Estimation of particulate matter and gaseous concentrations using low-cost sensors from broiler houses

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Abstract Particulate and gaseous emissions from intensive poultry facilities are major public and environmental health concern. The present study was aimed at exploratively monitoring particulate matter (PM) and gaseous concentrations in controlled-environment facilities using low-cost sensors in Lahore, Pakistan. The indoors and outdoors of 18 broiler houses, grouped into three categories based on the age of birds: group I (1–20 days), group II (21–30 days) and group III (31–40 days), were examined. Low-cost sensors Dylos 1700 and Aeroqual 500 series with different gas sensor heads were used to monitor PM and different gases such as nitrogen dioxide (NO2), hydrogen sulphide (H2S), carbon dioxide (CO2) and methane (CH4), respectively. Overall, the mean PM and gaseous concentrations increased with the age and activity of birds as compared with the non-activity time of birds. Statistically significant differences were observed in all measured parameters among the groups. The negative correlation between indoor and outdoor environments for PM and gas concentrations at some broiler houses demonstrates the contribution of additional sources to emissions in outdoor environments. The findings contribute to our knowledge of temporal characteristics of particulate and gaseous concentrations from poultry facilities particularly in Pakistan and generally to the capability of using low-cost sensors to evaluate emissions from such facilities.

Keywords Poultry facilities · Controlled environment · PM · Gases · Low-cost sensors

Introduction

There has been a steady increase in intensive agricultural practices such as poultry production to meet the food demands of a growing population worldwide. Simultaneously, concerns about emissions (including dust, gases and bioaerosols) from such controlled-environment facilities are increasing particularly environmental, climatic and public health impact Witkowska and Sowinska 2017. According to one estimate in all agricultural practices in Europe, intensive poultry is contributing almost 50% to total particulate matter (PM) emissions (Emep-Corinair 2007. Evidence is increasing on the potential impact of the emissions from these facilities, for example, for occupational exposure (Portejoie et al. 2002; Kocaman et al. 2005), vegetation stress, reduced visibility, odour and organic dust (Pope et al. 2002; Mostafa and Buescher 2011; Chen et al. 2014) and communities living in close proximity to these facilities (Mitchell et al. 2004; Hinz et al. 2008).
The typical sources of airborne dust in poultry facilities are feed, bedding material, bird’s droppings, bird’s age and bird’s down feathers (Vucemilo et al. 2008; Cambra-López et al. 2011). However, van Harn et al. (2012) have reported that bedding material has no effect on PM$_{10}$ concentrations while the age of birds adds a 4.8% increase in PM mass concentrations. The particulate fraction of emissions can be composed of feed, feathers, dried faecal matter, bacteria, fungi, moulds, endotoxins, pollens, animal dander, various enzymes, and infectious agents (Witkowska and Sowinska 2017). Hence, particulate emissions can vary in size and chemical composition (Cambra-López et al. 2010a, b). Studies have shown that particulate emission from these facilities is mostly coarse, primary in origin, and organic in nature, adsorbs various gases and odours and has microbes and their metabolic compounds (Donham et al. 2000; Radon et al. 2001; Donham et al. 2002; Homidan et al. 2003; Cambra-López et al. 2010a, b). The sources of microbes in these facilities are birds, feathers, faecal material, litter, feed, employees and air. The poultry facilities are also a rich source of gaseous emissions, and according to Broucek and Cermak (2015), the gaseous emissions depend on various factors such as decompositions of faecal matter, number of birds, movement of birds and ventilation rate. However, management practices, temperature, humidity building age and ventilation rate also play a role (Banhazi et al. 2008; Redding 2013). The different gases such as ammonia, carbon dioxide and volatile organic compounds are produced by the decomposition of organic matter with bacteria found in litter and faecal matter (Witkowska and Sowinska 2017).

