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The pollutants from livestock and poultry farming in China—geographic distribution and drivers

Ling Gan[1] · Xisheng Hu[2]

Abstract Livestock and poultry farming is a major source of agricultural pollution. However, our knowledge of the constraining factors of the geographic distribution of pollutants from livestock and poultry farming is still limited. In this study, using the optimized pollutant generation coefficients, we estimated the annual pollutant productions of eight livestock and poultry species at the provincial level in 2005 and 2013 and their growth rates during the study period in China; using canonical correlation analysis, we also explored the association between the eight pollutant measurements as dependent variables and 14 factors (including resource endowment, developmental level, and economic structure factors) as independent variables. Results indicate that there exist spatial disparity in the distribution of pollutants from livestock and poultry farming across regions, with provinces in the Huang-Huai-Hai region and the southwestern region accounting for approximately 50 % of the total productions in the nation. Cattle, pig, and poultry constitute the primary pollution sources in terms of livestock and poultry farming not only at the national level but also at the province level. While the species constitute and their respective growth rates of the pollutants can be also characterized by spatial disparity across regions, canonical correlation analysis shows that the observed regional patterns of the pollutants can be largely explained by the resource endowment factors (positive effects) and the developmental level factors (negative effects). In addition, we found that the development of livestock and poultry farming is negatively associated with the growing rate of both the resource endowment and the socioeconomic factors. This indicates that there exist different driving patterns in the gross and increment of the pollutant productions. Our research has significant implications for the appropriate environmental protection policy formulation and implementation in livestock sector.

Keywords Livestock and poultry farming · Pollutant · Distribution · Driver · Canonical correlation analysis · China

Introduction

The environmental impact of livestock and poultry farming has received increasing attention over the last years, because it is responsible for 18 % of the global emission of greenhouse gases (Steinfeld et al. 2006a). The rate of change and direction of livestock development vary greatly among world regions, with Asia showing the most rapid growth and structural change (Steinfeld et al. 2006b), especially in China. In the nation, the proportion of livestock and poultry output in agricultural products had increased from 18 % in 1980 to 30 % in 2010 and has increased more rapidly in recent years (Fu et al. 2012). As a result, China has become one of the global leaders in large-scale livestock and poultry farming (Peng et al. 2014). The rapid development of large-scale livestock farming has resulted in increased pressure on the environment in China (Chen 2012). On the one hand, livestock and poultry farming

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has improved the agricultural efficiency and income of farmers, but on the other, it has aggravated environmental pollution with a significant amount of manure and sewage being generated simultaneously. Specifically, there has been increasing evidences indicating that the diffusion of agricultural pollution from livestock and poultry farming has become a particularly serious problem in China's water quality management in recent years (Sun and Wu 2013). However, due to different natural and socioeconomic conditions, materials, and technical equipment, as well as numerous other factors and constraints, a significant gap has been observed in the development level and effects of livestock and poultry farming on environment across regions in China (Peng et al. 2014). Therefore, to gain more benefits from livestock and poultry farming and simultaneously promote the sustainable development of natural resources, it is a prerequisite to know the spatial distributions of the farming and their drivers.

Extensive research has been carried out into environmental pollution from livestock and poultry farming in China at different scales, such as national scales (e.g., Sun and Wu 2013), regional scale (e.g., Gu et al. 2008), and local scale (e.g., Peng et al. 2014). Research on livestock and poultry farming pollution in China began in the 1980s with investigations on water pollution (Sun and Wu 2013). The first nationwide pollution source census for livestock and poultry farming was launched in 2007. The census revealed that the livestock and poultry farming accounted for 38 and 56 % of total agricultural nitrogen and phosphorus non-point source pollution, respectively (MoEP 2010). Study on regional pollution from livestock and poultry rearing, such as the Yangtze Delta, indicated that animal husbandry was considered to be one of the main pollution sources of Tai Lake, which affected millions of people's daily drinking water (Gu et al. 2008). Local researches on livestock and poultry farming tend to focus on environmental and land-carrying capacity, such as animal manure load grading and land accommodation degree (Caldwell 1998; Duan et al. 2007). However, there are few studies on the spatial distribution of pollutants from livestock and poultry farming to be performed for all the provinces in China. Although Sun and Wu (2013) estimated pollutant loads from livestock and poultry raising from 2000 to 2010 at the province level, it used fixed parameter as the amount of pollutants produced per animal per day to estimate gross pollutants for different provinces, tending to ignore the spatial heterogeneity of pollutants generated coefficients in different regions. To improve the accuracy of estimated pollutant productions, Zhou et al. (2014) proposed the optimized pollutant generation coefficients of different livestock and poultry species for 31 provinces in China. With the consideration of spatial heterogeneity, the coefficients are more applicable to reveal the spatial distribution of pollutant production

of livestock and poultry farming. For this reason, this study will apply these optimized coefficients to estimate pollutant productions at the provincial and national levels in China.

Changes in the pollutants from livestock and poultry farming are associated with changes in their spatial distribution. Livestock and poultry distribution is driven by several processes operating at multiple scales, such as changes in (global or national) markets and trade, regional changes in resource suitability, agricultural and environmental policies, as well as local environmental constraints and both production conditions and technology (Neumann et al. 2011). Steinfeld et al. (2006a, b) discussed the drivers of global livestock production and described the global drivers of the livestock sector, including economic growth and income, demographic and land use changes, dietary adjustments and technological change, and potential policy options for environmental impact of livestock. At the national scale, Li (2009) highlighted that the economic reform program had stimulated the rapid development in livestock and poultry farming in China. Fu et al. (2012) pointed out that the spatial patterns of the livestock and poultry farming in China were influenced by agricultural scale and level, cultivated land area, as well as population density. At the regional and local scales, several works have reported that the regional development of livestock and poultry farming requires considerations of natural and socioeconomic conditions, materials, and technical equipment, as well as numerous other factors and constraints (Gu et al. 2008; Peng et al. 2014). Because of these interacting processes, China's livestock and poultry distribution is very heterogeneous, so does the pollutants, being characterized by regional concentrations which indicated there existed a potential uniform districting scheme for China's livestock and poultry farming (Fu et al. 2012). Although Fu et al. (2012) and Sun and Wu (2013) have investigated the spatial distribution of livestock and poultry farming and revealed the spatial-temporal distribution of pollution constitution at provincial and national levels in China, our knowledge of the constraining factors of the livestock and poultry farming is still limited. The correlation analysis involved in the natural and socioeconomic conditions with the pollutants from the livestock and poultry farming is insufficient. The pollution produced by animal husbandry requires a driving assessment to assist in the formation of appropriate policy.

Livestock and poultry often cover several major species: cattle, pig, sheep, horse, donkey, mule, rabbit, and poultry (Steinfeld et al. 2006b; Gu et al. 2008; Sun and Wu 2013). When exploring the effects of natural and socioeconomic conditions on the pollutants from livestock and poultry farming, study requires data that include both a set of natural and socioeconomic variables and a set of pollutant variables. Routine statistical approaches such as multiple linear regressions used to analyze the relationship between these two

groups of variables are usually challenged by the potential issues of multiple testing and multicollinearity (Sherry and Henson 2005), since canonical correlation analysis (CCA) assesses the correlation between two composite variables, which may be a useful method to evaluate the effect of natural and socioeconomic factors on pollutants from livestock and poultry farming (Kabir et al. 2014). CCA is the most general case of general linear model and thus it can be used to conduct the univariate and multivariate analyses (Fornell 1978; Baggaley 1981). Although CCA has been used currently in many branches of researches, such as social and behavioral research (Sherry and Henson 2005), bioinformatics (Tripathi et al. 2008), genetics (Hidalgo et al. 2014), environmental research (Liu et al. 2009), and animal breeding (Cankaya et al. 2008; Ventura et al. 2011), etc., there is, however, a lack of studies using CCA to observe the relationship between pollutants from the livestock and poultry farming and natural and socioeconomic factors. Hence, the objectives of this study are to (1) use the optimized pollutant generation coefficients to quantitatively estimate the spatial-temporal distribution of total amount and change rate of pollutants produced by livestock and poultry farming between 2005 and 2013 at the provincial and national levels and (2) apply CCA to estimate the relationship of the pollutants from the eight livestock and poultry species and the natural and socioeconomic factors.

Materials and methods

Data sources

The statistic populations of cattle (including dairy cattle and beef), pig, poultry (including laying hen, broiler, duck, and geese), sheep, horse, donkey, mule, and rabbit in 2005 and 2013 at the province level were collected from China Animal Industry Yearbook (2006, 2014). The resource endowment and socioeconomic data of 2005 and 2013 at the province level were obtained from China Statistical Yearbook for Regional Economy (2006, 2014).

