Spatial Layout Planning of Intensive Pig Farms in the Suburb: A Case Study of Nanyu, China

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Spatial layout planning of intensive pig farms in the suburb: A case study of Nanyu, China

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Abstract: A large number of livestock and poultry breeding were distributed in the suburbs, brought a strong environmental pressure to the cities. The issue of whether livestock and poultry breeding could be carried out in the suburbs was a key controversy in the present. To address this question, this study constructed a index system of suitability evaluation of spatial layout of intensive pig farms, calculated the average surface temperature from June to September, and obtained potential intensive pig farms in Nanyu Town. Combing above results and area index results of cultivated land spatial matched with intensive pig farm, spatial relation between cultivated land and potential intensive pig farm was built, the optimum potential intensive pig farm in Nanyu Town was determined, and its carrying capacity was calculated. Results showed that livestock and poultry breeding could be carried out in the suburbs. A total of 3,403 and 3, 253 cultivated lands occupying 52.01% and 49.67% of the total cultivated lands had a spatial relation between potential intensive pig farms taking N and P as indices, respectively. Moreover, 14 and 15 potential intensive pig farms taking N and P as indices, respectively, in Nanyu Town were determined as optimum potential intensive pig farms. Results also indicated that most of the optimum potential intensive pig farms were suitable for constructing small- and medium-sized pig farms. Results would provide scientific basis for the planning of spatial arrangement of livestock and poultry breeding and the suburb environmental pollution control.

Keywords: pig farm; suitability evaluation; spatial relation; geographic information system

Introduction

The rapid development of animal husbandry causes huge pollution problems in China (Qian et al., 2018; Yan et al., 2019). Especially in the early stage of insufficient environmental protection awareness, large- and medium-sized farms were located in the densely populated suburban areas or urban–rural areas (Wei et al., 2018; Zhang, 2019). These livestock farms were usually limited by the supporting cultivated land, which could not achieve the combination of planting and breeding (Zhang et al., 2019). Moreover, such areas easily caused serious environmental pollution (Zhang et al., 2019).

With the rapid development of urbanization and the gradual strengthening of environmental awareness, the social and environmental problems caused by livestock farms in suburban areas or urban–rural areas were increasingly gaining prominence. Therefore, solving these social and environmental problems necessitated the selection of scientific and reasonable spatial layout of livestock farms in the suburbs according to the actual situation of nature, society, and economy.

In view of this problem, many scholars had carried out some research on suitability evaluation, site selection, and spatial layout planning of livestock farms. The key to the suitability evaluation of livestock farms was the research on the index system of suitability evaluation of livestock farms (Zhao et al., 2006; Weersink and Eveland, 2006; Yan et al., 2010; Peng et al., 2014; Yan et al., 2016; Yan et al., 2017; Qiu et al., 2017; Liu et al., 2018). The current index system of suitability evaluation of livestock farms focused on the maximization of environmental benefits (Zhao et al., 2006; Yan et al., 2010), economic benefits (Weersink and Eveland, 2006; Yan et al., 2016), and comprehensive benefits (Peng et al., 2014; Yan et al., 2017; Qiu et al., 2017; Liu et al., 2018). Zhao et al. (2006) developed the decision-making auxiliary tools of sustainable animal husbandry production by establishing the index system of site selection for pig breeding to reduce the negative impact of pig breeding on the environment. Peng et al. (2014) constructed an evaluation index system for the spatial distribution suitability of livestock and poultry sector combing of social, economic, and environmental factors and applied in Putian, Fujian, China. Yan et al. (2017) proposed an index system of suitability evaluation on the spatial distribution of livestock and poultry farm and realized its application combining livestock manure nitrogen load on farmland.

In addition, many researchers had carried out research on site selection of livestock farm (Zeng et al., 2008; Chen, 2009; Khaleda et al., 2013) and spatial layout planning of livestock farm (Yan, 2018; Gallego et al., 2019). Using GIS technology, Zeng et al. (2008) carried out a study to determine the best location of pig farm considering land use status, soil type, slope, distance to road, distance to water, and other factors. With the support of multi-criteria evaluation technology and GIS technology, Khaleda et al. (2013) delimited the appropriate location of poultry farms in Gazipur, Bangladesh considering flood-free land, infrastructures related to the poultry business-enabling environment of the value chain. Yan (2018) conducted research on the spatial layout planning of livestock farms, spatial layout optimization of livestock farms, and the decision support system of spatial layout planning of livestock farms based on the suitability evaluation of spatial layout of livestock farms.

Overall, the current research focused on the construction of a suitability evaluation index system of livestock farm and site selection of livestock farm from the perspective of different maximization of benefits. Although some studies also put forward the idea of combining planting and breeding, the index of combining planting and breeding was rarely considered in the research process. In fact, the combination of planting and breeding was extensively used to control the environmental pollution caused by livestock and poultry breeding and to realize the sustainable development of livestock farms (Zhang et al., 2019). In addition, the results showed that the high temperature environment had a strong influence on the pig industry (Oliveira et al.,2019). With the increase in the environment temperature, the thermoregulation indices of pig such as food intake, evaporation and heat dissipation, respiratory rate, and so on, have changed dramatically (Xia et al., 2016; Perondi et al., 2018; Morales et al.,2019; Oliveira et al.,2019). However, few studies examined the spatial layout of intensive pig farms considering the current regional environment temperature.

