Measuring Pollutant Emissions of Cattle Breeding and Its Spatial-temporal Variation in China

Abstract

The rapid development of animal husbandry has brought serious pollution issues in livestock and poultry breeding industry, which increased the cost of environment management of world. This issue is particularly prominent in China due to its rapid economic development, giant domestic consumption and challengeable carbon neutrality target. The study analyses the pollution emission and spatial-temporal variation of cattle breeding industry of China. Using an emission coefficient method and a panel data of 31 provinces/municipalities of China during the time period of 2002 -2017, the study measures the total volume pollutant emissions and five major pollutants including chemical oxygen demand, nitrogen, phosphorus, copper and zinc of the cattle breeding industry of the country. The dynamic variation of the spatial distribution is further measured and analysed. The results show that both the total volume and the five major pollutants have decreased in different extents, though the spatial divergence is significantly strengthened. Specificly, the heavy pollution areas has transferred to the northwest of China.

Keywords: Cattle Breeding; Pollutant Emission; Spatial Distribution; Emission Factors

1. Introduction

The livestock and poultry breeding is important to livelihoods in the world, as it provides human increasing dietary consumption demand with the fast economic development (Tullo et al., 2019; Saka & Nguyen, 2017). Specifically, about 60% of the global biomass is consumed by the livestock industry each year which undermines the sustainability of the allocation of such a large amount of resources to the industry (FAOSTAT, 2016). Unfortunately, though it brings huge benefits to human being, poor management of the industry causes negative influences to the environment at both local and global level (Leip et al., 2015). This issue is particularly prominent in emerging economies due to its rapid economic development and challengeable carbon neutrality target, which has not yet been sufficiently studied though (Yang et al., 2020; Ayyildiz & Erdal,

2020).

The rapid development of animal husbandry has brought serious pollution issues in livestock and poultry breeding industry which aggravates the environment and increases the economic cost of environment management (Ramankutty et al., 2018; Leip et al., 2015). As one of the major sectors of the livestock and poultry breeding industry, the impacts of cattle breeding on the environment is extensive including the impacts on soil, land, water resources and climate (Li et al., 2016; Saka & Nguyen, 2017; Wang et al., 2021). The cattle breeding activities can lead to soil erosion and land degradation. For example, 26% of the land area in the world is used for livestock production, which leads to losing of land constantly (FAOSTAT, 2016). Meanwhile, the intensification of the cattle breeding is also related to surpluses of nitrogen and phosphorus inputs, which may lead to nonpoint source pollution of water resources of the environment (Mallin et al., 2015). Further, the cattle breeding is one of the major sources of greenhouse gases, freshwater usage and pollution, and also contributes to biodiversity (Syas et al., 2021; Yang et al., 2020). In order to balance the production of the livestock and the environment protection, it is important to develop efficient and sustainable treatments with pollutant emissions from the cattle breeding as is highly related to water, biodiversity, carbon sequestration, and resource protection (Rehman et al., 2021). As for the basic understanding of the pollutant emissions, it is crucial to measure and assess the specific environmental impact of livestock production in order to formulate strategies and make the system profitable, sustainable and resilient.

China is the largest producer and consumer of livestock and poultry products in the world, with its total output of meat and poultry eggs rank the first and milk the third of all countries (Animal Husbandry Department of the Agricultural Ministry in China, 2020); However, with the continuous expansion of scale of livestock and poultry breeding industry, the environmental cost has also risen greatly. The rapid development of animal husbandry of the country has brought serious pollution management issues in livestock and poultry feeding and nutrition industry of the country (Zhou, 2017; Lin, 2017; Rehman et al., 2021). According to China's 'Second National Pollution Source Census Bulletin' (SNPSCB, 2020), in the year of 2017, the total volume of chemical oxygen demand reached at 10,05,300 tons, accounting for 46.67% of the overall emission of all the industries and 93.76% of the agriculture industry of the country; the phosphorus of pollutants reached to 596,300 tons accounting for 93.76% of overall emission of all industries and 42.14% of the agricultural industries; the nitrogen of 119,700 tons accounting for 37.95% of all industries and 56.46% of the agricultural industries.

Previous studies on measurements of emissions of pollution is comprehensive by mixing all types of livestock and poultry with a few studies purely on pig breeding (Lin et al., 2017; Pei et al., 2008; Pan et al., 2016; Wang et al., 2017). Compared to pig feeding, researches on pollutant emissions from cattle breeding in China are even scarcer; However, the cattle breeding is significantly different from the pig breeding in terms of breeding methods, breeding scale, pollutant discharge treatments, and the conversion method through simple coefficients has major drawbacks. Though beef production in China is smaller than pork and poultry production, which was 6.346 million tons accounting for 7.33% of the overall meat production in 2017 (SNPSCB, 2020), the pollutant emissions from beef cattle breeding ranked the second in all the pollution emissions from livestock and poultry breeding (SNPSCB, 2020). The pollution emissions of dairy cattle breeding ranked the third just after the beef cattle breeding (SNPSCB, 2020).