Pollutants from livestock and poultry farming

It has been indentified that it has multiple relationships between the amount of manure and the productions of major compositions of pollutants from livestock and poultry farming, such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonia-nitrogen (NH_3-N), total phosphorus (TP), and total nitrogen (TN) (Costanza et al. 2008). With the consideration of main objects of this study to observe the spatial distribution and drivers of pollutants from livestock and poultry farming, we calculated the amount of manure to represent pollutant generation level instead of the specific chemical compound of pollutants. The measures of

total annual pollutant productions for each category of livestock and poultry species and those in each province are as Eqs. (1) and (2), respectively.

$$Q_{m,k} = G_{m,k} \times T_m \times Y_{m,k} \qquad (1)$$

$$Q_k = \sum Q_{m,k} \qquad (2)$$

where $Q_{m,k}$ represents the total annual pollutant production for livestock and poultry species m in province k, then Q_k the total annual pollutant production from livestock and poultry farming in province k; $G_{m,k}$ is pollutant generation coefficient for livestock and poultry species m in province k (Table 1); T_m is the rearing period of each livestock and poultry species in a year (365 days); $Y_{m,k}$ is the number of livestock and poultry species m per year in province k. To simplify the processes of environmental impact assessment, we assigned the coefficient values of pollutants from each livestock and poultry species in accordance with the nearest equivalent livestock category, e.g., poultry (laying hen, broiler, and duck) equates to the average value of broiler's and laying hen's coefficients and cattle (dairy cattle and beef) equates to the average value of dairy's and beef's coefficients. Pollutant generation coefficients of sheep, rabbit, horse, donkey, and mule equal to 1.7, 0.11, 15.988, 11.76, and 11.76 kg/day each, respectively, according to published values for the livestock and poultry (Zhou et al. 2014).

To further investigate the dynamic of livestock and poultry farming, the annual change rate of pollutant of each province was employed to reflect the dynamic degree of regional differences in livestock and poultry farming. The annual change rate was calculated as follows:

$$p_{m,k} = \left(\sqrt[t1-t0]{Q_{m,k}^{t1} \Big/ Q_{m,k}^{t0}} - 1 \right) \times 100 \ \% \qquad (3)$$

where $p_{m,k}$ is average annual change rate of pollutant for livestock and poultry species m in province k, and $Q_{m,k}^{t1}$ and $Q_{m,k}^{t0}$ are the total annual pollutants for livestock and poultry species m in year t_1 and t_0 in province k, respectively.

CCA

CCA is a multidimensional exploratory method that can facilitate the study of linear interrelationships between two groups of variables. CCA develops canonical variates that maximize the correlations between the two composite variables, which are based on correlation between a linear combination of dependent variables and a linear combination of independent variables (Hidalgo et al. 2014). Each linear combination (i.e., canonical variate) is independent (orthogonal) from the others so that they represent different relationships among the groups of dependent and independent variables (Stewart and

Table 1 Pollutant generation coefficients of the livestock industry at provincial level in China (kg/day)

Province	Dairy cattle	Beef	Pig	Broiler	Laying hen
Anhui	42.475	22.474	2.77	0.22	0.113
Beijing	42.393	24.432	4.288	0.107	0.16
Chongqing	44.983	23.897	5.135	0.06	0.12
Fujian	48.293	23.928	3.884	0.197	0.125
Gansu	39.247	23.348	5.03	0.18	0.095
Guangdong	46.065	23.026	4.315	0.088	0.121
Guangxi	51.267	26.218	5.13	0.06	0.12
Guizhou	51.238	27.455	5.063	0.06	0.12
Hainan	46.9	23.235	3.49	0.06	0.12
Hebei	42.02	21.555	3.215	0.12	0.165
Heilongjiang	47.745	23.271	4.303	0.14	0.12
Henan	42.157	22.049	4.477	0.077	0.117
Hubei	51.267	26.218	4.093	0.06	0.12
Hunan	53.45	27.436	4.4	0.06	0.12
Inner Mongolia	48.01	25.368	4.863	0.12	0.165
Jiangsu	46.478	23.474	3.547	0.197	0.123
Jiangxi	43.3	22.335	4.13	0.06	0.123
Jilin	47.057	23.099	4.303	0.14	0.12
Liaoning	45.15	22.623	4.665	0.14	0.133
Ningxia	36.935	22.963	5.098	0.17	0.103
Qinghai	39.247	23.348	5.03	0.18	0.095
Shandong	41.467	22.222	2.77	0.22	0.125
Shanghai	45.238	23.164	3.603	0.165	0.113
Shanxi	42.02	21.555	3.215	0.12	0.165
Shanxi	42.723	23.22	5.098	0.153	0.113
Sichuan	48.317	26.119	4.803	0.06	0.12
Tianjin	48.013	25.369	3.85	0.12	0.165
Tibet	48.317	26.119	4.983	0.06	0.12
Xinjiang	39.247	23.348	5.03	0.18	0.095
Yunnan	53.793	29.052	3.947	0.067	0.13
Zhejiang	44.581	23	3.747	0.17	0.15
Average	45.464	24.03	4.267	0.123	0.126

Note: data cited from Zhou et al. (2014)

Love 1968). Such combinations of variables are very useful for comparison and prediction (Johnson and Wichern 1986). Since loadings of the individual variables differ in each canonical variate and represent variables' contributions to the specific relationship being investigated (Kabir et al. 2014), we applied three criteria to choose the most legitimate canonical variate, which are (i) magnitude of the canonical correlation like multiple regression's R^2 statistic, (ii) level of significance, and (iii) redundancy measures of the percentage of variance accounted for from the two data sets (Hair et al. 1998). We also interpreted the most used test, the chi-square, for statistic significance of each canonical variate. In this analysis, we applied the criterion of a correlation significance level

of 5 % and redundancy coefficient of 0.15 to choose the interpretable canonical variates.

To determine the relative importance of each original variable in to each function, three methods have been proposed (i) canonical weights (standardized coefficients), (ii) canonical loadings (structural correlations), and (iii) canonical cross-loadings. As the canonical weights, like regression weights, are vulnerable to multicollinearity, most of the literature suggests using canonical loadings or crossing loadings (Thompson 1991). We used both loadings and cross-loadings; however, there is no established cutoff. There is a rule of thumb if any variable loading is >|0.30| then it can be considered to be an important contributing variable into the function (Kabir et al. 2014).

The dependent variables were the pollutant productions of the eight categories of livestock and poultry (cattle, pig, poultry, sheep, horse, donkey, mule, and rabbit) in each province. The independent variables were grouped into three categories: (i) resource endowment factors related to objective conditions of the breeding, including per capita water resources (PCWR), per capita forest area (PCFA), per capita wetland area (PCWA), per capita cultivated area (PCCA), percentage of nature reserves in the region (PNR), and population density (PD), which account for the resources carrying capacity and environmental suitability for a given type of livestock and poultry breeding; (ii) developmental level factors, including urbanization level (UL), unemployment rate (UR), per capita gross domestic or regional product (PCGDP), rural household consumption level (RHCL), and urban household consumption level (UHCL), which account for the potential effects of urban sprawl on land use and breeding industry in turn, and the market demand of livestock and poultry products; and (iii) economic structure factors, including proportion of primary industry output (PPIO), proportion of secondary industry output (PSIO), and proportion of tertiary industry output (PTIO), which account for the potential effects of social relations of production systems on the farming from a macroscopic and comprehensive angle. The description of the independent variables was presented in Table 2.

