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Spatial distribution of livestock and poultry farm based on livestock manure nitrogen load on farmland and suitability evaluation

Bojie Yan [a,*], Wenjiao Shi [b], Jingjie Yan [c], Kwok Pan Chun [d]

[a] Department of Geography, Minjiang University, Surveying Engineering and Technology Research Center of Fujian Province, Fuzhou 350108, China
[b] Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China
[c] College of Telecommunications and Information Engineering, Nanjing University of Posts and Telecommunications, Nanjing 210003, China
[d] Department of Geography, Hong Kong Baptist University, Hong Kong 999077, China

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ABSTRACT

A spatial distribution model of livestock manure nutrient was used to study the spatial distribution of livestock manure and livestock manure nitrogen load on farmland (LMNLF) at a patch scale. The spatial distribution of livestock and poultry farm (LPF) was also evaluated. The results showed that most regions (50.68%) in the town of Shangjie were forbidden and unsuitable areas for LPF. The highly, moderately and marginally suitable areas for LPF accounted for 25.53%, 23.17% and 0.62% of total area respectively. The combination of the LPF suitability evaluation and livestock manure nitrogen load on farmland (LMNLF) estimation results indicated that 38 LPF should be rectified, relocated or closed, and 14 optimum lands were identified for LPF. Moreover, a relocation plan was developed and visual expressed by GIS spatial analysis.

1. Introduction

The number of livestock and poultry farm (LPF) has been rapidly increasing, but this increase has posed a serious environmental pollution problem. LPF have gradually concentrated in suburban areas of cities in close proximity to markets to reduce the cost of transporting livestock feed and their products; consequently, they can reduce their livestock and poultry product prices. According to a recent report, 70% of LPF are located in eastern China and suburban areas of cities (Fischer et al., 2006; Meng et al., 2015). Most of these areas lack farmlands where livestock manure can be disposed of. The absence of an efficient manure disposal system inevitably leads to various environmental problems. At present, the living environmental conditions of rural and urban residents deteriorate with the inappropriate spatial distribution of LPF. Therefore, such spatial distribution should be adjusted, and LPB should be well coordinated with people's living environment to develop the LPB industry and maximise social, ecological and economic benefits simultaneously and integrally.

Many scholars have conducted studies on the spatial distribution of LPF. Liu et al. (2009) found LPF have strong spatial correlations with consumption markets, roads and residential points. Sullivan et al. (2000) and Zhou (2011) studied the relationship between environmental rules or regulations and LPF spatial distribution. In the United States, public health, animal rights, social economy and environmental pollution are the main factors influencing the spatial distribution of LPF (Harun and Ogneva-Himmelberger, 2013). Furthermore, Flamant et al. (1999) established an evaluation index system for the spatial distribution of LPF and used this system to assess LPF in different areas. Gerber et al. (2005) evaluated the livestock production on four aspects, namely economic benefit maximisation, environmental impact minimisation, public and animal health protection, and rural development and poverty reduction. Yan et al. (2010a) studied the spatial distribution of LPF by using an index system for suitability evaluation and considering the soil environmental pollution index. Peng et al. (2014) established an evaluation index system for the spatial distribution suitability of the livestock and poultry sector; their proposed evaluation index system is based on land suitability assessment as well as the integration of social, economic and environmental indices. Numerous scholars have also studied the spatial distribution and pattern of LPF at the city and county scales by spatial autocorrelation analysis (Basnet et al., 2002; Lenhardt and Ogneva-Himmelberger, 2013; Fu et al., 2012a,b; Benson and Mugarura, 2013). Zhao et al. (2006) and Gerber et al. (2008) assessed the regional layout of the production and construction of LPF by using multi-objective selection criteria and land-use planning technology.

* Corresponding author.
E-mail address: bnunercita@163.com (B. Yan).

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However, in the extant literature, most studies have analysed the spatial distribution of LPF at broad scales, such as national, provincial, city and county scales; however, only a few small-scale (e.g. town or village) analyses have been conducted. Moreover, these studies have regarded the results as uniform across an administrative unit and ignored the spatial differences in the region. Inevitably, these results considerably deviate from the actual situation. In addition, most studies on LPF spatial distribution have considered economic factors, whereas only a few have considered environmental factors.

In view of the current scenario, the objectives of this study are (i) to establish an index system for the suitability evaluation of the spatial distribution of LPFs by considering environmental (nature and ecological), economic, safety, land-use status and restrictive (laws and regulations) indices; (ii) to objectively and scientifically distribute livestock manure using the spatial distribution model of livestock manure and to calculate livestock manure load on a farmland at a patch scale; (iii) to livestock manure nitrogen load on farmland evaluate the spatial distribution of LPFs by combining the suitability evaluation results and the estimation results of livestock manure nitrogen load on farmland (LMNLF). The town of Shangjie in Minhou County, which is a suburban area in Fuzhou City, is selected as the study area.