Pollution emissions from the cattle breeding industry account for nearly one-third of the pollution emissions from the livestock and poultry breeding industry, which shows a necessity for more attention and in-depth research. There are several major chemical factor emissions in the cattle breeding industry may pose dangers to the environment as chemical oxygen demand, phosphorus, nitrogen, copper and zinc, which mainly have impact on soil and water (Tullo et al., 2019). The chemical oxygen demand shows an increasing trend in terms of the total volume. The pollutants discharged by beef and dairy cattle breeding reached to 1.6109 million tons and 1.4563 million tons in 2017 respectively, accounting for 16.1% and 14.55% of the total volume of livestock and poultry breeding industry (SNPSCB, 2020). Nutrients such as minerals and protein content are in surplus to the necessity of animals' needs. As a result of unbalanced application of the land and manure of cattle breeding, nutrients may seep from soils into surface ground, which cause the pollution of the quality of the water and soil (Almeida et al., 2017; Girard et al., 2014; Martinez, 2009). In addition of the nutrients, phosphorus can lead to eutrophication and ecological deterioration of the surface soil and water. Phosphorus is utilized inefficiently by the cattle, excreting 60 to 80% of that consumed (Knowlton et al., 2004). The combination of high soil content of the phosphorous with manure exceeds the crops need, which leads to the pollution in the environment (Carpenter et al., 1998). The copper and Zinc may also destroy the environment to the soil as they are even more difficult to be absorbed by plants (Mantovi et al., 2003).

This study estimates the emissions of chemical oxygen demand, phosphorus, nitrogen, copper and zinc emissions of the cattle breeding industry in 31 provinces/municipalities during the time period of 2002-2017 based on the characteristics of cattle breeding and pollutant treatment. Based on the country level

measurements, analysis of the spatial distribution of pollution emissions of cattle breeding at provincial level is further conducted.

2. Material and Method

2.1. Measurements on Pollution Emissions of Cattle Breeding Sites

This study adopts the emission coefficient method to calculate the pollution emissions of cattle breeding sites, which combines the methods in the guidelines in the "Manual of the First National Pollution Source Survey on Pollution Coefficients of Livestock and Poultry Farming Sources" published by the Ministry of Ecology and Environment of China. This emission coefficient method is widely used in the estimation of pollutant emissions from livestock manures believed a comprehensive and accurate estimation method of the true pollution emissions of livestock and poultry breeding (Lin et al., 2017; Pei et al., 2008; Pan et al., 2016; Wang et al., 2017).

2.1.1 Data Description

This paper targets on the five types of pollution emissions of cattle breeding site in 31 provinces of mainland China from 2002 to 2017. The data sources include the *China Animal Husbandry and Annual Statistics*, *China Agriculture Annual Statistics*, *China Dairy Industry Annual Statistics* and *China Agricultural Product Cost and Benefit Data Collection* (CBCDC). The emission coefficient data are obtained from *First National General Survey of Pollution Sources: Handbook of Pollution Emission Coefficients of Livestock and Poultry Breeding* (*National Pollution Source Survey*).

2.1.1.1 Feeding Amount and Cycle

Cattle breeding includes both beef cattle and dairy cattle breeding. The number of breeding is determined by the growth cycle. The average growth cycle of beef cattle is less than one year (CBCDC). The number of cattle slaughtered in that year is calculated as the breeding quantity. The breeding cycle is calculated according to the actual breeding days. The growth cycle of dairy cattle is longer than one year. The stock of the year is calculated as the feeding amount. The feeding cycle is 365 days.

2.1.1.2 Pollution emission Coefficient

The choice of emission coefficient is crucial to result of emission measurement. The statistical criteria and measurement methods of the emission coefficients vary in different regions of the country. We adopt the data from the first national pollution source census recommended by the Ministry of Environmental Protection of

China to avoid region differences (Wang et al., 2017). The coefficients are used to measure the five types of pollution emissions including chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), copper (Cu) and zinc (Zn) in 31 provinces of China (Tullo et al., 2019).

2.2. Measurement of Pollution Emission of Beef Cattle Breeding

The emission coefficients of the beef and the dairy cattle breeding are different. Thus we calculate the total emissions and emission factors of the two types of cattle in different ways. The total emissions of beef cattle breeding are mainly determined by the pollution emissions of single beef cattle and the number of beef cattle slaughtered by the end of the year. The calculation formula is as follows:

$$EBC_{it}^j = NSBC_{it} \times FD_{it} \times ECBC_{it}^j \qquad （1）$$

EBC_{it}^j is the total emissions of type j pollution caused by the beef cattle breeding in province i in year t (i=1,2, …31, t=2002, 2003,…2017, j= chemical oxygen demand, TN, TP , Cu, Zn). $NSBC_{it}^j$ represents the number of the beef cattle slaughtered in province i in year t. FD_{it} is the average days of the cattle breeding in province i in year t. $ECBC_{it}^j$ represents the comprehensive emission coefficients of type j pollutants in province i in year t.. Since the data in CBCDC only counts the number of days of beef cattle breeding in the major provinces, the study uses the national average to supplement the provinces without statistical data.

