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Study on Ecological Safety Monitoring Practice of County Cultivated Land: A Case Study from Huanghua City, Hebei Province of China

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ABSTRACT

Degradation of ecological environment and health functions of cultivated land can cause great threats to food safety. In order to effectively promote ecological safety monitoring and protection practices of county cultivated land, factors influencing cultivated land ecological environment in Huanghua City (Hebei Province) were analysed. An ecological security monitoring index system for current cultivated land utilization in China was constructed. A database was constructed, and a safety evaluation was carried out based on the agricultural land classification platform by using the single index evaluation method. Evaluation results overlapped in terms of the spatial consistency between management technologies and monitoring results. Cultivated lands were divided according to safety monitoring results. Corresponding management and monitoring measures were proposed. Results demonstrate the excessive application of chemical fertilizer is the leading threat to cultivated land ecological environment in Huanghua City. Arsenic and Ni content have low safety levels in a part of the region. High attention can be paid to their real-time monitoring. Moreover, cultivated land shortage, low unit yield, and small reserves all intensify pressure on cultivated land ecological environment in Huanghua City. Insufficient soil fertility and freshwater shortage are caused by poor physical and chemical properties of soil, and because of this cultivated land ecological environment in Huanghua City has no material basis. The study provides references to set up ecological safety monitoring system for the county cultivated land and practices.

INTRODUCTION

China Environmental State Bulletin (2016) reports that China is faced with low overall quality of cultivated land and heavy agricultural non-point source pollution. Although pesticide and chemical fertilizer are used increasingly less in some regions, the use intensity is still higher than the global average level. Not only can cultivated land resources be polluted, but the surrounding water bodies, air, and ecological environment can be also affected. Additionally, food security issues which are caused by degradation of cultivated land and imbalance of ecological environment are key problems of dispute. However, discussing ecological and even functional safety of cultivated land and under small-and low-quality cultivated land resources is of no significance (Chen Baiming et al. 2010, Wu Dafang et al. 2015). This is because China's food safety is a comprehensive issue involving multiple problems, such as quantity, quality, and ecological environment of cultivated land. Few studies concerning ecological safety of cultivated land have been reported. They mainly focus on agricultural production fields. Existing studies have discussed ecosystem risks of cultivated lands based on the relationship between ecological safety and sustainable utilization (Beesley et al. 2009, Rasul et al. 2003). In China, associated studies focus on quantity and quality safety of cultivated lands. However, studies have rarely explored the fundamental ecological safety. In addition, an agreement on connotation, evaluation index, and evaluation methods of cultivated land ecological safety has not yet been reached. Mid-and small-scale studies on comprehensive and dynamic evaluation and monitoring are severely lacking (Wang Qian et al. 2011, Zheng Rongbao et al. 2009).

Based on the above analysis, this study constructed a monitoring index system and a database for county cultivated land ecological safety by using existing study fruits and data platform of national farmland quality classification. Ecological safety of cultivated land in Huanghua City (Hebei Province) was also evaluated. This study aimed to promote monitoring practices of the county cultivated land ecological safety and facilitate perfection of the cultivated land safety protection system.

STATE OF THE ART

Land resource safety has been studied globally since middle and late 1990s. However, only few studies focused on the ecological safety of cultivated land. This is related with different abundance of cultivated land resources and different understanding of ecological safety of cultivated lands. Foreign studies mainly focus on ecological safety and risk assessment of endangered and rare landscapes (Rapport 1993, Herrmann et al. 2003). Studies concerning ecological safety of cultivated land concentrate on safety of soil ecological environment and health of land resources, aiming to establish a harmonious man-land relationship (Jiang Yuehua et al. 2014). Nevertheless, no comprehensive study has been reported. In 1989, Canadian Department of Agriculture enlisted monitoring health changes of agricultural soil caused by land utilization management into the national primary standard items (Ma Jianhui et al. 2012). With respect to agricultural ecological environmental safety, Parr J. F. (Parr et al. 1992) and Lowery B. (Lowery et al. 1995) monitored soil degradation and desertification. J. Bouma et al. implemented a quantitative dynamic simulation and real-time monitoring of soil water, nitrogen transformation, and biological quenchers (Bouma et al. 1999). Collins et al. analysed safety of regional land resources from agricultural land pollution (Collins et al. 2016). Considering heavy population pressure of cultivated land in China, land ecological safety from connotation to study keys shall have local characteristics. Existing Chinese literature has not reached a consensus on connotation of cultivated land ecological safety. After defining the terms “ecological safety” and “land resource safety,” theories of cultivated ecological safety were proposed by combining sustainable utilization and characteristics of cultivated land resources. For instance, Liu Hongzhi and Guo Fengzhi et al. elaborated the composition of cultivated land safety from perspectives of quantity safety, quality safety, ecological safety, space-time safety, and structural safety (Liu Hongzhi et al. 2008, Guo Fengzhi et al. 2004). These laid a foundation for theoretical study on cultivated land ecological safety in China. Chinese studies on ecological safety evaluation of cultivated land resources have been reported since the late 20th century. Subsequently, a series of studies concerning ecological safety evaluation of cultivated land (Wang Qin et al. 2011) and simulation prediction (Xu Qirong et al. 2007) was reported. However, these studies failed to reach a consensus on the connotation, evaluation index system, and evaluation methods of cultivated land ecological safety. Although evaluation indexes have been extended from single ecological safety factors to multiple factors (Wen Sen et al. 2007), the index system composition still lacked uniform standards. Moreover, determining the safety standard is difficult. Regarding practice study, macroscopic and large-scale static studies were numerous (Song Xiaoqing et al. 2012, Shen Renfang et al. 2012, Zhao Yafeng et al. 2014), but small-scale dynamic studies were few. Thus, guidance on ecological safety control and protection of cultivated lands is insufficient.

