Regional Distribution of Livestock and Poultry Manure and Its Water Environment Response Characteristics in Chongqing (Postprint)

Authors: Zhou Yuanyuan, Yin Jie, Yang Zhimin, Huang Lei, Chen Yucheng

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Abstract

To address the deficiencies in common estimation methods for pollutant discharge from livestock and poultry farming and to verify the current pollution status of livestock and poultry farming in Chongqing, this study proposes a correction method for calculating pollutant discharge from large-scale farms based on investigation of the local livestock and poultry farming industry and its emission status, and accounts for typical pollutant discharge from livestock and poultry under existing pollution control modes. Taking the five major functional zones of Chongqing as the research object and based on different water environment functional zonings, the equivalent standard pollution load ratio method was employed to investigate the functional zone distribution of equivalent standard emissions of chemical oxygen demand (CODCr), total nitrogen (TN), and total phosphorus (TP) and their potential water environment response characteristics, thereby identifying the major pollution areas and major pollutants from livestock and poultry farming, providing a decision-making basis for industrial development and environmental protection in different functional zones of Chongqing. The results indicate that in 2013, the livestock and poultry farming amount in Chongqing was 4.1181 million pig equivalents, with actual emissions of feces, urine, CODCr, TN, and TP being 2.27×10 t, 1.66×10 t, 3.03×10 t, 0.72×10 t, and 1.87×10 t, respectively. The equivalent standard emissions of CODCr, TN, and TP were 1.44×10 m^3, 7.94×10 m^3, and 1.02×10^{11} m^3, respectively. The major pollution areas were the urban development new area and the Northeast Chongqing ecological conservation development area, with TP being the major pollutant, and there was a significant correlation between the development of livestock and poultry farming in Chongqing and functional zoning. The comprehensive water environment quality index for the entire city due to livestock and poultry farming pollution ranged from 0.22 to 4.12. Water quality in the urban development new area and the Northeast Chongqing ecological conservation development area exceeded standards, while the remaining functional zones did not exceed limits.

Full Text

Preamble

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Regional Distribution of Livestock Manure and Response Characteristics of Water Environment in Chongqing*

ZHOU Yuanyuan[1], YIN Jie[2], YANG Zhimin[1], HUANG Lei[1], CHEN Yucheng[1]**
(1. 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; 2. Chongqing Academy of Environmental Science, Chongqing 401147, China)

Abstract

Accurate calculation of livestock pollutant discharges is essential for determining the impact of livestock on water environments. Existing estimation methods suffer from insufficient and confusing definitions of discharge coefficients, leading to errors in breeding cycle calculations and livestock elimination rates. To address these issues, this paper establishes calibration methods for calculating production coefficients, discharge coefficients, and breeding cycles based on livestock breeding data and pollution control practices in Chongqing, China. Using these methods, we estimated the production and discharge amounts of livestock pollutants in Chongqing. According to the ecological functions of Chongqing's five functional areas and the discharge characteristics of chemical oxygen demand (CODCr), total nitrogen (TN), and total phosphorus (TP), we employed the equivalent standard pollution loading ratio and comprehensive pollution index to investigate the regional distribution of livestock manure and water environment response, identifying main pollutants and polluted areas. The results provide decision support for industrial development and environmental protection. The breeding cycles of pigs, dairy cattle, beef cattle, laying hens, and broilers were determined to be 122, 365, 365, 52, and 365 days, respectively. The corresponding discharge coefficients for CODCr were 0.049, 0.626, 0.170, 0.002, and 0.001 kg·head^{1}·d^{1}; for TN were 0.013, 0.081, 0.048, 0.001, and 0 kg·head^{1}·d^{1}; and for TP were 0.012, 0.024, 0.030, 0.001, and 0.003 kg·head^{1}·d^{1}. In 2013, Chongqing raised a total of 411.81×10 equivalent pig heads, discharging 2.27×10 tons of manure, 1.66×10 tons of urine, containing 3.03×10 t, 0.72×10 t, and 1.87×10 tons of CODCr, TN, and TP, respectively. Pollution evaluation identified the urban development area and northeast ecological conservation development area as the main contaminated regions, with TP as the primary pollutant. The synthetic index of water potential quality ranged from 0.22–4.12. Development of livestock breeding showed significant correlation with functional regionalization. Water pollution was not the main environmental problem in the urban core function area—the political, economic, and cultural center—where some sections were designated as “forbidden regions for raising livestock.” The urban development area, as the main polluted region, should promote industrial planting to resolve contradictions between economic progress and environmental protection. The northeast ecological conservation development area, another main polluted region, requires establishment of ecological red lines to restrict project implementation and protect the Three Gorges Reservoir.

