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Regionalization of Agricultural Nonpoint Source Pollution over China with a Combination of Qualitative and Quantitative Method

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Abstract: Agricultural nonpoint source pollution has been a serious problem in China; however, currently a lack of basic data and quantitative analysis hinders control and reduction of agricultural nonpoint source pollution. Therefore, it is necessary to explore a regionalization method in the study of nationwide agricultural nonpoint source pollution over China. This paper proposes a method of combining both quantitative calculation and qualitative analysis. Based on agricultural nonpoint source pollution mechanism, we first proposed the natural environment index, which was calculated from relief degree of land surface, thermal humidity index, water resources quantity and precipitation index, and land cover index. Second, we proposed basic agricultural environment index, which was calculated based on the area of cultivated land use and the quality of integrated soil fertility. Third, we simplified the spatial distribution of natural environment and basic agricultural environment with the method of choropleth map classification, thematic map series, and gravity centers curve. Fourth, we conducted a qualitative analysis for both the natural environment and basic agricultural environment by overlaying the classification and existing regionalization maps to reveal the intra-region homogeneity and inter-region heterogeneity with a high reliability. The regionalization method used in this study resulted in a nationwide regional zoning of agricultural nonpoint source pollution over China, and China can be divided into 10 regions, which can be a trustworthy reference for agricultural nonpoint source pollution study and management.

Keywords: regionalization; agricultural nonpoint source pollution; mechanism; index system; spatial analysis; GIS

1. Introduction

In recent years, with livestock pollution playing a more and more prominent role in agricultural nonpoint source (NPS) pollution [1], agricultural nonpoint source (NPS) pollution has become a particularly serious problem for water quality management in China [2]. Although many studies have focused on agricultural NPS pollution estimation [3], evaluation [4–6], and management [7–11], studies on the entirety of China have rarely been carried out. This is because when Chinese scholars pay attention to the problem of agricultural NPS pollution, at first, the research area is limited only to the region where agricultural NPS pollution is located [8,9,11]. Under this circumstance, it is necessary to develop an environmental management policy on agricultural NPS pollution on a large scale, including livestock pollution. However, due to the heterogeneous problems and challenges [12], it is not sufficient to apply an uniform environmental policy on a national scale [13]. China’s management policy is
usually top-down, which considers the situation of the country as a whole. It is indispensable to carry out nationwide research on the division of regions first and to find out a regional zoning for the country to deal with the agricultural NPS problem. Therefore, developing and applying regional management policies to combat agricultural NPS pollution is necessary, which requires a regionalization map of agricultural nonpoint source pollution.

In recent years, many studies have been conducted in China to focus on regionalization of soil and water conservation [14], climate [15], ecological regionalization [16,17], hydrological regionalization [18], and relevant models such as hydrological models [19–21] and physical watershed models [4,22,23]. Quantitative methods are increasingly applied in these studies and can provide valuable information; however, these models require a large number of parameters which are difficult to acquire for nationwide analysis [5], especially for those involving different categories of spatial elements. Therefore, it is necessary to find a regionalization method in nationwide agricultural NPS pollution studies, as well as in livestock and poultry-breeding pollution studies. In this study, we aimed to explore a solution for nationwide agricultural NPS pollution regionalization over China. We combined qualitative and quantitative approaches to provide scientific results and basis for developing a strategic policy for agricultural NPS pollution management in China.

2. Materials and Methods

2.1. Data Collection

Topography, climate, hydrology, and soil are closely related to the diffusion and migration of agricultural nonpoint source pollution. Rainfall characteristics, land use, and soil properties were also proved to be the major factors affecting the migration and transformation of NPS pollutants [11]. Therefore, data used in this study include digital elevation model, average annual temperature, average annual air relative humidity, average annual precipitation, water area, land use types, normalized difference vegetation index, paddy fields area, dryland area, multiple cropping index, soil total nitrogen, soil total phosphorus, soil total potassium, and soil organic matter. All the data were processed into Krasovsky_1940_Albers projection at 1 km resolution.

Shuttle radar topography mission (SRTM) digital elevation model data were obtained from the National Science and Technology Infrastructure Platform—Data Sharing Infrastructure of Earth System Science (Cold and Arid Regions Scientific Data Sharing Platform). The data were sourced from the earth resources observation satellite data center of U.S. Geological Survey, GTOPO30 global digital elevation model data with grid resolution of 30 arc seconds. SRTM digital elevation model data were used to extract the relief degree of land surface (RDLS).

The average annual temperature data, data of average air temperature over 30 years from 673 meteorological stations, were obtained from the Chinese Ecosystem Research Network Data Sharing Platform, national meteorological/climate raster dataset. The annual average relative air humidity data, data of 680 meteorological stations’ cumulative monthly average relative humidity over 30 years, were also retrieved from the platform. Data from these two sources were used to calculate the thermal humidity index (THI).

The average annual precipitation data were obtained from the University of California, Berkeley, high-precision global terrestrial climate surface interpolation data sets—WorldClim [24]. The data cover a wide range of global, regional, national, and local meteorological stations’ cumulative average monthly climatological data over 50 years. The proportion of water area data at 1 km grid size were supplied by the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences. Data from these two sources were used to calculate the water resources quantity and precipitation index (WRI).

Land use data at 1 km grid size were also supplied by the Data Center for Resources and Environmental Sciences. Normalized difference vegetation index data, based on NASA’s MODIS data,
are the calculation of the mean value of every eight days and its annual average value. Data from these two sources were used to calculate the land cover index (LCI).

Data of the paddy fields and dryland area were derived from the land use datasets. Cropping index, based on the Chinese Farming Systems Regionalization, was rasterized by vector data, which were obtained from the Chinese Academy of Agricultural Sciences, the Institute of Agricultural Resources and Regional Planning. Data from the three sources were used to calculate the cultivated land use (CLU) [25].

