Postprint: Ammonia Emission Characteristics and Mitigation Strategies for Large-Scale Livestock and Poultry Farming in Chongqing

Authors: Liao Renjun, Chen Yucheng

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Abstract

As air quality degradation and livestock and poultry breeding pollution become increasingly serious, the environmental pressure on rapidly developing intensive livestock and poultry farming continues to grow. Quantifying ammonia emissions and their characteristics from intensive livestock and poultry farming can provide a scientific basis and countermeasures for atmospheric environment management and livestock and poultry breeding pollution prevention and control. Based on ammonia emission coefficients and activity level data for intensive livestock and poultry farming in Chongqing, this study estimated ammonia emissions from intensive livestock and poultry farming in Chongqing in 2013, analyzed emission characteristics, and discussed corresponding ammonia emission reduction measures. The results showed that total ammonia emissions from intensive livestock and poultry farming in Chongqing in 2013 were 17,102.92 t, with an emission intensity of 0.21 t · km 2; Hechuan, Fengdu, and Tongnan were the top three districts/counties in terms of ammonia emissions from intensive livestock and poultry farming, with their combined emission share accounting for 30.19% of total emissions; in terms of spatial distribution characteristics, Bishan District had the highest ammonia emission intensity at 1.17 t · km 2, while Chengkou County had the lowest emission intensity at 0.01 t · km 2; at the global spatial scale, the spatial distribution of ammonia emissions from intensive livestock and poultry farming in Chongqing exhibited significant positive spatial correlation; at the local spatial scale, four districts/counties exhibited "high-high" type areas, five districts/counties exhibited "low-low" type areas, and no "high-low" or "low-high" type areas appeared. Intensive pig farming was the largest ammonia emission contribution source for livestock and poultry farming in Chongqing, with emissions reaching 9,538.63 t and a contribution rate of 55.80%; followed by laying hens with a contribution rate of 15.87%. Ammonia emissions varied across the three stages of housing, storage management, and subsequent utilization (fertilization) for livestock and poultry. For poultry, the contribution rate of ammonia emissions during the housing stage exceeded 60%, followed by the subsequent utilization (fertilization) stage, with the manure storage stage having the smallest ammonia emissions. For livestock, the stage with the highest ammonia emission contribution rate was subsequent utilization (fertilization), followed by emissions within housing, with very little ammonia released during the storage stage. Dairy cow farming is a key control source for emission reduction. The main emission reduction measures for intensive livestock and poultry farming include low-nitrogen feed feeding, barn renovation, manure covering or sealing, and manure injection application, etc.

Full Text

Characteristics of Ammonia Emission from Large-Scale Livestock/Poultry Breeding and Its Mitigation Countermeasures in Chongqing

LIAO Renjun, CHEN Yucheng
(Key Laboratory of Eco-environments in the Three Gorges Reservoir Region, Ministry of Education / College of Resources and Environmental Sciences, Southwest University, Chongqing 400716, China)

Abstract: With growing environmental concerns over air quality and livestock/poultry pollution, rapidly developing large-scale livestock/poultry breeding faces increasing pressure to take mitigation actions. Quantifying ammonia emissions and their characteristics from large-scale livestock/poultry operations provides a scientific basis for atmospheric environmental management and pollution prevention. This study estimated ammonia emissions from large-scale livestock/poultry breeding in Chongqing for 2013 using emission coefficients and activity level data, analyzed emission characteristics, and explored corresponding mitigation measures. Results showed that total ammonia emissions from large-scale livestock/poultry breeding in Chongqing reached 17,102.92 t in 2013, with an emission intensity of 0.21 t · km ^{2}. Hechuan, Fengdu, and Tongnan were the top three districts for ammonia emissions, collectively accounting for 30.19% of the total. Spatially, Bishan District exhibited the highest emission intensity at 1.17 t · km ^{2}, while Chengkou County had the lowest at 0.01 t · km ^{2}. At the global spatial scale, ammonia emissions showed significant positive spatial autocorrelation. Local spatial analysis revealed four counties as "high-high" clusters and five counties as "low-low" clusters, with no "high-low" or "low-high" patterns detected. Large-scale pig farming was the dominant emission source, contributing 9,538.63 t (55.80% of total emissions), followed by layer chickens at 15.87%. Ammonia emissions varied across the three manure management stages: housing, storage, and subsequent utilization (fertilization). For poultry, housing-stage emissions exceeded 60% of the total, while for livestock, the utilization stage contributed most. Dairy cattle farming should be prioritized for emission control. Primary mitigation measures include low-nitrogen feed, housing renovation, covered/sealed manure storage, and manure injection