Keywords: Livestock breeding; Pollutant producing coefficient; Pollutant discharge coefficient; Pollutant discharging amount; Equivalent standard pollution loading; Regional distribution; Water environment

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1.1 Study Area Overview

Chongqing is the only directly-administered municipality in southwestern China and a critical region affecting the Three Gorges Reservoir. In recent years, Chongqing’ s livestock industry has developed rapidly, with total output value reaching 4.8×10^{1} yuan in 2013, accounting for 31.89% of the total agricultural output value. However, the consequent surge in livestock waste discharge has severely threatened water quality safety in the Three Gorges Reservoir. In 2013, the Chongqing Municipal Party Committee and government divided the city into five functional areas—Urban Core Function Area, Urban Function Expansion Area, Urban Development Area, Northeast Ecological Conservation Development Area, and Southeast Ecological Protection Development Area—to implement differentiated management for ecological and environmental protection. Against this backdrop, this study examines these five functional areas to explore current pollutant production and discharge patterns and their water environment response characteristics, providing decision-making support for healthy livestock development in each zone.

Data Sources

In November 2013, the Chongqing Environmental Protection Bureau launched the “Four Clarifications and Four Treatments” special campaign, which included clarifying environmental impact assessment “three simultaneous” compliance, pollution permits, environmental risk sources, and environmental supervision points, while treating livestock breeding zoning management, environmental protection procedures, pollution control facility construction and operation, key environmental supervision sources, and environmental risk sources. The campaign targeted livestock farms with inventories equivalent to 100 pigs or more. Through field investigations combined with pollution census data, environmental statistics, and public reports, the campaign compiled statistics on each farm’ s breeding conditions, treatment processes, environmental protection investment, and complaints. This study obtained current livestock breeding data in

Chongqing through this system. Relevant water environment evaluation data were sourced from the Chongqing Water Resources Bulletins (2011–2014), the 2014 Chongqing Environmental Quality Bulletin, and statistical yearbooks.

1.3.1 Pollutant Production Coefficients

The livestock pollutant production coefficient refers to the total amount of original pollutants produced per animal per day under normal production and management conditions, including manure, urine, and various pollutants contained therein. Based on domestic research on production coefficients and official documents, this study selected five major livestock types in Chongqing—pigs, beef cattle, dairy cattle, broilers, and laying hens. By averaging parameters from recent literature regarding manure production, urine production, and concentrations of chemical oxygen demand (CODCr, hereafter referred to as COD), total nitrogen (TN), and total phosphorus (TP) in manure and urine, we calculated the production coefficients for COD, TN, and TP using Equation (1) .

$$P_{ij} = \frac{Q_{Si} \times CS_{ij} + Q_{Ui} \times CU_{ij}}{1000}$$

where P_{ij} is the amount of pollutant j produced by animal i (kg · head ^{1} · d ^{1}); Q_{Si} is the manure amount produced by animal i (kg · head ^{1} · d ^{1}); CS_{ij} is the concentration of pollutant j in manure of animal i (mg · kg ^{1}); Q_{Ui} is the urine amount produced by animal i (kg · head ^{1} · d ^{1}); and CU_{ij} is the concentration of pollutant j in urine of animal i (mg · kg ^{1}).