Therefore, this study built up a index system of suitability evaluation of spatial layout of intensive pig farms, calculated the average surface temperature, proposed the area index results of cultivated land spatial matched with intensive pig farm, and carried out the spatial layout planning of intensive pig farms in Nanyu Town. The objectives of this study were (i) to answer whether livestock and poultry breeding can be carried out in the suburbs; (ii) to establish a index system of suitability evaluation of spatial layout of intensive pig farms considering the maximization of comprehensive benefits; (iii) to propose an area index of cultivated land spatial matched with intensive pig farm and build a spatial relation between cultivated land and potential intensive pig farm; and (iv) to identify the optimum potential intensive pig farms in the suburbs and calculate its carrying capacity for pigs considering the area index of cultivated land spatial matched with intensive pig farm and surface temperature during summer.

1 Materials and methods

1.1 Study area

Nanyu Town lies in the Suburbs of Fuzhou City, located at 27° N and 119 ° E, with a land area of 17,000 ha and a total population of 56 thousand. The climate of Nanyu Town is the central subtropical monsoon climate. The average annual rainfall in Nanyu Town is about 1,258.9 mm. In addition, the average annual temperature in Nanyu Town is 19.5 ℃ - 20 ℃. Nanyu Town is a typical suburban region with a prominent problem of centralized distribution of livestock farms producing massive livestock manure, reduction of cultivated land, and contradiction between humans and the land.

1.2 Data sources and disposing

Digital elevation model (DEM) is a global digital elevation data product of ASTER GDEMV2 30 m gained from Geospatial Data Cloud Platform of Computer Network Information Center of Chinese Academy of Sciences (http://www/gsclound.cn). On the basis of DEM, the aspect and slope of Nanyu Town were gained via ArcGIS10.3 software. The spatial locations of livestock farms were obtained using a global positioning system (GPS) and field investigation. The spatial and attribute data such as water; residential area; cultivated land including ordinary cultivated land, garden plot, and facility agriculture; roads, markets, land use status, and so on, were gained by vectoring using ArcGIS10.3 software and field investigation based on the aerial image (0.3 m) and administrative map of Nanyu Town in 2015. The landsat-8 data (June 7, 2015, July 25, 2015, August 26, 2015 and September, 27 2015) were processed through a geometric correction, radiometric calibration, and atmospheric correction and used as basic images for calculating the average surface temperature through the atmospheric correction method in ENVI 5.1.

The breeding cycle of pig and daily excretion coefficient of N, P content of pig manure were calculated as 199 d, 20.76 g/d, and 2.63 g/d by referring from literature (Zhu et al, 2014; Yan et al, 2020). The occupied area per pig in an intensive pig farm was determined as 1.2 m^2 from the construction criterion for standardized intensive pig farms (NY/T 1568-2007, 2007). The critical average distance of transporting pig manure to cultivated land was calculated according to the method by Li et al. (2016).

1.3 Methods

1.3.1 Suitability evaluation of the spatial layout of intensive pig farms

The index system of suitability evaluation of spatial layout of intensive pig farms was built up considering the evaluation factor including environmental factor such as slope, DEM, distance to water, and so on; economic factors such as distance to road, land use status, and so on; and safety factor such as distance to existing livestock farms by referring from literature (Ministry of Agriculture of the People's Republic of China, 2003; Ministry of Agriculture of the People's Republic of China, 2007; Yan et al., 2010; Peng et al., 2014; Yan et al., 2016; Yan et al., 2017; Yan et al., 2018; Yan et al., 2021), Delphi method, and practical investigation. Table 1 shows the result.

Table 1 The index system of suitability evaluation of spatial layout of intensive pig farms

Evaluation factor		Evaluation value					
	Slope (°)	<3	3-5	5-10	10-15	>15	>25
Environmental factor	Aspect	South	Southeast, East [157.5，247.5)	Southwest [247.5，292.5) or [112.5，157.5)	West [67.5，112.5 or [292.5，337.5)	North,Northeast,Northwest [0，67.5 or [337.5，360)	

	DEM (m)	<0.1	0.1-0.2	0.2-0.3	0.3-0.5	>0.5	
	Distance to water (km)	0.5-1	1-2	2-3	3-4	>4	<0.5
	Distance to residential area (km)	0.5-1	1-2	2-3	3-5	>5	<0.5
	Distance to cultivated land (km)	<0.5	0.5-1	1-2	2-3	>3	
	Distance to road (km)	0.1-0.5	0.5-1	1-3	3-5	>5	<0.1
Economic factors	Distance to market (km)	<1	1-3	3-5	5-8	>8	
	Land use status	Waste land	Grassland	Sand	Forest land	Garden plot	
Safety factor	Distance to existing livestock farms (km)	>4	3-4	2-3	1-2	0.5-1.0	<0.5
	Score	100	80	60	40	20	0

The dimensionless factors were rendered by the factor quantification method. Then, the values of the factor were standardized at 100 and divided into several suitability grades and assigned values of 0－100 referring from Yan et al. (2017). Furthermore, the analytic hierarchy process was adopted to calculate the weights of the factor in reference to the basis of existing literature (Peng et al., 2014;Yan et al., 2017; Huda et al., 2017; Ameen and Mourshed, 2019). The hierarchy of suitability evaluation of spatial layout of intensive pig farms was built into goal, criteria, and sub-criteria. Then pair-wise comparison was constructed by the paired comparison of each factor over another (Saaty,1994; Ameen and Mourshed, 2019). The nine-scale was adopted to determine the importance of the experts’judgments (Ameen and Mourshed, 2019). Finally, the consistency of judgment was determined by consistency ratio (CR) (Ameen and Mourshed, 2019). The weight of factors was acceptable when CR< 0.1 (Saaty, 1990; Yan et al., 2017). The result was showed in Table 2.