Soil total nitrogen, soil total phosphorus, soil total potassium, and soil organic matter data were obtained from the National Science and Technology Infrastructure Platform—Data Sharing Infrastructure of Earth System Science, the Chinese 1:4,000,000 soil fertility mass distribution atlas. The data are based on the second national soil survey results of the Chinese 1:4,000,000 and 1:1,000,000 soil maps. All above data were used to calculate the integrated soil fertility (ISF).

Many existing regionalization maps can provide abundant qualitative information. These regionalization maps were used in this research to explore partitioning scheme and identify strategic boundaries. Therefore, we collected data from the Physical Regionalization of China (PR) [26], Overall Regionalization of Agriculture in China (ORA) [27], the Comprehensive Livestock Regionalization of China (CLR) [28], and the Discharge Reduction Districting of Livestock of China (DRDL) [29]. The PR, ORA, and CLR were obtained from the National Sharing Platform of Agriculture Science Data. DRDL is the districting strategy used in the Ministry of Environmental Protection of People’s Republic of China.

2.2. Agricultural NPS Pollution Mechanism

Agricultural NPS pollution, man-made impact on the natural environment (NE), is caused by the agricultural activities such as planting and breeding. NPS pollution is tightly linked to land use activities that determine the sources and magnitude of pollutant loadings to stream water [30]. Fertilizer application and farmland management behavior have an important influence on NPS pollution in rural areas [31]. Soil NPS pollutant contents under different vegetations had significant temporal dynamics [11]. The prioritizing management strategies based on the contribution of sources across climate and hydrology variability will be critical for controlling nonpoint source pollution [32]. For NPS pollution, the most relevant social indicators are those related to behaviors and factors that influence water quality improvement or protection [33]. Therefore, relevant factors of agricultural NPS include land use patterns [30], farming habits [31], topography [34], soil [11,34], vegetation [11], climate [32], hydrology [11,32], and socio-economic factors [33].

Such factors can be classified into natural environment, basic agricultural environment (BAE), socio-economic environment (SE), agricultural cultivation and breeding situation (ACB), agricultural NPS pollution generation (APG), emission reduction measures (ERM), and agricultural NPS pollution discharge (APD) [35]. The agricultural NPS mechanism is shown in Figure 1.

![Figure 1. The agricultural nonpoint source (NPS) pollution mechanism.](image-url)
agricultural NPS pollution regionalization studies. SE and ACB represent human activity intensity in various areas, such as population, economy, energy consumption, crops cultivation, livestock, and poultry breeding. SE and ACB reflect the meso-scale differentiation under the existing macro ones. APG, ERM, and APD represent human disturbance to NE under existing human activity intensity. Livestock and poultry-breeding pollution is the principal part of agricultural NPS pollution. It is also consistent with the above-mentioned mechanism. Therefore, factors in agricultural NPS pollution mechanism should be considered in livestock and poultry breeding pollution regionalization studies.

2.3. NE Index System

As an important human activity, agricultural production is closely related to human survival and living environment. For the nationwide study, livestock distribution is closely linked to its product demand distribution, which is closely linked to population distribution. The viewpoint was also stated by Gerber, Chilonda, Franceschini, and Menzi [36]. Feng, Yang, Zhang, and Tang [37] analyzed the natural conditions of human habitat environment and selected topography, climate, hydrology, and vegetation as evaluation factors in the NE suitability study for human settlements in China. In order to simplify the calculation process, weight of variables in the habitat environment index (HEI) formula uses mean values from Feng’s research, and the meaning of variables in the formula is the same as that in Feng’s paper [37].

The NE index system in this study includes four single index models and one comprehensive model as follows:

(1) Relief degree of land surface (RDLS) is a synthetic representation of the altitude and relief amplitude of a region. The RDLS model can be formulated as:

\[
RDLS = \frac{1}{1000} ALT + \frac{[Max(H) - Min(H)] \times (1 - \frac{P(A)}{A})}{500}
\]  

where \( ALT \) is the regional average elevation calculated at grid size; \( Max(H) \) and \( Min(H) \) represent the highest and lowest altitude; \( P(A) \) and \( A \) are the flat area and total area of the region, \( A \) equals 25 km\(^2\) in this paper.

(2) Thermal humidity index (THI) characterizes regional climatic condition. The THI model can be formulated as:

\[
THI = T - 0.55(1 - f)(T - 58), \ T = 1.8t + 32
\]

where \( t \) is the average temperature of each month and \( f \) is the monthly average relative humidity.

(3) Water resources quantity and precipitation index (WRI) describes the regional water resource conditions. The WRI model can be formulated as:

\[
WRI = 0.8P + 0.2W_a
\]

where \( P \) is normalized precipitation; \( W_a \) is normalized water area.

(4) Land cover index (LCI) reflects regional land use status. The LCI model can be formulated as:

\[
LCI = \sum_{i=1}^{25} NDVI \cdot LT_i
\]

where \( NDVI \) is the normalized difference vegetation index of the region; \( LT_i \) is the weight of various land use types.

(5) Habitat environment index (HEI) is a comprehensive model, characterizing the NE suitability for human settlements in each region of China. The HEI model can be formulated as:

\[
HEI = 0.265NRDLS + 0.2625NTHI + 0.22125NWRI + 0.25125NLCI
\]
2.4. BAE Index System

BAE is an indispensable basis for agricultural production, which reflects the regional utilization of arable land and the regional soil quality. There are two single index models and one comprehensive model in the BAE index system, as follows:

(1) The area of cultivated land use (CLU) index is the area of arable land under the conditions of the region-specific farming systems (multiple cropping index), reflecting the regional utilization of arable land. The arable land is selected and also considered as the consumption area of livestock manure. The CLU model can be formulated as:

\[ CLU = (Sp + Sd) \cdot MCI \] (6)

where CLU is cultivated land use index; \( Sp \) is the surface area of paddy fields; \( Sd \) is the surface area of dry land; \( MCI \) is the multiple cropping index.