The available evidence base illustrates that building design, management practices, age and stocking density of birds along with relative humidity, temperature and ventilation rate can significantly influence emissions from such facilities (Ellen et al. 2000). A range of factors involving building design, use and management can significantly influence emission from such facilities. The availability of data on nature, magnitude and spatio-temporal characteristics of emissions is vital to propose proportionate regulations in order to manage public health risks as well as allow food production. However, the knowledge on temporal characteristics of emissions from such facilities is limited due to limitations of the sampling methods: labour/time intensive, costly, poor time resolution and considerable post-sampling treatment. Among the wide range of detection and quantification methods, low-cost sensors offer real-time data along with portability, affordability and ease of use. These measurements can provide an overview of the dynamics of emissions from poultry facilities and inform further probing into high-emission operation and scenarios. Although there are concerns on data quality (e.g. low accuracy) with low-cost sensors to be used for regulatory compliance, they can offer relative and aggregated information on the state of air quality (Castell et al. 2017; Rai et al. 2017). Several research projects are testing the capabilities of low-cost sensor platforms for air quality monitoring, and their findings relay a promising outlook for the use of low cost-sensors, particularly, in providing coarse information and raising community awareness about air pollution (Lewis et al. 2016; Castell et al. 2017; Clements et al. 2017; Rai et al. 2017; Morawska et al. 2018).

Poultry farming is a flourishing industry in Pakistan and has shown a tremendous progress over the last decade. The sector is playing an important role in fulfilling the demand of protein and has a significant contribution of 1.3% in the national GDP (Maqbool et al. 2005; Hussain et al. 2015). The sector is an important source of employment, and approximately 1.5 million people are associated with this profession (GOP 2014). Moreover, an overall increase in poultry production was noticed in various countries like India, China, Brazil, the USA and Russia from 1995 to 2005 (Scanes 2007). However, public health and environmental concerns about emissions (including dust, gases, and their bioaerosols) from these facilities are also increasing. At present, information on the concentrations from these facilities is scarce and fundamentally limited by access to state-of-the-art sampling equipment and the resultant methodological challenges. The aim of the present study was to investigate the extent to which low-cost sensors can inform temporal characteristics of particulate and gaseous concentrations from poultry facilities in Lahore, Pakistan.

Material and methods

Measurements were conducted in 18 randomly selected environmentally controlled shed (broiler) in outskirts of Lahore, Punjab, Pakistan. The poultry houses were of the same size and built on the same plane as
recommended by the Cobb guideline for warm regions. Representative design of environmentally control poultry sheds and their building characteristics are presented in Fig. 1 and Table 1.

The information on geographical position, length and width of the farm, total number of fans, number of working fans, number of vents, vents open at a particular day, age of bedding material, age of birds, type of feed, number of feeding lines, number of water lines, time and frequency of vaccination of birds and other activities was documented for each site at the time of visit.

The sheds were categorized into three groups according to the age of the birds: group 1 (1–20 days), group 2 (21–30 days) and group 3 (31–40 days). The particulate matter (PM) fractions PM$_{2.5}$ and PM$_{10}$, nitrogen dioxide, hydrogen sulphide, carbon dioxide and methane were monitored in each shed. The measurements for PM and gases were made for both indoor and outdoor, but due to a single set of equipment the indoor and outdoor monitoring was not parallel. The sensors were placed at the height of 1.5 m from the ground level and almost 20–25 ft away from the exhaust but in the centre according to the width of the shed. Outdoor monitoring was carried out at 15–20 ft away from the side wall of the shed. The particle counter Dylos 1700 was used to measure particle number concentrations of PM. It is a portable particle counter that logs particles in two size classes (2.5 μm and 10 μm) and records number concentrations. The gases, temperature and relative humidity were monitored by using Aeroqual 500 series sensors and probes. Time activity diaries were recorded during the period of monitoring in each shed. The number concentration of PM was converted to mass concentration by using a Dylos conversion sheet (www.fijnstofmeter.com/documentatie/Dylos-conversion.pdf).

In addition, correction factors were determined for Dylos 1700 PM$_{2.5}$ and PM$_{10}$ measurements by running it parallel to TSI DRX 8533. The mass concentrations calculated from Dylos 1700 were adjusted with these correction factors.

The data were statistically analyzed using SPSS 21.00 version by the Kolmogorov-Smirnov and Levene tests that confirmed data was non-parametric. The data was normalized and finally analyzed for parametric tests, i.e., one-way ANOVA by Games-Howell post hoc, LSD and Tukey HSD tests. The Kruskal-Wallis test was also applied for appropriate data (emission data for non-activity periods). Moreover, correlation analysis was carried out to examine the relation of indoor and outdoor PM and gases.