Results

Distribution, constitution, and growth rate

Figure 1 presented the distribution of pollutants from livestock and poultry farming at the province level in 2005 and 2013. The figure showed that, in both of the study years, the Huang-Huai-Hai region (i.e., Henan, Shandong, and Hebei) and the southwestern region (i.e., Sichuan, Yunnan, Guangxi, and Guizhou) had the highest level of pollutant productions from livestock and poultry farming, these areas accounting approximately for 50 % of the total

Table 2 Descriptive statistics for pollutants from livestock and poultry farming and resource and socioeconomic factors for periods of 2005, 2013, and 2005–2013, $n = 31$

Variables	2005		2013		2005–2013	
	Means	Standard deviations	Means	Standard deviations	Means	Standard deviations
Independent variables						
Per capita water resources (PCWR) (m³/person)	7400.610	28,687.034	6710.961	25,308.630	−0.054	4.721
Per capita forest area (PCFA) (ha/person)	0.328	0.890	0.348	0.838	2.695	3.093
Per capita wetlands area (PCWA) (ha/person)	0.112	0.357	0.148	0.440	2.919	6.392
Per capita cultivated area (PCCA) (ha/person)	0.116	0.077	0.103	0.071	−2.041	2.066
Percentage of nature reserves in the region (PNR) (%)	10.000	7.358	9.514	7.285	−0.587	3.907
Population density (PD) (person/km²)	1516.494	1351.470	2817.613	1192.996	11.810	11.850
Urbanization level (UL) (%)	45.299	15.677	54.451	13.941	2.595	1.227
Unemployment rate (UR) (%)	3.924	0.654	3.304	0.665	−2.235	1.947
Per capita gross domestic or regional product (PCGDP) (RMB Yuan/person)	16,204.940	10,947.669	47,046.550	20,776.724	15.406	3.007
Rural household consumption level (RHCL) (RMB Yuan/household)	2989.935	1610.711	8686.357	3884.625	14.538	1.749
Urban household consumption level (UHCL) (RMB Yuan/household)	8751.516	2720.551	21,496.730	6339.127	11.905	2.769
Proportion of primary industry output (PPIO) (%)	14.027	6.781	10.458	5.144	−3.848	2.520
Proportion of secondary industry output (PSIO) (%)	45.536	8.295	47.510	8.034	0.566	2.009
Proportion of tertiary industry output (PTIO) (%)	40.437	7.219	42.019	9.181	0.416	1.504
Dependent variables						
Cattle (10,000 t/year)	5704.749	4444.146	4312.474	3480.166	−3.195	6.411
Pig (10,000 t/year)	2387.224	2301.312	2369.259	2202.701	0.624	4.105
Poultry (10,000 t/year)	763.751	962.03	839.523	902.604	1.963	5.069
Sheep (10,000 t/year)	733.374	835.104	581.01	690.489	−3.052	5.676
Horse (10,000 t/year)	140.883	179.556	119.254	170.006	−5.948	5.689
Donkey (10,000 t/year)	100.934	163.613	88.008	149.841	−3.732	8.517
Mule (10,000 t/year)	51.779	79.669	34.505	63.855	−7.231	8.024
Rabbit (10,000 t/year)	26.183	52.301	63.174	146.806	9.638	12.327
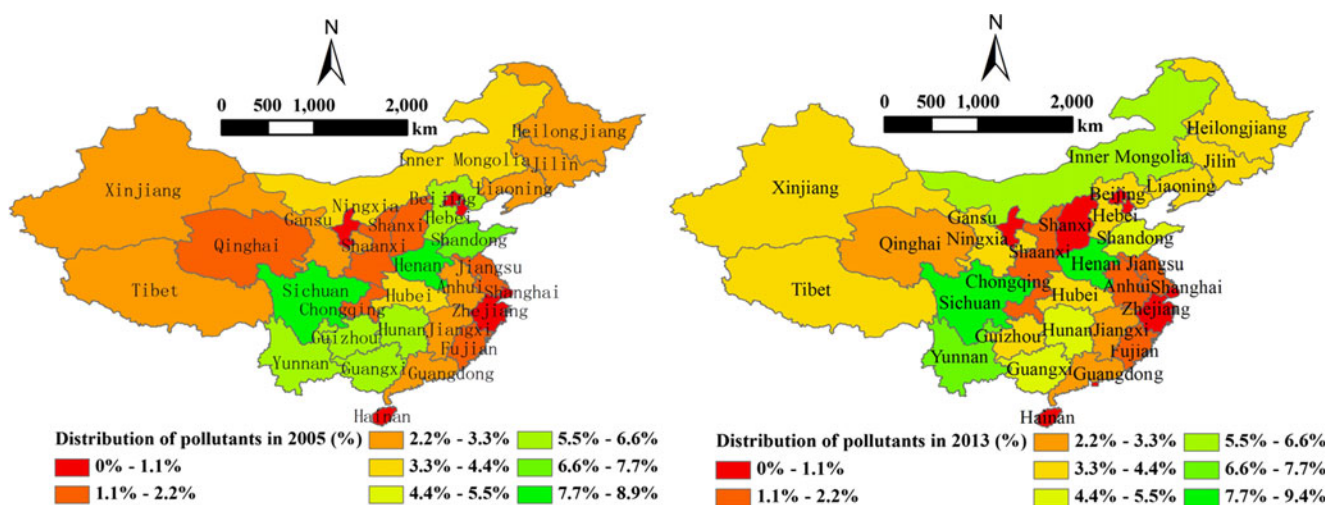
Fig. 1 Distribution of pollutants from livestock and poultry farming in each province in 2005 (*left*) and 2013 (*right*)

pollutant productions in China; the northeastern region (i.e., Heilongjiang, Jilin, and Liaoning) and the Neimenggu-Xinjiang plateau (i.e., Neimenggu, Xinjiang, and Gansu) had moderate level of pollutant productions, which shared nearly 35 % of the total pollutant productions in China; while in the eastern region (i.e., Fujian, Zhejian, and Jiangsu), the four municipalities (Beijing, Shanghai, Tianjin, and Chongqing), the Loess plateau, and the Qinghai-Tibet plateau (Qinghai, Shanxi, and Ningxia) had the lowest level of pollutant productions, which hold approximately 15 % or so of the total pollutant productions in China. Figure 1 also indicated that the pollutant productions had a high rate of persistence in spatial distribution at the province level from 2005 to 2013.

Figure 2 showed that the Neimenggu-Xinjiang plateau (i.e., Neimenggu and Gansu), the Qinghai-Tibet plateau (Qinghai, Xizang, and Ningxia), and the northeastern region (i.e., Heilongjiang, Jilin, and Liaoning) were the provinces to exhibit a trend, with pollutants increasing more than 20 % from 2005 to 2013, while the Huang-Huai-Hai region (i.e., Anhui, Hebei and Shandong), the Loess plateau (i.e., Shanxi and Shaanxi), and the southwestern region (i.e., Guizhou and Guangxi) were the provinces with pollutants decreasing more than 20 % from 2005 to 2013.

Figures 3 and 4 showed that the amount of pollutant discharged from cattle was the highest among all the livestock and poultry species, followed by pig and poultry in sequence in 2005; the pollutant productions of poultry increased from $23,676.280 \times 10^4$ t in 2005 to $26,025.224 \times 10^4$ t in 2013, while the pollutant productions of cattle decreased from $176,847.212 \times 10^4$ t in 2005 to $133,686.707 \times 10^4$ t in 2013. The increasing of pollutant productions in poultry and rabbit was offset by the reduction in cattle and other animal species, the total pollutant productions as a result decreased from $307,175.167 \times 10^4$ t in 2005 to $260,623.442 \times 10^4$ t in 2013 during the study period. Figures 3 and 4 also indicated that cattle, pig, and poultry constituted the primary pollution sources in terms of livestock and poultry farming not only at the national level but also at the province level.

Figures 5 and 6 showed that there existed spatial disparity in the pollutants from each livestock and poultry species at the province level in 2005 and 2013. The pollutants from cattle and pig were mainly distributed in the Huang-Huai-Hai region (i.e., Henan and Shandong) and southwestern region (i.e., Sichuan, Guangxi, Guizhou, and Yunan), accounting approximately for 30 to 35 % of the total pollutants from respective species in both of the years; the pollutants from poultry were mainly distributed in the Huang-Huai-Hai region (i.e., Henan, Shandong, and Hebei), contributing to about 40 and 32 % of the total pollutants from poultry in 2005 and 2013, respectively; sheep mainly located in the Neimenggu-Xinjiang plateau (i.e., NeiMongol and Xinjiang) and in the Huang-Huai-Hai region (i.e., Henan and Hebei), contributing to more than 40 % of the total pollutants from sheep in each year, respectively; horse mainly distributed in the Neimenggu-Xinjiang plateau (i.e., NeiMongol and Xinjiang), the southwestern region (i.e., Sichuan, Guangxi, Guizhou, and Yunan) and the northeastern region (i.e., Heilongjiang and Jilin), accounting for nearly 74 % in 2005 and 79 % in 2013 of the total pollutants from horse; donkey was mainly distributed in the Neimenggu-Xinjiang plateau (i.e., NeiMongol, Gansu, Xinjiang), Hebei, Liaoning, and Yunnan, accounting for nearly 80 % of the total pollutants from donkey in both of the years; mule had the same distribution as donkey, accounting for nearly 70 % of the total pollutants from mule in these areas in both of the years; and rabbit mainly distributed in the Huang-Huai-Hai region (i.e., Shandong, Hebei, and Henan) and the southwestern region (i.e., Sichuan), accounting for approximately 70 % of the total pollutants from rabbit in both of the years.