(2) The quality of integrated soil fertility (ISF) index characterizes the relative quality of soil fertility in various regions, including soil total nitrogen, total phosphorus, total potassium, and organic matter.

\[ ISF = 0.15 \times SOM + 0.15 \times STN + 0.3 \times STP + 0.4 \times STK \] (7)

where \( ISF \) is the quality of integrated soil fertility index; \( SOM \) is single factor fertility quality grade of soil organic matter; \( STN \) is single factor fertility quality grade of soil total nitrogen; \( STP \) is single factor fertility quality grade of soil total phosphorus; \( STK \) is single factor fertility quality grade of soil total potassium. The \( ISF \) index model was similarly proposed by a previous study [38].

(3) Integrated basic agricultural environment (IBAE) index is a comprehensive model, characterizing the basic agricultural conditions in all regions of China.

\[ IBAE = 100 \times \frac{NCLU \times NISF}{10000} \] (8)

where \( IBAE \) is the integrated BAE index; \( NCLU \) and \( NISF \) are normalized CLU and ISF.

2.5. Indicators Normalization

To facilitate the comparison among all indicators, each indicator was normalized. In general, NE indicators’ normalization method is similar to Feng [37], while the BAE indicators were done with positive normalized methods.

(1) The normalized relief degree of land surface (NRDLS)

\[ NRDLS = 100 - 100 \times \frac{RDLS - RDLS_{\text{min}}}{RDLS_{\text{max}} - RDLS_{\text{min}}} \] (9)

(2) The normalized thermal humidity index (NTHI)

\[ \begin{cases} 
NTHI = 0 & \text{THI} \leq 45 \\
NTHI = 100 \times \frac{\text{THI} - 45}{20} & 45 \leq \text{THI} \leq 65 \\
NTHI = 100 - 100 \times \frac{\text{THI} - 65}{15} & \text{THI} > 65 
\end{cases} \] (10)

(3) The normalized water resources quantity and precipitation index (NWRI)

\[ \begin{cases} 
NWRI = 100 & \text{WRI} > 80 \\
NWRI = 100 \times \frac{\text{WRI} - \text{WRI}_{\text{min}}}{80 - \text{WRI}_{\text{min}}} & \text{WRI} \leq 80 
\end{cases} \] (11)
(4) The normalized land cover index (NLCI)

\[
\begin{align*}
NLCI &= 100 & \text{if } LCI > 0.4 \\
NLCI &= 100 \times \frac{LCI - LCI_{\text{min}}}{0.4 - LCI_{\text{min}}} & \text{if } LCI \leq 0.4
\end{align*}
\]  

(12)

(5) The normalized habitat environment index (NHEI)

\[NHEI = 100 \times \frac{HEI - HEI_{\text{min}}}{HEI_{\text{max}} - HEI_{\text{min}}} \]

(13)

(6) The normalized cultivated land use (NCLU)

\[NCLU = 100 \times \frac{CLU - CLU_{\text{min}}}{CLU_{\text{max}} - CLU_{\text{min}}} \]

(14)

(7) The normalized integrated soil fertility (NISF)

\[
\begin{align*}
NISF &= 20 \times \frac{ISF}{1.5} & \text{if } ISF \leq 1.5 \\
NISF &= 20 + 20 \times \frac{ISF - 1.5}{2.5 - 1.5} & 1.5 < ISF \leq 2.5 \\
NISF &= 40 + 20 \times \frac{ISF - 2.5}{3.5 - 2.5} & 2.5 < ISF \leq 3.5 \\
NISF &= 60 + 20 \times \frac{ISF - 3.5}{4.5 - 3.5} & 3.5 < ISF \leq 4.5 \\
NISF &= 80 + 20 \times \frac{ISF - 4.5}{5 - 4.5} & 4.5 < ISF \leq 5
\end{align*}
\]  

(15)

(8) The normalized integrated basic agricultural environment (NIBAE)

\[NIBAE = 100 \times \frac{IBAE - IBAE_{\text{min}}}{IBAE_{\text{max}} - IBAE_{\text{min}}} \]

(16)

2.6. Regionalization Method

The multi-level division of quantitative indicators can provide more information for making qualitative determination, but the number of division levels should be determined in a subjective way. In this study, choropleth map classification (CMC), thematic map series (TMS), and gravity centers curve (GCC) methods were used to determine the levels of NHEI and NIBAE, as similarly done by Fu [1] and Ge and Feng [39]. Both CMC and TMS methods can clearly show the spatial distribution of quantifiable indicators for identifying their spatial patterns.

It should be noted that the value of NHEI and NIBAE can be divided into 16 levels from low to high according to the 16 levels in the choropleth map classification method. For NHEI, level 1–16 can be interpreted as the natural environment ranging from bad to good. For NIBAE, level 1–16 can be interpreted as the basic agricultural conditions ranging from barren to rich. The methods of TMS and GCC can help us to find the spatial distribution classification of NHEI and NIBAE. Exploring spatial distribution and combination relationship between different levels of the two indicators can help us define priorities for agricultural land management practices to mitigate NPS pollution. More attention should be paid to NPS treatment in areas with good natural environment and rich BAE conditions.