2. Data and methods

2.1. Study area

Shangjie is a town located in the western suburbs of Fuzhou, Fujian Province. It has a total area of 151.75 km^2 and a population of 77,360. A subtropical monsoon climate prevails in the area, with a mean annual temperature of 21 °C and a mean annual rainfall of 2152.6 mm. The town comprises 23 administrative villages and 132 natural villages. LPF rapidly increased with the economic development in the area. At present, a sharp imbalance exists between the number of farmlands and amount of livestock manure in the study area.

2.2. Data collection and processing

The 2011 basic geographical data of Shangjie, including data from administrative map, road map, water system map and land-use map as well as farmland data and livestock and poultry data, were collected and processed. According to the land-use map and farmland data, the town had 1096 farmlands, which were classified into four types, namely cultivated land, vegetable land, garden land and facility agricultural land (e.g. plastic house and greenhouse). This classification was based on the fertilisation method adopted by the farmlands. Furthermore, 58 LPF were identified using the Global Positioning System, statistical data and actual investigation.

Livestock coefficients, including feeding cycle and excretion coefficient of livestock and poultry, nitrogen content of livestock manure and conversion coefficient between the pigs and other livestock and poultry animals, were drawn from the relevant literature (Yan et al., 2010b; Zhu et al., 2014). The land occupation standard per livestock and poultry unit was determined on the basis of the technical specification of LPF design in the standards for the agricultural sector (Ministry of Agriculture of the PRC, 2003). The livestock coefficients and land occupation standard per livestock and poultry unit are presented in Table 1.

2.3. Spatial distribution model of livestock manure nitrogen

Based on the economic hauling distances for different types of livestock manure (Araji et al., 2001; Bartelt and Bland, 2007; Zeng and Hong, 2008) and our previous studies (Yan et al., 2010b; Yan and Pan, 2014), the spatial distribution model of livestock manure was used to determine the spatial distribution of livestock manure nitrogen (LMN) at a patch scale. The LMN spatial distribution model is

$$W = \sum_{i=1} (Amount_i \times D_i \times \delta_i \times \varphi_i \times \xi_i) \tag{1}$$

$$M = \sum_{x=1}^{b} \left(\left(\frac{\lambda_1}{d_i \sum_{i=1}^{c} (1/d_i)} + \frac{\lambda_2 s_i}{\sum_{i=1}^{c} s_i} + \lambda_3 m_j + \frac{\lambda_4}{n_i \sum_{i=1}^{c} (1/n_i)} \right) \times W \right) \tag{2}$$

where W is the total amount of LMN, $Amount_i$ is the number of livestock and poultry units, D_i is the feeding period of livestock and poultry, δ_i is the excretion coefficient of the livestock, φ_i is the LMN coefficient, ξ_i is the LMN loss, M is the total amount of LMN in a farmland, d_i is the distance between the LPF and farmlands, s_i is the farmland area, m_j is the farmland type, n_i is the farmland fertility and a is the number of livestock and poultry types in LPF. The weights of influences are denoted as follows: λ_1 is the weight of the influence of distance on the spatial distribution of livestock manure, λ_2 is the weight of the influence of farmland area on the spatial distribution of livestock manure, λ_3 is the weight of the influence of farmland type on the spatial distribution of livestock manure and λ_4 is the weight of the influence of farmland fertility on the spatial distribution of livestock manure. Moreover, b is the number of LPF to be distributed amongst the farmlands, c is the number of farmlands within the economic hauling distance between the LPF and farmlands and λ_i are estimated using the analytic hierarchy process (AHP) method. In this study, the spatial distribution of livestock manure was obtained using SuperMap and C# programming language.

2.4. Estimation of livestock manure nitrogen load on farmland

The livestock manure nitrogen load on farmland (LMNLF) is the loading capacity of LMN per unit of farmland area (Foissy et al., 2013; Yang et al., 2016). This parameter was used as the index for the environmental pollution potential of livestock manure. Currently, livestock manure is mainly used as organic fertiliser. Therefore, regional farmland areas were taken as the loading areas of LMN. The LMNLF can be estimated by the following equation:

$$F_{load} = M / S_{farmland} \tag{3}$$

where F_{load} is the LMNLF, M is the total LMN amount and $S_{farmland}$ is the farmland area.

2.5. Suitability evaluation of the spatial distribution of LPF

To reflect the local conditions, ecological and economic benefits, environmental safety and production convenience, environmental (nature and ecological), economic, safety indices, land-use status and restrictive (laws and regulations) indices were selected and integrated into the Delphi-based suitability evaluation of the LPF spatial distribution. The original indices should be dimensionless to ensure the accuracy of the analysis results. In this study, index quantification was used to render the indices dimensionless, and the values of the indices were standardised at 100 by least squares method. Subsequently, the evaluation indices were divided into several suitability grades and assigned values of 0–100 in accordance with the requirement of the suitability evaluation. Finally, the index system for the suitability evaluation of the spatial distribution of LPFs was established (presented in Table 2). On this basis, a single index of classification diagram, such as a slope classification diagram and a land-use classification diagram, was generated