Table 1 Pollutants producing coefficients of different livestock and poultries (kg · head ^{1} · d ^{1})

Index	Pigs	Beef Cattle	Dairy Cattle	Broilers	Laying Hens
Manure amount					
Urine amount					
COD					
TN					
TP[1]					

[1] Due to ineffective reduction by pollution treatment measures, the total phosphorus production coefficient is identical to its discharge coefficient.

1.3.2 Pollutant Discharge Coefficients

The discharge coefficient refers to the final amount of pollutants actually released into the environment per animal per day after treatment and utilization by various processing facilities. The discharge coefficient is primarily influenced by waste management practices, including manure cleaning methods and utilization approaches. In Chongqing, manure cleaning methods include bedding with straw/padding and dry separation; manure utilization includes direct application, organic fertilizer production/sale, and biogas projects; wastewater can be treated through anaerobic-aerobic processes or advanced treatment for recycling.

In 2011, the Ministry of Environmental Protection established the "Twelfth Five-Year Plan" for total pollutant emission reduction accounting, which calculated reduction rates for COD and ammonia nitrogen by various treatment measures in large-scale farms. Referring to these reduction rates and statistical data on the implementation proportions of corresponding treatment patterns in Chongqing' s livestock farms, we employed a combined cumulative deduction method to calculate discharge coefficients for various livestock types using Equation (2). Since treatment measures have no reduction effect on phosphorus—merely transferring phosphorus from manure to biogas residues—the TP discharge coefficient equals its production coefficient.

$$D_{ij} = P_{ij} \times \prod_{k=1}^{n} (1 - r_{jk})^{n_k}$$

where D_{ij} is the amount of pollutant j discharged by animal i; n_k is the implementation proportion of treatment pattern k in animal i farms; and r_{jk} is the removal rate of pollutant j by treatment pattern k.

Variance tests between our calculated results and the discharge coefficients for Southwest China from the *Handbook of Generation and Discharge Coefficients from Livestock and Poultry for the First National Pollution Source Survey* (values in parentheses in Table 2) showed no significant differences, confirming their applicability to Chongqing' s current livestock breeding conditions.

Table 2 Discharge coefficients of different livestock and poultries under different treatment patterns in Chongqing, 2013

Livestock/Poultry	Treatment Pattern	Proportion (%)	COD Removal Rate (%)	COD Discharge Coefficient (kg · head ^{1} · d ^{1})	TN Removal Rate (%)	TN Discharge Coefficient (kg · head ^{1} · d ^{1})	TP Discharge Coefficient (kg · head ^{1} · d ^{1})
Dairy Cattle	Bedding + agricultural utilization			(0.086)^{1}			
	Bedding + organic fertilizer production			(1.460)			
	Dry cleaning + direct utilization + anaerobic/aerobic/advanced treatment			(0.547)			
Beef Cattle	Bedding + agricultural utilization			(0.002)			

Livestock/Poultry	Treatment Pattern	Proportion (%)	COD Removal Rate (%)	COD Discharge Coefficient (kg · head^{1} · d^{1})	TN Removal Rate (%)	TN Discharge Coefficient (kg · head^{1} · d^{1})	TP Discharge Coefficient (kg · head^{1} · d^{1})
	Bedding + organic fertilizer production			(0.004)			
	Dry cleaning + direct utilization + anaerobic/aerobic/advanced treatment			(0.005)			
Laying Hens	Bedding + agricultural utilization			(0.082)			

Livestock/Poultry	Treatment Pattern	Proportion (%)	COD Removal Rate (%)	COD Discharge Coefficient (kg · head ^{1} · d ^{1})	TN Removal Rate (%)	TN Discharge Coefficient (kg · head ^{1} · d ^{1})	TP Discharge Coefficient (kg · head ^{1} · d ^{1})
	Bedding + organic fertilizer production			(0.034)			
	Dry cleaning + direct utilization + anaerobic/aerobic/advanced treatment			(0.001)			
Broilers	Bedding + agricultural utilization			(0.000)			

Livestock/Poultry	Treatment Pattern	Proportion (%)	COD Removal Rate (%)	COD Discharge Coefficient (kg · head ^{1} · d ^{1})	TN Removal Rate (%)	TN Discharge Coefficient (kg · head ^{1} · d ^{1})	TP Discharge Coefficient (kg · head ^{1} · d ^{1})
	Dry cleaning + biogas production + anaerobic/aerobic/advanced treatment						