Figure 7 showed that the pollutants from rabbit and poultry increased dramatically in majority of provinces during 2005 and 2013, while the pollutants from cattle, sheep, horse, donkey, and mule decreased notably in majority of provinces during the period. Generally, the growth rates of pollutants from livestock and poultry farming in Shanghai, Qinghai, Liaoning, NeiMongol, and Xizang were all higher than 4 %,
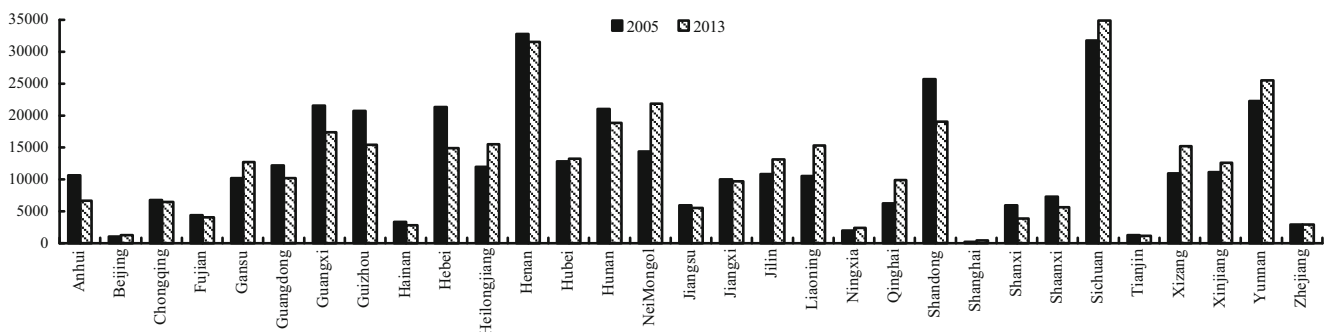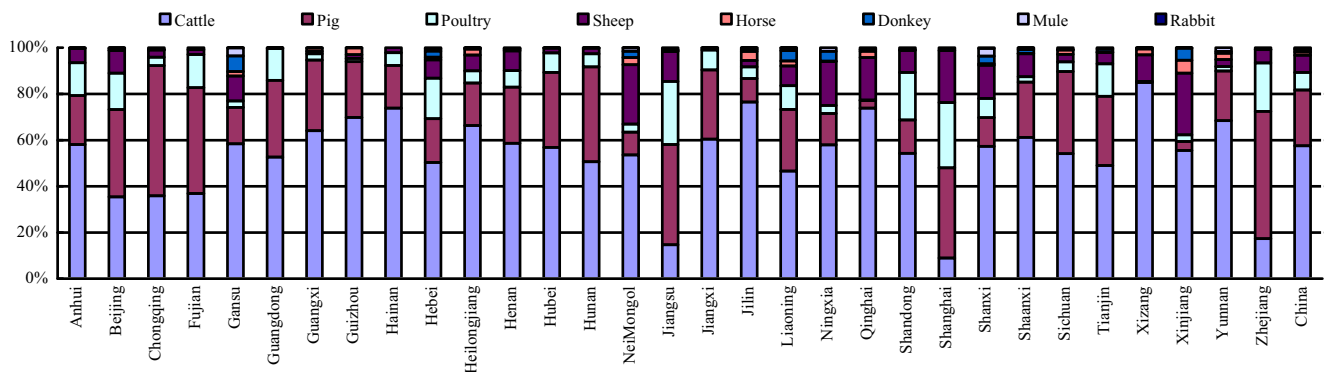

Fig. 2 Pollutant productions from livestock and poultry farming in each province in 2005 and 2013 (10^4 t)

Fig. 3 Constitution of pollutants from livestock and poultry farming in each province in 2005

respectively, while those in Anhui, Hebei, and Shanxi were all lower than −4 %, respectively, with others ranging between −4 and 4 %.

Canonical correlation analysis

Tables 3 and 4 represented the correlation coefficients between the resource, socioeconomic factors, and pollutants from livestock and poultry farming in 2005 and 2013, respectively. In 2005, variables of UL, PCGDP, RHCL, and PTIO were all negatively correlated with pollutants from all livestock and poultry species, and variable of UR was positively correlated with pollutants from all species except for the poultry and rabbit. While in 2013 variables of UL, RHCL, and PTIO were all negatively correlated with pollutants from all species, variables of UR, PPIO, and PSIO were all positively correlated with pollutants from all species.

Table 5 represented the correlation coefficients between the growth rates of resource, socioeconomic factors, and the growth rates of pollutants from livestock and poultry farming during the period of 2005 and 2013. PTIO was proved to be the only variable to be negatively correlated with pollutants from all species, and variables of PCFA, PNR, PD, PCGDP, and PSIO were positively correlated with most of the pollutant categories.

The canonical correlation coefficients and the redundancy indices were presented in Table 6. All the first correlations were statistically significant ($P < 0.05$). Moreover, their redundancy indices were the highest. Therefore, only the first functions were noteworthy for the years 2005 and 2013 and the period between the two years in the context of this study.

The loadings and cross-loadings of the variables for the first canonical functions were presented in Table 7. The loadings of the variables for function 1 in 2005 and 2013 revealed that the most important predictor of pollutants from livestock and poultry farming was the resource endowment factors (i.e., PCWR, PCFA, PCWA, PCCA, and PNR). Though the developmental and economic structure factors were less important than the resource endowment factors in both of the years, the developmental level factors became more influential negatively to the pollutants from the year of 2005 to the year of 2013, especially the factors such as UL, PCGDP, RHCL, and UHCL, and PPIO was among the only economic structure factor being strongly positively correlated with the pollutants from livestock and poultry farming in both of the years. Loadings of the pollutant indicators demonstrated that the most important measurements of pollutants from livestock and poultry farming were sheep and pig in 2005, while cattle, horse, and poultry became the most
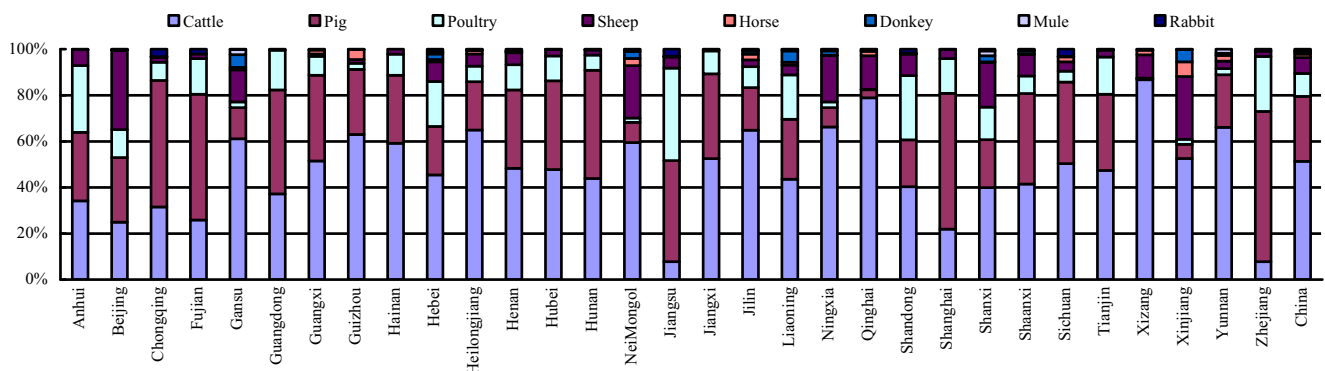
Fig. 4 Constitution of pollutants from livestock and poultry farming in each province in 2013
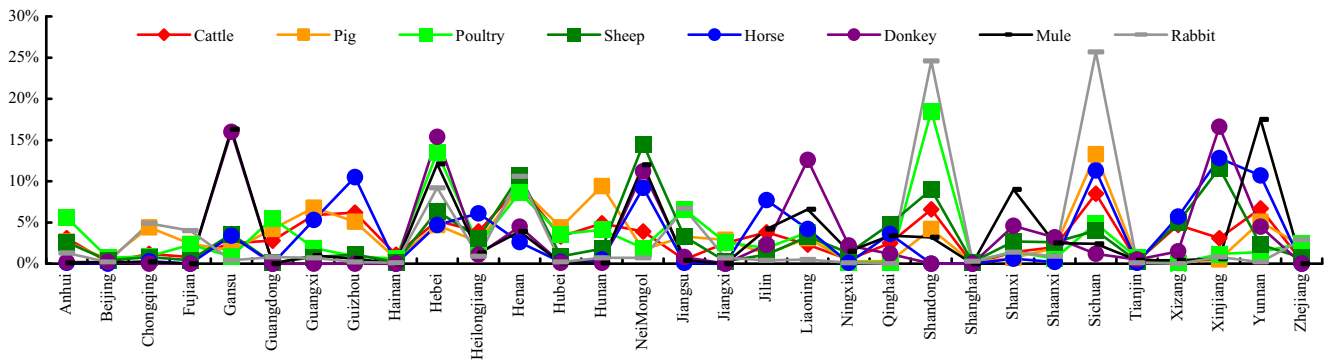
Fig. 5 Proportion of pollutants from each livestock and poultry species for each province in 2005

