health burden from non-culturable microorganisms or allergenic and toxic parts of microorganisms, which also occur in bioaerosols, was not even assessable in the scope of the measurements.[5]

An association could be demonstrated in the present study between residential bioaerosol pollution (<200 m from the plant) and irritative airway complaints. This association was found when comparing with less exposed subjects living in the same neighbourhood further away from the same site (>400–500 m) and also, to a greater extent, when comparing with unexposed controls. Furthermore, an association of these complaints with the duration of bioaerosol exposure (>5 years) could also in part be demonstrated. If at least two irritative mucous membrane symptoms are reported in association with chronic exposure to bioaerosols, this is suggestive of airway inflammation.[9]

Complaints of airway inflammation are to be expected after frequent exposure to microorganisms in the range of concentration of 10^4–10^5 CFU m^{-3} air.[4] These concentrations are similar to those measured 200 m from the site in this study (table 2). Furthermore, due to the meteorological and topographical conditions, this exposure is likely to have existed frequently.

Irritative airway complaints (increased frequency of coughing, shortness of breath, and self diagnosed bronchitis) have already been reported in health studies concerning exposure to microorganisms: At workplaces with handling of garbage and compost, increased frequencies of airway related mucous membrane irritation, coughing, and tracheobronchitis, among others, have been reported[2 11]; similarly, airway symptoms have been reported in residents of mouldy or damp homes.[20–22]

The high OR found in both analyses, comparing highest exposed to unexposed controls as well as least exposed are not considered to be due to unrecognised bias. They are considered to result from high measurable concentrations of airborne microorganisms in residential air (200 m from the site), dropping sharply within 300 m and reaching near background concentrations at 550 m.

It could be shown that perceived odour annoyance, considered to be a strong bias on self reported complaints, had no influence on these irritative airway complaints (table 5). Odour annoyance was only associated with general complaints. This could have been expected on the basis of previous reports.[24–26] Comparable results were found when studying odour annoyed (90%) neighbours of another composting site. Rates of health complaints showed no association (versus controls in a neighbourhood without a composting site) with residency near the composting site (data not shown).

Examiners and study population were blinded to the results of microbiological measurements during the field work as samples for these measurements were obtained during the ongoing survey. Further aspects speak against a reporting bias, based on prejudices regarding the plant: self reported lifetime diagnoses of illnesses were not associated with exposure, although occurrence of some diseases (for example, infections and allergies) had been feared by the residents beforehand. They had stated this during the public event which took place prior to the survey. Furthermore, respondents knew interviewers would not be able to prove or disprove during the house calls whether reported illnesses actually existed.

Additional aspects speak against general over reporting of all health complaints in the neighbourhood of the composting site. Skin irritation (data not shown), occurring when in close occupational contact with waste,[2] was not reported more often, for instance. The same applies for perceived hay fever. It was reported least very close to the site (table 3).

Bioaerosol exposure from other everyday sources or exposure to respiratory irritants also cannot explain the findings of this study, as they were reported the same or less frequently by the group near the site than by the unexposed control group (table 1). Addressing a possible bias due to the low participation rate in the unexposed group, the following should be considered. In a sample with a low participation rate, those more health conscious or health impaired would be more likely to participate in this unexposed sample. This in turn would then lead to higher rates of health complaints in these controls compared to the exposed population, and underestimate the true health effects.

Specific allergic and infectious diseases are reported in subjects exposed to various bioaerosols working at composting sites, indoors, and in the environment.[3 4 13–15 17 19] Severe toxic-irritative reactions (ODTS, pulmonary mycotoxicosis, or toxic pneumonitis), occurring after a single inhalation of very high levels of spores (10^6–10^9 spores m^{-3} air),[3 6 8] and pulmonary haemorrhage[21] have also been described concerning occupational settings and in case reports of indoor environmental exposure. Actinomycetes and mould spores, as well as endotoxins and glucanes,[32] are discussed as their causes. There was no indication in the presented study that the exposure detected in the scope of this study led to any of the above illnesses in the five years since the composting site started operating. However, in this context the limitations of relying on self reported health status have to be taken under consideration.

In the present study, as claimed by others,[4 18] the health related problems of environmental bioaerosols were assessed by measuring microbiological pollution in the residential environment and simultaneously collecting medical histories. Odour annoyance, always associated with bioaerosols, was taken into consideration. To the authors' knowledge it was found for the first time that there can be a demonstrable bioaerosol pollution of the residential environment, which is in part still detectable at a distance of 550 m. This bioaerosol exposure in turn could be associated, as far as concentrations of bioaerosols and duration of exposure were concerned, with symptoms suggestive of airway inflammation also reported at respective workplaces.

Due to methodological shortcomings, cross sectional studies are not able to prove or disprove a causal relationship. Nevertheless it is believed that on the basis of this study irritative airway complaints pointing at MMI-like airway inflammation can be seen as associated with measurable residential bioaerosol pollution.

The health complaints found here in association with residential bioaerosol exposure were not accompanied by increased self reports of diseases diagnosed by a doctor. This

might have been anticipated, as on the one hand diagnosing airway irritation related to environmental exposure is not common by general physicians. On the other hand, higher rates of diseases with clear laboratory findings or organ impairment could not have been expected. Nevertheless, several considerations should be made when considering their relevance as far as public health is concerned. For airway inflammation related to bioaerosol exposure, a toxic or non-specific genesis is hypothesised. It can be accompanied by an increase in bronchial reactivity as a sign of an inflammatory process as well as possibly being the onset of chronic bronchitis.[2 7 9] An effect of the bioaerosol concentration in the residential air with regard to excessive tiredness and shivering (table 5) was also detected in the present study. At workplaces with garbage or compost handling, and in homes containing mould, single general complaints of general disturbances, for example, toxic pneumonitis, including shivering and tiredness, are often observed.[11]

This study forms the basis for further studies using more sophisticated designs (for example, prospective panel study) to study the clinical relevance of these irritative airway symptoms. Clinical parameters, for example, lung function examinations could be included, particularly since connections have been found in the workplace between symptoms of airway inflammation and changes in lung function.[9] Risk groups for airway effects (for example, children) could be particularly looked at. Due to the small sample of children this was not possible in the present study.

Furthermore, mucous membrane lavage could be carried out to document inflammatory changes and evidence of specific antibodies in the sense of exposure manifestation.[2 12] As the amount of time spent outdoors in the residential area is relatively small, and therefore exposure to outdoor air only represents a small part of the day, the possible accumulation in interior rooms of airborne microorganisms from emission sources should be measured in the future.

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