[1] Values in parentheses are discharge coefficients for Southwest China from the *Handbook of Generation and Discharge Coefficients from Livestock and Poultry for the First National Pollution Source Survey.*

1.3.3 Adjustment Coefficient

Current discharge calculations in China are based on actual breeding cycles, but this approach contains errors. Using pigs as an example with a 145-day breeding cycle, the annual inventory situation is illustrated in Figure 1 [Figure 1: see original paper]. Using Equation (3) fails to account for the discharge from Inventory 3, yielding underestimated results. Using Equation (4) calculates a full breeding cycle for Inventory 3, but since some of this inventory' s discharge is actually accounted for in the following year, the result is overestimated.

$$\text{Discharge} = (\text{Slaughter } 1 + \text{Slaughter } 2) \times \text{Daily coefficient} \times \text{Breeding cycle} \quad (3)$$

$$\text{Discharge} = (\text{Inventory } 1 + \text{Inventory } 2 + \text{Inventory } 3) \times \text{Daily coefficient} \times \text{Breeding cycle} \quad (4)$$

The actual discharge should be calculated using Equations (5) and (6). For large-scale farms where each inventory batch is constant, the annual inventory is $(n+1)$ times the year-end inventory, while slaughter amount is n times the year-end inventory. Consolidating these formulas yields Equation (7), making $365/(n+1)$ the adjusted breeding cycle coefficient.

$$\text{Discharge} = [\text{Slaughter}\times\text{Breeding cycle}+\text{Year-end inventory}\times(365 - n\times\text{Breeding cycle})]\times\text{Daily coefficient} \tag{5}$$

$$\text{Actual discharge} = \text{Annual inventory} \times \text{Daily coefficient} \times \frac{365}{n+1} \tag{7}$$

According to the *Notice on Developing District and County Livestock Breeding Pollution Prevention Planning* from the Chongqing Environmental Protection Bureau, livestock breeding cycles in Chongqing were obtained. Applying the method described in Section 1.3.3, the adjusted breeding cycles for pigs, beef cattle, dairy cattle, broilers, and laying hens were determined to be 122 days, 365 days, 365 days, 52 days, and 365 days, respectively.

Figure 1 Explanatory view of pig inventory and marketing period for one year

1.4 Estimation of Livestock Breeding Pollutant Discharge

Based on the calibrated parameters above, livestock breeding pollutant discharge is calculated as:

$$Q_{mj} = \sum_{i=1}^{n} N_{mi} \times T_i \times D_i \tag{8}$$

where Q_{mj} is the annual discharge amount of pollutant j in functional area m ($\mathrm{kg} \cdot \mathrm{a}^{1}$); N_{mi} is the breeding quantity of animal i in functional area m (heads); T_i is the adjusted breeding period of animal i (days); and D_i is the daily discharge coefficient of pollutant j for animal i ($\mathrm{kg} \cdot \mathrm{head}^{1} \cdot \mathrm{d}^{1}$).

1.5.1 Equivalent Standard Pollution Load Ratio

The equivalent standard pollution load method is commonly used for comprehensive pollution source evaluation. The equivalent standard discharge amount for livestock breeding pollutants is defined by Equation (9). Due to its additive and comparable properties, the main polluted areas and pollutants can be identified using Equation (10).

$$P_{mj} = \frac{Q_{mj}}{S_j} \times 10^6 \tag{9}$$

$$K_j(m) = \frac{P_{mj}}{\sum_{m=1}^{n} P_{mj}} \times 100\% \tag{10}$$

where Q_{mj} is the annual discharge amount of pollutant j in functional area m (kg · a^{1}); S_j is the surface water environmental quality standard for pollutant j in the water function zone where area m is located (mg · L^{1}); P_{mj} is the equivalent standard discharge amount of pollutant j in functional area m (m^{3} · a^{1}); and $K_j(m)$ is the equivalent standard pollution load ratio of pollutant j (functional area m).