application.

Keywords: Large-scale livestock/poultry breeding; Ammonia emission; Management stage; Mitigation countermeasure; Chongqing

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Introduction

Ammonia (NH) is a key component in atmospheric nitrogen cycling and a crucial precursor to fine particulate matter PM . . It reacts with atmospheric SO and NO to form secondary particles such as ammonium nitrate and ammonium sulfate, reducing visibility and causing haze. As an important alkaline substance, NH buffers atmospheric acidification in the lower troposphere and constitutes a major component of acid deposition. Additionally, atmospheric NH emissions can disrupt methane oxidation, exacerbating the greenhouse effect, while deposition into surface waters causes eutrophication.

As air pollution becomes increasingly prominent, researchers worldwide have focused on ammonia emission characteristics and factors. Studies have identified livestock breeding as the primary ammonia source. In 2011, agricultural ammonia emissions accounted for 93.7% of Europe' s total, with 80-90% originating from livestock operations. The United States emitted 3.92 million tons of ammonia in 2011, with agriculture contributing 81.8% and livestock specifically 54.3%. Chinese research indicates that livestock contributed 40.79% of China' s total ammonia emissions in 2006. In the Yangtze River Delta region, livestock breeding contributed 44.1% of emissions in 2004. Beijing' s livestock industry generated 44,300 tons of ammonia in 2012, with an average intensity of 2.70 t · km ^{2}. In Sichuan Province, livestock was the dominant anthropogenic source in 2012, accounting for 63.31% of total emissions, particularly from pigs and cattle.

Existing research has primarily focused on large-scale (national or provincial) ammonia emission inventories and characteristics, with limited studies specifically targeting livestock breeding emissions or discussing mitigation measures based on emission characteristics. Europe pioneered ammonia mitigation research, with mature technologies already implemented in practice, while domestic research remains scarce. Only a few scholars have proposed control frameworks and mitigation measures for China' s agricultural ammonia emissions by adapting European and American experiences to Chinese conditions.

Chongqing' s livestock industry has developed rapidly, with total output value reaching 4.8×10^{1} yuan in 2013, representing 31.89% of agricultural output value. Consequently, ammonia emissions have increased significantly, causing serious pollution. Previous research by Zhang et al. reported that fertilizer application was the largest agricultural ammonia source (66.7% of total), followed by livestock breeding (26.3%). As the industry continues developing toward large-scale and intensive operations with relatively inadequate management practices and technologies, the environmental pressure from large-scale breeding intensifies. This study synthesizes recent domestic and international research to estimate 2013 ammonia emissions from large-scale livestock/poultry breeding in Chongqing, analyze spatial distribution characteristics, and explore mitigation efficiency under different measures to provide scientific support for atmospheric environmental management and pollution prevention.

1.1 Study Area and Objectives

Using 2013 as the baseline year, the study covered 36 districts and counties in Chongqing with large-scale livestock/poultry breeding operations, spanning five functional zones: core urban area, expanded urban area, new urban development area, northeastern Chongqing ecological conservation area, and southeastern Chongqing ecological protection area. The estimated emission sources included large-scale layer chickens, broilers, dairy cows, beef cattle, and pigs.