The *National Pollution Source Survey* provides the major pollution emission coefficients include two groups of organizers as large-scale breeding farms and individual households. The Survey defines a standard for differentiating the two scales as follows: large-scale farms are defined as with the slaughter scale of beef cattle more than 200 heads; Individual households between 10 to 200 beef cattle. The statistics of less than 10 cattle are not available. Considering that the small-scale breeding sites may deal with pollutants such as beef cattle manure by artificial methods, the pollutant emission coefficient is similar to the professional ones. Therefore, this study adopts the individual households for the small-scale for substitute value of the emission coefficient. Due to the fact that the classifications of the large-scale farms in the CBCDC and the *China Animal Husbandry and Veterinary Annual Statistics* does not match with the *National Pollution Source Survey*, the study uses the number of 200 as for the line of the large-scale of beef cattle breeding. Further it re-builds the pollution emission coefficient $ECBC_i^j$ with the coefficient of large-scale and individual household of beef cattle breeding. The calculation formula is as follows:

$$ECBC_i^j = (\phi_{1i}\theta_{1i}^j + \phi_{2i}\theta_{2i}^j)/(\phi_{1i} + \phi_{2i}) \qquad （2）$$

ϕ_{1i} represents the total number of beef cattle slaughtered by all farmers in province i, where the number of beef cattle slaughtered is less than 200, while ϕ_{2i} represents the number larger than 200 heads. θ_{1i}^j and θ_{2i}^j

represent the pollution emission coefficient of the type j for the large-scale farms and individual household of livestock and poultry breeding respectively.

2.3. Measurement of Pollution Emission of Dairy Cattle Breeding

The *National Pollution Source Survey* divides the feeding cycle of dairy cattle into two stages: The production of breeding and milk. The average emission coefficient of major pollutants of the two stages is provided via fixed-point observations in different regions with the measurement unit of grams/head/day. As the average breeding period of dairy cattle exceeds more than 1 year, the number of breeding days per year is recorded as 365 days. The formula of calculating the main pollutant emissions of dairy cattle breeding in each province is shown as follows:

$$EC_i^j = NC_i \times ECC_i^j \times 365 = \{[\delta_{1i}^j \times \lambda_i + \eta_{1i}^j \times (1 - \lambda_i)]\varphi_{1i} + [\delta_{2i}^j \times \lambda_i + \eta_{2i}^j \times (1 - \lambda_i)]\varphi_{2i}\} \times 365 \qquad （3）$$

Where EC_i^j represents the total emissions of the main pollutant j from dairy breeding in province i in the year. NC_i is the number of dairy cattle, including the number of bred cattle dairy cattle. ECC_i^j refers to the comprehensive emission coefficient of pollutant j from dairy cattle breeding in the area. δ_{1i}^j represents the emission coefficients of dairy cattle in breeding sites where the number of dairy cattle is less than 100, while δ_{2i}^j represents the size more than 100. η_{1i}^j indicates the number of dairy cattle less than 100, while η_{2i}^j indicates the number more than 100. $\varphi_{1i}\ and\ \varphi_{2i}$ represent the total number of dairy cattle of the above two types scale size in the province respectively. Similarly to the beef cattle, as the *National Pollution Source Survey* does not provide the emission coefficient of the scale for less than 5 dairy cattle, this study adopts the data of individual household for the small-scale breeding sites. The coefficient of the dairy cattle by individual household is valued as φ_{1i}. $\lambda_{i\_}$i is the ratio of the number of bred dairy cattle to the total number. The study sets the parameter to 57.5% as following the previous studies (Lin et al., 2017).

3. Results and Discussions of pollutant emissions of cattle breeding

3.1. Development Trend of Emission Factors

The emission factor (EB_i^j) is used to measure the average emission value of pollutants j per cattle in a certain area. It is calculated by the weighted average of the intensity of the pollutant emission of beef and dairy cattle breeding in the area. The formula is as follows:

$$EB_i^j = (EBC_i^j + EC_i^j)/(NSBC_i + NC_i) \qquad （4）$$

where EB_i^j is the emission factor of pollutant emission from cattle breeding in province i in that year. (The measurements of EBC_i^j and NC_i as for the emission of beef and dairy cattle has been illustrated above.)
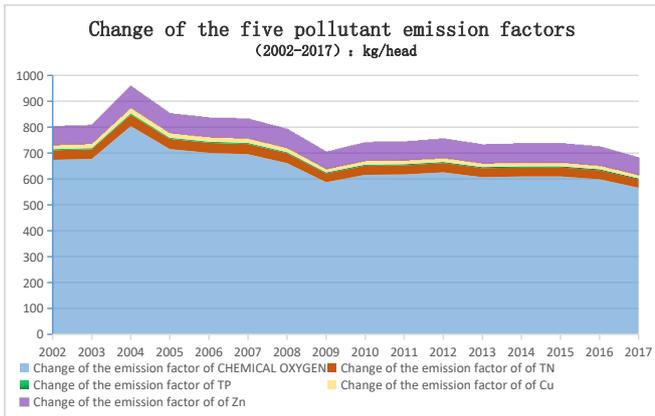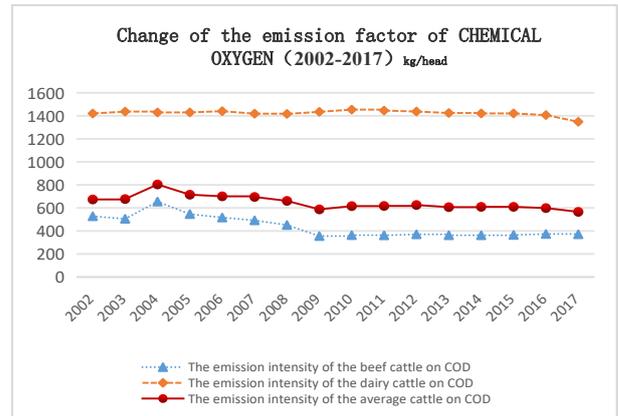
Figure 1：Change of the five pollutant emission factors
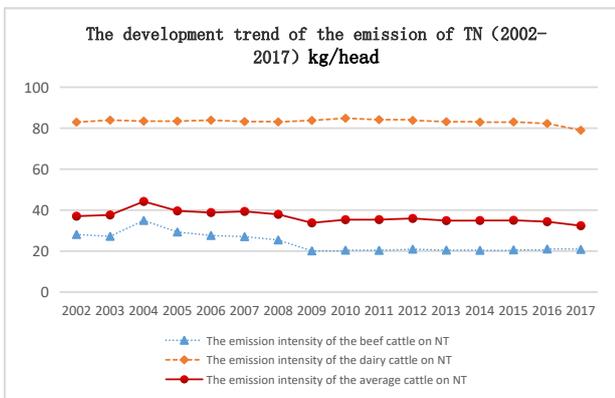

Figure 2a： Change of the emission factor of COD

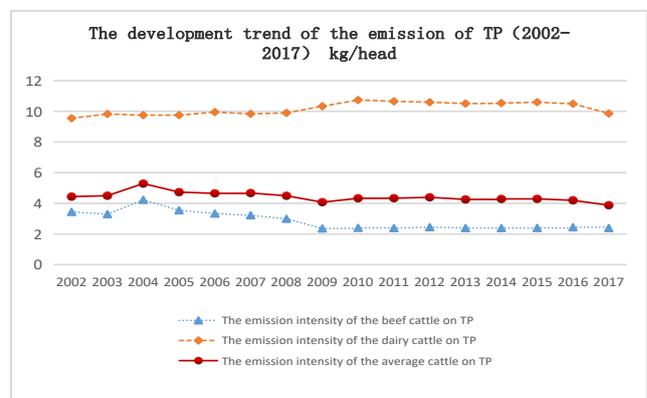Figure 2b： The development trend of the emission of TN

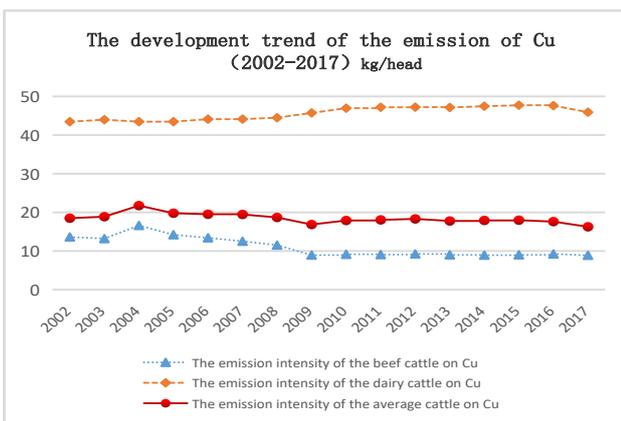Figure 2c： The development trend of the emission of TP

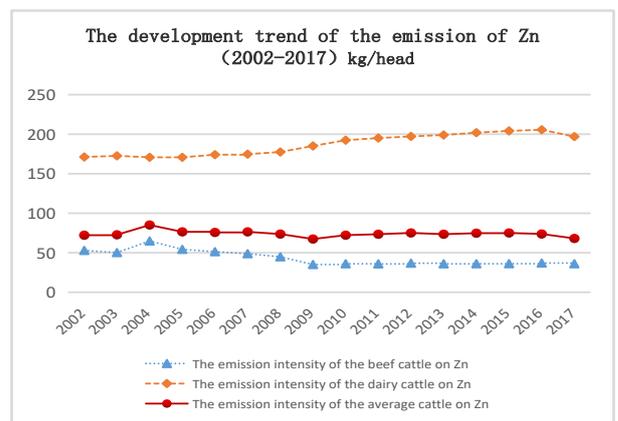Figure 2d： The development trend of the emission of Cu

Figure 2e： The development trend of the emission of Zn

During the time period between 2002 and 2017, the chemical oxygen demand of cattle breeding in China showed a downward trend, from 673.78 kg/head in 2002 to 565.89 kg/head in 2017 with a decreasing rate of

19.06% (See Figure 1). Specificly, it shows a rapid decrease from 2016 to 2017 with a dropping rate of 5.8%. The other four types of pollutants including the nitrogen, phosphorus, copper and zin show a similar overall decreasing trend with fluctuation in some specific years (e.g. an obvious increasing in 2004 and dropping in 2009).