Table 2 Hierarchy of suitability evaluation of spatial layout of intensive pig farms

Goal	Criterion	Sub criterion	Global weight
Suitability evaluation of spatial layout of intensive pig farms	Environment indexes (0.6079)	Slope (0.0863)	0.0525
		Aspect (0.0714)	0.0434
		DEM (0.1134)	0.0689
		Distance to water (0.1774)	0.1078
		Distance to residential area (0.2209)	0.1343
		Distance to cultivated land (0.3306)	0.2010
	Social, economic indexes (0.2721)	Land use (0.1638)	0.0445
		Distance to road (0.5390)	0.1467
		Distance to market (0.2973)	0.0809
	Safety factor (0.1200)	Distance to existing livestock farms (0.1200)	0.1200

On the basis of these results, the index system of suitability evaluation of spatial layout of intensive pig farms can be gained using a multi-factor weighted evaluation model as follows:

$$S = \sum_{i=1}^{n} (A_i \times \lambda_i)\,, \tag{1}$$

where S denotes the suitability evaluation values of the spatial layout of intensive pig farms; A_i denotes the value of factors; λ_i is the weight of factors; and n is the number of factors.

1.3.2 Area index of cultivated land spatial matched with intensive pig farm

In view of the principle that intensive pig farm should be matched with sufficient cultivated land, the area index of cultivated land spatial matched with intensive pig farm is constructed using GIS spatial analysis method. The area index of cultivated land spatial matched with intensive pig farm can be calculated as follows:

$$f = \frac{S_c}{S_{max}}, \tag{2}$$

$$S_{max} = \frac{[(\frac{S_A}{S_a}) \times \eta \times \delta]}{W_{max}}. \tag{3}$$

The area of cultivated land around the potential pig farm within a critical average distance of transporting pig manure to cultivated land can be gained via a spatial buffer analysis and spatial overlay analysis according to the principle of nearest distance realized by component GIS development technology. Furthermore, the distance between potential livestock farm and cultivated land used via spatial buffer analysis can be calculated as follows (Patel and Upadhyay, 2020; Yan et al., 2021):

$$d_c = \sqrt{(X_i - x_i)^2 + (Y_i - y_i)^2}, \tag{4}$$

$$d_c \le D_{\max}. \tag{5}$$

where f is area index of cultivated land spatial matched with intensive pig farm; S_A is area of potential livestock farm gained by suitability evaluation of spatial layout of pig farm, m^2; S_a is occupied area per pig in pig farm, m^2; S_c is area of cultivated land around the potential pig farm within critical average distance of transporting pig manure to cultivated land, m^2; S_{max} is the maximum area of cultivated land spatial matched with pig farm, m^2; W_{max} is the maximum pig manure nutrient load of cultivated land, kg/ha; η is the feeding cycle of pig, δ is the daily excretion coefficient of N, P content of pig manure. d_c is the distance between potential livestock farm gained by suitability evaluation of spatial layout of pig farm and cultivated land, km; D_{max} is the critical average distance of transporting pig manure to cultivated land, km; X_i is the x coordinate of the geometric center of livestock farm; Y_i is the y coordinate of the geometric center of livestock farm, x_i is the x coordinate of the geometric center of cultivated land; and y_i is the y coordinate of the geometric center of cultivated land.

1.3.3 Carrying capacity of potential intensive pig farm calculation

The carrying capacity of potential intensive pig farm calculation can be calculated as follow:

$$A = \begin{cases} \frac{S_A}{S_a}, f = 1 \\ \frac{W_{max} \times S_c}{\eta \times \delta}, 0 < f < 1 \end{cases}. \tag{6}$$

where A is carrying capacity of potential pig farm; S_A is area of potential livestock farm gained by suitability evaluation of spatial layout of pig farm, m^2; S_a is occupied area per pig in pig farm, m^2; S_c is area of cultivated land around the potential pig farm within critical average distance of transporting pig manure to cultivated land; W_{max} is the maximum pig manure nutrient load of cultivated land, kg/ha; η is the feeding cycle of pig; and δ is the daily excretion coefficient of N, P content of pig manure.

2 Results

2.1 Suitability evaluation result of the spatial layout of intensive pig farms

According to the multi-factor weighted evaluation model in formula (1) and the weight of each factor, the grid layers of each factor were weighted stack using the raster calculator of map algebra based on ArcGIS 10.3 software. On this basis, the suitability evaluation result of the spatial layout of intensive pig farms of each evaluation index grid unit in Nanyu Town was obtained. The natural breaks method was used to divide the suitability evaluation result of the spatial layout of a large-scale pig farm into five grades, namely, high suitable area, moderate suitable area, low suitable area, critical suitable area, and unsuitable area. Furthermore, the prohibited area for intensive pig farms in Nanyu Town was gained via ArcGIS 10.3 software according to literature (State Environmental Protection Administration of China, 2001; Ministry of Agriculture of the People's Republic of China, 2007; Yan et al., 2010; Yan et al., 2016; Yan et al., 2017). Then, the prohibited area, high suitable area, moderate suitable area, low suitable area, critical suitable area, and unsuitable area for intensive pig farm in Nanyu Town were combined through spatial analysis with ArcGIS 10.3 software. Figure 1 illustrates the results.

