Estimation of Non-Point Source Pollution Load of the Livestock and Poultry Breeding in Sichuan Province, China

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Abstract—The study was to estimate the livestock and poultry breeding (LPB) non-point source pollution load in Sichuan province and provide support for control of LPB non-point source pollution. In the study, an improved export coefficient method was proposed to estimate LPB non-point source pollution loads from the stages of generation, discharge and export. Based on the established model, total nitrogen (TN), total phosphorus (TP) and chemical oxygen demand (COD) loads of LPB non-point source pollution were estimated in 21 administrative institutions of Sichuan province in 2012. The results indicated that the generation, discharge and export loads of TN, TP, and COD in Sichuan province were 421860.34 t, 73183.22 t and 7192384.64 t, 169302.65 t, 23737.94 t and 3228082.48 t, and 97086.62 t, 13620.3 t and 1861604 t , respectively. In 21 administrative institutions, Aba was the maximum per area generation loads region of TN, TP and COD, while Suining was the region in which the surface water pollution caused by TN, TP and COD from LPB was the most serious. The results show that LPB non-point source pollution in some areas of Sichuan province are serious and controlling LBP non-point source pollution should to be attached importance.

Keywords-livestock and poultry breeding; non-point source pollution load; TN; TP; COD

I. INTRODUCTION

In recent years, LPB has been the major source of agricultural non-point source pollution with the increasing demand of livestock and poultry products in China. For its pollution control, estimation and evaluation studies on LPB non-point source pollution load have been the basic work. In the study area, a lot of methods can be used, for example transport coefficient model [1], SWAT [2], inventory method [3] and export coefficient model [4]. In all methods, export coefficient model was regarded as a simple and convenient model and had been applied in many areas.

To the end of 2012, output value of animal husbandry in Sichuan province was ¥ 226.986 billion, accounting for 41.8% of gross output value of agriculture [5]. However, there is lack of systemic research of LPB non-point source pollution in Sichuan province. The objective of the study was to estimate the LPB non-point source pollution load in Sichuan province in 2012 and provide support for control of LPB non-point source pollution.

II. MATERIALS AND METHOD

A. Study area

Sichuan is located in the southwest of China and contains 21 administrative institutions. The cultivated field was 39910 km^2 and surface water resource was 292.1 billion m^3. In 2012, the annual slaughter of pig, cattle, sheep, poultry and rabbit was 91.94 million, 3.04 million, 19.16 million, 988.98 million, and 100.32 million, respectively. The other used data of 21 administrative institutions can refer to reference [5].

B. Methods

1) Study framework

In this study, formation progress of LPB non-point source pollution load was divided to three processes, namely generation process, discharge process and export process. The research technical route is shown in Figure 1.

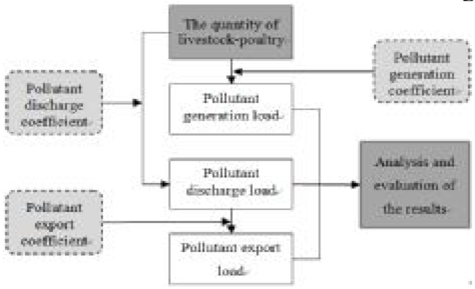

Figure 1. The research technical route

2) *Estimation model*

Depending on the export coefficient model, an improved LPB non-point source pollution load estimation model was established from the stages of generation, discharge and export as follows:

a) *The pollutant generation model*

$$T_i=Q_j \cdot P_j \cdot E_{ij} \cdot 10^{-6} \quad (1)$$

Where T_i is the total LPB pollutant generation load of *ith* pollutant ($t \cdot y^{-1}$); Q_j is the quantity of livestock and poultry (capita) (Table I); P_j is the breeding cycle of this kind of livestock and poultry (d). The breeding cycle of cattle, sheep, pig, poultry and rabbit is 365 d, 365 d, 150 d, 60 d and 90 d, respectively. E_{ij} refers to LPB pollutant generation coefficient ($g \cdot capita^{-1} \cdot d^{-1}$) (Table II).