Based on the above mentioned study fruits, China cannot blindly copy foreign experiences in ecological safety protection of cultivated land because of varying backgrounds of national land utilization. Instead, China should pay attention to safety of ecosystem and ecological environment of cultivated lands as well as material basis and external pressure of ecological safety. Without medium-level comprehensive study on ecological safety monitoring of cultivated lands, this study analyzed influencing factors of cultivated land ecological safety comprehensively, established the monitoring index system and database by using the farmland quality classification data platform, and evaluated ecological safety of cultivated land in Huanghua City with single index evaluation method, and related conclusions laid foundations for ecological safety monitoring and protection of regional cultivated lands.

RESEARCH METHODOLOGIES

Data Acquisition and Database Construction

Farmland quality classification database of Huanghua City in 2015 was used as the main data source to extract the cultivated land layer and attribute data. The attribute data structure of cultivated land resources was expanded according to the established ecological safety evaluation system. Missing data were supplemented by combining investigation data of land use changes in Huanghua City (2015), geological investigation data of agriculture in Hebei Province (2010-2015), field investigation data of study (2014-2015), and land economic survey data in Huanghua City (Economic Statistical Yearbook of Huanghua City, 2015). Currently, ArcGIS10.0 was used as farmland quality classification in China. Database construction, grading of evaluation indexes, statistics of evaluation results, and map compiling were accomplished by the same software with farmland quality classification to quickly acquire ecological safety data of cultivated land and maximize the use of farmland classification data of the same period. After the database was constructed, a total of 12,619 evaluation units was formed.

Soil Sampling and Detection Analysis Methods

In the study, field investigation and soil sampling complied with the China Technical Regulations for Farmland Productivity Investigation and Quality Evaluation (NY/T 1634-2008). According to landform in Huanghua City, spatial distribution of soil types, regional difference of soil fertility, crop category, and management level, a total of 678 sampling units were set based on the principle of comprehensive control, uniform distribution, and reflection of actual changes (Yu Shuqiong et al. 2014). The control area of each unit was 1 km^2. Soil samples were collected from the surface layer (0-20 cm) in two batches, after autumn in 2014 and before sowing in 2015. Sampling density increased properly in regions with complicated soil categories and landform conditions. Spatial locations of sampling spots were determined by GPS device. Meanwhile, farming system and production capacity of sampling plots were investigated and recorded. Soil samples of different units were mixed, and 1.5 kg mixture was retained by quartering for detection analysis. Three parallel experiments were conducted, and abnormal values were eliminated to reduce experimental error. Test items of soil samples included soil organic matters, soil alkali-hydrolysable nitrogen, soil available P, soil available K, soil pH, soil As, Hg, Cu, Zn, Ni, Pb, Cd, and Cr contents. Testing was performed according to conventional methods which were specified in Chemical Analysis of Soil Agriculture (Bao Shidan 2000) and the National Soil Environmental Quality Standards (GB15618-1995).

Study Idea and Establishment of Evaluation Index System

Study idea: Safety utilisations of cultivated lands in different regions are different. This is determined by population and resource conditions of regions. First, this study analyzed the connotation and element of cultivated land resource safety based on existing theoretical study fruits, constructed a framework system of county cultivated land resource safety, and determined the evaluation indexes. Second, this study focused on the adjustment of evaluation indexes according to the established evaluation index system and actual situation and existing data of the study area. At the same time, data were processed, and a database was constructed. On this basis, evaluation standards and evaluation methods were set scientifically and reasonably. Cultivated land safety in the base period was monitored, evaluated, and diagnosed. Third, influencing factors of cultivated land safety were identified, and the spatial locations of insecure factors were locked. The cultivated land safety monitoring goal was determined. Specific safety monitoring system and partition measures were proposed. Protection and management strategies were formulated according to spatial combinations of influencing factors.

