

## Article

# Sustainability Assessment of Smallholder Farmland Systems: Healthy Farmland System Assessment Framework

Yahui Lv <sup>1,2</sup> , Chao Zhang <sup>1,2,\*</sup>, Jiani Ma <sup>1,2</sup>, Wenju Yun <sup>2,3</sup>, Lulu Gao <sup>1,2</sup> and Pengshan Li <sup>4</sup> <sup>1</sup> College of Land Science and Technology, China Agricultural University, Beijing 100083, China<sup>2</sup> Key Laboratory for Agricultural Land Quality Monitoring and Control, Ministry of Natural Resources, Beijing 100035, China<sup>3</sup> Land Consolidation and Rehabilitation Center, Ministry of Natural Resources, Beijing 100035, China<sup>4</sup> Chengdu Land Planning and Cadastre Center, Chengdu Municipal Bureau of Planning and Natural Resources, Chengdu 610074, China

\* Correspondence: zhangchaobj@cau.edu.cn; Tel.: +86-10-6273-8489

Received: 17 July 2019; Accepted: 14 August 2019; Published: 21 August 2019



**Abstract:** Agriculture sustainability assessment is conducive to promoting sustainable agriculture construction and sustainable development. Modern agriculture and modern small-peasant production have different requirements for agriculture sustainability. Related studies provided assessment frameworks for many parts of the world. However, existing frameworks have distinct limitations and are not applicable to modern small-peasant economy (MSE) areas, such as China. The purpose of this study is regarding China as an example to construct a healthy farmland system assessment framework (HFSAF), to assess smallholder farmland systems' sustainability. HFSAF's theoretical basis, indicator system, data preparation methods, multi-level aggregation rule and results description method are presented in this paper. HFSAF is a multi-level indicator system with adjustable parameters, covering environment, economy and society aspects, including three dimensions, nine visions, 15 themes and 40 basic indicators. Taking Da'an City, Jilin Province, China as the study area to implement HFSAF. The assessment results prove HFSAF can be used to assess agricultural sustainability in MSE areas with limited agro-resource supplies, to assist the sustainable decision-making and regional agriculture remold.

**Keywords:** sustainable agriculture; smallholder farmland system; sustainability assessment; multi-level indicator system

## 1. Introduction

Contradictions between humans and nature, resource supply and demand have become increasingly prominent with the advances in economy and society. The idea of sustainable development has received universal attention [1]. Sustainable agriculture has become one of the core goals in sustainable development [2–4], which is used to explore dynamically relationships between agricultural economic development and agro-resources/ecological environment. Current international “quasi-sustainable agriculture” concepts are sustainable crop production system [5], sustainable agricultural production system [6], high-quality farmland [7], healthy farmland [8], well-facilitated farmland [9], etc. Related studies had a similar systematic perspective to represent distinct region needs, but were not unified or complete yet. Even though agro-modernization has become a global trend, different countries still have diverse agriculture sustainability demands, because they are at disparate stages of agriculture modernization.

Modern agriculture with high-level mechanization and agro-productivity has been basically realized in countries with sufficient cultivated land resources and developed industries, such as the European Union (EU), the United States (US), etc. While some developing countries (China, Thailand, etc.) and developed countries with limited arable land resources (Japan, South Korea, etc.) are still dominated by modern small-peasant production. MSE is a long-time transitional stage between traditional smallholder production and modern agro-production. Compared with the former, the production–operation scale has been increased, and advanced agro-machinery has been introduced into some production links. Compared with the latter, mechanization level, production capacity and efficiency are still limited by the production–operation scale and specialization degree. The goal of sustainable agriculture in modern agriculture regions is to protect and improve habitat and biodiversity, focusing on ecological function sustainability. While the goal in small-peasant economy (MSE) areas is very different. In this paper, China was considered as a typical example in MSE areas. The following reasons were taken into account: China has less arable land per household with a huge population, farmland is fragmented and the agro-production scale is small. The number of smallholders is huge, approximately 97% of which own less than 3.33 ha of cultivated land. So the concept of Chinese sustainable agriculture at this stage was presented, as healthy farmland system, referring to smallholder farmland system that satisfies following characteristics: (1) have safe ecological basis without ecological threats; (2) continuously and steadily produce safe and healthy agro-products, basing on sufficient-good-stable agro-resources (including natural resources and engineering facilities) and appropriate agro-management; (3) adequately perform ecological functions and environment benefits, depending on self-regulation and resilience; (4) provide stable high social welfare and fair distribution for farmers, relying on relative independence from policy and economic changes. Smallholder farmland systems, referred to as small-scale divisible cells, take the farmer family as a unit that could be used to complete local common agro-production independently and were similar to farmland ecosystems in connotation and composition [10–12].

