



COMMENTARY

10.1002/2017GH000103

Key Points:

- The rapid expansion of large-scale livestock farms near residential areas raises questions about public health implications
- A series of recent studies on air pollutant emissions from agriculture emphasize respiratory health risks among neighboring residents
- There is a clear need to firmly embed public health perspectives in the decision-making process in environmental and agricultural planning

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Citation:

Smit, L. A. M., & Heederik, D. (2017). Impacts of intensive livestock production on human health in densely populated regions. *GeoHealth*, 1. <https://doi.org/10.1002/2017GH000103>

Received 15 AUG 2017

Accepted 1 SEP 2017

Accepted article online 13 SEP 2017

Impacts of Intensive Livestock Production on Human Health in Densely Populated Regions

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Abstract In several regions worldwide, the presence of livestock in close proximity to residential areas raises questions about public health implications. The rapid expansion of large-scale livestock farms, increasingly interwoven with urbanized areas, and its potential impact on neighboring residents' health has hardly been accompanied by any research. The current situation in densely populated livestock farming areas could be regarded as a "natural experiment." Most scientific and public health initiatives have focused on emerging zoonoses and antimicrobial resistance as potential health threats. In this commentary, we emphasize the importance of respiratory health effects of noninfectious air pollutant emissions from livestock farms.

Plain Language Summary In several regions worldwide, in particular, in the Western world and Asia, large-scale livestock farms are located in densely populated areas. The presence of large numbers of farm animals raises questions about health risks for neighboring residents who are not farmers themselves. Large-scale livestock farms expanded rapidly in the last few decades, but their potential impact on neighboring residents' health has hardly been accompanied by any research. In our commentary, we argue that the current situation in densely populated livestock farming areas could be regarded as a "natural experiment," with residents being exposed to potentially harmful bacteria, viruses, and air pollutants. We discuss studies in people living near farms, with examples of infectious diseases that can be transmitted from animals to humans, and transmission of bacteria that are resistant to antibiotics. It is less well known that people living close to livestock farms are also exposed to air pollutants that may affect the airways, such as fine dust and ammonia. Recent studies have shown that air pollution from livestock farms is associated with a worsening in lung function.

1. Introduction

The Netherlands is one of the world's most densely populated countries with more than 500 inhabitants per km² land area, but it is also characterized by a remarkably high concentration of intensive livestock farms (Robinson et al., 2011). The intensification and expansion of livestock farming is a relatively recent phenomenon. Around the 1950s, Dutch livestock farming was still characterized by small-scale mixed farming, especially in the sandy regions in the east and the south. In 1950 there were almost 271,000 pig keepers, who kept on average around seven pigs, mostly on mixed farms (Bieleman, 2010). Since the end of the 1950s, a rapidly increasing flow of imported feedstuffs through the port of Rotterdam, together with a process of scaling up and specialization led to highly intensified livestock farms (Bieleman, 2010). Because of the import of soy and other raw materials for animal feed, the numbers of intensively raised animals are disproportionately high relative to land area availability. Currently, the Netherlands is home to 12.5 million pigs that are kept on just over 3,000 specialized pig farms. Furthermore, more than 100 million broilers and laying hens, 4.2 million cows and veal calves, 1 million minks, 0.8 million sheep, and 0.5 million goats are kept (Statistics Netherlands, 2017).

The presence of such a large number of animals in close proximity to residential areas raises questions about public health implications. The situation in the Netherlands, and also in several other regions worldwide, in particular, in the Western world and Asia (Robinson et al., 2011), can be seen as a "natural experiment." The rapid expansion of large-scale livestock farms, increasingly interwoven with urbanized areas, and its potential impact on neighboring residents' health have hardly been accompanied by any research. Although various occupational health risks of livestock farming are well described (Schenker et al., 1998), they cannot be directly generalized to the surrounding population's situation. In the first place, levels of exposure to potentially harmful agents such as gases (ammonia, H₂S) and organic dust are much higher in farmers than

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in neighboring residents. On the other hand, farmers are a “healthy worker” population, whereas young children, elderly, and people with chronic illnesses are probably more vulnerable to the effects of environmental pollution. Moreover, because of the industrialization of agriculture and animal production, a growing number of residents in livestock-dense areas do not have a farming background. This population may be more susceptible to farm-related illnesses, especially to livestock-related zoonotic infections, as they have no or limited immunity to specific zoonotic pathogens.

So which agricultural pollutants are of potential relevance for general public health? Water and soil quality may be affected, depending on local conditions, manure treatment methods, and environmental regulations. A striking example was recently brought to the public’s attention by a series of Pulitzer Prize winning editorials in a small newspaper in Iowa, which focused on water pollution by agricultural companies (Cullen, 2017). According to one of the editorials: “Anyone with eyes and a nose knows in his gut that Iowa has the dirtiest surface water in America.” The editorials covered a water utility lawsuit over nitrate pollution into rivers used for drinking water supplies and revealed how powerful agricultural corporations secretly financed the defense. In this commentary, we will, however, mainly focus on air pollutants.