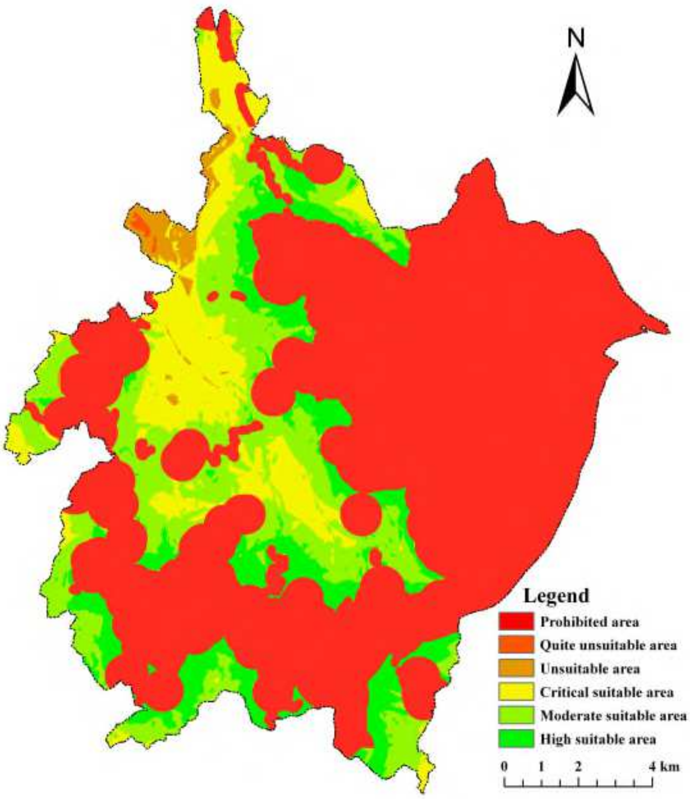

Figure 1 Suitability evaluation result of spatial layout of intensive pig farms

The high suitable area for intensive pig farms was 1,482.57 ha, accounting for 8.72% of the total area of Nanyu Town, which was concentrated in the north, middle, and south of Nanyu Town. These areas had convenient transportation, relatively flat terrain, moderate distance from roads, markets and residential areas, far distance from existing farms, and rich land resources. Therefore, it was highly suitable for the construction of intensive pig farms. The total area of moderate suitable areas for intensive pig farm was 2,519.82 ha, accounting for 14.82% of the total area of Nanyu Town, which was distributed in the north, south, west, and central parts of Nanyu Town. These areas had low elevation, low slope, certain land resources, and convenient transportation. Therefore, it was moderately suitable for the construction of intensive pig farms.

The total area of critical suitable area for intensive pig farms was 1,734.14 ha, accounting for 10.20% of the total area of Nanyu Town. It distributed in the north and west of Nanyu Town. These areas had low elevation, an average slope of 16.45°, and limited land resources and traffic conditions. The unsuitable area for intensive pig farms was 255.57 ha, accounting for 1.50% of the total area of Nanyu Town, which was distributed in the northwest of Nanyu Town. Most of unsuitable area for intensive pig farms were in low and middle mountains region, with an average elevation of 490.86 m, an average slope of more than 24°, inconvenient transportation, and less land resources. The relatively unsuitable area for intensive pig farms was 22.73 ha, only accounting for 0.14% of the total area of Nanyu Town. It distributed in the northwest corner of Nanyu Town. The average elevation was over 537.30 m, and the slope was extremely large in these areas. In addition, these areas have high mountains and deep valleys, poor traffic conditions, and extremely scarce land resources. The total area of the forbidden area for intensive pig farms was 10,985.16 ha, accounting for 64.62% of the total area of Nanyu Town, which was in the eastern and southern areas of Nanyu Town. These areas were residential areas, cultural and educational areas with concentrated population, convenient transportation, water systems concerned, and livestock farms gathered.

2.2 Results of average surface temperature from June to September in 2015 in Nanyu Town

The average surface temperature from June to September 2015 in Nanyu Town was taken via the atmospheric correction method in ENVI 5.1. Then, the natural breaks method was used to divide the average surface temperature into six grades. Figure 2 presents the results.