3. Results

3.1. NE Indicators

Figure 2a shows the spatial distribution of the normalized habitat environment index in China at 1 km grid size. The NHEI in East China is larger than that in West China, and the NHEI in South China is larger than that in West China. Figure 2b indicates the spatial patterns of CMC for NHEI, where the NHEI values were equally divided into 16 levels, providing abundant information on the spatial distribution of NHEI. Figure 2c shows the spatial patterns of NHEI at each level determined by TMS,
depicting the gradual transition of NHEI from Northwest China (low value) to Southeast China (high value). Based on the 16 levels, the gravity center of each level was identified and connected (Figure 2d).

![Figure 2](image.png)

**Figure 2.** Natural environment (NE) indicators (a) Spatial distribution of normalized habitat environment index (NHEI) in China; (b) choropleth map classification (CMC) for NHEI; (c) thematic map series (TMS) for NHEI; (d) gravity centers curve (GCC) for NHEI; (e) The adjusted classification map for NHEI (this is to reclassify).

Table 1 lists the Euclidean distances between adjacent gravity centers of NHEI. According to the spatial distribution and distances between adjacent gravity centers, demarcation can be selected from 3–4, 8–9, 9–10, 10–11, 11–12. Demarcations are the distance breakpoint between the centers of gravity of different levels of NHEI, which can help us reclassify NHEI. In order to simplify the classification, level 1–3, 4–8, 9–10, 11, 12–16 are the five new levels. The adjusted classification map is given in Figure 2e.

| GC.n | Dist.    | GC.n | Dist.    | GC.n | Dist.    | GC.n | Dist.    |
|------|----------|------|----------|------|----------|------|----------|
| 8–9  | 854.6 km | 3–4  | 445.6 km | 14–15| 224.3 km | 15–16| 136.1 km |
| 10–11| 661.9 km | 12–13| 348.6 km | 2–3  | 220.7 km | 1–2  | 115.4 km |
| 11–12| 643.3 km | 4–5  | 324.2 km | 13–14| 169.2 km | 5–6  | 64.8 km  |
| 9–10 | 511.8 km | 7–8  | 239.6 km | 6–7  | 162.6 km |      |          |

GC.n represents gravity centers number. Dist. represents the Euclidean distances.

### 3.2. BAE Indicators

Figure 3a shows the spatial distribution of the normalized integrated basic agricultural environment in China at 1 km grid size. The high value of NIBAE is mostly distributed in East China, Northeast China, and Central China. The low value of NIBAE is virtually distributed in West China. Figure 3b shows the spatial patterns of CMC for NIBAE. By dividing NIBAE values into 16 equal levels, the values are gradually increased from level 1 to level 16. The CMC map provides sufficient information on the spatial distribution of NIBAE. As shown in Figure 3c, TMS indicates the spatial patterns of NIBAE at each level. It is shown in Figure 3d that GCC of NIBAE, gravity centers of 16 levels, are calculated by mean center tools in ArcMap. GCC of NIBAE is formed by connecting every gravity center in order of the level (1–16).
Figure 3. BAE indicators (a) Spatial distribution of NIBAE in China; (b) CMC for NIBAE; (c) TMS for NIBAE; (d) GCC for NIBAE; (e) The adjusted classification map of NIBAE (this is to reclassify).

Table 2 lists the Euclidean distances between adjacent gravity centers of NIBAE. According to the spatial distribution and distance between adjacent gravity centers, demarcation can be selected from 1–2, 10–11, 15–16. Demarcations are the distance breakpoints between the centers of gravity of different levels of NIBAE, which can contribute to the reclassification of NIBAE. In order to simplify the classification, four new levels, level 1, 2–10, 11–15, 16 have been formed. The adjusted classification map is shown in Figure 3e.

Table 2. Euclidean distances between adjacent gravity centers of NIBAE.

| GC.n  | Dist.  | GC.n  | Dist.  | GC.n  | Dist.  | GC.n  | Dist.  |
|-------|--------|-------|--------|-------|--------|-------|--------|
| 1–2   | 1284.8 | 11–12 | 83.2   | 2–3   | 51.1   | 7–8   | 29.7   |
| 15–16 | 433.3  | 14–15 | 78.8   | 5–6   | 39.1   | 6–7   | 25.1   |
| 10–11 | 102.4  | 8–9   | 70.5   | 4–5   | 36.1   | 3–4   | 14.4   |
| 9–10  | 95.3   | 12–13 | 65.8   | 13–14 | 32     |       |        |

GC.n represents gravity centers number. Dist. represents the Euclidean distances.

3.3. Regionalization Map of Agricultural Nonpoint Source Pollution

According to the need of national management, Chinese scholars have done a lot of national level regionalization research by using a variety of spatial factors. These regionalizations show the macro differentiation at the national level and provide the national regionalization in the fields of natural, agricultural, and livestock in terms of various spatial factors. The present regionalizations, as a reference for qualitative analysis, are national management references commonly used by the government.

Based on the overlay analysis between the new classification maps and related regionalization and districting schemes of China, the regionalization scheme of livestock pollution in China is thus determined. Such regionalization refers to the Physical Regionalization of China, Overall Regionalization of Agriculture in China, the Comprehensive Livestock Regionalization of China, and the Discharge Reduction Districting of Livestock.

Based on the spatial distribution of adjusted classification map of NHEI (Figure 2e) and NIBAE (Figure 3e), we overlaid them with the existing regionalization maps of PR, ORA, CLR, and DRDL (Figure 4).
We can see that the Overall Regionalization of Agriculture in China and the Comprehensive Livestock Regionalization of China better match the differentiation of the two indicators; therefore, we combined NHEI, NIBAE, ORA, and CLR for the final agricultural NPS regionalization in two steps as follows.