Agriculture sustainability assessment is an intuitive measure of sustainable agriculture, which is a strong basis for making policies and agriculture remolding. In recent years, a series of agriculture sustainability assessment frameworks have been developed around the world, such as the Initiative for Sustainable Productive Agriculture (INSPIA) [13], Response-Inducing Sustainability Evaluation (RISE) [14], Indicateurs de Durabilité des Exploitations Agricoles or Farm Sustainability Indicators (IDEA) [15], Monitoring Tool for Integrated Farm Sustainability (MOTIFS) [16], Sustainability Assessment of Food and Agriculture systems (SAFA) [17], Sustainable Agro–Food Evaluation Methodology (SAEMETH) [18], Sustainability Assessment of Farming and the Environment (SAFE) [19], SOSTARE [20], Life Cycle Sustainability Assessment (LCSA) [21], Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) [22], Framework for the Evaluation of Sustainable Land Management (FESLM) [23], SEAMLESS [24], Framework for Assessing the Sustainability of Natural Resource Management Systems (MESMIS) [25], high nature value farmland (HNVf) [7], Indicator of Sustainable Agricultural Practice (ISAP) [26], Agriculture Sustainability Index (ASI) [27], Agro–Environmental Sustainability Information System [28], Measuring Farm Sustainability [29], Dex [30], Agriculture Sustainability Composite Indicators [31], Assess and Compare Sustainability in Agricultural Plant Production Systems [32], Livestock Farming Sustainability Indicators [33], the protocol for evaluating the sustainability of agro-food production systems [34], Nature Value Index for Pastoral Farmland [35], Agriculture Sustainability Indicators [36], etc. Implementations of these frameworks generally followed three steps: (1) determine specific agricultural sustainability goals and criteria, based on the sustainable agriculture definitions that were mainly given by UN/EU; (2) construct multi-level indicator system, by referring to indicators and data sources from existing research or works; (3) calculate and evaluate the results of indicator system, by aggregating layer by layer. Thus, four common features are summarized as follows: (1) sustainable agriculture in specific space-time is realizable, definable and quantifiable, while in different space-time has dynamic, uncertain demands and definition, so it is difficult to form a unified standard; (2) agriculture

sustainability assessment is generally required to take environmental, economic and social dimensions (three-dimension) into account. The environmental dimension is the focus, while the social dimension is often hidden to simplify the evaluation problem [21,36]. The three-dimension perspective was adopted in this study; (3) no consensus on relationships among three dimensions have been drawn, since some scholars think conflicts and complementarities exist [29], while others say a potential balance can be achieved [37]; (4) the general basic idea of international agriculture sustainability assessment means to hierarchically decompose sustainable agriculture demands to all or part of “dimension-vision-theme-basic indicator” architecture [38], and the general architecture was also inherited by this paper.

Some limitations are worth noting in frameworks above: (1) international authoritative explanations on sustainable agriculture were relatively broad to adapt to common parts of vast areas' needs. Framework for each region should meet local agro-production actuality, while dynamically adjust indicator system to be suitable for continuous development of sustainable agriculture connotation. So, existing frameworks can only be used directly in a specific time and space, and forming an internationally unified and unique approach is extremely difficult. The most evaluation objects of existing frameworks were farms in modern agriculture, while modern small-scale peasant production is mainly relying on smallholder plantation farmland systems. Compared with the former, more spatial differentiation exists in the production-management mode and utilization intensity of the latter. Higher spatial fineness and sensitivity are required in sustainability assessment results for smallholder farmland systems. Especially, Chinese agro-production reality is unusually complicated, affected by population, policies and farmland ownership, agro-plots are more fragmented, and production scale of smallholders is generally smaller and more scattered; (2) indicator systems were given directly after determining agricultural sustainability criteria, relevant processes were slightly brief and short of discussion for theoretical support, specific operations and intra-hierarchical or inter-hierarchical relationships. The weighted sum method (WSM) was the most common way of multilevel sustainability assessment, without sub-case discussion on different influence mechanism of various components to evaluation results. So, existing frameworks need to be inherited and made up to applicable to China and other areas of MSE [37].