Establishment of a cultivated land ecological safety evaluation index system: Existing cultivated land safety theories in China were analyzed comprehensively through literature review and comparison. An ecological safety evaluation index system of cultivated land conforming to China's national conditions was constructed. Associated Chinese studies mainly focused on safety of ecological environmental effect of cultivated land at early stages (Zhao Qiguo et al. 2002). Studies in the development stage believed that ecological safety of cultivated land should include environmental safety of cultivated land, ecological safety of cultivated land, and social and economic safety of cultivated land (Zhu Hongbo 2008). Recent studies, represented by Wu Dafang et al., defined the safety of China's cultivated land resources as the organic unity of quantity, quality, and ecological environment of cultivated land while considering the composition of cultivated land ecological safety system (Wu Dafang et al. 2015). They deemed that ecological safety of cultivated land was the fourth highest level of security, only next to quantity security, quality security, and ecological environmental security of cultivated land. In the present study, ecological safety of cultivated land also should emphasize equilibrium of cultivated land resource allocation based on these theories. Two elements, "time" and "space," were added. They represented fair resource allocation between generations and resource supply balance between regions. Therefore, ecological environment safety and ecosystem safety were in the core of the ecological safety system of cultivated land. Quantity safety was the basic guarantee, and quality safety was the outcome of utilization. Time-space balance ran through the whole process of quantity, quality, and ecological protection. In addition, supplementing that "reserve supply safety" was absolutely an essential element to China who was witnessing continuous growth of population, was necessary. It could ensure continuous supply and stability of cultivated lands and relieve pressure on ecological environment brought by excessive utilization of cultivated land. Therefore, an ecological safety evaluation index system of cultivated lands in China was constructed based on quantity safety, quality safety, ecological environmental safety, reserve supply safety, and time-space equilibrium (Table 1).

Influenced by intergeneration length (years) (Dan Chenglong 2007), evaluation indexes related with fair allocation of cultivated land resources between generations' required long time series data. However, this study only discussed the safety state of cultivated land resources in the base period. Thus, the time-space equilibrium indexes were omitted.

Index Evaluation and Classification Methods

Index evaluation method: All monitoring indexes that influence ecological safety of cultivated land in the study area were assessed one by one using the single-factor evaluation method to refine the safety evaluation process. After

Table 1 Evaluation index system of county land resource ecological safety in China.

Target layer	Diagnosis layer	Index layer	Unit	Safety trend
Cultivated land resource safety	Quantity safety	Per capita cultivated land area	hm^2	Positive
		Grain yield per unit area	kg/hm^2	Positive
		Per capita grain possession	kg/per capita	Positive
		Cultivated land carrying rate	%	Positive
	Quality safety	Soil texture	-	Positive
		Soil profile configuration	-	Positive
		Organic matter content	%	Positive
		Probability of irrigation	%	Positive
		Drainage condition	-	Positive
		Alkali-hydrolysable nitrogen content in surface layer	g/kg	Positive
		Available P content in surface layer	mg/kg	Positive
		Available K content in surface layer	mg/kg	Positive
	Ecological environmental safety	Degree of salinity	-	Negative
		Soil pH	-	Moderate
		Usage of chemical fertilizer	kg/hm^2	Negative
		Usage of pesticide	kg/hm^2	Negative
		Usage of mulching film	kg/hm^2	Negative
		Content of heavy metal elements	mg/kg	Negative
	Reserve supply safety	Reserve resources per capita	hm^2	Positive
	Time-space equilibrium	Intergeneration gains and losses of cultivated land	-	Positive
		Coordination degree of per capita cultivated land quantity	%	Positive

Note: Heavy metal elements generally use Cd, Hg, As, Cu, Pb, Cr, Zn, and Ni in evaluation.
Cultivated land carrying rate = total grain output ÷ per capita grain demands ÷ total population×100%. Coordination degree of per capita cultivated land quantity = actual per capita cultivated land area/per capita cultivated land area of county -1.

the safety standards of each index were established, the safety value of each index was calculated, or safety classification was performed directly. The calculation formula is as follows:

$$P_{ij} = \frac{C_{ij}}{S_{ji}} \qquad i=1,2,3\ldots\ldots \qquad \ldots(1)$$

Where, P_{ij} is the safety index of factor j in the unit I; C_{ij} is actual value or score of factor j in the unit I; and S_{ij} is the safety standard or safety evaluation standard of factor j in the unit i.