**Figure 4.** Overlay maps (a) Overall Regionalization of Agriculture in China (ORA); (b) Physical Regionalization of China (PR); (c) Comprehensive Livestock Regionalization of China (CLR); (d) Discharge Reduction Districting of Livestock (DRDL).
The first step was to select the Overall Regionalization of Agriculture in China districting scheme as the original reference and then to merge regions according to the variation of the normalized habitat environment index and the normalized integrated basic agricultural environment. In this step, relatively homogeneous areas were selected as references for merging zones. NIBAE matched the boundary of the Overall Regionalization of Agriculture in China, the Physical Regionalization of China and the Comprehensive Livestock Regionalization of China in West China, thus NIBAE was selected as the reference for West China. Correspondingly, NHEI was selected as the reference for South China along with both NHEI and NIBAE for Central China, East China, and North China. The second step was to adjust the regions depending on CLR in areas with larger NIBAE and NHEI variations, mostly in East China and North China.

The Agricultural NPS Pollution regional zoning map is shown in Figure 5. There are 10 regions, namely Gansu–Xinjiang–Inner Mongolia Region (I), Northern Inner Mongolia–Heilongjiang Region (II), Qinghai–Tibet Region (III), Northeast Region (IV), Loess Plateau Region (V), Inner Mongolia and along the Great Wall Region (VI), Huang–Huai–Hai Region (VII), Southwest Region (VIII), The Middle and Lower Reaches of the Yangtze River Region (IX), and South China Region (X).

![Figure 5. Map of the agricultural NPS pollution regional zoning in China.](image)

### 3.4. Regional Properties of Each Agricultural NPS Pollution Region

Table 3 lists the grid number percentage of all levels in each region (row). Each agricultural NPS pollution region has its major types and is different from other regions, reflecting the inter-regional differences. Table 4 lists regional properties of the 10 regions.

| Region | NHEI Level (Row) | NIBAE Level (Row) |
|--------|------------------|-------------------|
|        | 1 2 3 4 5        | 1 2 3 4           |
| I      | 45.4 53.7 0.9 0.0 0.0 92.8 5.6 1.5 0.0 |
| II     | 1.1 78.5 20.0 0.4 0.0 83.9 10.5 5.3 0.3 |
| III    | 58.0 31.2 6.5 1.6 2.7 97.2 2.5 0.3 0.0 |
| IV     | 0.0 37.8 61.8 0.3 0.0 27.9 37.0 33.0 2.1 |
| V      | 1.3 39.9 51.4 7.0 0.4 18.9 67.5 13.1 0.5 |
| VI     | 5.3 77.8 16.8 0.0 0.0 32.1 59.6 8.3 0.0 |
| VII    | 0.0 0.0 28.9 44.3 26.8 6.3 25.2 66.2 2.3 |
| VIII   | 0.0 0.8 8.0 25.8 65.4 22.5 53.8 18.4 5.3 |
| IX     | 0.0 0.0 0.0 3.2 96.7 22.9 41.1 23.9 12.1 |
| X      | 0.0 0.0 0.1 1.8 98.1 33.7 50.8 13.7 1.8 |
### Table 4. Regional properties of each agricultural NPS pollution region.

| Regions | Climate, Land, and Population Distribution | Dominant Land Use and Coverage | Agricultural | NHEI Level | NIBAE Level | Pollution Risk Area |
|---------|------------------------------------------|-------------------------------|--------------|------------|-------------|---------------------|
| X       | Climate is hot and rainy, less land, densely populated. | Hills | Developed, agricultural production level varies widely throughout the region. | H. 5 (98.1%) | L. and M. 1–3 (98.2%) | YES |
| IX      | Climate is warm and moist (annual precipitation mostly 900–2000 mm), less land, densely populated. | One quarter is plain. Three quarters are hilly. | Developed, agriculture, forestry, animal husbandry and fishery are more developed, and agricultural production level is higher. | H. 5 (96.7%) | L. and M. 1–3 (87.9%) | YES |
| VIII    | Climate is warm and moist, located in the subtropical zone, with good water and heat conditions but poor light conditions, densely populated. | Mountains and hills, Chengdu plain in the Sichuan basin. | Developed, an important agricultural and forestry base in China, agricultural production areas in this area are complex and diverse. | H. 4–5 (91.2%) | L. and M. 1–3 (94.7%) | YES |
| VII     | Continental monsoon climate (annual precipitation mostly 500–800 mm), fertile land, densely populated. | Vast plains | Developed, the cultivated land area is the first of all agricultural areas, and animal husbandry is developed. | M. and H. 3–5 (100%) | M. and H. 3 (66.2%) | YES |
| IV      | Climate is cold, fertile land, densely populated. | Vast plains | Developed, rich in the land, water and forest resources, mainly planting agriculture. | M. 3 (61.8%) | M. and H. 2–3 (70%) | YES |
| VI      | Climate is dry. Rainfall is small and the variation rate is large, spring drought is heavy, and the water and heat conditions are insufficient. | Meadow steppe, arid grassland, desert steppe and desert. | Underdeveloped, northern part is pastoral area, central part is semi-agricultural and semi pastoral area, and southern part is an agricultural area. | L. 2 (77.8%) | L. 1–2 (91.7%) | NO |
| V       | Climate is dry (annual precipitation mostly 400–600 mm), a crisscross terrain of tableland, beams, hills, and gullies. 70% of the land is covered with deep loess layer, with serious soil erosion. | Underdeveloped, a crisscross area of agriculture and animal husbandry. | L. and M. 2–3 (91.3%) | L. and M. 2 (67.5%) | NO |
| III     | Climate is very cold. Land is vast and sparsely populated. | Alpine plateau, the roof of the world. | Underdeveloped, alpine pastoral area in the west of China, high mortality rate of livestock, low productivity. | L. 1–2 (89.2%) | L. 1 (97.2%) | NO |
| II      | Climate is cold, cool and humid. Land is vast and sparsely populated. | Mountains are round and vast, rivers and valleys are wide and shallow. | Underdeveloped, timber forest, economic forest, and wild animal and plant resources. | L. 2–3 (98.5%) | L. 1 (83.9%) | NO |
| I       | Climate is dry (annual precipitation ≤250 mm). Land is vast and sparsely populated, and ethnic minorities live together. | Desert, great mountain, desert steppe, and steppe. | Underdeveloped, mainly irrigation agriculture and desert grazing. | L. 1–2 (99.1%) | L. 1 (92.8%) | NO |