However, few studies have been done to build appropriate frameworks for China. Research related to sustainable agriculture of Chinese scholars mostly focused on policy formulation, while research on agriculture sustainability assessment is still in infancy. Healthy production capacity evaluation for cultivated land proposed by Yun Wenju et al. [39] was regarded as the prototype of Chinese agriculture sustainability assessment. In the study above, cultivated land was evaluated from production capacity, production environment, self-recovery capacity and agro-product quality. But systematic thinking, specific indicator system and quantitative description were still lacked. Therefore, the aim of this study is to build an agriculture sustainability assessment framework applicable to China and other MSE regions, basing on smallholder farmland system. First, the concept of Chinese sustainable agriculture called a healthy farmland system was proposed, combining Chinese MSE characteristics and existing international research. Then, HFSAF was constructed, which was the relevant agriculture sustainability assessment framework. Da'an City, Jilin Province, China was selected as the study area. Finally, HFSAF results of Da'an City were analyzed with regional reality, at level of smallholder farmland systems and townships, to verify the scientificity of HFSAF.

## 2. Methodology

### 2.1. Construction of HFSAF

A healthy farmland system is the conceptual basis of constructing HFSAF. Above all, the structure of HFSAF could be divided into 2 parts, major structure and basic indicators. HFSAF's major structure was made up of sustainability dimensions, visions and themes. Sustainability themes were seen as cores because they are often directly related to specific sustainability assessment principles. The identification

of sustainability themes is complicated and lacks uniform rules in current research. Based on existing frameworks above, the relevant process in this paper was carried out as follows: (1) from a three-dimensional viewpoint, original themes in existing frameworks/studies were classified into 106 common themes by splitting over-broad original themes, expanding over-specific original themes and summarizing over-similar original themes; (2) 32 concise themes were gotten by compacting 106 common themes; (3) initial theme set with 12 members was obtained by summarizing 32 concise themes; (4) sustainable visions were determined from sustainable agriculture demands of Chinese agro-modernization, aiming to selectively adjust the initial theme set to the relief connotation-overlap problem; (5) the initial theme set was optimized to get a final theme set with 15 members, basing on a variety of scientific theories (see Table 1); (6) subordination between visions and final themes was sorted out to form HFSAF's major structure.

**Table 1.** Scientific theories for optimizing theme set.

Scientific Theory	Stressed Sustainability Theme
Healthy farmland [8]	Production function, quality of agro-products, self-regulation ability
Healthy production capacity [39,40]	Soil environment, landscape environment, natural production resources, engineering facilities resources, self-regulation ability, utilization intensity, quality of agro-products, production function, ecological safety, welfare of members
Soil quality [41]	Ecological function, production function, soil environment, landscape environment, member well-being
Soil health [42]	Production function, ecological function, environmental quality, member welfare
Cultivated land health [43]	Production function, ecological function, environmental quality, quality of agro-products, self-regulation ability

For HFSAF's basic indicators, selection process commonly follows four steps: (1) inherit indicators from existing frameworks optionally, which are common, high-frequency or consistent with local agro-reality or prior knowledge; (2) define focuses from the 15 sustainability themes above, including soil production function, soil and landscape ecological functions, soil and landscape environment, landscape self-regulation, agro-product quality, etc.; (3) identify critical impact factors from the focuses above, including soil health [44–46], landscape ecology [47], ecological environment quality [48,49], etc.; (4) determine basic indicators from relevant studies around the factors above, considering data availability. The soil production function is mainly affected by a variety of soil properties in soil health theory, through an extremely complicated mechanism. So, multi-temporal remote sensing vegetation index analysis was adopted to represent soil basic productivity indirectly [50] in this paper. Landscape ecological functions mainly include biodiversity and habitat diversity maintenance, buffer filtration and gas regulation, etc. Landscape ecological functions are mainly affected by indicators such as important landscapes (semi-natural buffer zones, wetlands, etc.) and environment purification capacity in landscape ecology theory. The soil environment is mainly affected by many kinds of soil degradation in soil health theory, while landscape environment mainly involves atmospheric environment, irrigation water environment and regional disaster in ecological environment quality theory. Landscape self-regulation is closely related to landscape ecological quality and pattern evaluation theory, source-sink landscape theory [47] and farmland landscape mosaic elastic evaluation. Current agro-product quality testing methods are costly and time-consuming, so toxic/harmful substances and beneficial substances content of agro-product growing areas was adopted in this paper to represent agro-product quality indirectly. Internationally, the other sustainability themes, related to economy, society or agro-management, are clearly defined and uniformly described. So corresponding high-frequency indicators were directly adopted in this study. Two aspects are given to basic indicator



integration: (1) place recurring indicators to the most related theme selectively; (2) some indicators that difficult to be obtained with current technologies are omitted or replaced intentionally.