**Results**

PM concentrations in broiler houses increased with the age of birds (Table 2 and Fig. 2a). The mean PM$_{2.5}$ and PM$_{10}$ concentrations were lowest in group 1 (0.37 ± 0.17 and 4.21 ± 2.84 mg/m$^3$); however, an increase in group 2 (0.70 ± 0.44 and 7.66 ± 4.81 mg/m$^3$) and group 3 (0.74 ± 0.35 and 8.26 ± 6.13 mg/m$^3$) was observed (Table 2). One-way ANOVA showed a statistically significant difference in PM$_{2.5}$ and PM$_{10}$ concentrations among all three groups at a 0.05 significance level.

There has been an increase in concentrations with activities (intake of feed by birds or walk by employees...
to activate the birds) in comparison with no-activity periods (Fig. 2b). The mean PM$_{2.5}$ and PM$_{10}$ concentrations at the time of activity for group 1 were $0.58 \pm 0.15$ and $8.32 \pm 5.77$ mg/m$^3$, respectively, whereas, for groups 2 and 3, these were $0.96 \pm 0.21$ and $16.2 \pm 6.5$ and $0.98 \pm 0.31$ and $13.16 \pm 5.77$ mg/m$^3$, respectively (Table 2). In contrast, the concentration of PM$_{2.5}$ and PM$_{10}$ during no activity was $0.31 \pm 0.8$ and $3.13 \pm 2.5$ mg/m$^3$ for group 1, $0.59 \pm 0.5$ and $5.35 \pm 4.2$ mg/m$^3$ for group 2, and $0.63 \pm 0.3$ and $5.73 \pm 4.7$ mg/m$^3$ for group 3, respectively. For the concentrations, during activities, a statistically significant difference in PM$_{2.5}$ and PM$_{10}$ concentrations was noticed for group 1 with group 2 and group 3, but no difference was found between group 2 and group 3. However, for the non-activity periods, a significant difference was present among all the three groups.

The average concentration of PM$_{2.5}$ for an outdoor environment was $0.07$, $0.22$ and $0.12$ mg/m$^3$ for groups 1, 2 and 3, respectively. While the PM$_{10}$ concentration was $0.35$, $0.81$ and $0.42$ mg/m$^3$ for groups 1, 2 and 3, respectively (Table 2). A significant difference for outdoor concentrations of PM$_{2.5}$ was present among all the groups. However, for the PM$_{10}$, a significant difference was noticed in group 1 with group 2 and group 3, but no difference was found between group 2 and group 3. The Pearson correlation showed that PM$_{2.5}$ and PM$_{10}$ had a positive relationship between the indoor and outdoor environments of group 1 and group 2 (only for PM$_{2.5}$). An inverse relation was present between indoor and outdoor environments for group 2 and group 3 at a 0.01 significant level.

The relative humidity and temperature ranged between 51 and 60% and 31–34 °C for indoors, while for outdoors relative humidity and temperature were 32–33% and 37–41 °C. Relative humidity had an inverse relation with PM$_{2.5}$ and PM$_{10}$ at a 0.05 significance level, but a positive relation was seen with all monitored gases.

All gaseous concentrations showed an increase with age of birds in different poultry farm categories (Fig. 2c, d). The average concentration for NO$_2$ and H$_2$S gases ranged between 0.02–0.06 and 0.14–0.32 ppm

### Table 1 Building characteristics of the environmentally controlled shed

| Size       | No. of birds | Orientation  | Side walls       | Roof                  | Heating system                                      | Ventilation system                  | Lighting                           |
|------------|--------------|--------------|------------------|-----------------------|-----------------------------------------------------|-------------------------------------|------------------------------------|
| 5715 m$^3$ | 26,500-30,000 | Long axis    | Filled with      | Reflective materials  | A well-maintained heating system present in each site but not working at the time of visit | A negative ventilation system working to bring fresh air and removal of stale air | The lighting system was present |
|            |              | oriented     | insulating       | to prevent heat       |                                                     |                                     |                                    |
|            |              | east-west    | materials        | absorbance by         |                                                     |                                     |                                    |
|            |              |              |                  | conduction            |                                                     |                                     |                                    |