1.2 Data Sources

Livestock breeding data (year-end inventory and annual slaughter numbers) were obtained from the "Four Clarifications and Four Treatments" special campaign statistics conducted in Chongqing in 2013. Emission factors were primarily based on the *Technical Guidelines for Preparation of Atmospheric Ammonia Source Emission Inventory* (Trial), adjusted according to specific breeding conditions in Chongqing.

1.3 Estimation Method

Ammonia emissions in large-scale livestock/poultry breeding primarily originate from animal excreta. Animal waste typically remains in housing for a period before collection for storage and decomposition, followed by subsequent utilization (fertilization). Therefore, manure management includes three stages: housing, storage treatment, and subsequent utilization (fertilization), with waste existing in both liquid (urine) and solid (feces) forms. The ammonia emission calculation formula is:

$$E = \sum_{i} \sum_{j} A_{ij} \times EF_{ij} \times 1.214$$

where E is ammonia emission (t), A is activity level (t), F is emission coefficient (% TAN, percentage of total ammoniacal nitrogen emitted as atmospheric ammonia), 1.214 is the conversion coefficient from NH -N to NH , EI is ammonia emission intensity ($\mathrm{t} \cdot \mathrm{km}\ {}^{2}$), S is land area (km^{2}), i represents different livestock categories, and j represents different manure management stages including housing, storage treatment, and subsequent utilization (fertilization).

1.3.1 Determination of Ammonia Emission Coefficients The emission coefficient represents the amount of nitrogen emitted as atmospheric ammonia per unit mass of total ammoniacal nitrogen (TAN). Based on actual conditions in Chongqing's large-scale livestock/poultry industry and the *Technical Guidelines*, emission coefficients for each breeding stage were determined . Since nitrogen losses during storage (released as N O, NO, and N) must be considered when calculating activity levels for manure utilization, emission coefficients for N O, NO, and N during storage are also included in Table 1.

1.3.2 Determination of Activity Level (A_{ij}) Activity level represents the total ammoniacal nitrogen content of livestock manure at different management stages and in different forms. The TAN content at housing, storage, and utilization stages relates to indoor excreta TAN, with waste distinguished as liquid and solid forms. The calculation method is:

$$\text{TAN}_{\text{indoor}} = \text{Annual livestock number} \times \text{Excretion rate per animal} \times \text{Nitrogen content} \times \text{Ammonium nitrogen ra}$$

where $\text{TAN}_{\text{indoor}}$ is indoor excreta ammoniacal nitrogen (t), A_{housing}, A_{storage}, and $A_{\text{fertilization}}$ are activity levels for housing, storage, and utilization stages (t), X_{liquid} is the mass proportion of liquid manure (50%), R is the proportion of manure used as ecological feed (e.g., chicken manure for fish farming), EF_{housing} and EF_{storage} are ammonia emission coefficients for housing and storage (including liquid and solid forms), $EF_{\text{storage-liquid-N O}}$, $EF_{\text{storage-liquid-NO}}$, $EF_{\text{storage-liquid-N}}$ and $EF_{\text{storage-solid-N O}}$, $EF_{\text{storage-solid-NO}}$, $EF_{\text{storage-solid-N}}$ are emission coefficients for N O, NO, and N during storage, $ENN_{\text{loss-liquid}}$ and $ENN_{\text{loss-solid}}$ are nitrogen losses during storage (t), and f is the conversion ratio from TAN to organic nitrogen during solid manure storage (10%). Livestock excretion rates, nitrogen content, and other parameters are detailed in Table 2, with breeding cycles adjusted for Chongqing conditions. For animals with cycles exceeding one year (layers, dairy cows, beef cattle), annual numbers were calculated using year-end inventory; for animals with cycles less than one year (broilers, meat poultry), annual numbers used slaughter volume.