## 2.2. Designation of Indicator System

Above all, the designation of HFSAF's indicator system in this paper is shown in Table 2. For dimension level, Envi-D was considered more important than other dimensions, because of its foundation role and apparent comparability [51]. For vision level, production-resource, management and environmental-influence are involved in international Envi-D. In this paper, environmental-influence was extended to ecological-security, and system-elastic was supplemented to Envi-D according to soil health theory. Economic-benefit, economic-stability and economic-independence are included in international Eco-D. In this paper, economic-independence was removed from Eco-D, considering tiny spatial differentiation of Chinese regional economic policies. Member-welfare, agro-product-quality and intergenerational-continuation are related to international Soc-D. Intergenerational-continuation was deleted from Soc-D in this paper, because it's not a key factor for current Chinese sustainable agriculture.

For the theme level, 15 members were determined in this paper. Two themes were involved in ecological-security. Stress and risk of soil were emphasized by the soil-environment-quality while environmental conditions were depicted by landscape-environment-quality. Two themes were related to production-resource. Engineering-facility was put forward according to land consolidation, representing mechanization and human utilization level. Two themes included in management were used to reflect management level and reasonableness, respectively corresponding to the tillage method and farming structure. Three themes in system-elastic aimed to describe functional sustainability and landscape restorability of smallholder farmland systems. Two themes were contained in agro-product-quality, while economic-benefit and economic-stability in Eco-D, and agro-activity-dependence in Soc-D were regarded as themes directly. For basic indicator level, commonly international indicators were selectively inherited and improved, combining Chinese agricultural practices with various basic theories. For example, indicators for soil-environment-quality were closely related to typical soil degradation in the study area, including organic matter degradation, erosion, acidification and alkalization, salinization, pollution, etc. Indicators for landscape-environment-quality were connected with environmental elements, such as air, water, etc. Field-conditions was used to describe field parcel condition from flatness, neat degree and size. Indicators for ecology-function-sustainability were selected basing on farmland systems' dual scales of soil and landscape.

**Table 2.** Indicator system of the healthy farmland system assessment framework (HFSAF).

Dimension	Vision	Theme	Sub-Theme	Basic Indicator
Environmental (Envi-D)	Ecological-security	Soil-environment-quality		Soil-cleanliness; Soil-organic-matter-degradation-degree; Soil-PH; Soil-salinization-degree; Soil-erosion-degree
		Landscape-environment-quality		Irrigation-water-environment; Atmospheric-bulk-deposition; Historical-meteorological-disaster-rate
	Production-resource	Natural-resource	Cultivated-land-quantity-retention-rate	Cultivated-land-perennial-average-reduction-rate
		Engineering-facility	Soil-basic-productivity	Soil-productivity; Feasible-productive-capacity
			Ditch	Ditch-density
			Road	Road-accessibility
	Management	Use-intensity Planting-structure	Shelterbelt	Shelterbelt-density
			Field	Field-conditions
	System-elastic	Production-function-sustainability		Soil-productivity-fluctuation; Potential-productivity
		Ecology-function-sustainability		Pedodiversity; Soil-microbial-activity; Soil-texture; Soil-organic-matter; Agrobiodiversity; Wetland-proportion; Emi-Natural-buffer-proportion; Soil-water-conservation-capacity; Gas-regulation-capacity; Environmental-purification-capacity
		System-self-regulation-ability		Terrain; Landscape-diversity; Landscape-heterogeneity; Vegetation-coverage; Source-Sink-landscape-area-ratio
Economic (Eco-D)	Economic-benefit	Economic-benefit		Average-annual-output
	Economic-stability	Economic-stability		Per-capita-GDP
Social (Soc-D)	Member-welfare	Member-welfare		Per-capita-income
	Agro-product-quality	Agro-product-security		Food-safety
		Agro-product-character		Main-nutrient-content
	Agro-activity-dependence	Agro-activity-dependence		Agricultural-labor-proportion

### 2.3. Regionalization of Indicator System

The indicator system still needs to be regionalized for different study areas, including indicator preparation and normalization, indicator system correlation analysis and weighting, etc.