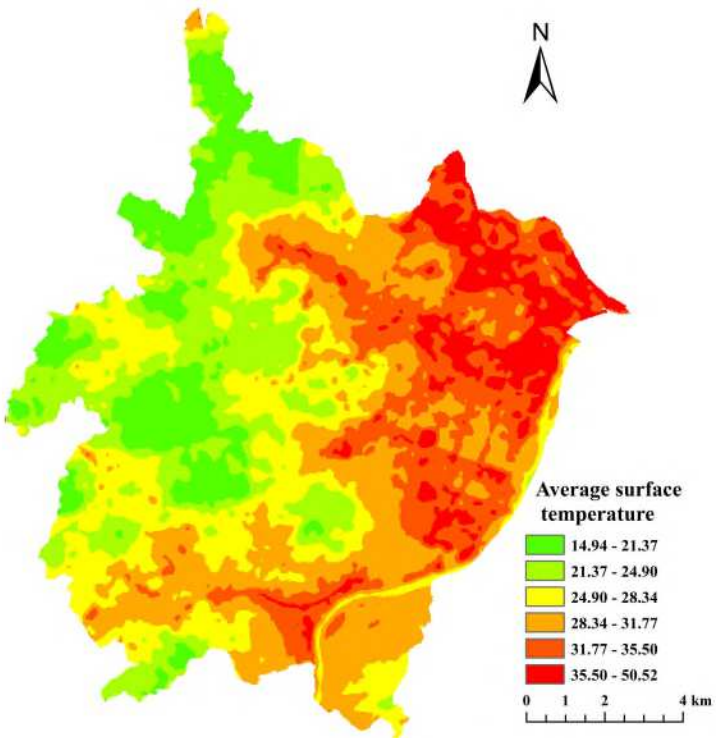

Figure 2 Spatial distribution results of average surface temperature from June to September in 2015 in Nanyu Town

The spatial distribution of average surface temperature from June to September in Nanyu Town was uneven, showing the spatial characteristics of low in the western part of Nanyu Town and high in the eastern part of Nanyu Town. Furthermore, the average surface temperature slowly increased from the West to the East and from the North to the South. The areas with high average surface temperature were concentrated in the eastern and southern parts of Nanyu Town, which were a population concentration region including residential areas, cultural and educational areas, and road traffic network intensive areas. The areas with low average surface temperature were distributed in the northwest and western parts of Nanyu Town, which belonged to the forest areas with a sparse population and road traffic network.

According to the analysis of the statistical results, the highest and lowest average surface temperatures from June to September in 2015 of Nanyu Town were 50.52 ℃ and 14.94 ℃, respectively. Although the average surface temperature could not represent the temperature of the region at that time, the average surface temperature gained based on landsat-8 data could reflect the temperature difference in Nanyu Town.

2.3 Spatial distribution results of potential intensive pig farms in Nanyu Town

Combing the construction land area of constructions for intensive pig farms (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, 2008), spatial distribution results of the total 40 most suitable areas for intensive pig farms in Nanyu Town were gained on the basis of the suitability evaluation result of the spatial layout of intensive pig farms and results of the average surface temperature by GIS spatial analysis. Figure 3 shows the results. Moreover, these 40 most suitable areas for intensive pig farms were taken as potential intensive pig farms in Nanyu Town.

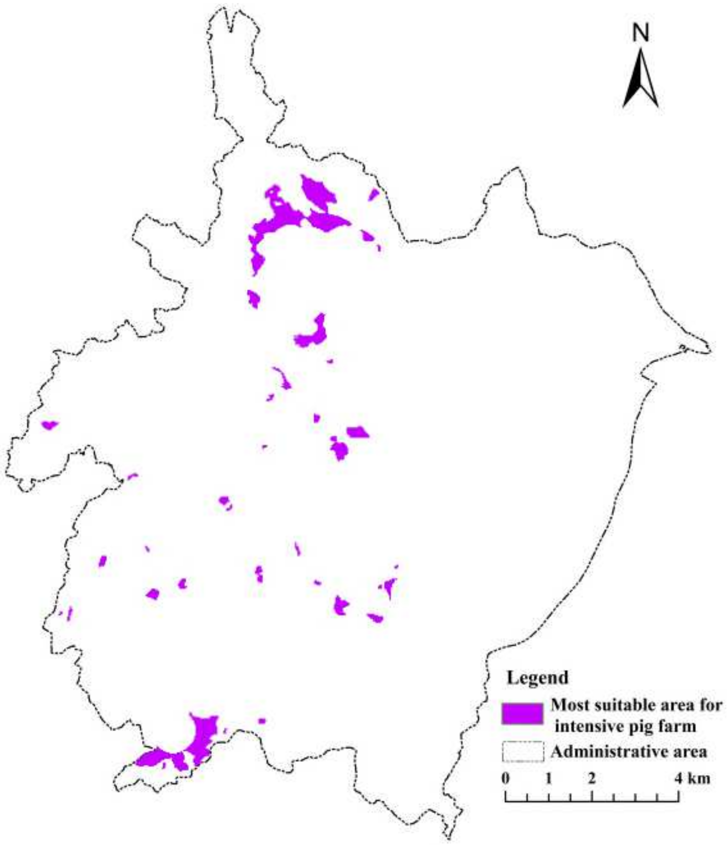

Figure 3 Spatial distribution results of the suitable area for intensive pig farms in Nanyu Town

The spatial distribution of potential intensive pig farms was uneven in Nanyu Town. The potential intensive pig farms were distributed in the northwest and southwest parts of Nanyu Town, and a few were scattered in the central and western parts of Nanyu Town. Moreover, the potential intensive pig farms were in various sizes. The total area of 40 potential intensive pig farms was 654.46 ha, occupying 3.85% of the total area of Nanyu Town. Furthermore, the maximum, minimum, and average areas of these potential intensive pig farms were 144.93 ha, 0.54 ha, and 16.36 ha.