In terms to the specific contributions of each pollutants of cattle breeding breeds (Figure 2a-2d), it is found that the emission intensity of the dairy cattle is stronger than that of the average as two times larger than the general. Conversely, the emission intensity of the beef cattle is lower than the general. Overall, the emission intensity of the beef cattle shows a decreasing trend whilst that of the cattle breeding shows in an opposite way, particularly for the factors of phosphorus, copper and zinc pollutants.

The sub-national region differences are significant, compared with the relatively smooth fluctuation of the pollutants emission of the country within 16 years. Figure 3 shows the development trend of chemical oxygen demand emission in the major provinces between 2002 and 2017. With the background of the national average value decreasing significantly, provinces show inconsistent evolvement trends. Taking Jilin province for example, the emission factor has declined rapidly from 1008 kg/head to 511 kg/head with a decreasing rate of 97.28%; That of Inner Mongolia has also fallen by more than 50%. For the provinces such as Beijing and Shanxi the change is relatively insignificant. For the provinces as Ningxia and Anhui the emission factors have increased. The emission factor changes of various provinces show a more obvious trend of divergence. It is also found that the absolute value of emission factors of each provinces also varies greatly.
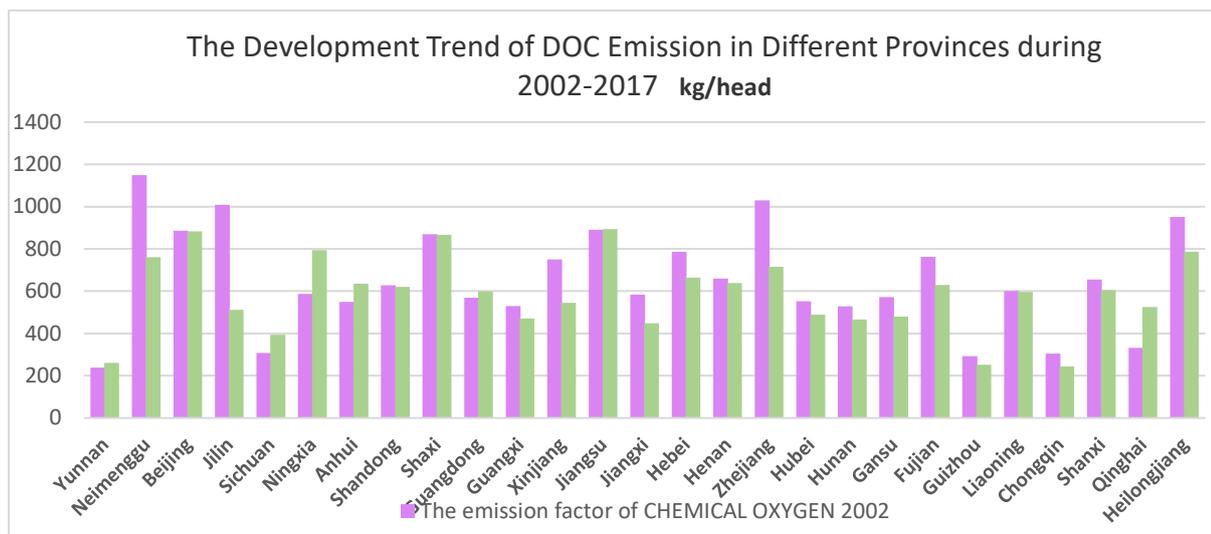

The Development Trend of DOC Emission in Different Provinces during 2002-2017 kg/head

The emission factor of CHEMICAL OXYGEN 2002

Figure 3： The Development Trend of DOC Emission in Different Provinces during 2007-2017
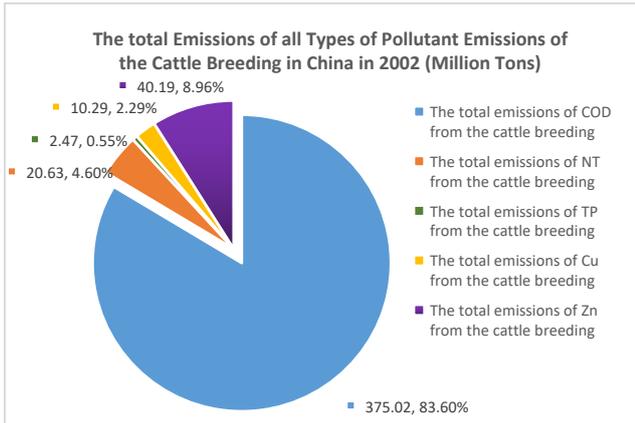
3.2.   Results of the Total Emissions