1.5.2 Potential Water Pollution Index from Livestock Breeding

To reflect the potential pollution degree of livestock breeding emissions on surface water without considering self-purification, we adopted single and comprehensive pollution index methods:

$$I_j = \frac{Q_{mj}}{W_m \times S_j} \tag{11}$$

$$I = \sum_{j=1}^{n} I_j \tag{12}$$

where I_j is the single pollution index for pollutant j; W_m is the surface water resource amount in functional area m (excluding transit water) (10 m^{3}); and I is the comprehensive potential water pollution index from livestock breeding.

2 Results and Analysis

Based on the above methods, livestock breeding quantities in Chongqing' s five functional areas were obtained, and pollutant discharge amounts for each area were calculated . The total livestock breeding quantity in Chongqing for 2013 was 411.81×10 pig equivalents, with actual discharge amounts of 2.27×10 t · a^{1} of manure, 1.66×10 t · a^{1} of urine, 3.03×10 t · a^{1} of COD, 0.72×10 t · a^{1} of TN, and 1.87×10 t · a^{1} of TP. The urban development area had the largest breeding quantity and discharge amount, exceeding half of the city' s total, while the urban core function area had the smallest—nearly 1,900 times less than the maximum. This demonstrates a significant relationship between livestock breeding development and functional zoning. The urban core function area, as Chongqing' s political, economic, and cultural center, has minimal primary industry development, with many regions designated as "no-breeding zones," making water pollution a secondary environmental concern. In contrast, the urban development area, as the city' s primary industrial and agricultural region, faces conflicts between rapid development and environmental protection.

Table 3 Discharge amounts of pollutants from livestock breeding in different functional areas of Chongqing, 2013

Functional Area	Breeding Quantity (10 pig equivalents)	Manure (10 t · a ^{1})	Urine (10 t · a ^{1})	COD (t · a ^{1})	TN (t · a ^{1})	TP (t · a ^{1})
Urban Core Function Area						
Urban Expansion Function Area						
Urban Development Area						
Northeast Ecological Conservation Development Area						
Southeast Ecological Protection Development Area						
Total	**411.81**	**2.27×10**	**1.66×10**	**3.03×10**	**0.72×10**	**1.87×10**

2.2 Main Polluted Areas and Pollutants from Chongqing’ s Livestock Industry

According to water function zoning regulations, Chongqing’ s water environment functional zones range from Class I to V. Based on each functional area’ s water function classification, we calculated pollutant equivalent standard discharge amounts and equivalent standard pollution load ratios . In 2013, the total equivalent standard discharge amount from Chongqing’ s livestock industry was 1.12×10^{11} m^{3}, comprising 1.44×10 m^{3} of COD, 7.94×10 m^{3} of TN, and

1.02×10^{11} m^3 of TP.

By ranking the equivalent standard pollution load ratios from largest to smallest and calculating cumulative ratios, the main pollutants (areas) are identified when the cumulative ratio reaches approximately 80%. The results indicate that the main polluted areas are the urban development area and the northeast ecological conservation development area, with TP as the primary pollutant. These findings align with the 2014 *Chongqing Environmental Quality Bulletin* regarding major pollutant emissions in the five functional areas.

Table 4 Equivalent standard discharge amounts and equivalent standard pollution loading ratios of livestock breeding in different functional areas of Chongqing, 2013

Functional Area	Equivalent Standard Discharge (10 $m^3 \cdot a^{1}$)	Equivalent Standard Pollution Loading Ratio (%)	Cumulative Ratio (%)
	COD	TN	TP
Urban Development Area			
Northeast Ecological Conservation Development Area			
Southeast Ecological Protection Development Area			
Urban Expansion Function Area			

Functional Area	Equivalent Standard Discharge (10 m³ · a ¹)	Equivalent Standard Pollution Loading Ratio (%)	Cumulative Ratio (%)
Urban Core Function Area			

The urban development area, as an industrial and agricultural center with policies promoting livestock breeding, represents a major pollution source. The northeast ecological conservation development area, a primary component of the Three Gorges Reservoir region and a key ecological barrier for the Yangtze River basin, has fragile ecological conditions vulnerable to water pollution. Therefore, strict ecological red lines and total quantity control measures must be established for the Three Gorges Reservoir.