2.4 Spatial distribution results of the area index of cultivated land spatial matched with potential intensive pig farm

According to formulas (2)–(5) and the principle of minimizing transportation cost, the spatial distribution results of the area index of cultivated land spatial matched with potential intensive pig farm in Nanyu Town taking N and P as indices were gained by using GIS spatial analysis technology and critical average distance of livestock manure transportation. Figures 4.a and 4.b present the results, respectively.

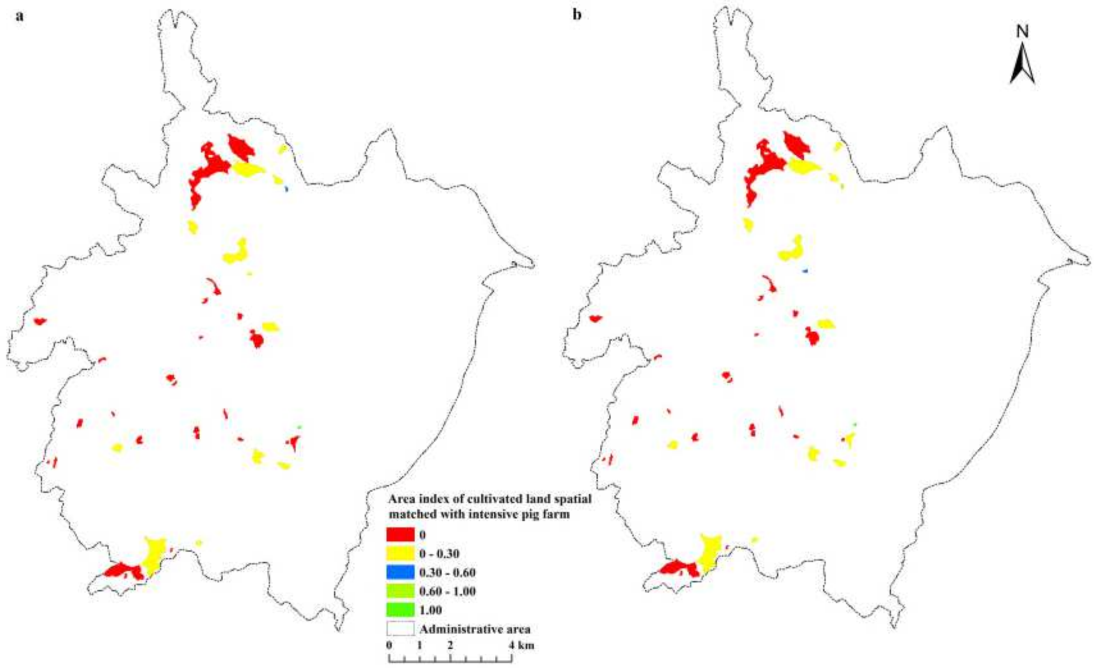

Figure 4 Spatial distribution results of area index of cultivated land spatial matched with intensive pig farm in Nanyu Town

The spatial distribution results of the area index of potential intensive pig farm spatial matched with cultivated land were uneven. Most of potential intensive pig farms had no area index of potential intensive pig farm spatial matched with cultivated land. Only 14 and 15 potential intensive pig farms, occupying 35.00% and 37.50% of the total potential intensive pig farms, had an area index of potential intensive pig farm spatial matched with cultivated land taking N and P as indices, respectively. The maximum, minimum, and average values of the area index of potential intensive pig farm spatial matched with cultivated land in 14 potential intensive pig farms taking N as index were 1.0000, 0.1240, and 0.0002, respectively. Moreover, the maximum, minimum, and average values of the area index of potential intensive pig farm spatial matched with cultivated land in 15 potential intensive pig farms taking P as index was 1.0000, 0.1485, and 0.0003.

In addition, the spatial relation between cultivated land and 14 and 15 potential intensive pig farms in Nanyu Town was constructed taking N and P as indices, respectively, by using the component GIS technology and software development technology. Figures 5.a and 5.b present the results. Obvious differences exist in the spatial relation between cultivated land and different potential intensive pig farms in Nanyu Town.

Owing to the unreasonable distribution of cultivated lands, only 3,403 and 3,253 cultivated lands distributed in the east of in Nanyu Town occupying 52.01% and 49.67% of total cultivated lands, had a spatial relation between potential intensive pig farm taking N and P as indices, respectively. The potential intensive pig farm having a spatial relation with the most cultivated land regardless whether it takes N or P as index was labeled No .6, followed by No. 7, and the least was labeled No. 3. The total, maximum, minimum, and average areas of cultivated land having a spatial relation with potential intensive pig farm taking N as index in 14 potential intensive pig farms were 411.2323 ha, 109.4440 ha,1.0621 ha, and 29.3737 ha. Moreover, the total, maximum, minimum, and average areas of cultivated land having a spatial relation with potential intensive pig farm taking P as index in 15 potential intensive pig farms were 391.7028 ha, 101.9387 ha,1.0621 ha, and 26.1135 ha.