For indicator preparation, Chinese smallholder farmland systems were short of related works for collecting long-term statistical, or micro-data. In this paper, spatiotemporal consistency and reliability of data sources were guaranteed by combining remote sensing images with limited statistical data, field surveying, sample testing, etc. Preparation method was closely related to connotation and restrictive intensity of each indicator in the particular region: (1) indicators with simple connotations, sub-components or existing data products were obtained directly; (2) indicators with simple connotations but complicated sub-components were gotten by summarizing sub-components through a short board method (SBM), WSM or continuous multiplication method (CMM). SBM and CMM were adopted by strongly restrictive indicators (soil-cleanliness, irrigation-water-environment, atmospheric-bulk-deposition, food-safety, etc.), while WSM was applied to weakly restrictive indicators; (3) indicators with complicated connotations, sub-components, limited data sources or high cost (soil-organic-matter-degradation-degree, cultivated-land-perennial-average-reduction-rate, soil-productivity, ditch-density, road-accessibility, shelterbelt-density, field-conditions, cultivation-intensity, soil-productivity-fluctuation, soil-microbial-activity, main-nutrient-content, etc.) were acquired by math variants or models, relying on spatial analysis, remote sensing image feature analysis, statistical analysis, indirect characterization, etc.; (4) other indicators with intuitive acquisition methods or historical research weren't separately discussed in this paper. Then the original values of indicators were obtained.

The purpose of normalization is to eliminate the indicators' fundamental units and systematic error, mapping data to a scalar quantity within the range of 0–1. Min–max normalization and Z-Score normalization are commonly current methods. However, discrete indicators (soil-texture, etc.) are unsuitable for the method above. Indicators strongly restricted by international norms (soil heavy metals content in soil-cleanliness, etc.) can't be processed by the method above. So normalized score set of all indicators can be obtained by dividing "very-sustainable, sustainable, basic-sustainable, low-sustainable, unsustainable" series levels' thresholds, instead of directly normalizing original indicator values. These discrete normalized scores would be used for evaluation calculating. The threshold is usually determined based on existing laws and regulations (soil-cleanliness, soil-PH, soil-salinization-degree, soil-erosion-degree, irrigation-water-environment, atmospheric-bulk-deposition, soil-texture, terrain, food-safety, etc.), research conclusions, regional references or expert opinions. Chinese regulations are referenced in this paper, including soil environmental quality risk control standard for soil contamination of agricultural land (trial implementation) (GB 15618-2018) [48], standards for classification and gradation of soil erosion (SL 190-2007) [52], standards for irrigation water quality (GB 5084-2005) [53], procedural regulation regarding environment quality monitoring of air in agricultural regions (NY/T 397-2000) [54], specification of land quality geochemical assessment (DZ/T 0295-2016) [45], Technical Criterion for Ecosystem Status Evaluation (HJ 192-2015) [55], farmland environmental quality evaluation standards for edible agricultural products (HJ 332-2006) [49], etc.

Pearson and Spearman are common methods of correlation analysis; the former is suited for discrete data, while the latter is suited for continuous data [20]. In this paper, correlation analysis was applied to different elements, which need to be aggregated through WSM in each level of indicator system, and used to provide a reference for setting elements' weightings.

Weighting determination method combining subjective and objective has become mainstream in many kinds of evaluations, because of taking expert experience and data characteristics into account, avoiding over-rely on prior knowledge and improving result reliability. In this paper, the indicator system was weighted by combining correlation analysis and importance ranking [56]. Here, the weighting assignment process of multiple basic indicators belonging to the same sustainability theme is taken as an example. First, each indicator was assumed as having the same initial weighting.

Second, all indicators were ranked through relative importance basing on expert experience and regional practical status. Initial weightings were adjusted to determine reasonable weightings. Third, the final weighting was equal to reasonable weighting if indicators' correlation wasn't high. Otherwise, the final weighting of the less important indicator was half of its reasonable weighting and weighting of the other indicators were changed by an equal proportion. Forth, final weightings of all indicators were obtained, whose sum was unity.

#### 2.4. Method of Multi-Level Aggregation

At present, SBM, WSM, CMM, etc. are common aggregation methods used in evaluations. For a complex indicator system and assessment process, the fusion of multiple aggregation methods is needed, as is consideration of elements' restrictive intensity, inter-element relationship and aggregation results' physical meaning.