TABLE I. THE QUANTITY OF LIVESTOCK AND POULTRY IN SICHUAN IN 2012 (10^4 CAPITA) [5,6]

Unit	Pig	Cattle	Sheep	Poultry	Rabbit
Chengdu	1095.30	5.7947	60.1620	11270.4140	648.7421
Zigong	279.54	6.4900	157.1700	4309.6200	2755.0900
Panzhihua	67.91	4.0400	37.9100	610.6400	-
Luzhou	494.00	11.6000	67.2000	5756.0000	55.9900
Deyang	450.00	14.1000	33.9000	11600.0000	183.0000
Mianyang	590.00	1.3000	5.2100	1286.6700	5.5000
Guangyuan	399.80	10.4000	48.6536	2874.5200	690.0000
Suining	481.69	9.7700	71.3400	3338.5000	-
Neijiang	423.78	1.3588	33.5500	4517.5500	470.5000
Leshan	382.79	7.2772	8.4810	5825.6800	867.2000
Nanchong	784.69	20.6400	268.9800	3135.0000	612.7300
Meishan	35.07	1.5700	-	4712.0100	1984.3100
Yibin	597.78	9.4767	71.4300	19379.9300	976.3800
Guang'an	537.70	7.4500	54.6400	4856.8000	470.2000
Dazhou	318.09	20.1200	73.9700	5974.2100	41.5000
Ya'an	148.15	9.7700	33.2900	1648.8800	100.7085
Bazhong	533.76	16.1100	88.6900	748.0000	8.9200
Ziyang	700.90	5.0700	301.9600	4267.3600	97.7200
Aba	38.17	55.2800	43.1800	36.1515	63.2252
Ganzi	223.10	40.3106	24.5099	-	-
Liangshan	612.15	45.6200	431.6400	2749.7700	-

"-" indicates that the quantity of this kind of livestock and poultry has not been announced.

TABLE II. POLLUTANT GENERATION COEFFICIENT OF LPB [8-12]

Livestock and poultry species	TN ($g \times capita^{-1} \times d^{-1}$)	TP ($g \times capita^{-1} \times d^{-1}$)	COD ($g \times capita^{-1} \times d^{-1}$)
Pig	15.355	3.39	272.845
Cattle	104.10	10.17	2235.21
Sheep	6.247	1.233	12.055
Poultry	0.71	0.06	13.05
Rabbit	0.99	0.33	10.44

b) *The pollutant discharge model*

$$L_i=Q_j \cdot P_j \cdot R_{ij} \cdot 10^{-6} \quad (2)$$

Where L_i is the total LPB pollutant discharge load of the *ith* pollutant ($t \cdot y^{-1}$); R_{ij} refers to LPB pollutant discharge coefficient ($g \cdot capita^{-1} \cdot d^{-1}$) (Table III).

TABLE III. POLLUTANT DISCHARGE COEFFICIENT OF LPB [8-12]

Livestock and poultry species	TN ($g \times capita^{-1} \times d^{-1}$)	TP ($g \times capita^{-1} \times d^{-1}$)	COD ($g \times capita^{-1} \times d^{-1}$)
Pig	7.19	0.94	110.275
Cattle	34.90	3.91	931.20
Sheep	2.186	0.432	4.219
Poultry	0.22	0.04	10.41
Rabbit	0.347	0.116	3.132

c) *The pollutant export model*

$$I_i=L_i \cdot C \quad (3)$$

Where I_i is the total LPB pollutant export load of the ith pollutant ($t \cdot y^{-1}$); C is the pollutant export coefficient. Pollutant export coefficient of livestock and poultry waste is associated with local rainfall, local topography and the distance between the area of pollutant producing and the river. Firstly, in terms of the distance between the area of pollutant producing and the river, estimation units were grouped into two classes of A and B. A is on behalf of the units which possess main streams or tributaries. B refers to the units which possess the secondary tributaries. The basis pollutant export coefficient of A and B is 30% and 25%. Secondly, the basis pollutant export coefficient was revised in teams of the local rainfall and topography. Correction factor to the basis pollutant export coefficient is shown in Table IV and Table V. Finally, pollutant export coefficient of livestock and poultry waste was confirmed.

TABLE IV. TERRAIN CORRECTION COEFFICIENT TO POLLUTANT EXPORT COEFFICIENT

Type	Correction coefficient	Unit and category
plain	1.0	Chengdu (A)
hill	1.2	Zigong(A), Luzhou(A), Deyang(B), Mianyang(B), Guangyuan(A), Suining(B), Neijiang(A), Nanchong(A), Meishan(A), Guang'an(A), Ziyang(A)
mountainous region	1.5	Panzhihua(A), Leshan(A), Yibin(A), Dazhou(B), Ya'an(B), Bazhong(B), Aba(A), Ganzi(A), Liangshan(A),