Figure 4a. The total Emissions of all Types of Pollutant Emissions of the Cattle Breeding in China in 2002
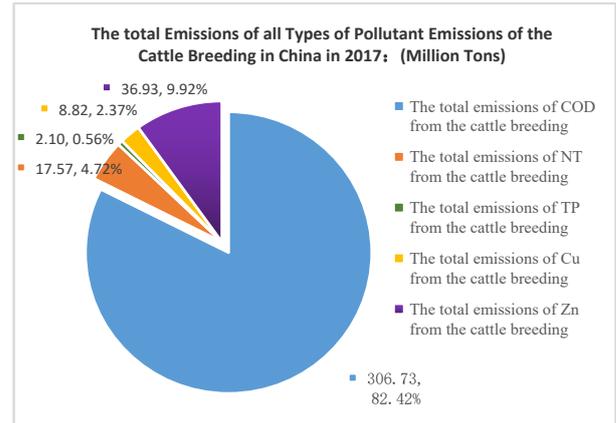

Figure 4b. The total Emissions of all Types of Pollutant Emissions of the Cattle Breeding in China in 2017

The total emissions of pollutants from the cattle breeding is equal to the product of the emission factors of all pollutants and the total number of the cattle breeding in the year. During the time period of 2002-2017, the five types of the pollutant emissions have decreased in varying extents in China. The chemical oxygen demand decreased most significantly as from 3.75 million to 3.06 million tons with the decreasing rate at 22.26%. Meanwhile the reduction of other pollutant emissions was about 17%. In terms of the distribution of all types of the emission, the zinc increased the fastest from 8.96% to 9.92%. The chemical oxygen demand decreased most significantly with a decreasing rate of 1.18% over the 15 years (see Figures 4a and 4b).
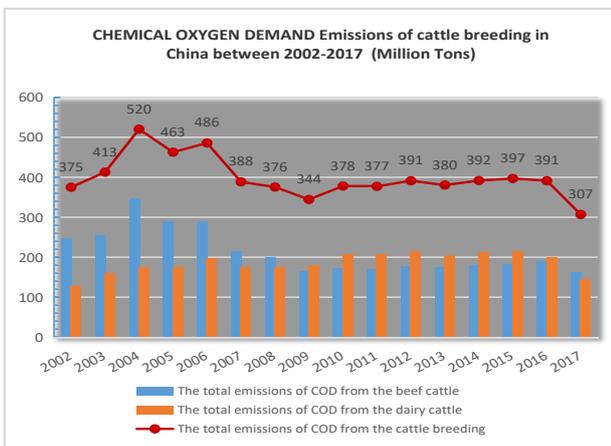

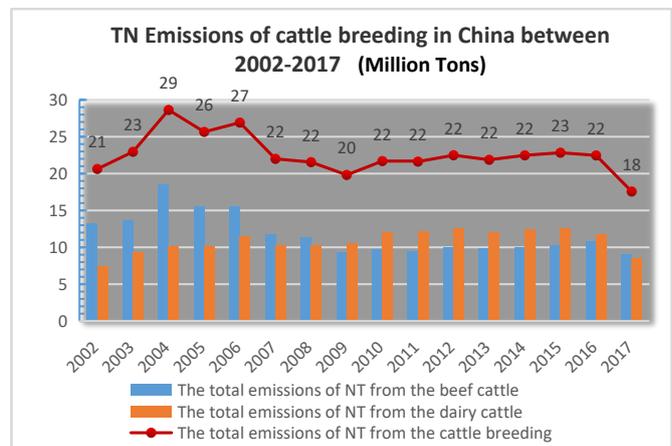Figure 5a： CHEMICAL OXYGEN DEMAND Emissions of cattle breeding in China between 2002-2017

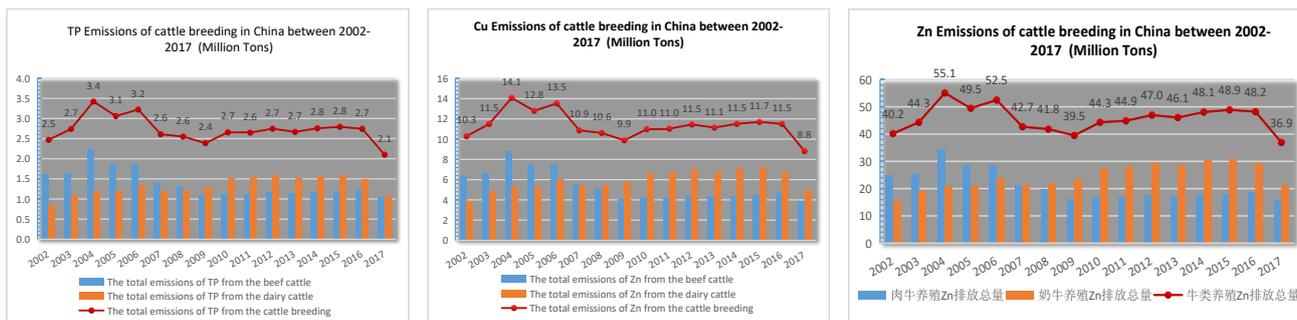Figure 5b： TN Emissions of cattle breeding in China between 2002-2017