Index safety classification method: Safety levels of each index were determined according to the principle of matching range of safety indexes with ecological safety levels of cultivated land. Currently, no uniform standard on ecological safety classification of cultivated land has been formed. Based on the related case studies (Ren Jiaqiang et al. 2014, Song Ge et al. 2012), ecological safety of cultivated land was divided into five levels: high safety, low safety, critical safety, low unsafety, and high unsafety. Classifications of all indexes were sent to five experts from College of Resource Environment of Agricultural University of Heibei and College of Land Science and Technology of China University of Geosciences on October 2015. Finally, the index classifications were adjusted according to the expert comments.

Determination of Safety Evaluation Indexes

Differences in attributes, statistical standards, and safety trend of indexes were considered in the evaluation system. Safety standards and references of different indexes were determined by diverse methods. Therefore, evaluation standards of each index were determined for safety classification.

Evaluation standards of quantity safety indexes: In quantity safety monitoring indexes, evaluation standards of per capita cultivated land area and grain yield per unit area were determined according to the average levels (0.1 hm^2 and 5262 kg/hm^2) of Hebei Province in 2015, which were issued by the National Bureau of Statistics. According to the well-off grain consumption standard determined by Chinese Nutrition Society, the evaluation standard of per capita grain possession was determined as 450 kg/per capita. Thus, safety values of these indexes were calculated from Equation (1). The critical safety standard of cultivated land carrying rate was determined from the state when actual total population of the region was equal to population affordable by cultivated lands in the region. The evaluation standard of cultivated land carrying rate was set to 1.

Evaluation standards of indexes in the farmland quality rating system: Data information of soil texture, soil profile configuration, probability of irrigation, drainage condition, organic matter content, and degree of salinity came from the farmland classification database of Huanghua City. Classification rules of farmland classification indexes in Huang-Huai River area were adopted. Safety values of these six indexes in different units were calculated according to scores of the corresponding rating index. Low scores of indexes (<70) inhibited farmland productivity significantly, and a score of 70 was used as the evaluation standard of all safety indexes when calculating their safety values.

Evaluation standards of quality safety indexes and soil pH: In quality safety indexes of cultivated land, three additional indexes were available aside from those of farmland classification indexes. These three indexes were alkali-hydrolysable nitrogen content, available P content, and available K content. Soil pH influenced both quality and ecological environment of cultivated land. Soil pH was classified into the diagnosis layer of ecological environmental safety because it greatly influenced activity of heavy metal elements in the soil. Evaluation standards of these four indexes were determined the level-III in the Technical Regulations for Cultivated Land Productivity Investigation and Quality Evaluation (NY/T1634-2008) of Huanghua City. Their safety levels were determined directly (Table 2).

Evaluation standards of ecological environmental safety indexes: In ecological safety indexes, evaluation standards of Cd, Hg, As, Cu, Pb, Cr, Zn, and Ni contents were determined according to the national Environmental Quality Standard for Soils (GB15618-1995), Technical Regulations for Geochemistrical Evaluation of Land Quality which was issued by National Bureau of Geological Investigation (DD2008-06), and the Environmental Quality Evaluation Standards for Producing Area of Edible Agricultural Products (HJ/T332-2006), which was formulated by the Ministry of Environmental Protection. If differences were noted among these three standards, the strictest one was used. The pH values of all regions in Huanghua City were higher than 7.5. Thus, limits of evaluation indexes when pH ≥7.5 were used as the safety evaluation standards, and their safety values were calculated. Evaluation standards are listed in Table 3.

In ecological safety indexes of cultivated lands, the upper limit of chemical fertilizer usage of international level (225 kg/hm^2) was used as the evaluation standard (Luan Jiang et al., 2013). The Agricultural Department of Hebei Province formulated the quantitative index of "zero growth in usage of pesticide" in 2016 because the annual average usage of pesticide per unit area in China was more than double that in developed countries. The Agricultural Department of Hebei Province used decreased by 1% of pesticide usage as implementation of standards. Therefore, the evaluation standard was determined by annual growth rate of pesticide usage (%). The evaluation standard to calculate the safety value was -1%. According to investigations, the use of mulching film in Huanghua City decreased annually, and the degradable mulching film was promoted gradually at the same time. Thus, the safety evaluation of usage of mulching film was omitted.

Evaluation standards of reserve supply safety and time-space equilibrium indexes: The city average value (0.14 hm^2/ per capita) was used as the evaluation standard of reserve supply safety. When calculating coordination degree of per capita cultivated land quantity, the county per capita cultivated land area was determined the mean of 2015 (0.11 hm^2). This index was classified directly according to range of safety degree corresponding to coordination degree of per capita cultivated land quantity.

Classifications of part of quality safety and pH indexes of cultivated land are shown in Table 2. Classifications of other safety indexes are shown in Table 4.

Partitioning Method

After obtaining the evaluation results of all safety indexes, an evaluation result map was divided and overlapped in

Table 2: Safety classification of part of cultivated land quality safety indexes and pH.