2. Agriculture: A Key Contributor to Air Pollution

Air quality is diminished in livestock farming areas, due to emissions of both coarse and fine particles, (odorous) gases, and endotoxin, the major component of the outer membrane of Gram-negative bacteria. Potentially pathogenic viruses and bacteria, and antimicrobial-resistant (AMR) bacteria can also be found in airborne particulate matter (PM) surrounding livestock farms (de Rooij et al., 2016; McEachran et al., 2015; Ssematimba et al., 2012). Although the main sources of PM emitted from livestock houses are of organic nature, for example, manure, bedding material, straw, animal feed, feathers, skin flakes, and hair (Winkel, 2016), recent studies have emphasized the large contribution of livestock farming to anthropogenic fine PM (PM_{2.5}) pollution, which constitutes mainly of secondary inorganic aerosols, including ammonium sulfate and ammonium nitrate (Bauer et al., 2016; Brunekreef et al., 2015; Lelieveld et al., 2015; Vieno et al., 2016). Inorganic ammonium compounds are formed by gaseous ammonia, which is mainly emitted from livestock production, and combustion-based gases. Long-range transport substantially contributes to ambient concentrations of PM_{2.5}, and therefore, agricultural ammonia emissions have been identified as major contributors to PM_{2.5} in urban areas and other nonagricultural areas as well. Vieno et al. argued that while the contribution of agricultural ammonia emissions to particular PM air pollution events is well established by scientific analyses, translation into communicating outside the atmospheric science arena needs improvement. The lack of public awareness of agricultural emissions as a key contributor to air pollution may eventually result in a weaker policy mandate for any emissions reduction targets for ammonia (Vieno et al., 2016).

3. Health Effects From Livestock-Related Air Pollution

Potential health effects from farm emissions are equally diverse and include zoonotic infections, infections with AMR bacteria, and respiratory disorders. Within the One Health concept, the multidisciplinary and collaborative approach to address potential or existing risks that originate at the animal-human-environment interface (Coker et al., 2011; One Health Initiative, 2017), most research initiatives have focused on zoonotic infections and emerging antimicrobial resistance as a potential threat to both human and animal health. However, a series of recent studies on air pollutant emissions from agriculture emphasize the environmental health risks posed by noninfectious farm emissions. Lelieveld et al. showed that agriculture has a remarkably large impact on PM air pollution-related mortality, and is even the leading source category in Europe, Russia, Turkey, Korea, Japan, and the Eastern USA (Lelieveld et al., 2015). Large-scale air pollution by secondary inorganic aerosols can affect a large proportion of the population, also outside livestock farming areas. People living at closer proximity to farms are also exposed to other agents that may affect the airways, such as endotoxin, larger particles, and ammonia. Living near a large number of livestock farms is associated with an increased risk of airway obstruction (Borlée et al., 2017; Radon et al., 2007). Furthermore, higher ammonia concentrations in the air are associated with acute deficits in lung function in adults and asthmatic children living in livestock-dense areas (Borlée et al., 2017; Loftus et al., 2015). Ammonia is considered to be a marker for other livestock-related air pollutants, as the levels in

residential areas are probably too low to cause respiratory effects. Although the average effect on lung function is modest, peak exposures may cause airway symptoms in vulnerable subjects. Patients with chronic obstructive pulmonary disease (COPD) living near livestock farms report more symptoms and are more often diagnosed with an exacerbation than patients living further away from farms (Borlée et al., 2015; van Dijk et al., 2016). The incidence of pneumonia is also found to be increased in livestock-dense areas, especially near goat and poultry farms (Beninca et al., 2017; Freidl et al., 2017; Smit et al., 2017; van Dijk et al., 2017). Since there is no evidence of zoonotic pathogens playing a role, except during outbreak situations (Huijskens et al., 2016), we hypothesized that endotoxin and other farm-related air pollutants may predispose to respiratory infections through chronic airway inflammation and subsequent host immune responses. In hospitalized pneumonia patients living close to poultry farms, the abundance of *Streptococcus pneumoniae*—not a zoonotic pathogen—in the upper airway microbiome was increased, suggesting a role for noninfectious air pollutant emissions (Smit et al., 2017), a hypothesis supported by a growing number of experimental studies (Poroyko et al., 2015; Rylance et al., 2015).