L., M., and H. stand for low, medium, and high level, respectively. The regions are displayed with high pollution risk at the top in descending order of risk.
4. Discussion

4.1. Comparison of Regionalization Schemes

The Physical Regionalization of China and the Discharge Reduction Districting of Livestock were applied in the qualitative comparison and quantitative analysis. Figure 6 shows agricultural NPS pollution regional zoning overlay maps.

![Agricultural NPS pollution regional zoning overlay maps.](image)

The first step was to make a qualitative comparison between regionalization maps. The agricultural NPS pollution regional zoning map, representing the normalized habitat environment index variation of level 2, level 3, and level 4, is better than the Physical Regionalization of China in eastern monsoon region (Figure 4b), especially in VI, VII regions. For the normalized integrated basic agricultural environment, the agricultural NPS pollution regional zoning map, representing the differentiation of each level, also overmatches PR, especially in the boundary at all levels.

For the Discharge Reduction Districting of Livestock, only South Region, Eastern Region, and Northeast Region are compliant with the normalized habitat environment index variations (Figure 4d). All six regions are not clearly in accordance with the normalized integrated basic agricultural environment differentiation. Thus, the agricultural NPS pollution regional zoning map better represents the **NHEI** and **NIBAE** differentiation than DRDL.

4.2. Similarity within Regions

Table 5 lists the grid number percentage of all regions in each level (line). Several regions have similar grid number percentage in the same level of the normalized habitat environment index and the normalized integrated basic agricultural environment, reflecting the regional similarity.

1. For NHEI level 1, region I, III, and region II, V, and region IV, VII–X are similar pairs;
2. For NHEI level 2, region II, VI, and region IV, V, and region VII–X are similar pairs;
3. For NHEI level 3, region II, VI, VIII, and region III, VII, and region IX, X are similar pairs;
4. For NHEI level 4, region I, VI, and region II, IV, and region III, V, IX are similar pairs;
5. For NHEI level 5, region I, II, IV, V, VI is a similar pair.
6. For NIBAE level 1, region I, III, and region VI, X, and region VIII, IX are similar pairs;
7. For NIBAE level 2, region II, III, and region IV–VI are similar pairs;
8. For NIBAE level 3, region I, VI, and region IV, IX, and region V, X are similar pairs;
9. For NIBAE level 4, region I, III, VI is a similar pair.

![Figure 6. Agricultural NPS pollution regional zoning overlay maps.](image)
Table 5. The grid number percentage (%) for all regions in each level (Line).

| Region | NHEI Level (Line) | NIBAE Level (Line) |
|--------|-------------------|---------------------|
|        | 1 2 3 4 5         | 1 2 3 4             |
| I      | 45.6 42.6 1.9 0.0 0.0 | 39.3 6.1 3.4 3.4 0.1 |
| II     | 0.2 9.9 6.9 0.3 0.0 | 5.7 1.8 1.9 0.6 0.1 |
| III    | 53.0 22.5 12.7 6.5 2.8 | 37.5 2.4 0.6 0.6 0.1 |
| IV     | 0.0 7.7 34.6 0.4 0.0 | 3.1 10.4 18.7 6.7  |
| V      | 0.2 5.3 18.7 5.2 0.1 | 1.3 12.2 4.8 1.0  |
| VI     | 1.0 11.8 7.0 0.0 0.0 | 2.6 12.3 3.5 0.1  |
| VII    | 0.0 0.0 11.0 34.2 5.2 | 0.5 4.8 25.5 4.9  |
| VIII   | 0.0 0.3 7.1 46.4 29.7 | 3.8 23.5 16.3 25.8 |
| IX     | 0.0 0.0 0.0 5.6 42.4 | 3.8 17.4 20.5 57.2 |
| X      | 0.0 0.0 0.0 1.4 19.8 | 2.4 9.1 4.9 3.7  |

Therefore, qualitative comparison and quantitative analysis show that regional zoning map reflects not only the similarities but also the differences between regions. The key agricultural NPS pollution risk regions are region IV (Northeast region), region VII (Huang–Huai–Hai region), region VIII (Southwest region), region IX (The Middle and Lower Reaches of the Yangtze River region), and region X (South China region).

5. Conclusions

NE and BAE index system is a good way to describe natural background and its basal condition of agrarian production, which represents one of the fundamental mechanisms in the agricultural NPS pollution. However, dividing the index into several levels needs a subjective methodology, which could be addressed with choropleth map classification, thematic map series, and gravity centers curve methods. By overlaying the existing regionalization boundaries, the spatial distribution of NE and BAE could be further improved for regionalization. By taking advantage of the series of above-mentioned methods and quantitative calculation and qualitative analysis, it is feasible to produce a nationwide agriculture NPS regionalization map in China.