### Table 2 Summary concentration of particulate matter (mg/m$^3$) in poultry farm categories and outdoors

| PM concentration scenario | Group 1 Mean (± SD) (mg/m$^3$) | Group 2 Mean (± SD) (mg/m$^3$) | Group 3 Mean (± SD) (mg/m$^3$) |
|---------------------------|---------------------------------|---------------------------------|---------------------------------|
| Indoor total              |                                 |                                 |                                 |
| PM2.5                    | 0.37 (± 0.17)                   | 0.70 (± 0.44)                   | 0.74 (± 0.35)                   |
| PM10                     | 4.21 (± 2.84)                   | 7.66 (± 4.81)                   | 8.26 (± 6.13)                   |
| Activity                 |                                 |                                 |                                 |
| PM2.5                    | 0.58 (± 0.15)                   | 0.96 (± 0.21)                   | 0.98 (± 0.31)                   |
| PM10                     | 8.32 (± 5.77)                   | 16.2 (± 6.5)                    | 13.16 (± 5.77)                  |
| Non-activity             |                                 |                                 |                                 |
| PM2.5                    | 0.31 (± 0.8)                    | 0.59 (± 0.5)                    | 0.63 (± 0.3)                    |
| PM10                     | 3.13 (± 2.5)                    | 5.35 (± 4.2)                    | 5.73 (± 4.7)                    |
| Outdoor                  |                                 |                                 |                                 |
| PM2.5                    | 0.07 (± 0.06)                   | 0.22 (± 0.04)                   | 0.12 (± 0.06)                   |
| PM10                     | 0.35 (± 0.3)                    | 0.81 (± 0.41)                   | 0.42 (± 0.13)                   |
for groups 1, 2 and 3, respectively. The second most abundant gas was CH$_4$: 15.55, 31.88 and 41.64 ppm in groups 1, 2 and 3, respectively (Table 3). The levels of CO$_2$ were 868 ± 201, 1005 ± 340, and 1706 ± 199 ppm for groups 1, 2 and 3, respectively (Table 3).

In outdoors, the concentrations of different gases for groups 1, 2 and 3 were as follows: NO$_2$, 0.09, 0.05 and 0.28 ppm; H$_2$S, 0.41, 0.07 and 0.02 ppm; CH$_4$, 1.93, 42.22 and 5.61 ppm; and CO$_2$, 488, 435 and 548 ppm, respectively. The gaseous concentrations in outdoors showed no trend according to age groups or effect of indoor emissions highlighting additional sources to indoor emissions. A significant difference in all indoor and outdoor gases was present at 0.05 levels among all groups except outdoor CO$_2$ and H$_2$S (Table 3).

Pearson correlation revealed that indoor CO$_2$ and outdoor CO$_2$ in groups 1 (0.52) and 3 (0.30) were positively correlated at 0.01. However, a negative correlation was present for group 2 (−0.30). There was an inverse correlation for NO$_2$ in groups 1 (−0.19) and 3 (−0.29) while a very weak correlation was observed for group 2 (0.08). A positive correlation was present among all groups for CH$_4$ and H$_2$S.

Fig. 2 Summary statistics of particulate matter and gaseous emissions from poultry farm categories. a Particulate matter. b Particulate matter during the activity and non-activity time. c CO$_2$ and CH$_4$. d NO$_2$ and H$_2$S
The intensive agriculture facilities are a source of the odour, dust, allergens, bacteria, viruses, fungi and toxins along with gases like CH$_4$, H$_2$S, NO$_2$, CO$_2$ and various trace gases (Copeland 2010). In the present study, the concentrations of PM were corrected using the reference method and TSI DRX 8533 was run parallel to Dylos 1700. However, the results obtained for both fractions of PM were comparable with a number of studies (Conceicao et al., 1989; Ellen et al. 2000; Lim et al. 2003; Al Homidan et al., 2004). This showed that the result of low-cost sensors such as Dylos 1700 can be reliable and can be used to get an estimation of particulate matter.

Overall, it was noticed that the poultry sector is flourishing from the last few decades to fulfil a gap between demand and supply. Approximately, 1.5 million people are also affiliated with the sector (Hussain et al. 2015). Furthermore, technologies becoming advanced day by day and an increase in the use of real-time sensors to improve animal safety and production are also observed, as these sensors seem to be helpful and alert the cattle farmers before time by the early indication of medical problems (Halachmi et al. 2019). Although several research projects are testing the capabilities of low-cost sensors for air quality monitoring and their findings relay a promising outlook for the use of low-cost sensors, at present, these sensor systems have demonstrated their usefulness for providing information and raising community awareness about air pollution (Lewis et al. 2016; Castell et al. 2017; Rai et al. 2017; Morawksa et al. 2018).