Levels	High safety	Low safety	Critical safety	Low unsafety	High unsafety
pH	≤6.5–7.5	≤5.5–6.5 ≤7.5–7.9	≤4.5–5.5 ≤7.9–8.5	≤4.0–5.5 ≤8.5–9.0	<4.5>9.0
Alkali-hydrolysable nitrogen (mg/kg)	≥150	≤120–150	≤90–120	≤60–90	<60
Available P (mg/kg)	≥40	≤20–40	≤10–20	≤5–10	<5
Available K (mg/kg)	≥200	≤150–200	≤100–150	≤50–100	<50

Table 3: Limits of heavy metal contents in the study area (mg/kg).

pH	Cd	Hg	As	Cu	Pb	Cr	Zn	Ni
≥7.5	0.6	1.0	20	100	80	250	300	55

Table 4: Classification of cultivated land ecological safety evaluation indexes.

Levels	High safety	Low safety	Critical safety	Low unsafety	High unsafety
Per capita cultivated land	≥2.0	[1.5, 2.0)	[1.0, 1.5)	[0.5, 1.0)	<0.5
Grain yield per unit area	≥2.0	[1.5, 2.0)	[1.0, 1.5)	[0.5, 1.0)	<0.5
Per capita grain possession	≥2.0	[1.5, 2.0)	[1.0, 1.5)	[0.5, 1.0)	<0.5
Cultivated land carrying rate	≥2.0	[1.5, 2.0)	[1.0, 1.5)	[0.5, 1.0)	<0.5
Soil texture	≥1.3	(1.0, 1.3)	=1.0	(0.7, 1.0)	≤0.7
Soil profile configuration	≥1.2	(1.0, 1.2)	=1.0	(0.7, 1.0)	≤0.7
Probability of irrigation	≥1.2	(1.0, 1.2)	=1.0	(0.7, 1.0)	≤0.7
Drainage condition	≥1.3	(1.0, 1.3)	=1.0	(0.7, 1.0)	≤0.7
Organic content	≥1.2	(1.0, 1.2)	=1.0	(0.8, 1.0)	≤0.8
Degree of salinity	≥1.3	(1.0, 1.3)	=1.0	(0.7, 1.0)	≤0.7
Usage of chemical fertilizer	≤0.5	(0.5, 1.0)	=1.0	(1.0, 1.5)	≥1.5
Usage of pesticide	≥2.0	[1.0, 2.0)	[0, 1.0)	(“1.0, 0)	≤-1.0
Hg content	≤0.5	(0.5, 1.0)	=1.0	(1.0, 1.5)	≥1.5
As content	≤0.5	(0.5, 1.0)	=1.0	(1.0, 1.5)	≥1.5
Cu content	≤0.5	(0.5, 1.0)	=1.0	(1.0, 1.5)	≥1.5
Pb content	≤0.5	(0.5, 1.0)	=1.0	(1.0, 1.5)	≥1.5
Cr content	≤0.5	(0.5, 1.0)	=1.0	(1.0, 1.5)	≥1.5
Zn content	≤0.5	(0.5, 1.0)	=1.0	(1.0, 1.5)	≥1.5
Ni content	≤0.5	(0.5, 1.0)	=1.0	(1.0, 1.5)	≥1.5
Per capita cultivated land reserves	≥2.0	[1.5, 2.0)	[1.0, 1.5)	[0.5, 1.0)	<0.5
Per capita cultivated land coordination degree	≥1.0	[0.5,1.0)	[0, 0.5)	[“0.5, 0)	<-0.5

terms of the spatial consistency between management techniques and monitoring measures. The study area was divided into different management regions. Specific countermeasures were proposed for different regions.

RESULT ANALYSIS AND DISCUSSION

Evaluation results: State-owned cultivated land resources were removed from the evaluation result map of grain yield per unit area, per capita cultivated land area, and per capital cultivated land quantity because the state-owned farm in Huanghua City was unrelated to quantity safety of local cultivated land.