2.3 Potential Water Environment Response to Livestock Breeding in Chongqing

To further analyze the potential impact of livestock breeding on Chongqing’ s water environment, we compiled surface water resource amounts (excluding transit water) for each functional area and calculated COD, TN, and TP pollution concentrations from livestock breeding using Equations (11) and (12), deriving single and comprehensive pollution indices . The single pollution indices show no exceedances for COD or TN, but severe TP exceedances. The comprehensive pollution indices range from 0.22 to 4.12, with only the urban development area and northeast ecological conservation development area exceeding standards.

Table 5 Potential water pollution index of livestock breeding in different functional areas of Chongqing, 2013

Functional Area	Surface Water Resource (10 m³)	Potential Water Pollution Index	Comprehensive Index
		COD	TN
Urban Core Function Area			
Urban Expansion Function Area			

Functional Area	Surface Water Resource (10 m^3)	Potential Water Pollution Index	Comprehensive Index
Urban Development Area			
Northeast Ecological Conservation Development Area			
Southeast Ecological Protection Development Area			

3 Discussion and Conclusions

The primary pollutant from Chongqing’ s livestock industry is TP, with the main polluted areas being the urban development area and northeast ecological conservation development area. Although these two functional areas face similar environmental problems, their different functional positions and environmental characteristics require differentiated protection policies. For the urban development area, ecological red lines should be established for important water sources, industrial planning implemented, and pollutant discharge standards for agricultural products formulated to support agricultural development. For the northeast ecological conservation development area, an ecological red line system should be implemented to protect the Three Gorges Reservoir water conservation zone, prohibiting projects that may damage ecological conservation functions. Although not a major polluted area, the southeast ecological protection development area has fragile ecology and underdeveloped environmental infrastructure, requiring resolution of conflicts between economic development and ecological security.

This study calculated livestock discharge coefficients based on Chongqing’ s actual breeding conditions and treatment patterns, proposing a breeding cycle correction method that resolves previous overestimation and underestimation issues. However, the pollutant reduction rates under various treatment patterns were adopted from national recommended coefficients, which may result in underestimation. Future research should investigate the effectiveness of various treatment measures on pollutant reduction in Chongqing. Additionally, to further analyze pollution status and risk levels, the range of pollutants should be expanded and refined to include ammonia nitrogen, phosphate, antibiotics, etc.

When analyzing potential water environment response characteristics, this study linked livestock pollution with the five functional areas based on Chongqing’ s special functional zoning, conducting comprehensive evaluations according to corresponding water environment standards in different regions. This approach more accurately reflects the pressure and actual response of livestock breeding on each functional area, providing scientific support for pollution prevention strategies. However, due to the lack of relevant water environment monitoring data at the district/county scale, analysis at that level was not conducted. Therefore, we recommend strengthening water environment monitoring systems to enable more detailed district- and county-level analyses.

In 2013, Chongqing’ s livestock breeding quantity was 411.81×10 pig equivalents, with actual discharge amounts of 2.27×10 t·a^{1} of manure, 1.66×10 t·a^{1} of urine, 3.03×10 t·a^{1} of COD, 0.72×10 t·a^{1} of TN, and 1.87×10 t·a^{1} of TP. The equivalent standard discharge amount was 1.12×10^{11} m^3, comprising 1.44×10 m^3 of COD, 7.94×10 m^3 of TN, and 1.02×10^{11} m^3 of TP. Based on pollutant discharge patterns and water environment functional zoning, the main polluted areas were identified as the urban development area and northeast ecological conservation development area, with TP as the primary pollutant. The comprehensive water quality index resulting from livestock breeding pollution ranged from 0.22 to 4.12, with exceedances occurring only in the urban development area and northeast ecological conservation development area.

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Note: Figure translations are in progress. See original paper for figures.