The aggregation process strictly follows the indicator system structure. When basic indicators are aggregated to themes, strongly restrictive themes' indicators are integrated by SBM, based on the piecewise function idea of indicators' multi-level thresholds. Because strongly restrictive indicators may directly lead to unsustainable results. For example, multiple indicators were separately contained in soil-environment-quality, landscape-environment-quality or agro-product-security theme, and farmland system wouldn't be able to continue for agro-production when any indicators above had exceeded the unsustainable-level threshold. Weakly restrictive themes' indicators were combined by WSM, because they just contribute to or influence themes' sustainability but can't directly lead to irreversible results. When themes are aggregated to visions, strongly restrictive visions' themes are amassed by CMM, reflecting not only each theme contribution but also theme interrelationships. For instance, soil-environment-quality and landscape-environment-quality themes related to ecological-security vision could be influenced by each other, and ecosystem would be assessed as unsustainable when one of two themes had lost sustainability. The agro-product-quality vision had two contents (agro-product-security and agro-product-character), and farmland system would be assessed as unsustainable when agro-product had been no longer safe, no matter how much amount of beneficial ingredient. Weakly restrictive visions' themes were accumulated by WSM, because they would not lead straight to an unsustainable situation. When visions were aggregated to dimensions, strongly restrictive visions are functional foundations or bottom-line goals for farmland system, with "one-vote veto" ability, such as ecological-security vision in Envi-D and agro-product-quality vision in Soc-D. So strongly restrictive visions are regarded as multiplication factors to be gathered with weighted sum results of the other visions in the same dimension, by CMM. Weakly restrictive visions were aggregated by WSM, as same as weakly restrictive indicators and themes. One event is worth noting: three dimensions would not be aggregated further in this paper.

During the aggregation process above, weightings were needed in WSM steps. A method of combining correlation analysis with importance rank was used to determine relevant element weightings. Impact of redundant information was reduced and indicator system was simplified effectively by correlation analysis. A combination of expert experience and regional characteristics was realized by importance ranking method.

#### 2.5. Method of Composite Assessment

Three kinds of methods for agriculture sustainability assessment are internationally mainstream: (1) single indicator, such as using birds' number to recognize HNVf, is unable to completely describe the complex mechanism of evaluation; (2) indicators list, such as using arrays to describe multi-item sustainability, effectively avoids ambiguous polymerization but usability is poor; (3) comprehensive indicator, such as using a composite index to express aggregation results, generally lacks polymerization theory and results' reliability. The indicator system in this paper was aggregated in order of basic indicator-theme-vision-dimension, level by level, to obtain three-dimensional array scores (3D Evaluation Scores) of farmland systems' sustainability.

Internationally, assessment results are mainly represented by radar map and other methods. However, assessment results' description should reflect not only the sustainability of each indicator system level for the same object, but also sustainability differences of the same indicator system level among different objects. A combination of the radar map, multidimensional parallel coordinate system chart, polyline trend chart and statistical analysis can be used to analyze results and reveal spatial differentiation law on the farmland system level. Further, an administrative division is usually taken as a basic implementation unit of agricultural policies and activities in China. So, farmland systems were summarized and counted according to the administrative division in this paper to further analyze and guide actual production.

### 3. Study Area and Data

#### 3.1. Study Area

Da'an City is located in the northwest of Jilin Province, China and the hinterland of Songnen Plain, with a geographical range of  $44^{\circ}57'00''$ – $45^{\circ}45'51''$  N and  $123^{\circ}08'45''$ – $124^{\circ}21'56''$  E. Location and nearby areas of Da'an City is shown in Figure 1. The total area of the study region is approximately 4879 km<sup>2</sup>. It is a mid-temperate, semi-arid continental monsoon climate with four distinct seasons. The average daily temperature in the coldest month is  $-17^{\circ}\text{C}$ , which in the warmest month is  $25^{\circ}\text{C}$ . Average annual rainfall is 413.7 mm. The terrain of the whole region is low and flat, with altitude almost in the range of 120–160 m. Soil types and distribution of Da'an City are shown in Figure 2 and Table 3. Ten types-eighteen subtypes of soil are widely distributed in the local area. Among them, chernozem and meadow soil are major types. Da'an City governs five streets, 10 towns and eight townships. Its total population is more than 390,000, of which agricultural population accounts for more than 60%. Da'an City is rich in vast waters and wetlands, providing a living environment for a large number of wildlife and rare animals. Such a living environment guarantees biodiversity and habitat diversity of local and surrounding areas, and has high natural value and ecological significance. Da'an City is an important commodity grain base in China and the famous gold corn-belt around the world. Cultivated land resources account 30% of total area and are mainly distributed in north and central, 90% of which are protected by Chinese laws. However, local per capita arable land is only about 0.52 ha. Da'an City is located in the center of the Songnen Soda saline-alkali area. Salinized land accounts for 51.49% of total area, of which moderate-severe salinized land makes up 66%. So, available farmland is seriously deficient. Meanwhile, local farmland is facing other problems, soil degradation, agricultural water restrictions, ecological environment degradation, etc. So, Da'an City is a typical area with limited agricultural resources supply. Research demand for sustainable agriculture is pressing and important.