The entirety of China can be divided into 10 regions with high reliability. Each region has its distinctive characteristics. Five of these regions are identified as agricultural NPS pollution risk areas, all of which have high NHEI and NIBAE level. That is to say, the NE index system and BAE index system can help us identify agricultural NPS pollution risk areas by having one of NHEI and NIBAE at a high level. By observing these five regions, it has been found that these regions are distributed in the east coast of China and some areas extending inland. This area is the southeast part of China, the main agricultural area and the main population gathering area. Therefore, the result of NE and BAE index system revealed the common factors of agricultural NPS pollution:

1. There exists an environment (with higher HEI) that is suitable for human aggregation. That is to say, there are three conditions: Flat terrain (with smaller RDLS), humid climate (with higher THI and WRI), and luxuriant vegetation (with higher LCI).
2. There exist a good agricultural environment (with higher IBAE) and developed agriculture. To be specific, there are two conditions: More cultivated land (with higher CLU) and more fertile soil (with higher ISF).

This scheme can function as a trustworthy reference for agricultural NPS studies and management. Therefore, how to apply the result to policy decision-making is of great significance. Firstly, managers can use the adjusted classification map for NHEI and NIBAE. The calculation of these indicators involves the multi-year average data, which are close to the mathematical expectation of the mean value of the elements and represent the equilibrium of the regional elements. The strictness of the policy declined with the decrease of NHEI or NIBAE. Secondly, managers can utilize the agricultural NPS pollution regional zoning map, which can warn managers to focus more on the agricultural
development in the five risk areas, especially in regions with high NHEI level. These areas are the South China Region (X), the Middle and Lower Reaches of the Yangtze River Region (IX), the Southwest Region (VIII) and the Huang–Huai–Hai Region (VII). It should be noted that the most common feature of these areas is population aggregation.

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**References**

1. Fu, Q.; Zhu, Y.Q.; Kong, Y.F.; Sun, J.L. Spatial analysis and districting of the livestock and poultry breeding in China. *J. Geogr. Sci.* 2012, 22, 1079–1100. [CrossRef]
2. Ongley, E.D.; Zhang, X.L.; Yu, T. Current status of agricultural and rural non-point source Pollution assessment in China. *Environ. Pollut.* 2010, 158, 1159–1168. [CrossRef] [PubMed]
3. Chhabra, A.; Manjunath, K.R.; Parighray, S. Non-point source pollution in Indian agriculture: Estimation of nitrogen losses from rice crop using remote sensing and GIS. *Int. J. Appl. Earth Obs. Geoinf.* 2010, 12, 190–200. [CrossRef]
4. Cho, J.; Park, S.; Im, S. Evaluation of Agricultural Nonpoint Source (AGNPS) model for small watersheds in Korea applying irregular cell delineation. *Agric. Water Manag.* 2008, 95, 400–408. [CrossRef]
5. Yang, F.; Xu, Z.; Zhu, Y.; He, C.; Wu, G.; Qiu, J.R.; Fu, Q.; Liu, Q. Evaluation of agricultural nonpoint source pollution potential risk over China with a Transformed-Agricultural Nonpoint Pollution Potential Index method. *Environ. Technol.* 2013, 34, 2951–2963. [CrossRef] [PubMed]
6. Dogruoz, N.; Ilhan-Sungur, E.; Goksay, D.; Turetgen, I. Evaluation of microbial contamination and distribution of sulphate-reducing bacteria in dental units. *Environ. Monit. Assess.* 2012, 184, 133–139. [CrossRef] [PubMed]
7. Lindau, C.; Bollich, P.; Bond, J. Soybean Best Management Practices for Louisiana, USA, Agricultural Nonpoint Source Water Pollution Control. *Commun. Soil Sci. Plan.* 2010, 41, 1615–1626. [CrossRef]
8. Liu, M.; Huang, G.H.; Liao, R.F.; Li, Y.P.; Xie, Y.L. Fuzzy two-stage non-point source pollution management model for agricultural systems-A case study for the Lake Tai Basin, China. *Agric. Water Manag.* 2013, 121, 27–41. [CrossRef]
9. Shi, Q.L.; Deng, X.Z.; Wu, F.; Zhan, J.Y.; Xu, L.R. Best management practices for agricultural non-point source pollution control using PLOAD in Wuiliangsuhai watershed. *J. Food Agric. Environ.* 2012, 10, 1389–1393.
10. Zhang, X.; Huang, G.H.; Nie, X. Possibilistic stochastic water management model for agricultural nonpoint source pollution. *J. Water Resour. Plan. Manag.* 2010, 137, 101–112. [CrossRef]
11. Rong, Q.Q.; Cai, Y.P.; Chen, B.; Shen, Z.Y.; Yang, Z.F.; Yue, W.C.; Lin, X. Field management of a drinking water reservoir basin based on the investigation of multiple agricultural nonpoint source pollution indicators in north China. *Ecol. Indic.* 2018, 92, 113–123. [CrossRef]
12. Huang, B.R.; Fan, T.; Li, Y.M.; Wang, Y. Division Scheme for Environmental Management Regionalization in China. *Environ. Manag.* 2013, 52, 289–307. [CrossRef] [PubMed]
13. van der Kolk, A.J.; Dekker, J.N. Functions in integrated region-oriented environmental policy: A classification system. *Land Use Policy* 1999, 16, 107–119. [CrossRef]
14. Zhao, Y.; Wang, Z.G.; Sun, B.P.; Zhang, C.; Ji, Q.; Feng, L.; Shi, M.C. A study on scheme of soil and water conservation regionalization in China. *J. Geogr. Sci.* 2013, 23, 721–734. [CrossRef]
15. Xiao, M.Z.; Zhang, Q.; Singh, V.P.; Chen, X.H. Regionalization-based spatiotemporal variations of precipitation regimes across China. *Theor. Appl. Climatol.* 2013, 114, 203–212. [CrossRef]
16. Yang, J.C.; Zhang, S.W.; Li, Y.; Bu, K.; Zhang, Y.B.; Chang, L.P.; Zhang, Y.Z. Dynamics of Saline-alkali Land and Its Ecological Regionalization in Western Songnen Plain, China. *Chin. Geogr. Sci.* 2010, 20, 159–166. [CrossRef]