1. Evaluation results of quantity safety indexes demonstrated that per capita grain possession and cultivated land carrying rate were above the critical safety level. The grain yield per unit area of Hebei Province was in the low unsafety level (Fig. 1a). Generally, 31.9% of per capita cultivated land area was in high unsafety level, 6.08% was in low unsafety level, and 37.98% of regions were in the unsafety level (Fig. 1b).
2. Evaluation results of quality safety indexes showed that soil texture and soil profile configuration had slight safety issues. However, the study area was struggling with severe shortage of alkali-hydrolysable nitrogen. A total of 99.92% of regions were in the unsafety level (Fig. 1c). Less than 10% of regions were in low unsafety level in terms of available P content, which was attributed to the gradual growth of P application. Available K content had no safety problems, but about 50% of regions just reached the critical safety level. Organic matter content in the county was relatively low, and about 83.37% of regions were below the critical safety level (Fig. 1d). Moreover, 95.70% of regions had low probability of irrigation (Fig. 1e), which was caused by freshwater resource shortage.
3. According to evaluation results of ecological environmental safety indexes, cultivated land in Huanghua City was facing prominent salinity problems. A total of 26.16% of regions were identified as critical safety, indicating the existence of moderate salinity. Another 9.16% of regions were evaluated in high unsafety, which reflected the heavy salinity (Fig. 1f). Soil pH of 95.18% of regions was in critical safety, ranging between 7.5 and 8.5 (Fig. 1g). Evaluation results of usage of chemical fertilizer and usage of pesticide revealed that usage of chemical fertilizer in the study area was basically in low unsafety and high unsafety, but the usage of pesticide was decreasing annually. According to the evaluation results of heavy metal contents, 88.71% of regions were identified as low safety in terms of As content and 61.32% of regions were identified as low safety in terms of Ni content. Although no safety problems had been observed, heavy metals shall be monitored closely.
4. Viewed from evaluation results of reserve supply safety and per capita cultivated land reserves, about 85% of regions were below the critical safety (Fig. 1j).

5. About 32% of regions were below the critical safety in terms of coordination degree of per capita cultivated land quantity, which reflected the time-space equilibrium (Fig. 1k).

Analysis of monitoring and management partitioning strategy: Effective dynamic monitoring of ecological safety of county cultivated land had important significance in safety protection and sustainable utilization of national land resources. Safety protection and management could be implemented thoroughly under the high-efficiency scientific monitoring system and close monitoring of indexes with safety problems. According to the partitioning method, Huanghua City was divided into different regions, and specific management measures were proposed.

1. ***Strict cultivated land protection region*****:** Evaluation results of per capita cultivated land quantity and coordination degree of per capita cultivated land quantity were overlapped to get the strict cultivated land protection region (Fig. 2a). As an important quantity safety monitoring region, quantity changes and spatial changes of cultivated land resources shall be monitored closely. Huanghua City is suggested to not occupy or to occupy few cultivated land resources for construction projects, and strictly implement the system of Dynamic Balance of Total Amount of Cultivated Land. Besides, it shall develop cultivated land reserves and reclaim part of cultivated lands from homestead through the new rural construction.

2. ***Fertility improvement region*****:** Huanghua City generally suffers from poor fertility and excessive usage of chemical fertilizers, thereby resulting in the contradiction between quality safety and ecological environmental safety of cultivated land. Small regions have insufficient available P and K. These regions are scattered in areas with insufficient alkali-hydrolysable nitrogen and organic matters. Unsafe regions in terms of organic matter content and alkali-hydrolysable nitrogen were overlapped significantly in space. Hence, unsafe regions in terms of alkali-hydrolysable nitrogen, available P, available K, and organic matter content were overlapped. The merged area was determined to be the fertility improvement region. This region was further divided according to problem severity and type composition of each monitoring unit (Fig. 2b). Choosing high-efficiency fertilizers according to monitoring results is suggested to standardize fertilizing techniques and combination method. This can reduce usage of fertilizers, prevent and relieve potential risks of land pollution, and can effectively increase soil fertility.

3. ***Remediation engineering and technology demonstration region*****:** Soil pH in Huanghua City was over 7.5, and salinity problem was threatening 35.32% of cultivated lands. Influenced by coastal geographical conditions, many conventional salinity remediation measures failed to achieve the ideal effect in Huanghua City. Besides, low probability of irrigation was universal owing to inadequate construction of water conservancy works or freshwater shortage. Regions with moderate and higher salinity were divided into remediation engineering and technology demonstration region because of irrigation shortage and soil alkalinity (Fig. 2c). Perfecting farmland water conservancy facilities in necessary regions is suggested rather than large-scale water and soil remediation. More efforts should be made in monitoring and studying motion law of soil moisture and salt content in the demonstration region, and salinity control measures shall be explored by combining with local climate changes. Furthermore, existing “hidden tube drainage salt” system and “platform fields-shallow pond” utilization pattern shall be improved. They shall promote the sea ice water irrigation technology, create land use patterns suitable for coastal saline-alkali land, improve grain crop varieties vigorously and enhance their ability to adapt to saline environments, and establish farmland ecosystem and cultivation system of coastal saline-alkali land.

4. ***Heavy metal pollution control region*****:** The evaluation results showed that 88.71% of regions were in the low safety level in terms of As content, and 61.32% of regions were in the low safety in terms of Ni content. These regions were determined as the heavy metal pollution control region (Fig. 2d). Heavy metal contents in these regions are monitored closely to monitor changes of pollution risks, eliminate pollution source, and control pollution in the safety level.