TABLE V. PRECIPITATION CORRECTION COEFFICIENT TO POLLUTANT EXPORT COEFFICIENT

Type	Correction coefficient	Unit
600-700 mm	1.1	Chengdu
700-800 mm	1.2	Panzhihua, Mianyang, Ganzi
800-900 mm	1.3	Deyang
900-1000 mm	1.4	Guangyuan, Meishan, Aba
1000-1100 mm	1.5	Zigong, Suining, Guang'an, Ziyang
1100-1200 mm	1.6	Nanchong, Dazhou, Bazhong
1200-1300 mm	1.7	Neijiang, Yibin, Liangshan
1300-1400 mm	1.8	Luzhou, Leshan
1700-1800 mm	2.2	Ya'an

III. RESULTS AND DISCUSSION

A. *Pollutant generation loads of LPB*

According to the equation (1), TN, TP and COD generation loads of LPB were estimated in each unit in Table VI (column 2). The total generation loads of TN, TP, and COD was 421860.34 t, 73183.22 t and 7192384.64 t, respectively. In Sichuan province, the maximum of TN, TP and COD loads appeared in Liangshan, which accounted for 10%, 9% and 9% of total pollutant generation loads of Sichuan, while the minimum generation loads appeared in Panzhihua.

According generation loads of LPB and cultivated field areas in each administrative institution in 2012, per area pollutant generation loads of TN, TP and COD were calculated (Figure 2). In Fig. 2, it can be found that per area TN, TP and COD generation loads of Aba were the maximum, which were 381.70 kg·hm^{-2}, 40.94 kg·hm^{-2} and 7810.34 kg·hm^{-2}, respectively. The annual per hectare limited load of TN and TP was 170 kg and 35 kg [11,13]. In Sichuan province, per area TN loads of Aba and Ganzi were over the limited level, while per area TP loads of Aba was over the limited level. In Aba, per area TN load was 2.25 times than the limited level, while per area TP load was 1.17 times than the limited level.

TABLE VI. TOTAL POLLUTION LOAD OF LPB IN STAGES OF GENERATION, DISCHARGE AND EXPORT IN SICHUAN PROVINCE IN 2012 (T)

Unit	Generation			Discharge			Export		
	TN	*TP*	*COD*	*TN*	*TP*	*COD*	*TN*	*TP*	*COD*
Chengdu	34180.29	6653.87	592536.94	14721.29	2060.15	274021.94	4858.03	679.85	90427.24
Zigong	16778.88	3343.12	233902.16	6524.90	1125.66	105402.39	3523.44	607.86	56917.29
Panzhihua	4223.74	687.88	67203.14	1630.13	227.84	29362.48	880.27	123.03	15855.74
Luzhou	19819.86	3468.86	345369.35	8118.92	1112.04	158285.42	5261.06	720.60	102568.95
Deyang	21599.76	3436.17	393244.55	8508.21	1186.69	195851.31	3318.20	462.81	76382.01
Mianyang	14754.95	3119.81	262429.44	6741.88	890.12	110144.19	2427.08	320.44	39651.91
Guangyuan	16108.74	2946.41	279605.24	6619.77	929.88	122128.73	3336.37	468.66	61552.88
Suining	17855.65	3253.31	306128.24	7449.47	1011.23	134835.47	3352.26	455.05	60675.96
Neijiang	13385.69	2658.72	225794.63	5754.50	827.36	104776.42	3521.76	506.35	64123.17
Leshan	15029.49	2722.07	270171.12	6162.88	887.32	127014.84	4991.93	718.73	102882.02
Nanchong	33930.46	6261.69	531679.48	13843.45	1964.31	225400.91	7973.83	1131.44	129830.92
Meishan	5179.63	995.58	82701.50	1819.91	392.11	46161.85	917.23	197.62	23265.57
Yibin	28123.7	4700.62	486029.63	11087.25	1657.80	255989.69	8481.75	1268.22	195832.11
Guang'an	18949.14	3571.15	325695.03	7972.02	1116.29	146766.35	4304.89	602.80	79253.83
Dazhou	19239.92	2924.65	344755.98	7385.34	1000.00	159572.51	4431.21	600.00	95743.51
Ya'an	8675.74	1355.10	155663.46	3357.07	450.90	68808.35	2769.58	371.99	56766.88
Bazhong	20763.93	3740.9	359727.4	8617.94	1141.25	149109.45	5170.77	684.75	89465.67
Ziyang	26860.02	5293.88	375837.34	11208.17	1649.37	164749.31	6052.41	890.66	88964.63
Aba	22939.92	2460.52	469401.62	7822.55	918.30	195272.85	4928.21	578.53	123021.89
Ganzi	21014.03	2741.12	421260.73	7736.66	928.51	174291.86	4177.80	501.40	94117.60
Liangshan	42446.81	6847.79	663247.81	16220.32	2260.80	280136.21	12408.55	1729.51	214304.20