4. Risk of Zoonotic Infections

The importance of zoonotic infections is increasingly recognized, not in the least because the implications of an outbreak can be far reaching. Between 2007 and 2010, an unprecedented outbreak of Q fever, a zoonosis caused by *Coxiella burnetii*, occurred in the Netherlands with more than 4,000 human cases (Dijkstra et al., 2012), showing that the risk of resurgence or emergence and spread of zoonotic infections among the general population is more than theoretical. Dairy goat farms with *C. burnetii*-induced abortions were implicated as the major source of infection in the neighboring human population. *C. burnetii* is transmitted primarily through contaminated air, and people living several kilometers from an infected farm were still at increased risk of Q fever. In 2012, the epidemic was declared ended, most likely as a consequence of implemented control measures, including culling of pregnant animals and compulsory vaccination, in combination with a rise in seroprevalence in the human population (Van den Brom et al., 2015). Although other zoonotic infections, such as hepatitis E, psittacosis, and avian influenza are suspected of environmental transmission via infected farms to neighboring residents, there is limited or no scientific evidence of current health risks for the surrounding, nonfarming population (Hogerwerf et al., 2017; van Gageldonk-Lafeber et al., 2017). For example, in a recent study in more than 2,400 individuals living in a livestock-dense area in the Netherlands, the presence of hepatitis E virus (HEV) antibodies was strongly age related, but not associated with residential proximity to pig farms, suggesting that airborne spread of HEV is unlikely (van Gageldonk-Lafeber et al., 2017). The increasing incidence of HEV in Europe is more likely a result of HEV-contaminated pork consumption (Slot et al., 2017).

5. Antimicrobial Resistance

Infection with AMR bacteria is another potential health risk. Antimicrobial drugs are frequently used in the livestock industry to treat or prevent bacterial infections. Antibiotics can also be administered at subtherapeutic doses to promote growth, a practice that was banned in the EU in 2006, but still common in the United States. In the past decade, a specific clone of methicillin-resistant *Staphylococcus aureus* (MRSA), referred to as livestock-associated MRSA (LA-MRSA) has emerged in livestock and people in direct contact with livestock, in particular, pigs and veal calves (Graveland et al., 2010; Voss et al., 2005). Although airborne transmission is a likely route of exposure in farmers (Bos et al., 2016), it is unclear whether LA-MRSA is transmitted to nonfarming residents through the environment, for example, by air. In a large population survey, only 10 out of 2,492 Dutch adults carried LA-MRSA, but carriers lived closer to a livestock farm than noncarriers, a difference that remained statistically significant after adjustment for farm animal contact (Zomer, Wielders, et al., 2017). In the United States, living near high-density livestock production was associated with infection with other MRSA strains than the European LA-MRSA (Casey et al., 2014). Other examples of AMR bacteria occurring in livestock are Enterobacteriaceae that produce extended-spectrum β -lactamases (ESBLs) and/or plasmid-mediated AmpC (pAmpC), and *Clostridium difficile*, an enteric pathogen in humans and piglets. While there is ample evidence that transmission can take place via direct contact with animals (Dierikx et al., 2013; Keessen et al., 2013), there is currently no epidemiologic evidence that people living near livestock farms are at increased risk of infection with AMR bacteria compared with people living further away.

In Dutch population-based studies, residential distance to farms was not a risk factor for carriage of ESBLs or pAmpC producing Enterobacteriaceae (Huijbers et al., 2013; Wielders et al., 2017) or *Clostridium difficile* (Zomer, van Duijkeren, et al., 2017).

6. Perspective

A pertinent question is how to protect neighboring residents from potentially harmful farm emissions while maintaining (family) farm viability and food safety, ensuring healthy working conditions, and optimizing animal welfare. The strategy required will depend on the specific exposure considered. The risk of transmission of AMR bacteria from livestock production industries has been considerably reduced by a more than 60% reduction in use of antimicrobials in the Netherlands over the last 5 years. This reduction in antimicrobial use has been accompanied by a reduction in antimicrobial resistance in all livestock production sectors (Dorado-Garcia et al., 2016). For other risks, such as zoonoses, animal disease management, including improving biosecurity, vaccination, and last but not least surveillance are the most effective strategies. For gas and dust emissions, emission reduction by the use of alternative housing systems is required. Implementing “safe distances” between large-scale farms and residential areas is hardly an option in densely-populated regions. Furthermore, because of the dispersion characteristics of the different emissions and lack of knowledge on exposure-response relations, there is no scientific basis for a distance-based policy.

However, decision making may also lead to—sometimes unforeseen—trade-offs between these objectives. For example, the transition in the laying hen sector from cage housing to alternative housing systems with littered floors has substantially increased the contribution of the livestock sector to total PM emissions (Winkel, 2016). Due to public health concerns highlighted by recent research discussed in our commentary, the Dutch government now plans to reduce the emissions from poultry houses by 50% over the next 10 years (van Dam & Dijk, 2017), creating an urgent need for emission-reducing technologies. The present global interest in reduction of antimicrobials in livestock production is of major importance, but lacks broader production chain-based approaches that take other risks and changes in livestock production in consideration and may come into conflict with other public or animal and environmental health-related issues when not considered adequately in a broader context.

There is a clear need to firmly embed public health perspectives in the decision-making process in environmental planning and agricultural development. Research on exposure and health risks of animal farming should extend beyond infectious disease monitoring, and more awareness of agriculture as a contributor to large-scale air pollution should be raised. Our decision making requires more scientific underpinning and should consider a broad specter of potential health risks. This makes science-based decision making a complex and challenging process that is urgently needed. After all, we do not want our rural citizens to be part of an ongoing natural experiment.

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