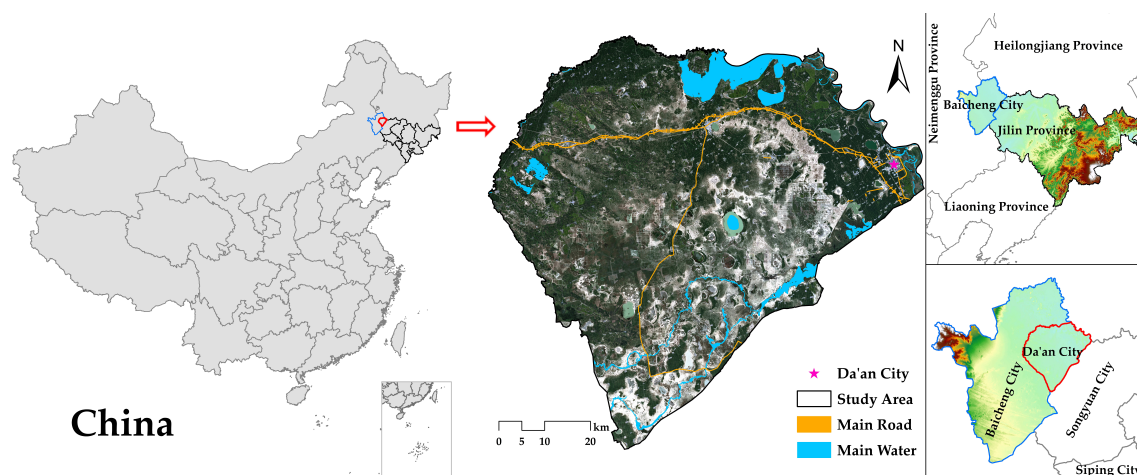
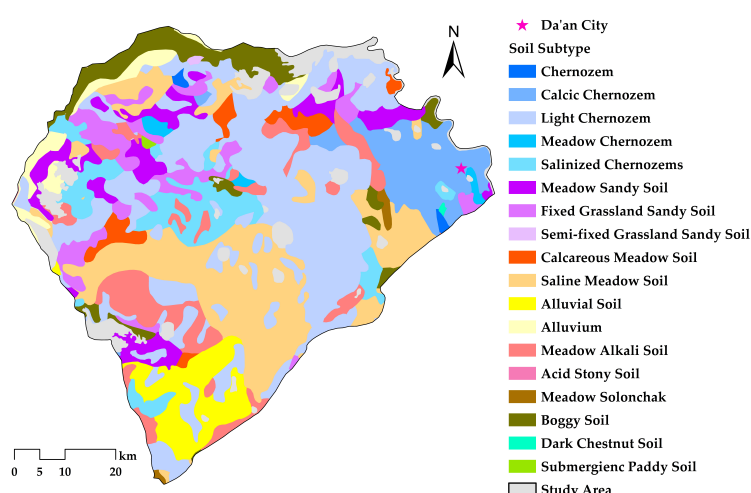


Figure 1. Location of Da'an City.





**Figure 2.** Soil types and spatial distribution of Da'an City.

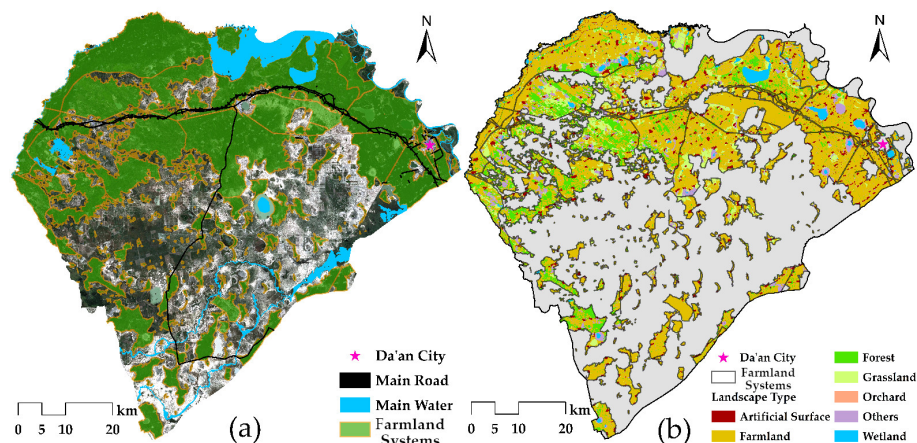
**Table 3.** Soil types and area distribution of Da'an City.