17. Zhou, H.R.; Xia, D.N. Ecological function regionalization of fluvial corridor landscapes and measures for ecological regeneration in the middle and lower reaches of the Tarim River, Xinjiang of China. *J. Arid Land* 2010, 2, 123–132. [CrossRef]

18. Jin, X.L.; Xu, C.Y.; Zhang, Q.; Chen, Y.D. Regionalization study of a conceptual hydrological model in Dongjiang basin, south China. *Quat. Int.* 2009, 208, 129–137. [CrossRef]

19. Gorsevski, P.V.; Boll, J.; Gomezdelcampo, E.; Brooks, E.S. Dynamic riparian buffer widths from potential non-point source pollution areas in forested watersheds. *For. Ecol. Manag.* 2008, 256, 664–673. [CrossRef]

20. Volk, M.; Bosch, D.; Nangia, V.; Narasimhan, B. SWAT: Agricultural water and nonpoint source pollution management at a watershed scale-Part II. *Agric. Water Manag.* 2017, 180, 191–193. [CrossRef]

21. Volk, M.; Bosch, D.; Nangia, V.; Narasimhan, B. SWAT: Agricultural water and nonpoint source pollution management at a watershed scale. *Agric. Water Manag.* 2016, 175, 1–3. [CrossRef]

22. Yang, S.T.; Dong, G.T.; Zheng, D.H.; Xiao, H.L.; Gao, Y.F.; Lang, Y. Coupling Xinanjiang model and SWAT to simulate agricultural non-point source pollution in Songtao watershed of Hainan, China. *Ecol. Model.* 2011, 222, 3701–3717. [CrossRef]

23. Jabbar, F.K.; Grote, K. Statistical assessment of nonpoint source pollution in agricultural watersheds in the Lower Grand River watershed, MO, USA. *Environ. Sci. Pollut. R* 2019, 26, 1487–1506. [CrossRef] [PubMed]

24. Hijmans, R.J.; Cameron, S.E.; Parra, J.L.; Jones, P.G.; Jarvis, A. Very high resolution interpolated climate surfaces for global land areas. *Int. J. Climatol.* 2005, 25, 1965–1978. [CrossRef]

25. Liu, Z.; Han, X. *China Farming System Regionalization*; Beijing Agricultural University Press: Beijing, China, 1987.

26. Xi, C.; Zhang, J.; Qiu, B. *Outline of Physical Regionalization of China*; Science Press: Beijing, China, 1984.

27. Zhou, L.; Sun, H.; Shen, Y. *Overall Regionalization of Agriculture in China*; Agriculture Press: Beijing, China, 1981.

28. Chinese Academy of Agricultural Sciences. *The Comprehensive Livestock Regionalization of China*; Agriculture Press: Beijing, China, 1984.

29. Fu, Q.; Zhu, Y.; Yang, H.; Wu, G.; Yan, L.; Yang, F.; Kong, X. Regional differences of livestock and poultry breeding output in scale and policy suggestions during 2002–2009 in China. *Trans. Chin. Soc. Agric. Eng.* 2012, 28, 185–191.

30. Wu, Y.P.; Liu, S.G. Modeling of land use and reservoir effects on nonpoint source pollution in a highly agricultural basin. *J. Environ. Monit.* 2012, 14, 2350–2361. [CrossRef]

31. Shao, J.A.; Huang, Z.L.; Deng, H. Characteristics of nonpoint source pollution load from crop farming in the context of livelihood diversification. *J. Geogr.Sci.* 2018, 28, 459–476. [CrossRef]

32. Kaushal, S.S.; Groffman, P.M.; Band, L.E.; Elliott, E.M.; Shields, C.A.; Kendall, C. Tracking Nonpoint Source Nitrogen Pollution in Human-Impacted Watersheds. *Environ. Sci. Technol.* 2011, 45, 8225–8232. [CrossRef]

33. Persaud, A.; Alsharifa, K.; Monaghan, P.; Akiwumi, F.; Morera, M.C.; Ott, E. Landscaping practices, community perceptions, and social indicators for stormwater nonpoint source pollution management. *Sustain. Cities Soc.* 2016, 27, 377–385. [CrossRef]

34. Diebel, M.W.; Maxted, J.T.; Robertson, D.M.; Han, S.; Vander Zanden, M.J. Landscape planning for agricultural nonpoint source pollution reduction III: Assessing phosphorus and sediment reduction potential. *Environ. Manag.* 2009, 43, 69–83. [CrossRef]

35. Yang, H.X.; Fu, Q. Analysis index system of influencing factors for provincial livestock and poultry waste generation: A case study in Henan province. *Tianjin Agric. Sci.* 2019, 25, 56–61. [CrossRef] [PubMed]

36. Gerber, P.; Chilonda, P.; Franceschini, G.; Menzi, H. Geographical determinants and environmental implications of livestock production intensification in Asia. *Bioresour. Technol.* 2005, 96, 263–276. [CrossRef] [PubMed]

37. Feng, Z.M.; Yang, Y.Z.; Zhang, D.; Tang, Y. Natural environment suitability for human settlements in China based on GIS. *J. Geogr. Sci.* 2009, 19, 437–446. [CrossRef]
38. Yu, D.S.; Shi, X.Z. Chinese 1:4,000,000 Integrated Soil Fertility Distribution Atlas (1980s). National Geographic Resource Science Data Center, National Science & Technology Infrastructure of China. 2008. Available online: http://www.geodata.cn (accessed on 2 January 2020).

39. Ge, M.L.; Feng, Z.M. Classification of densities and characteristics of curve of population centers in China by GIS. J. Geogr. Sci. 2010, 20, 628–640. [CrossRef]