CONCLUSION

To address problems concerning ecological safety use and poor protection of cultivated land resources in China, the ecological safety evaluation index system of cultivated land resources, evaluation method, and dynamic monitoring in Huanghua City (a county-level city) were studied by combining China’s population, cultivated land, and resource environment. The following conclusions could be drawn:

1. Farmland quality classification works and data platform can lay foundations for ecological safety monitoring and protection of county cultivated land in China.

2. High usage of chemical fertilizer is the leading threat against ecological environmental safety of cultivated land in Huanghua City. Although As and Ni pollutions

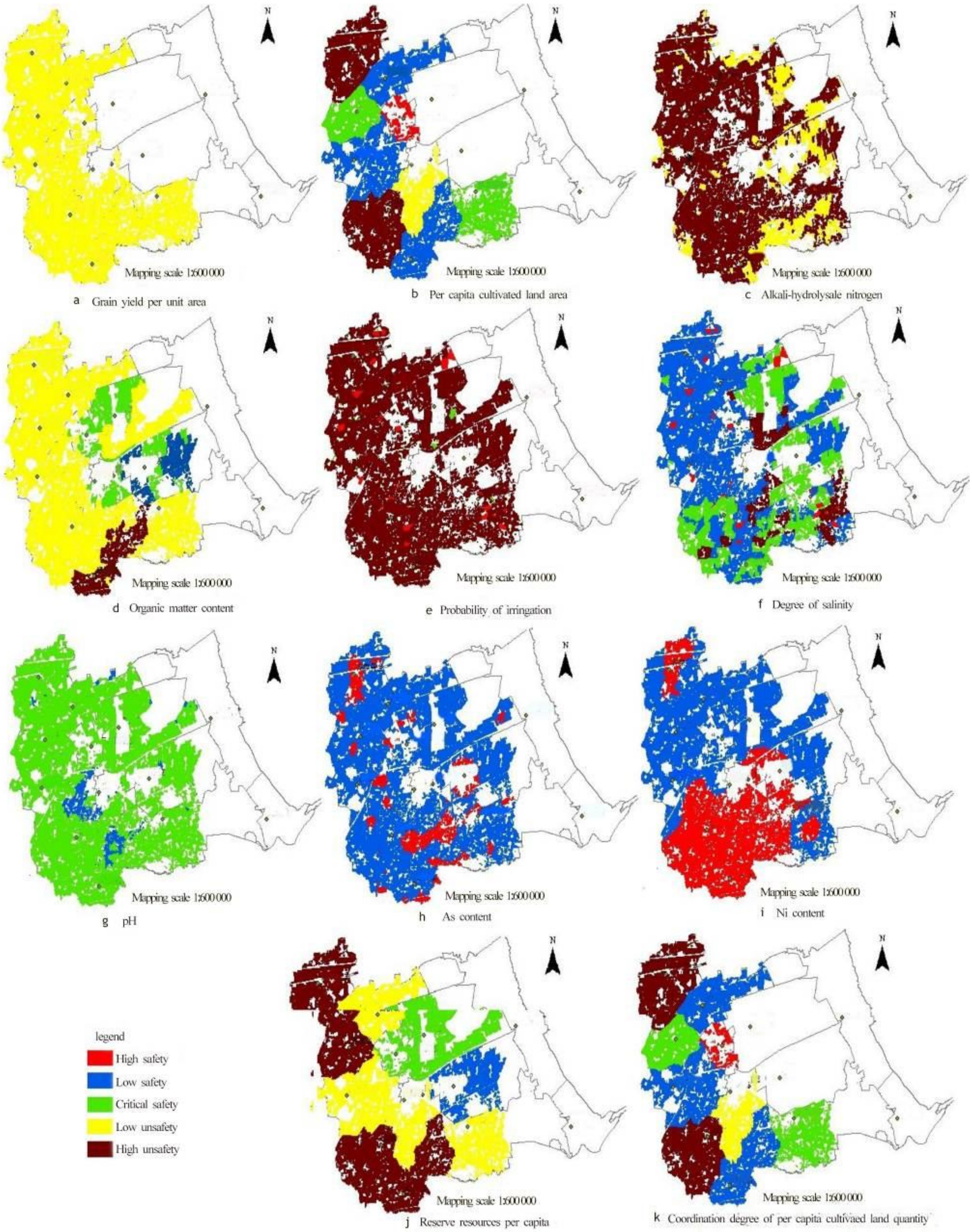

Fig. 1: Evaluation results of some cultivated land safety indexes in Huanghua City.
Note: State-owned farm does not belong to collectively owned land and is excluded from evaluation result map of grain yield per unit area, per capita cultivated land, and coordination degree of per capita cultivated land quantity.