In the present study, the PM$_{2.5}$ and PM$_{10}$ concentrations increased with the age of birds and this trend is in agreement with Le Bouquin et al. (2013), Burns et al. (2009) and Zhang et al. (2019) who reported the age of birds acts as a determinant factor for PM concentrations along litter management practices and temperature. Similarly, Redwine et al. (2002) had also reported age enhanced PM and ammonia emissions. The present study also demonstrated that activities in controlled-environment facilities result in higher concentration of dust as also reported by Lim et al. (2003), Vucemilo et al. (2007), Li et al. (2009), Calvet et al. (2009) and Shen et al. (2019) and that the airborne dust in poultry houses increased with the age and activity of birds.

In the current study, the mass concentration of coarse particles (PM$_{10}$) was higher as compared with fine particles (PM$_{2.5}$) and this trend had been recorded in previous studies elsewhere as well. Cambra-López et al. (2010a, b) have reported that in poultry facilities feathers and manure contribute mostly to PM$_{10}$ concentrations compared with PM$_{2.5}$. Similarly, according to Casey et al. (2006), the most probable sources for PM concentrations in controlled-environment facilities were feed, faecal material, bird’s skin and feathers along with bedding material.

These findings can inform the development of need-based appropriate emission control technologies as well as strategies. It has been reported that the relative humidity (RH) can play a role in controlling particulate emissions in the environmentally controlled facilities to reduce the risk of exposure to both birds and employees Corkery et al. (2013). In the current study, RH was between 50 and 60% and it showed an inverse relation with both fractions of PM (PM$_{2.5}$ and PM$_{10}$) and temperature with a 0.01 significance level. The particulate and gaseous concentrations in controlled-environment facilities are strongly related to ventilation rate, the age of birds, the activity of birds and management practices. The role of facility management, particularly, ventilation rate, is very important for the control of heat,

| Gases (ppm) | Indoor |   |   |   | Outdoor |   |   |   |
|-------------|--------|---|---|---|---------|---|---|---|
|             | Group 1 | Mean ± SD | Group 2 | Mean ± SD | Group 3 | Mean ± SD | Group 1 | Mean ± SD | Group 2 | Mean ± SD | Group 3 | Mean ± SD |
| NO$_2$      | 0.02 ± 0.02 | 0.03 ± 0.03 | 0.06 ± 0.05 | 0.10 ± 0.12 | 0.06 ± 0.03 | 0.29 ± 0.35 |
| CH$_4$      | 15.5 ± 15.2 | 31.9 ± 32.6 | 41.6 ± 29.0 | 1.93 ± 1.51 | 42.2 ± 107.2 | 5.62 ± 7.75 |
| H$_2$S      | 0.14 ± 0.2  | 0.22 ± 0.2  | 0.32 ± 0.2  | 0.42 ± 0.76 | 0.08 ± 0.09  | 0.02 ± 0.02 |
| CO$_2$      | 868 ± 201   | 1005 ± 340  | 1706 ± 199  | 488 ± 71   | 434 ± 16    | 547 ± 189  |

Table 3 Summary concentrations (ppm) of different gases in poultry farm categories and outdoors
humidity, PM and gases as reported by many studies (Roumeliotis and Van Heyst 2007; Kocaman et al. 2005, 2006; Broucek and Cermak 2015). It was also seen that concentrations of NO2 and H2S were low as compared with those of CH4 and CO2 as shown in Fig. 2c, d. The H2S is produced by anaerobic decomposition of sulphate-containing organic compounds present in manure and causes respiratory problems when present in high concentrations (Barrasa et al. 2012).

Wang et al. (2011) mentioned a 100% mortality rate in Leghorn males (breed of chicken) when exposed to 4000 mg/kg of hydrogen sulphide for 15 min, and exposure of 2 mg/kg was recommended as least toxic. The maximum production of hydrogen sulphide in the present study was 0.14–0.20 ppm for groups 1 to 3 (Table 3), and the average concentration reported by Barrasa et al. (2012) for H2S was 0.10 ppm in fattening broiler houses which is lower than that in the present study. The concentration of NO2 (0.02–0.06 ppm) among all the three groups was slightly higher as compared with NO2 concentrations (0.01 and 0.02 ppm) reported by Almuhanna et al. (2011) in two mechanically ventilated poultry houses in Al-Ahsa, Saudi Arabia, for a complete growth cycle. There is a scarcity of data on NO2 emission in poultry farms. The most published data is for ammonia and nitrous oxide.