important measurements of pollutants from livestock and poultry farming in 2013. Specifically, the CCA revealed that the pollutants of pig and sheep were dramatically influenced by the resource endowment factors (i.e., PCWR, PCFA, PCWA, PCCA, and PD) in 2005, while the pollutants of cattle, poultry, horse, and mule not only were dramatically influenced by the resource endowment factors (i.e., PCWR, PCFA, PCWA, PCCA, and PNR) but also by developmental level factors (i.e., UL, UHCL, RHCL, and PCGDP) and some of economic structure factors (i.e., PPIO) in 2013. The effects of the resource endowment factors on the pollutants from livestock and poultry farming were positive, while the effects of the developmental level factors were negative.

Table 7 also indicated that the growth of PCCA was among the most negative predictor of pollutants from livestock and poultry farming, while growth of UHCL was among the most positive predictor of pollutants from livestock and poultry farming. Loadings of the pollutant indicators demonstrated that the growth of mule, donkey, sheep, and rabbit was the most important measurement of pollutants from livestock and poultry farming, among which the growth of sheep played a significantly positive role of the pollutants, while the others acting as negative indicators. These also indicated that the growth of pollutants from sheep, donkey, mule, and rabbit tended to be affected greatly by the changes of PCCA, UHCL, PCFA, PPIO, and PCGDP.

Discussions

Spatial distribution, constitution, and implication

We corroborated the previous study (Sun and Wu 2013), which have concluded that cattle, pig, and poultry contribute the most to the pollutants excreted by livestock and poultry farming. However, our results varied from the other published figures, i.e., Sun and Wu (2013) indicated that the southeastern provinces (Liaoning, Hubei, Sichuan, and Jiangxi) suffered from the most serious pollution from animal husbandry. While our analysis revealed that the Huang-Huai-Hai region (Henan, Shandong, and Hebei) and the southwestern region (Sichuan, Yunnan, Guangxi, and Guizhou) experienced the most severe pollution from livestock and poultry farming. Sun and Wu (2013) showed that the southeastern also had the fast growth in pollution from the farming during the period of 2000 and 2010, while our results showed that the Neimenggu-Xinjiang plateau, the Loess plateau, and the Qinghai-Tibet plateau and the northeastern region were the regions with the highest growth rate in the pollutants from 2005 to 2013. The disparity appeared to result from our use of updated census data and optimized coefficients to estimate pollutants. Due to the current harsh climatic conditions, lack of economic and technical support, and the vulnerability and fragility of the ecosystem (Godber and Wall 2014), these areas, with
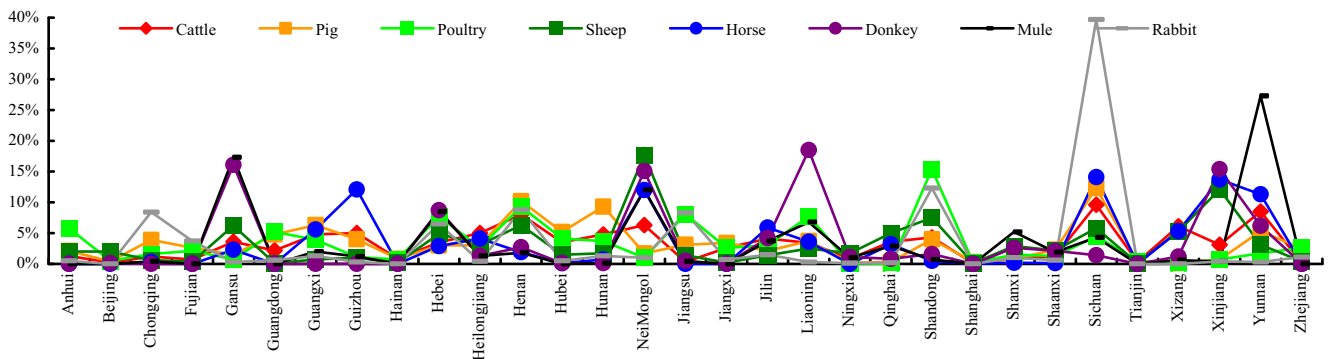
Fig. 6 Proportion of pollutants from each livestock and poultry species for each province in 2013
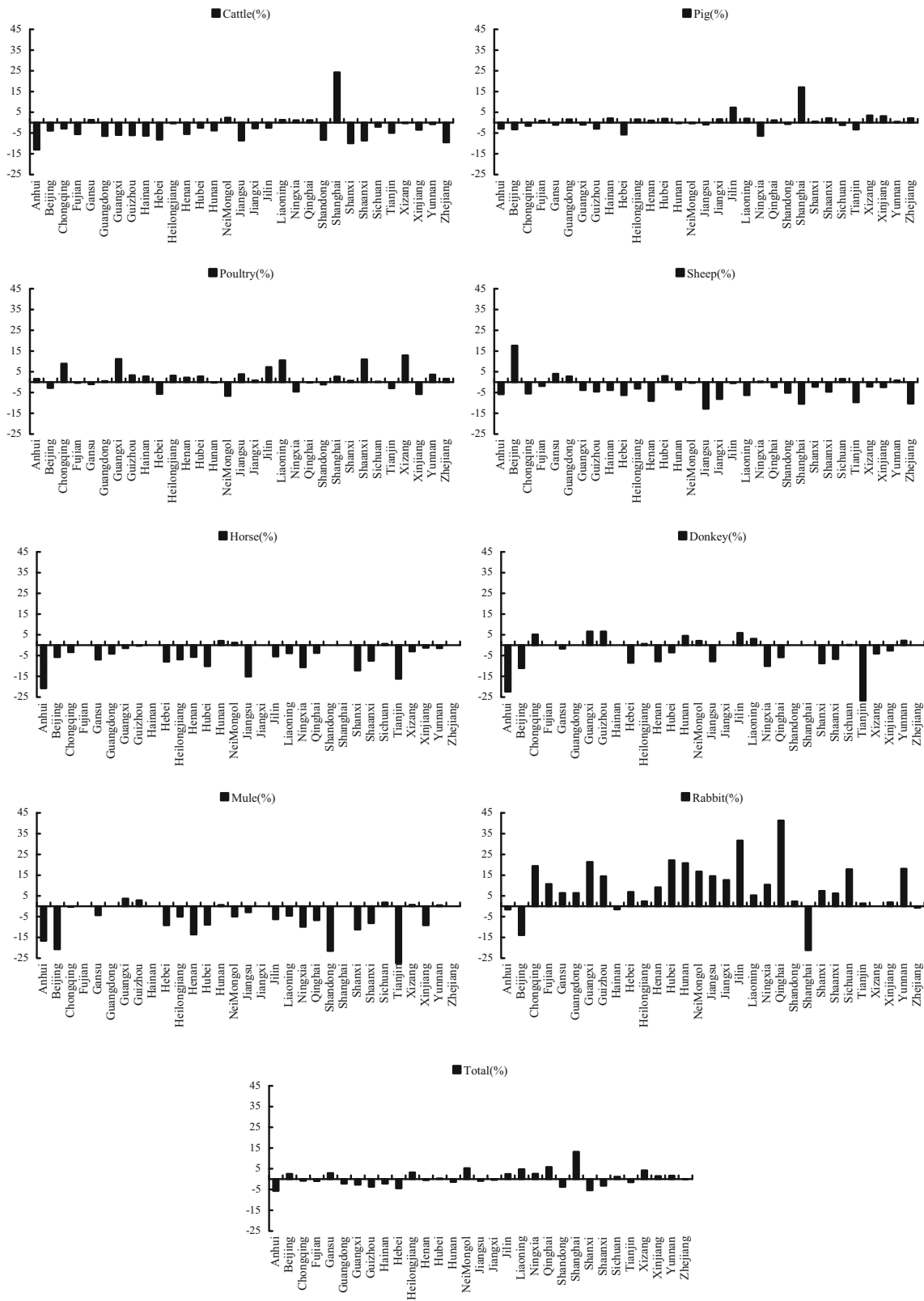
Fig. 7 Average annual growth rates of different livestock and poultry species' pollutants in each province during 2005 and 2013

the most severe pollution or the highest growth rate in livestock and poultry farming, should be priority regions in policy making to control pollutants from livestock and poultry farming.