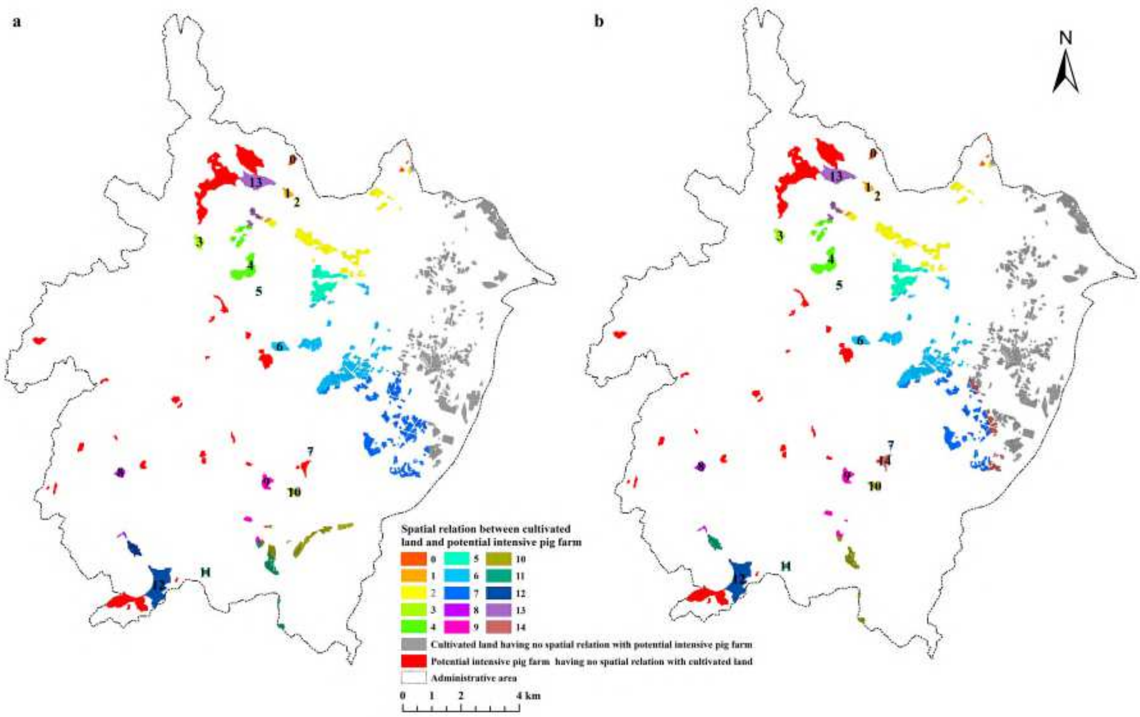

Figure 5 Spatial relation between cultivated land and potential intensive pig farm in Nanyu Town

2.5 Calculation results of carrying capacity of potential intensive pig farm

Based on the above results, the 14 and 15 potential intensive pig farms taking N and P as indices, respectively, were determined as the optimum potential intensive pig farms.

The results of the carrying capacity of potential intensive pig farm in Nanyu Town in 14 and 15 optimum potential intensive pig farms taking N and P as indices were calculated on the basis of formula (6) and GIS spatial analysis technology. The results were graded according to a construction criterion for standardized intensive pig farms (NYT 1568-2007). Figures 6.a and 6.b show the results, respectively. Most of the optimum potential intensive pig farms were suitable for constructing small- and medium-sized pig farms. Only 2 and 4 optimum potential intensive pig farms taking N and P as indices respectively were suitable for constructing large intensive pig farms.

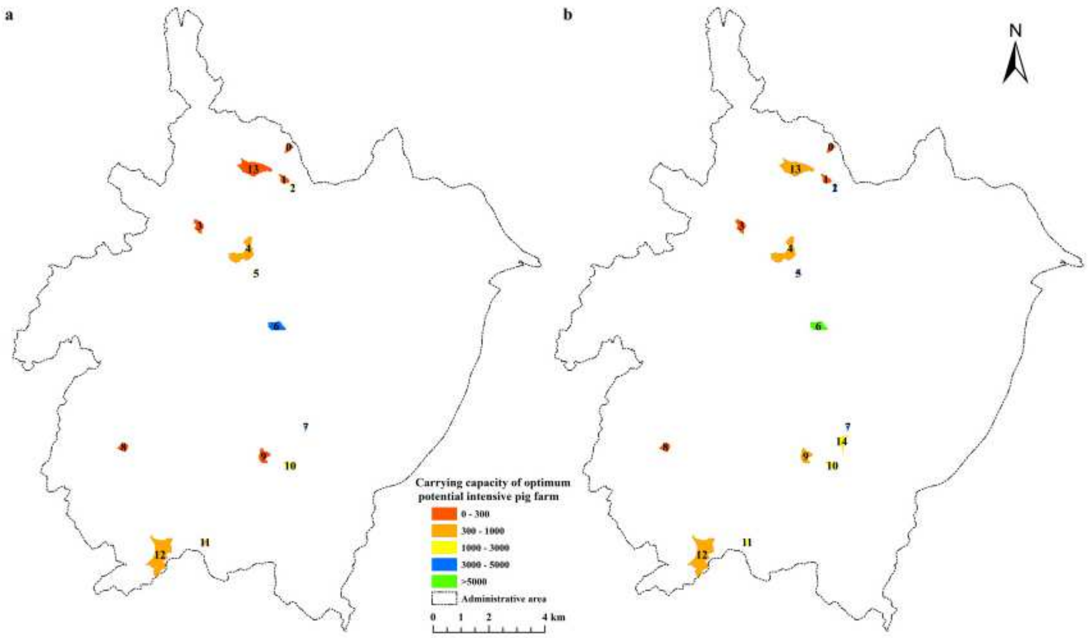

Figure 6 Spatial distribution results of calculation of carrying capacity of optimum potential intensive pig farm in Nanyu Town

The statistical results showed that the total, maximum, minimum, and average carrying capacity of potential intensive pig farm taking N as index in 14 optimum potential intensive pig farms were 16,922.15; 4,503.61; 43.70; and 1,208.73. Moreover, the total, maximum, minimum, and average carrying capacity of potential intensive pig farms taking P as index in 15 optimum potential intensive pig farms were 26,194.85; 6,817.08; 71.02; and 1,746.32.