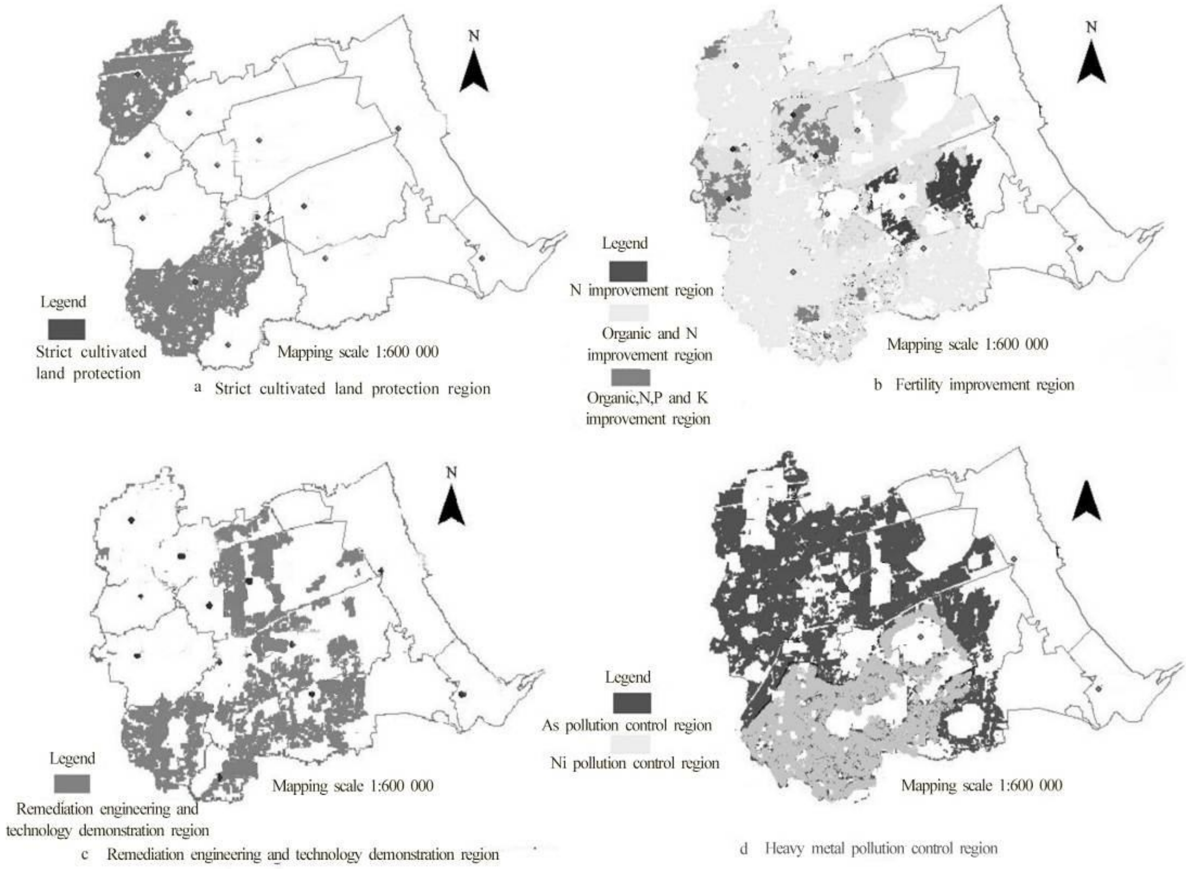

Fig. 2: Partition of cultivated land resources.

have not occurred, the pollution risk will increase dramatically if they are not controlled in a timely manner.

3. Low grain yield per unit area, less per capita cultivated land area, insufficient reserve supply, and development difficulties are all major threats to quantity safety and reserve supply safety for Huanghua City, further resulting in long-term absence of fundamental guarantee for ecological environmental safety of cultivated land in the area. Thus, heavy pressure is exerted on cultivated land safety. Unfair spatial distribution of per capita cultivated land resources is equal to increased cost of food safety to a certain degree.
4. Poor soil fertility and tough production environment and conditions are dominant influencing factors of quality safety of cultivated land in Huanghua City. Specifically, large-scale alkali-hydrolysable nitrogen and organic shortage, freshwater shortage, serious salinity, and high soil pH are root causes of poor material basis for ecological environmental safety of cultivated land.

In the study, Huanghua City is divided into different management and monitoring regions according to ecological safety problems and risks. Specific countermeasures are proposed. Study results have certain significance in deepening and increasing ecological safety protection efficiency of county cultivated land resources. However, without late monitoring data, this study can only conduct a safety evaluation based on the monitoring data obtained during the base period. The Territorial Resource Management Department of Huanghua City shall further promote ecological safety monitoring of cultivated land and formulate a normative working system based on this study, aiming to discover safety risks and prevent deterioration in a timely manner.

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