Table 3 Correlation coefficients between the two groups of variables in 2005 (10^4 t/year)

Variables	Cattle	Pig	Poultry	Sheep	Horse	Donkey	Mule	Rabbit
PCWR (m^3/person)	0.116	−0.193	−0.172	0.094	0.135	−0.069	−0.108	−0.103
PCFA (ha/person)	0.137	−0.209	−0.202	0.173	0.211	−0.02	−0.039	−0.133
PCWA (ha/person)	0.081	−0.268	−0.203	0.169	0.147	−0.042	−0.069	−0.138
PCCA (ha/person)	0.197	−0.180	−0.186	0.514	0.569	0.448	0.428	−0.152
PNR (%)	0.032	−0.245	−0.355	0.186	0.338	0.151	0.143	−0.049
PD (person/km^2)	0.043	−0.005	0.065	0.083	−0.283	0.258	0.277	−0.028
UL (%)	−0.610	−0.378	−0.110	−0.312	−0.404	−0.204	−0.278	−0.159
UR (%)	0.181	0.170	−0.134	0.060	0.351	0.130	0.021	−0.032
PCGDP (RMB Yuan/person)	−0.509	−0.328	−0.011	−0.198	−0.373	−0.176	−0.252	−0.049
RHCL (RMB Yuan/household)	−0.486	−0.214	−0.038	−0.310	−0.415	−0.269	−0.300	−0.041
UHCL (RMB Yuan/household)	−0.324	−0.135	0.023	−0.258	−0.329	−0.235	−0.240	−0.011
PPIO (%)	0.494	0.341	−0.027	0.158	0.402	0.101	0.077	0.044
PSIO (%)	−0.072	0.013	0.417	0.181	−0.190	0.120	0.123	0.258
PTIO (%)	−0.381	−0.335	−0.455	−0.356	−0.160	−0.233	−0.214	−0.338

We found that the pollutant output of poultry increased fast between 2005 and 2013. This result was in line with previous studies, which declared that globalization and a growing demand for meat products in developing regions have led to rapid expansion of poultry meat in Asia in recent years (Prosser et al. 2011; Godber and Wall 2014). An unexpected outcome of our analysis was that the total production of cattle, pig, and sheep decreased from 2005 to 2013 in China. While the previous study showed that pork product was expected to be rapidly expanding (Prosser et al. 2011), these results may have resulted from the implementation of environment protection laws and regulations by government in the last decade (Sun and Wu 2013), with the species of higher pollutant generation coefficient replaced by lower ones. Specifically, the

decrease in the cattle, pig, and sheep industry as a result was offset by the increase in poultry and rabbit industry in many of the provinces in China during the study period. Moreover, the quantities of draught animals, such as horse, donkey, and mule, were all observed to decrease consistently in most of the provinces. These characteristics may imply a tendency in the agricultural operation mode changing from tradition to mechanization.

Meat demand per capita is expected to rise by almost 13 % in developing nations over the period 2008 and 2017 (OECD-FAO 2008). Combining this expectation and the analysis above, poultry farming (i.e., chickens, ducks, and geese) will still make up major part of livestock production, and this trend is likely to continue in a long term. These changes will

Table 4 Correlation coefficients between the two groups of variables in 2013 (10^4 t/year)

Variables	Cattle	Pig	Poultry	Sheep	Horse	Donkey	Mule	Rabbit
PCWR (m^3/person)	0.227	−0.197	−0.200	0.115	0.113	−0.067	−0.073	−0.085
PCFA (ha/person)	0.305	−0.214	−0.251	0.248	0.217	0.023	0.019	−0.107
PCWA (ha/person)	0.213	−0.291	−0.262	0.221	0.126	−0.034	−0.052	−0.124
PCCA (ha/person)	0.382	−0.161	−0.177	0.573	0.490	0.482	0.365	−0.151
PNR (%)	0.364	−0.179	−0.332	0.305	0.317	0.189	0.116	0.084
PD (person/km^2)	0.108	0.150	−0.131	−0.045	0.021	0.001	−0.054	−0.045
UL (%)	−0.609	−0.272	−0.035	−0.287	−0.434	−0.144	−0.280	−0.130
UR (%)	0.307	0.307	0.070	0.071	0.275	0.01	0.119	0.220
PCGDP (RMB Yuan/person)	−0.527	−0.307	0.021	−0.109	−0.336	−0.078	−0.265	−0.094
RHCL (RMB Yuan/household)	−0.534	−0.227	−0.006	−0.284	−0.361	−0.209	−0.266	−0.028
UHCL (RMB Yuan/household)	−0.471	−0.177	0.029	−0.208	−0.312	−0.134	−0.205	−0.084
PPIO (%)	0.488	0.254	0.006	0.205	0.414	0.204	0.243	0.049
PSIO (%)	0.128	0.258	0.336	0.172	−0.019	0.148	0.048	0.213
PTIO (%)	−0.386	−0.370	−0.296	−0.265	−0.216	−0.243	−0.177	−0.215

Table 5 Correlation coefficients between the growth rates of the two groups of variables during 2005 and 2013 (10^4 t/year)

Variables	Cattle	Pig	Poultry	Sheep	Horse	Donkey	Mule	Rabbit
PCWR (m^3/person)	0.230	−0.177	−0.230	0.542	0.130	0.110	−0.085	−0.330
PCFA (ha/person)	−0.109	−0.174	0.163	−0.126	−0.024	0.266	0.450	0.129
PCWA (ha/person)	0.190	−0.010	0.138	−0.08	0.268	0.250	0.327	0.186
PCCA (ha/person)	−0.074	0.328	0.404	−0.515	0.034	0.443	0.478	0.293
PNR (%)	0.041	0.091	0.120	0.190	0.235	0.252	0.139	−0.024
PD (person/km^2)	0.198	0.200	−0.170	0.108	0.222	0.163	0.144	−0.012
UL (%)	−0.282	−0.223	0.136	−0.300	0.147	0.139	0.446	0.202
UR (%)	−0.136	0.038	−0.243	−0.426	−0.053	−0.065	0.067	0.301
PCGDP (RMB Yuan/person)	0.103	0.089	0.323	−0.249	0.225	0.354	0.496	0.552
RHCL (RMB Yuan/household)	0.169	0.207	−0.06	−0.181	−0.154	−0.119	−0.048	0.204
UHCL (RMB Yuan/household)	0.156	−0.142	−0.124	0.563	0.039	−0.113	−0.322	−0.371
PPIO (%)	0.070	0.293	0.060	−0.024	0.018	0.239	0.290	−0.025
PSIO (%)	0.013	0.157	0.258	−0.172	0.210	0.250	0.357	0.576
PTIO (%)	−0.085	−0.202	−0.211	−0.128	−0.131	−0.109	−0.143	−0.439

lead to an increased threat of emerging zoonotic diseases (Prosser et al. 2011), since the viruses show varying degrees of pathogenicity and transmissibility among poultry species, with ducks potentially serving as silent propagators of the viruses (Li et al. 2004; Sturm-Ramirez et al. 2005). However, the information on spatial distributions of its main host, poultry, is scarce (Prosser et al. 2011). Thus, by analyzing the distribution of poultry, we offer useful knowledge on spatial distributions of main host distributions of (HPAI) type H5N1 for epidemiological controller, livestock sector planner, and policy maker to propose appropriate bio-security measures. Our research reveals that poultry mainly distributes in the Huang-Huai-Hai region of China.