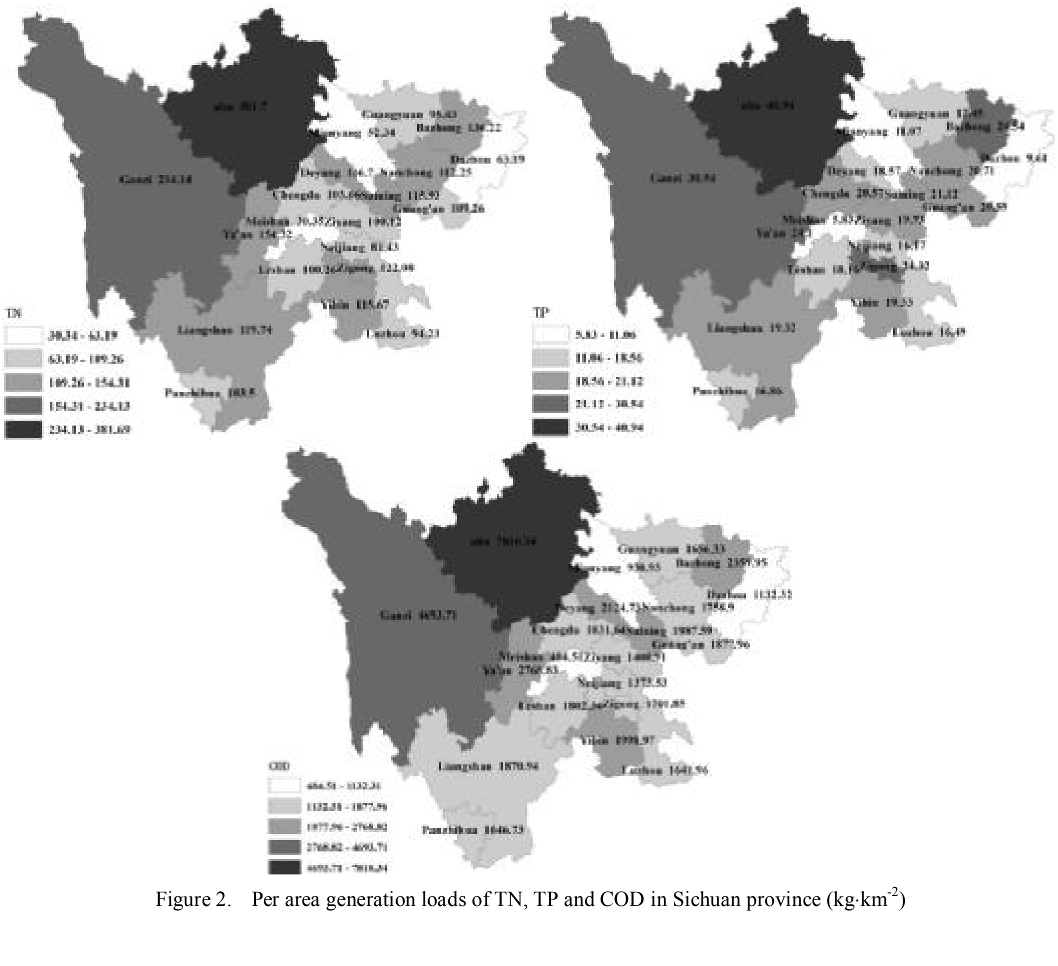

Figure 2. Per area generation loads of TN, TP and COD in Sichuan province (kg·km^{-2})

B. *Pollutant discharge load of LPB*

According to the equation (2), TN, TP and COD discharge loads of LPB were estimated in each unit in Table VI (column 3). The total pollutant discharge loads of TN, TP, and COD in Sichuan province were 169302.65 t, 23737.94 t and 3228082.48 t, which were 40%, 32%, and 45% of the total pollutant generation loads, respectively. Among 21 units, TN, TP and COD discharge loads of Liangshan were the maximum, which accounted for 10%, 10% and 9% of total pollutant discharge loads of Sichuan province.

C. *Pollutant export load of LPB*

According to the equation (3), TN, TP and COD export loads of LPB were estimated in each unit in Table VI (column 4). The total export loads of TN, TP, and COD in Sichuan province were 97086.62 t, 13620.3 t and 1861604 t. In 21 units, TN, TP and COD export loads of Liangshan were the maximum, which accounted for 13%, 13% and 12% of total pollutant export loads of Sichuan province.