1.4 Spatial Autocorrelation Analysis

Spatial autocorrelation measures the correlation of a variable across different spatial locations, quantifying the degree of clustering in spatial units and analyzing statistical distribution patterns of spatial data. The primary statistical indicator is Moran' s I index, analyzed at both global and local scales.

1.4.1 Global Spatial Autocorrelation Global spatial autocorrelation detects overall spatial patterns across the study area using a single value to reflect the degree of autocorrelation. While it can describe whether clustering exists globally, it cannot identify specific cluster locations. The global Moran' s I index measures overall spatial association and differentiation:

$$I = \frac{n \sum_i \sum_j W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i \sum_j W_{ij} \sum_i (x_i - \bar{x})^2}$$

where I is the global Moran' s I index, n is the number of regions, x_i and x_j are attribute values for regions i and j, $\bar{x}$ is the mean attribute value, and W_{ij} is the spatial weight matrix defining relationships between geographic units. Moran' s I ranges from [-1, 1], with positive values indicating clustering, negative values indicating dispersion, and zero indicating no spatial autocorrelation. Significance is tested using z-statistics.

1.4.2 Local Spatial Autocorrelation Local spatial autocorrelation indices reflect the correlation between a spatial unit' s attribute value and neighboring units' values. The Local Indicator of Spatial Association (LISA) is the local form of Moran' s I, measuring spatial association while identifying specific cluster locations, thereby compensating for limitations of global analysis:

$$I_i = \frac{(x_i - \bar{x})}{S^2} \sum_j W_{ij}(x_j - \bar{x})$$

where N, X, and W_{ij} are as defined in the global formula, and $S^2 = \frac{1}{N} \sum_i (x_i - \bar{X})^2$. Significance is tested using Z-statistics; positive I_i indicates high-high or low-low clustering (H-H or L-L), while negative I_i indicates high-low or low-high clustering (H-L or L-H).

2.1 Ammonia Emissions from Large-Scale Livestock/Poultry Breeding by District/County

Due to differences in economic levels, ecological conditions, and agricultural structure, ammonia emissions vary across Chongqing' s districts and counties [Figure 1: see original paper]. Hechuan, Fengdu, and Tongnan were the top three emitters, with annual emissions of 2,563 t, representing 30.19% of the total. Hechuan, having the highest pig production, contributed 19.76% of municipal emissions, with other livestock numbers also relatively high, making its total contribution 13.49%. Jiulongpo, Nan' an, and Jiangbei districts had low emissions (0.08%, 0.04%, and 0.03% of total, respectively) due to urban planning and environmental protection requirements; other counties contributed 0.2-7.8%.

Analysis of emissions by livestock category revealed pig farming as the dominant source, emitting 9,538.63 t (55.80% of total) [Figure 2a: see original paper]. As the traditional staple meat in China, pork consumption represents a large proportion of meat consumption. Layer chickens ranked second, emitting 2,712.34 t (15.87%); despite lower emission coefficients, large production volume (15.79

million birds annually) resulted in substantial emissions. Dairy and beef cattle had similar emissions (1,858.85 t and 1,840.89 t, respectively, representing 10.87% and 10.77%), while broilers contributed the least at 1,142.32 t (6.68%).

Further analysis of emission contributions across manure management stages [Figure 2b: see original paper] showed distinct patterns. For poultry, housing-stage emissions dominated, exceeding 60% of the total, followed by utilization (fertilization), with storage contributing minimally. For livestock, the utilization stage contributed most, followed by housing, with storage again contributing little.

2.3.1 Spatial Distribution of Emission Intensity

Chongqing' s 2013 livestock breeding ammonia emission intensity was 0.21 t · km^{2}, with Bishan District highest (1.17 t · km^{2}), followed by Hechuan (1.09 t · km^{2}) [Figure 3: see original paper]. Chengkou County had the lowest intensity (0.01 t · km^{2}). The spatial distribution aligned with Chongqing' s five functional zone strategy: high-intensity districts belonged to the new urban development zone, while core urban and southeastern ecological protection zones had low intensity. The new urban development zone, as the primary industrial region with intensive breeding, faces development-environment conflicts, whereas core urban and southeastern zones designated as "no-breeding areas" do not prioritize breeding pollution.