The main sources of CH4 in these environments are manure storage practices and decomposition of organic matter; however, a small amount can be produced due to the monogastric digestive physiology of birds (Broucek and Cermak 2015). The range of CH4 concentrations (15.5–42.2 ppm) measured in the current study showed a significant increase among the groups, and levels were higher as compared with 2.56 ppm (Winter) to 15.68 ppm (summer) in broiler houses in Bursa, northwest of Turkey (Kilic and Yasioglu 2013). A study designed in a respiration chamber by Wang and Huang (2005) for investigation of poultry enteric fermentation reported an estimated emission factor of 15.87 mg bird−1 life cycle−1 for CH4. Methane and carbon dioxide have the ability to displace oxygen and can cause suffocation in controlled environments (Barrasa et al. 2012). Carbon dioxide was the highest concentration gas recorded in this study. Its production depends on the stocking density of birds, the age of birds, the activity of birds, type of feed, consumption rate and temperature. Additionally, decomposition and moisture level of bedding material and management practices, such as the ventilation rate of the building, also play a role in determining CO2 levels in poultry sheds. The recommended levels for CO2 in poultry houses should be less than 5500 mg/m3 (Council Directive 2007/43/EC, 2007). The CO2 concentrations in the present study were 883–1706 ppm (1170–3306 mg/m3) and increased with the age of the birds (Table 3). Barrasa et al. (2012) reported the highest level of CO2 with the largest variation during the monitoring period in poultry houses as compared with cattle and pig farms, and the production of all gases generally increased with the age of birds (Calvet et al. 2011). Ventilation rate has been reported to significantly impact the level of indoor CO2 concentrations in poultry facilities. A study conducted in a tunnel-ventilated commercial broiler house by Broucek and Cermak (2015) has shown CO2 emissions increased with the age of birds, and an inverse correlation was observed between ventilation rate and CO2 concentrations. It was noticed in the present study that poultry facilities could be a higher source of PM and gases in comparison with other intensive agricultural facilities. Herron et al. (2015) also reported poultry facilities were found as more contaminated sites as compared with other livestock units (cow and swine farms). The poultry facilities were also rich in organic dust and gaseous emissions that may cause various health problems for the farm workers (Donham et al. 2000; Portejoie et al. 2002; Donham et al. 2002; Kocaman et al. 2005; Oppliger et al. 2008; Skora et al., 2016; Li et al., 2019; Shen et al. 2019). Enforcement of the existing occupational health and safety laws (for example, the use of PPE) and good management practices can significantly reduce the risk of exposure to poultry workers.

The outdoor sampling carried out for the PM and gaseous concentrations revealed a correlation with indoor levels in the majority of cases, but an inverse relation was also seen showing that the outdoor environment was least affected by indoor emissions. The levels in outdoors seem to depend on wind speed/direction and various other factors such as feed storage houses, leftover of bedding materials, vegetation, use of fertilizer on particular days and other high-energy activities in the surroundings. A study by Shen et al. (2018) showed that PM10 and TSP were significantly higher inside the poultry house compared with the outside.
Conclusions

The knowledge on spatio-temporal characteristics of concentrations from intensive poultry facilities is vital to better understand the nature and magnitude of these emissions and their potential public and environmental health impact. Recent advancements in sensor technologies have resulted in the development of a range of lower cost sensors for particulate and gaseous air pollution monitoring. In the present study, age of the birds was a predominant factor for the increased PM and gaseous concentrations, along with the fact that the concentrations of both were found higher during different activities in comparison with non-activity periods. The outdoor concentrations in the vicinity of these facilities were not solely dependent on indoor emissions and might have different additional external sources. There is potential in low-cost sensors such as Dylos 1700 and Aeroqual 500 series used in this study to provide overview trends in spatio-temporal concentrations from such facilities for non-regulatory applications. In particular, these can identify high emission activities and time periods over the growth cycle of birds. However, the data presented in this study provide a snapshot view of particulate and gaseous concentrations from poultry facilities. Further studies are needed to improve understanding of the nature and magnitude of the emission from poultry facilities and their resultant health and environmental impact. Key attention should be given to the chemical and biological characterisation of particulate emissions, in particular, cellular responses associated with biological molecules such as endotoxin emitted from poultry facilities.

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