The ratio of the export loads and the quantity of surface water resource can be used to describe the surface water pollution degree caused by LPB. Figure 3 showed that the ratios of TN, TP and COD in 21 units. As shown in Fig. 3, the ratios in east of Sichuan province were larger than those in west of Sichuan province. In all 21 units, Suining was the region in which surface water pollution caused by TN, TP and COD from LPB was the most serious.

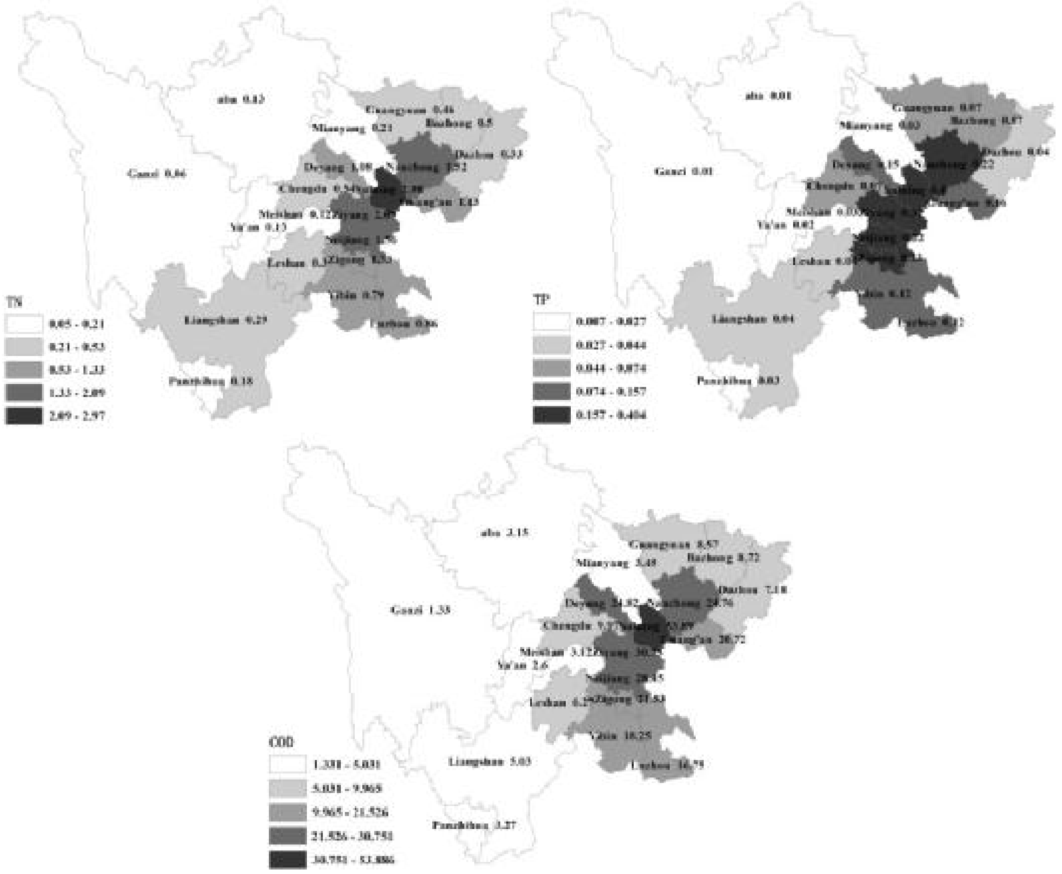

Figure 3. The ratios of export loads and quantity of surface water resource in Sichuan province (mg·L^{-1})

IV. CONCLUSION

In the study, TN, TP and COD loads of LPB of Sichuan province in 2012 were estimated from the stages of generation, discharge and export. The generation, discharge and export loads of TN, TP, and COD were 421860.34 t, 73183.22 t and 7192384.64 t, 169302.65 t, 23737.94 t and 3228082.48 t, and 97086.62 t, 13620.3 t and 1861604 t , respectively. In three processes, Liangshan had the maximum TN, TP and COD loads. In 21 administrative institutions of Sichuan province, Aba was the maximum per area generation loads region of TN, TP and COD, while Suining was the region in which surface water pollution caused by TN, TP and COD from LPB was the most serious. Therefore, Aba and Suining were the critical regions of LPB non-point source pollution control. In Sichuan province, controlling LBP non-point source pollution should to be attached importance with the development of LPB industry.

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