Figure 5c：TP Emissions of cattle breeding in China between 2002-2017   Figure 5d：Cu Emissions of cattle breeding in China between 2002-2017   Figure 5e：ZN Emissions of cattle breeding in China between 2002-2017

Figures 5a-5d show the development trend of the five major pollutant emissions from the cattle breeding in China from 2002 to 2017. As shown in the figures the trends of all types of the pollutants emissions evolve similarly. All of them present an M-shaped curve which signifies that the emissions increased rapidly from 2002-2004, decreased gradually from 2004-2009, increased slowly from 2009-2016, and dropped sharply in 2017. This is highly consistent with the development trend of the emission factors. In terms of the differences from the beef and dairy cattle, it is noticed that the emissions from the beef cattle accounted for a large proportion before 2009. The emissions from the dairy cattle have exceeded that of the beef since 2009. However, the proportions of emissions from the two types of cattle diverged in different types of the pollutant emissions in 2017: For the emissions of chemical oxygen demand and the nitrogen, the beef cattle exceeds the dairy cattle. For the emissions of phosphorus, copper and zinc, the dairy cattle exceeds the beef one.

3.3.   Results of Spatial-temporal Variation

Both of the total emissions and the five types of emission factors declined from 2002 to 2017 in China, which indicates that the pollution is managed and controlled to a certain degree during the period; However, the alleviation of the pollution varies among provinces. Figures 6a and 6b present and development trends of the total emissions and the five types of pollutant emission and compare the provincial differences in China during the time period of 2002-2017 by adopting the median method. In 2002, the areas with high chemical oxygen demand emissions from cattle breeding in China were mainly located in the north, northeast of the country and Xinjiang province; The medium-pollutant emission areas were in the central and southern of the country; The low-pollution emission areas were mainly in the eastern coast area, and several other provinces/municipalities as Chongqing, Guizhou and Qinghai. The five emission factors including total nitrogen, total phosphorus, copper and zinc keep consistent development trends compared with that of the total emissions. It further shows that the high pollution areas had gradually transferred to the northwest of the country by 2017, which is

consistent with the previous studies (Pei et al., 2008; Wang et al., 2017). Taking chemical oxygen demand emissions for instance, with the exceptions of Northeast and Xinjiang, which had been of high-pollution provinces since 2002, Gansu and Sichuan have turned into high-pollution areas from low-pollution ones by 2017; Qinghai and Ningxia have turned into medium-changed from low-pollution areas. However, Anhui province has turned into the low-pollution area from high pollution one.

Spatial Distribution of Pollutant Emissions of the Cattle Breeding at Provincial level of China in 2002
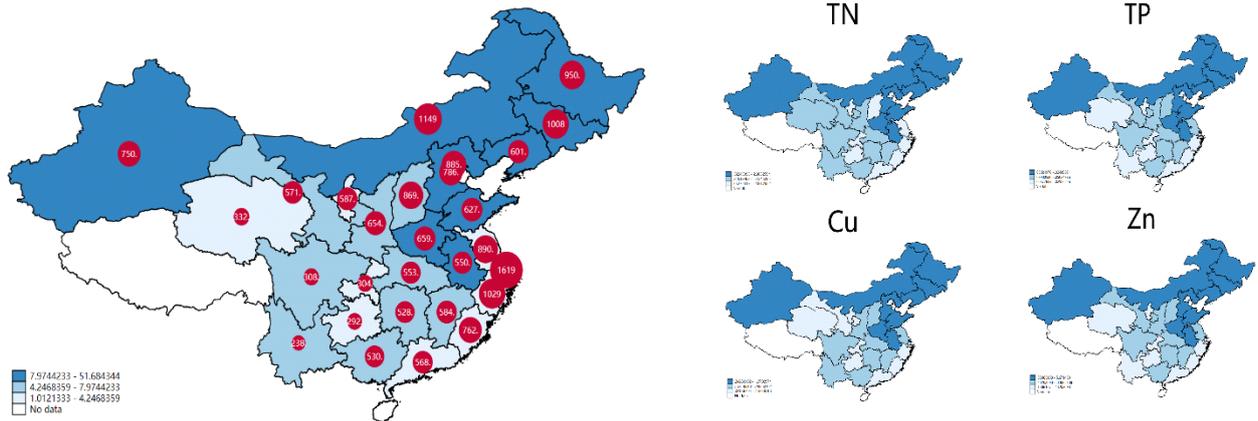

Figure 6a. Spatial Distribution of Pollutant Emissions of the Cattle Breeding at Provincial level of China in 2002