Drivers

CCA was used to measure each pollutant variable instead of separate linear regression, since it simultaneously models effects of multiple independent variables on multiple dependent variables. Compared to multiple linear regression, CCA is a more efficient method of examining the relationship between the two groups of variables, because it uses information from all the variables in both the dependent and independent variable sets and maximizes the estimation of the effects of resource and socioeconomic factors on pollutants from livestock and poultry farming (Hidalgo et al. 2014). Furthermore, CCA can avoid multicollinearity with the latent variable approach (Liu et al. 2009). This analysis gives a global view of association between pollutants from livestock and poultry species and resource and socioeconomic factors. We found that the relationships between the two sets of variables were statistically significant at 5 % level. Based on the variable loadings to the composite scores, CCA might contribute to narrow down fewer variables to assess the association between two sets of variables (Combes et al. 2008). Thus, CCA could be used as a comprehensive approach to extract information from

Table 6 Canonical correlation analysis of the two groups of variables for the periods of 2005, 2013, and 2005–2013

Canonical variates	Canonical correlation			Chi-square			P value			Redundancy index, $R_{Y/X}$		
	2005	2013	2005–2013	2005	2013	2005–2013	2005	2013	2005–2013	2005	2013	2005–2013
Variate 1	0.950	0.985	0.998	165.316	179.615	448.098	**0.011**	**0.001**	**0.000**	**0.196**	**0.177**	**0.179**
Variate 2	0.946	0.942	0.989	123.409	116.815	117.106	0.094	0.184	0.179	0.145	0.117	0.061
Variate 3	0.909	0.921	0.973	83.013	77.609	79.073	0.510	0.675	0.632	0.065	0.173	0.109
Variate 4	0.797	0.802	0.945	51.432	43.585	49.587	0.906	0.985	0.934	0.082	0.089	0.128
Variate 5	0.738	0.629	0.797	33.254	25.067	27.272	0.967	0.999	0.996	0.041	0.021	0.039
Variate 6	0.633	0.593	0.773	19.083	16.015	17.185	0.991	0.998	0.997	0.044	0.030	0.027
Variate 7	0.501	0.472	0.606	9.878	8.216	8.081	0.995	0.999	0.999	0.023	0.012	0.055
Variate 8	0.440	0.349	0.425	4.676	3.686	3.500	0.990	0.997	0.998	0.005	0.012	0.027
Variate 9	0.208	0.269	0.374	0.800	1.347	1.509	0.992	0.969	0.959	0.002	0.004	0.013

Bold data are *P*-value, that means significance level.

Table 7 Canonical weights, loadings, and cross-loadings for the first composite scores of the two groups of variables for the periods of 2005, 2013, and 2005–2013

Variables	2005		2013		2005–2013	
	Loadings	Cross-loadings	Loadings	Cross-loadings	Loadings	Cross-loadings
Independent variables						
PCWR (m^3/person)	**0.370**	**0.352**	**0.585**	**0.576**	0.170	0.170
PCFA (ha/person)	**0.415**	**0.394**	**0.662**	**0.652**	−0.383	−0.383
PCWA (ha/person)	**0.455**	**0.432**	**0.602**	**0.593**	−0.121	−0.121
PCCA (ha/person)	**0.337**	**0.320**	**0.436**	**0.429**	−0.808	−0.808
PNR (%)	0.219	0.208	**0.810**	**0.797**	0.021	0.021
PD (person/km^2)	**−0.316**	**−0.300**	0.046	0.045	−0.074	−0.074
UL (%)	0.078	0.074	**−0.503**	**−0.496**	−0.049	−0.049
UR (%)	0.067	0.064	0.189	0.186	−0.293	−0.293
PCGDP (RMB Yuan/person)	0.130	0.124	**−0.416**	**−0.409**	−0.315	−0.315
RHCL (RMB Yuan/household)	−0.009	−0.009	**−0.426**	**−0.420**	−0.187	−0.187
UHCL (RMB Yuan/household)	−0.008	−0.008	**−0.441**	**−0.434**	0.464	0.464
PPIO (%)	−0.034	−0.032	**0.351**	**0.345**	−0.380	−0.380
PSIO (%)	0.028	0.026	−0.170	−0.167	−0.143	−0.143
PTIO (%)	0	0	−0.049	−0.048	−0.126	−0.126
Dependent variables						
Cattle (10,000 t/year)	0.019	0.018	**0.647**	**0.637**	−0.165	−0.165
Pig (10,000 t/year)	**−0.397**	**−0.377**	0.106	0.105	**−0.375**	**−0.375**
Poultry (10,000 t/year)	0.129	0.123	**−0.415**	**−0.409**	−0.303	−0.303
Sheep (10,000 t/year)	**0.495**	**0.470**	**0.354**	**0.348**	0.554	0.554
Horse (10,000 t/year)	0.219	0.208	**0.618**	**0.609**	−0.116	−0.116
Donkey (10,000 t/year)	0.034	0.032	0.188	0.185	**−0.537**	**−0.537**
Mule (10,000 t/year)	−0.265	−0.252	**0.318**	**0.313**	**−0.565**	**−0.565**
Rabbit (10,000 t/year)	−0.064	−0.061	0.239	0.235	**−0.476**	**−0.476**

data to simultaneously identify both of the variables so that the assessment of the relationship between them can be further preceded.

CCA revealed a significant interaction between the pollutants and resource endowment and socioeconomic factors through the score plot of composite scores (Table 6). The result showed that the pollutant measurements were not uni-dimensional constitute and that different species of livestock and poultry have varying explanatory dimensions. This was supported by the characteristics of distribution in the livestock and poultry farming in our study. It also indicates that it is necessary to analyze the spatial inequalities in the different livestock and poultry species, respectively, when identifying the mechanisms and the effect of influence factors on the farming. For example, spatial distributions of poultry were characterized by high chicken densities across much of eastern China, particularly the Yellow River Basin and high duck densities in southeastern China and the Sichuan Basin (Prosser et al. 2011). Basically, such spatial distribution of livestock and poultry faming depends on resource endowment, such as vegetation index, cropland, water area, and

climate condition (Steinfeld et al. 2006b; Prosser et al. 2011). In this study, on one hand, we confirm that the resource factors are the most strongly positively associated with the pollutant measures, while on the other hand, an unexpected outcome of this study is that the growth rates of the pollutants are negatively associated with the rates of resource factors, especially variables of PCCA and PCFA. This is mainly because livestock farming often occupies areas unsuitable for crop production, e.g., cattle and sheep farming in grassland. Simultaneously, the expansion of livestock husbandry may result in the encroachment of cultivated area. In addition, the implementation of environmental protection policy in China, such as forest (water conservation forest in particular) conservation and returning grazing land to forest, imposes restriction on the development of livestock and poultry farming.

A regional socioeconomic development is likely to promote per capita income. This in turn increases individual consumption of livestock products (Steinfeld et al. 2006b), but this does not mean livestock and poultry industry will automatically parallel socioeconomic level in each province. On the contrary, our study shows that both livestock and poultry

farming and their growth rates at the province level are generally negatively associated with the socioeconomic development level and their growing speed, respectively. Therefore, the rate of change and direction of livestock and poultry development varies greatly among regions. Different ways of local policy implementation are due to different weighing of the value of livestock production in the local economy, which varies with overall socioeconomic development (Zheng et al. 2014). The leading cadres of each government level prefer to support major economic sectors, in order to get more revenues and a better personal performance evaluation (Edin 2003; He et al. 2012). It is in line with the livestock and poultry distribution in China, with the lowest productions in the most developed area, such as eastern region (i.e., Fujian, Zhejian, and Jiangsu) and the four municipalities (Beijing, Shanghai, Tianjin, and Chongqing), while the highest productions in the less developed area, such as the Huang-Huai-Hai region (i.e., Henan, Shandong, and Hebei) and the southwestern region (i.e., Sichuan, Yunnan, Guangxi, and Guizhou). The exception is that the least developed area, such as the Loess plateau and the Qinghai-Tibet plateau (Qinghai, Shaanxi, and Ningxia), also had the lowest production. This result indicates that the production of livestock and poultry farming was affected by a complicated group of factors, including not only socioeconomic factors but also nature resource factors. Awful weather, sparse population, lack of infrastructure, and technique may restrict the development of livestock and poultry industry in the least developed area, such as the Loess plateau and the Qinghai-Tibet plateau. However, these areas had a rapid development trend between 2005 and 2013 as the improvement of infrastructure. Therefore, governmental officials should pay more attention to livestock production in these regions and make their policies and measures more environmentally sound.

Conclusions

Applying the optimized coefficients, we estimated the pollutant productions from livestock and poultry farming at the provincial and national levels in China in 2005 and 2013 and the growth rates of the productions between the 2 years. We conclude that there exist spatial disparity in the amount of pollutants, constitutions, and growth rates across the regions. Provinces in the Huang-Huai-Hai region and the southwestern region ranked the highest level in China in terms of the pollutant productions, accounting for around 50 % of the total productions in the nation. During 2005 and 2013, the Neimenggu-Xinjiang plateau, the Qinghai-Tibet plateau, and the northeastern region were the provinces to exhibit a trend, with pollutants increasing more than 20 %, while the Huang-Huai-Hai region, the Loess plateau, and the

Southwestern region were the provinces with pollutants decreasing more than 20 %.