2.3.2 Global Spatial Autocorrelation of Ammonia Emissions

Geoda spatial analysis software calculated a global Moran' s I index of 0.4798 for 2013 emissions across 36 districts/counties. The standardized Z-value of 5.7389 significantly exceeded the critical value of 1.96 (=0.05), indicating significant positive spatial autocorrelation. This demonstrates clear clustering: districts with high emissions are surrounded by high-emission neighbors, and low-emission districts are surrounded by low-emission neighbors.

2.3.3 Local Spatial Autocorrelation of Ammonia Emissions

Local Moran' s I indices were calculated for all districts at =0.05 significance, mapped using ArcGIS 9.3 to create LISA cluster maps revealing local homogeneity and heterogeneity [Figure 4: see original paper]. The "high-high" (H-H) cluster comprised Rongchang, Dazu, Tongliang, and Tongnan, indicating high emissions with low local variation—these new urban development zone districts concentrate most breeding resources. The "low-low" (L-L) cluster included central urban districts and southeastern Youyang and Xiushan counties, showing uniformly low emissions with low local variation. No "high-low" (H-L) or "low-high" (L-H) clusters were identified.

2.4 Mitigation Measures for Large-Scale Livestock/Poultry Breeding

Regression analysis of breeding numbers versus emissions (Equation 12) identified dairy cattle as the most influential factor: each additional dairy cow increased emissions by 38.050 kg. Therefore, dairy farming should be the primary focus for mitigation research.

$$y = 38.050x_4 + ... \quad (R^2 = 0.99)$$

where y is total ammonia emission, and x_1 through x_5 represent annual breeding numbers for pigs, layers, broilers, dairy cows, and beef cattle, respectively.

Mitigation efficiencies vary by measure and breeding stage . Primary strategies for Chongqing include: (1) low-ammonia feed for high-emitting pigs, and increased silage or corn feed for dairy and beef cattle; (2) housing renovation, including biofilters and ventilation in large pig and chicken houses; (3) covered or sealed manure storage to reduce volatilization, particularly for pig manure; and (4) manure injection application for subsequent utilization.

3 Discussion and Conclusion

This study estimated 2013 ammonia emissions from Chongqing' s large-scale livestock/poultry breeding, analyzed spatial distribution characteristics, and proposed mitigation strategies based on existing research, providing scientific support for atmospheric environmental management and pollution prevention.

Key findings include: (1) Total emissions of 17,102.92 t with intensity of 0.21 t · km ^{2}, with Hechuan, Fengdu, and Tongnan contributing 30.19%; (2) Results are lower than other regional studies due to focusing on large-scale operations only, excluding free-range grazing, and using different methods and coefficients; (3) Bishan District had the highest intensity (1.17 t · km ^{2}); (4) Significant positive spatial autocorrelation with four "high-high" and five "low-low" clusters, aligning with functional zone strategies; (5) Pig farming dominated emissions (9,538.63 t, 55.80%), followed by layers (15.87%); (6) Housing and utilization stages contributed most emissions; (7) Dairy cattle were the key control factor, with mitigation measures including low-nitrogen feed, housing renovation, sealed storage, and manure injection.

Uncertainty in emission estimates stems from: (1) Activity level uncertainties; (2) Emission factor and parameter selection, as factors vary with animal composition, age, and manure storage form. This study primarily used national guideline coefficients, lacking local calibration. Future research should focus on localized emission factors, control technology trials, policy development, and government guidance. Current mitigation strategies are literature-based; further experimental studies on mitigation efficiencies will enhance reliability and scientific validity.

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