Spatial Distribution of Pollutant Emissions of the Cattle Breeding at Provincial level of China in 2017
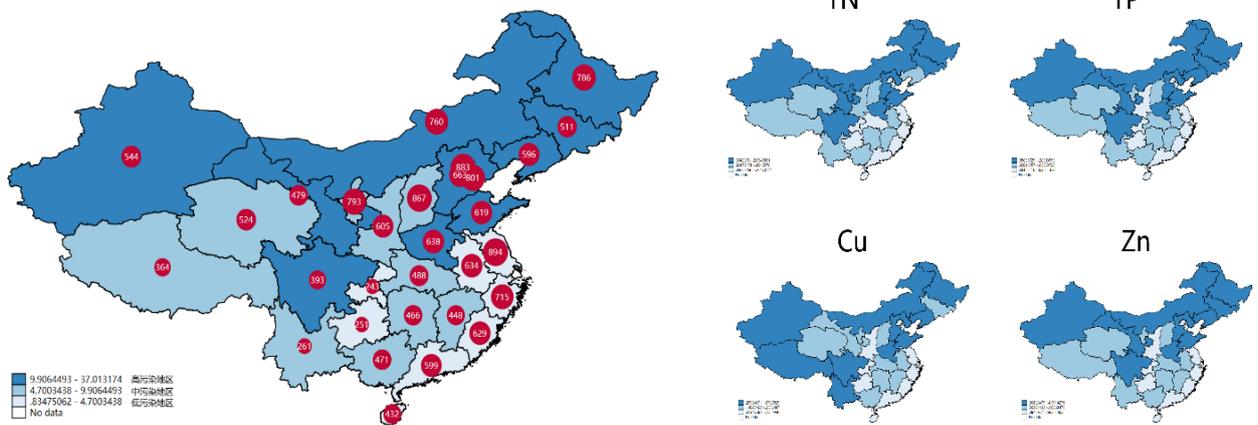

Figure 6b. Spatial Distribution of Pollutant Emissions of the Cattle Breeding at Provincial level of China in 2017

Combined with the results of pollution emission factors at provincial level, it is found that the emission factors in the eastern coastal areas are comparatively high though the total pollution emissions is low. A possible explanation could be related to the small scale of the cattle breeding in these areas. Due to the small scale of the cattle breading, it is difficult to form a scale effect of management of the pollutant emissions.

Therefore, the pollutant emission factors in the above provinces have been kept high during all these years. In contrast, the emission factors of provinces as Sichuan, Gansu, and Jilin with high total emissions level are comparatively low, namely, at 393, 479, and 511 respectively, which are all smaller than the national average emission factor of the year. It signifies a comparatively high efficiency in pollution emission control from, which also contributes to pollution management for the whole industry.

4. **Conclusions and Practical Implications**

By using the emission coefficient method, this paper measures the total and emission factors of the major five pollutants of the cattle breeding industry, including chemical oxygen demand, the total nitrogen, total phosphorus, copper and zinc of the country and 31 provinces/municipalities respectively. It further measures the spatial-temporal variation. There are major four conclusions related to the results of the measurements. First, as the second largest source of pollution emissions of the animal husbandry, the chemical oxygen demand emissions from the cattle breeding account for almost one third of the whole livestock breeding industry, which shows a significant role in pollution management of ecological agriculture economics of the country. Second, all types of emissions and emission factors of the pollutants from cattle breeding showed a decreasing trend during the observation period from 2002 to 2017. Specificly, the total emissions of chemical oxygen demand declined the fastest with the other four types of pollutants also declined though in a more mild speed. Compared with the dairy cattle breeding, the reduction of the pollutant emissions from the beef cattle breeding are more obvious. Third, the development trends of five emission factors vary in different provinces. From 2002 to 2017, the pollutant emission factors of most provinces showed a downward trend with exceptions of a few provinces in an opposite way. Fourth, in terms of the spatial distribution of pollutant emissions from the cattle breeding, the provinces in the northern areas of the country are generally more serious than those of the central and southern areas; whilst the provinces in the eastern coastal areas are with the lowest emissions. During the observation period, the high pollution of the industry had gradually moved towards the northwest of the country. It is assumed that this transferring may be related to the agglomeration of the industry in the northwest areas of China.

The study provides two practical implications for the management of the pollution and ecological environment particularly in the livestock and poultry breeding industry of the agriculture economy. First, it is important and urgent to include the small-scale cattle breeding sites into the general monitoring and statistics system. The current statistical system lacks data on breeding sites for beef cattle with the small number;

However, it is found that the small-scale breeding sites actually accounts for a considerable proportion of the total number of the pollutant emissions. The high emission factor of small-scale cattle breeding sites may be also related to the lack of systematic monitoring and management. Second, the governance of the pollutant emissions of the industry should be heterogeneous in accordance with different types of the emissions. Due the significant differences in types of cattle, regions, scale of the sites, and discharge treatments of the emissions, heterogeneous standards and policies in in monitoring and management, and also ecological resource utilization treatments technologies are urgently needed and encouraged.

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