There existed spatial disparity in the pollutants from each livestock and poultry species at the province level in 2005 and 2013. Cattle, pig, and poultry contributed the most to the pollutants produced by livestock and poultry farming, which occupied approximately 80 % of the total pollutants both at the national and provincial level. The pollutants from rabbit and poultry in most of the provinces increased dramatically during 2005 and 2013, while the pollutants from cattle, sheep, horse, donkey, and mule displayed an opposite trend during the study period.

Since the pattern matches empirical data, CCA suggests that observed regional patterns can be largely explained by the resource endowment factors, such as PCWR, PCFA, PCWA, PCCA, and PNR and the developmental level factors, such as UL, PCGDP, RHCL, and UHCL. The former is positively associated with the pollutant measures, while the latter's effect is negative. In addition, we also found that the development of livestock and poultry farming is negatively associated with the growth rates of both the resource endowment and the socioeconomic factors. Our research has significant implications for the appropriate environmental protection policy formulation and implementation in livestock sector. It is also methodologically important because CCA can offer an efficient, practical, and more comprehensive approach to assess the associations between two sets of variables, by taking the pollutants from livestock and poultry farming at the species level into account.

References

Baggaley AR (1981) Multivariate analysis: an introduction for consumers of behavioral research. Eval Rev 5:123–131

Caldwell WJ (1998) Land-use planning, the environment, and siting intensive livestock facilities in the 21st century. J Soil Water Conserv 53(2):102–106

Cankaya S, Ocak N, Sungu M (2008) Canonical correlation analysis for estimation of relationships between sexual maturity and egg production traits upon availability of nutrients in pullets. Asian-Aust J Anim Sci 21:1576–1584

Chen B (2012) Planning environmental impact assessment methods and practices in livestock and poultry farming. China Agriculture Press, Beijing (in Chinese)

Combes S, González I, Déjean S, Baccini A, Jehl N, Juin H, Cauquil L, Gabinaud B, Lebas F, Larzul C (2008) Relationships between sensory and physicochemical measurements in meat of rabbit from three different breeding systems using canonical correlation analysis. Meat Sci 80(3):835–841

Costanza JK, Marcinko SE, Goewert AE, Mitchell CE (2008) Potential geographic distribution of atmospheric nitrogen deposition from intensive livestock production in North Carolina, USA. Sci Total Environ 398:76–86

Department of Comprehensive Statistics and Department of Rural Survey of National Bureau of Statistics (2006) China statistical yearbook for regional economy. China Statistics Press, Beijing (in Chinese)

Department of Comprehensive Statistics and Department of Rural Survey of National Bureau of Statistics (2014) China statistical yearbook for regional economy. China Statistics Press, Beijing (in Chinese)

Duan Y, Zhang YZ, Li YF, Niu ZY (2007) Environmental risk assessment and the load of livestock manure in Minjiang River watershed. J Ecol Rural Environ 23(3):55–59 (in Chinese with English abstract)

Edin M (2003) Local state corporatism and private business. J Peasant Stud 30:278–295

Editing committee of China Animal Industry Yearbook (2006) China animal industry yearbook. China Agriculture Press, Beijing (in Chinese)

Editing committee of China Animal Industry Yearbook (2014) China animal industry yearbook. China Agriculture Press, Beijing (in Chinese)

Fornell C (1978) Three approaches to canonical analysis. J Mark Res Soc 20:166–181

Fu Q, Zhu YQ, Kong YF, Sun JL (2012) Spatial analysis and districting of the livestock and poultry breeding in China. J Geogr Sci 22(6): 1079–1100

Godber OF, Wall R (2014) Livestock and food security: vulnerability to population growth and climate change. Glob Chang Biol 20:3092–3102

Gu P, Shen RF, Chen YD (2008) Diffusion pollution from livestock and poultry rearing in the Yangtze Delta, China. Environ Sci Pollut Res 15(3):273–277

Hair JF, Anderson RE, Tatham RL, Black WC (1998) Multivariate data analysis, 5th edn. Prentice Hall International, NY

He GZ, Lu YL, Mol APJ, Beckers T (2012) Changes and challenges of China's environmental management. Environ Dev 3:25–38

Hidalgo AM, da Silva LP, Mota RR, Martins EN (2014) Canonical-correlation analysis applied to selection-index methodology in quails. Livest Sci 169:35–41

Johnson RA, Wichern DW (1986) Applied multivariate statistical analysis. Springer, Berlin

Kabir A, Merrill RD, Shamim AA, Klemn RD, Labrique AB, Christian P, West KP, Nasser M (2014) Canonical correlation analysis of infant's size at birth and maternal factors: a study in rural northwest Bangladesh. PLoS One 9(4):e94243

Li PJ (2009) Exponential growth, animal welfare, environmental and food safety impact: the case of China's livestock production. J Agric Environ Ethics 22:217–240

Li KS, Guan Y, Wang J, Smith GJ, Xu KM, Duan L, Rahardjo AP, Puthavathana P, Buranathai C, Nguyen TD, Estoepangestie AT, Chaisingh A, Auewarakul P, Long HT, Hanh NT, Webby RJ, Poon LL, Chen H, Shortridge KF, Yuen KY, Webster RG, Peiris JS (2004) Genesis of a highly pathogenic and potentially pandemic H5N1 influenza virus in eastern Asia. Nature 430:209–213

Liu J, Drane W, Liu XF, Wu TJ (2009) Examination of the relationships between environmental exposures to volatile organic compounds and biochemical liver tests: application of canonical correlation analysis. Environ Res 109:193–199

Ministry of Environmental Protection of People's Republic of China (MoEP) (2010) The report of China pollution resource census. Beijing, China (in Chinese)

Neumann K, Verburg PH, Elbersen B, Stehfest E, Woltjer GB (2011) Multi-scale scenarios of spatial-temporal dynamics in the European livestock sector. Agric Ecosyst Environ 140(1):88–101

OECD-FAO (2008) Agricultural outlook 2008–2017. Organisation for Economic Co-operation and Development, Paris. pp. 20–22

Peng LH, Chen WW, Li M, Bai Y, Pan YP (2014) GIS-based study of the spatial distribution suitability of livestock and poultry farming: the case of Putian, Fujian, China. Comput Electron Agric 108:183–190

Prosser DJ, Wu JX, Ellis EC, Gale F, Van Boeckel TP, Wint W, Robinson T, Xiao XM, Gilbert M (2011) Modelling the distribution of chickens, ducks, and geese in China. Agric Ecosyst Environ 141 (3):381–389

Sherry A, Henson RK (2005) Conducting and interpreting canonical correlation analysis in personality research: a user-friendly primer. J Pers Assess 84:37–48

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, De Haan C (2006a) Livestock's long shadow: environmental issues and options. FAO, Rome

Steinfeld H, Wassenaar T, Jutzi S (2006b) Livestock production systems in developing countries: status, drivers, trends. Rev Sci Tech 25(2): 505–516

Stewart D, Love W (1968) A general canonical correlation index. Psychol Bull 70:160–163

Sturm-Ramirez KM, Hulse-Post DJ, Govorkova EA, Humberd J, Seiler P, Puthavathana P, Buranathai C, Nguyen TD, Chaisingh A, Long HT, Naipospos TS, Chen H, Ellis TM, Guan Y, Peiris JS, Webster RG (2005) Are ducks contributing to the endemicity of highly pathogenic H5N1 influenza virus in Asia? J Virol 79:11269–11279

Sun C, Wu HJ (2013) Assessment of pollution from livestock and poultry breeding in China. Int J Environ Stud 70(2):232–240

Thompson B (1991) A primer on the logic and use of canonical correlation analysis. Meas Eval Couns Dev 24:80–95

Tripathi A, Klami A, Kaski S (2008) Simple integrative preprocessing preserves what is shared in data sources. BMC Bioinf 9:111

Ventura HT, Lopes PS, Peloso JV, Guimarães SEF, Carneiro APS, Carneiro PLS (2011) A canonical correlation analysis of the association between carcass and ham traits in pigs used to produce dry-cured ham. Genet Mol Biol 34:451–455

Zheng CH, Bluemling B, Liu Y, Mol APJ, Chen JN (2014) Managing manure from China's pigs and poultry: the influence of ecological rationality. AMBIO 43:661–672

Zhou TM, Zhu YQ, Fu Q, Hu ZW, Yang F (2014) Pollutant generation coefficients of the livestock industry at provincial level in China. Glob Chang Res Data Publisher Repository. doi:10.3974/geodb. 2014.01.10.V1, http://www.geodoi.ac.cn/WebCn/doi.aspx?DOI= 10.3974/geodb.2014.01.10.V1