3 Discussion and conclusions

This study carried out a suitability evaluation of the spatial layout of intensive pig farms, calculated average surface temperature and area index results of cultivated land spatial matched with intensive pig farm, and determined optimum potential intensive pig farms and its carrying capacity for pigs in Nanyu Town. Results showed that most of the total areas in Nanyu Town were unsuitable for constructing intensive pig farms. A total of 3,403 and 3,253 cultivated lands had spatial relations between potential intensive pig farms taking N and P as indices, respectively. In addition, 14 and 15 optimum potential intensive pig farms in Nanyu Town taking N and P as indices, respectively, were gained. Moreover, most of the optimum potential intensive pig farms were only suitable for constructing small- and medium-sized pig farms.

The suitability evaluation of the spatial layout of livestock and poultry farms was the premise of the spatial layout planning of livestock farms. Many studies showed that the suitability evaluation of the spatial layout of livestock farms could consider comprehensive indicators based on the maximization of comprehensive benefits and gained scientific results (Peng et al., 2014;Yan et al., 2017; Liu et al., 2018). Accordingly, this research carried out the suitability evaluation of the spatial layout of intensive pig farms based on the principle of maximizing comprehensive benefits. Compared with many studies (Zhao et al., 2006; Yan et al., 2010; Peng et al., 2014; Yan et al., 2016; Yan et al., 2017; Qiu et al., 2017; Liu et al., 2018), the current research determined the optimum potential intensive pig farms considering the suitability evaluation result of the spatial layout of intensive pig farms average surface temperature and area index results of cultivated land spatial matched with intensive pig farm. Furthermore, the existing research results had shown that the high temperature environment had a profound impact on the pig industry (Xia et al., 2016; Perondi et al., 2018; Morales et al., 2019; Oliveira et al., 2019). Therefore, selecting the region with relatively low temperature in summer as the potential location for spatial layout planning of intensive pig farms is highly valuable.

At present, the idea of determining the carrying capacity of livestock and poultry by cultivated land and combining planting and breeding had been highly recognized by government departments and many scholars (Zheng et al., 2013; Yin et al., 2019; Zhang et al., 2019). Some studies also attempted to carry out the application of combined planting and breeding (Yin et al., 2019; Zhang et al., 2019). However, recent research on the spatial layout or site selection of livestock farms seldom considered the index of combination of planting and breeding. Thus, the present study considered the index of combination of planting and breeding and proposed the area index of cultivated land spatial matched with intensive pig farm. Using this area index, we could quickly determine whether a potential intensive pig farm exists with adequate cultivated lands to dispose of livestock manure. Moreover, the results of the spatial layout planning of intensive pig farms would be scientific when considering the area index of cultivated land spatial matched with intensive pig farm. In addition, the carrying capacity of optimum potential intensive pig farms in this paper was calculated strictly according to the principle of determining the carrying capacity of livestock and poultry by cultivated land. Furthermore, the spatial relationship between potential intensive pig farm and cultivated lands was constructed in this result which clarified the matching relationship between potential intensive pig farm and cultivated lands with its corresponding visual presentation.

The current research determined the optimum potential intensive pig farms in the suburb and proposed the combination of planting and breeding in township scale. Therefore, we can realize the recycling of regional resources and the non-export of livestock manure and thus form a relatively closed agricultural recycling region. The results also indicated that livestock and poultry breeding can be carried out in the suburbs. The research results were highly valuable to the spatial arrangement of livestock and poultry breeding, the suburban environmental pollution control, and the division of prohibited areas, namely, restricted and suitable areas. In addition, developing intensive pig farms in the suburb not only reduces the cost of breeding, transportation, and selling but also avoids or slows down the current soaring prices for pork.

Although this research achieved some results, some limitations persist. The following points require further in-depth study in the future. First, the average surface temperature was used as average environmental temperature in this paper. Although it could reflect the temperature differences in regions, we should use average air temperature as average environmental temperature in the future to gain more accurate results. Second, the limit stipulated by the European Union (i.e., 35, 170kg/hm^2) was taken as the maximum pig manure nutrient load of cultivated land due to the lack of a unified standard for the livestock manure nutrient load of cultivated land in China. Therefore, future research should consider the actual maximum livestock manure nutrient that could be disposed of by cultivated lands. Third, this research involved the calculation of many spatial data, except the area index of cultivated land spatial matched with intensive pig farm. Moreover, the spatial relation between potential intensive pig farm and cultivated lands was subjected to automatic calculation via programming and component GIS technology. The automatic calculation of the suitability evaluation of the spatial layout of intensive pig farms and carrying capacity of optimum potential intensive pig farm requires further study.

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