Soil Type	Soil Subtype	Area (ha)	Summation (ha)
Chernozem	Chernozem	1354.64	198,803.39
	Calcic Chernozem	34,280.55	
	Light Chernozem	130,613.35	
	Meadow Chernozem	3364.83	
	Salinized Chernozems	29,190.02	
Sandy Soil	Meadow Sandy Soil	25,235.59	54,003.52
	Fixed Grassland Sandy Soil	28,354.89	
	Semi-fixed Grassland Sandy Soil	413.04	
Meadow Soil	Calcareous Meadow Soil	13,941.96	115,781.26
	Saline Meadow Soil	101,839.30	
Alluvial Soil	Alluvial Soil	26,701.07	39,736.32
	Alluvium	13,035.25	
Alkali Soil	Meadow Alkali Soil	36,897.74	36,897.74
Stony Soil	Acid Stony Soil	35.48	35.48
Solonchak	Meadow Solonchak	1601.59	1601.59
Boggy Soil		24,927.55	24,927.55
Chestnut Soil	Dark Chestnut Soil	243.87	243.87
Paddy Soil	Submergienc Paddy Soil	442.31	442.31

Small-peasant production has been continued in Da'an City for a long time in history. The average household cultivated land is less than 1.67 ha. Traditional agro-activities mainly depended on smallholder plantation and imperfect industrial system, with low production efficiency and living standard. In recent years, the government has actively advanced a number of measures: fiscal subsidy, poverty alleviation, land consolidation, infrastructure construction, technical training, low-yield field transformation, environmental governance, wetland conservation, organic agriculture promotion, healthy production capacity pilot, etc. Simultaneously, the level of intensification, mechanization and technology in the agro-production process has been improved effectively, by attracting advanced enterprises, scientific teams and technology. At present, Da'an City has become one of Chinese typical MSE areas and modern agriculture core potential regions.

### 3.2. Data and Processing

Evaluation cells of this paper were smallholder farmland systems, which were obtained by delineation process as follows: (1) combine cultivated land with adjacent plots to obtain initial polymerized patches; (2) incise initial polymerized patches with linear and planar block elements to obtain rational polymerized patches; (3) select effective polymerized patches from rational polymerized patches by the principle of cultivated land main body; (4) obtain final polymerized patches by spatial geometry optimizing. Spatial distribution and main landscape types of smallholder farmland systems are shown in Figure 3a,b.



**Figure 3.** Spatial distribution and main landscape types of smallholder farmland systems in Da'an City: (a) spatial distribution; (b) main landscape types.

The fundamental data set included basic geographic data, remote sensing images and data products, historical survey data and statistical data from Chinese government departments, and field survey data from the author team. Basic geographic data such as ASTER GDEM were mainly obtained from Geospatial Data Cloud, to extract terrain feature. Remote sensing images such as GF-1 WFV were mainly obtained from the China Centre for Resources Satellite Data and Application, to classify crops after pre-processing. Geochemical Survey Data from Western Jilin Province, Annual Land Use Change Survey Data, Cultivated Land Quality Annual Update Data, Soil Nutrient Elements Survey Data, Soil Data, Forest Network Data, Groundwater Document, Water Survey Report, Statistic Yearbook, etc. were mainly received from government departments of Da'an City. Spatial historical data were obtained by spatial analysis or sample interpolation. Remote sensing data products were mainly acquired from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. Detailed indicator data were gotten by raster encryption, such as Soil Erosion Spatial Distribution Data, Terrestrial Ecosystem Service Value Spatial Distribution Data Set, Annual NDVI Spatial Distribution Data Set, Farmland Produce Potential Data Set, Quarterly NDVI Spatial Distribution Data Set, GDP Km-Grid Spatial Distribution Data Set, etc. Field survey data were mainly obtained from the authors' team to get detailed indicator data by sample interpolation.

## 4. Results and Discussion

### 4.1. Necessary Weightings of HFSAF

For the basic indicator level, three indicators included in the natural-resource theme were significantly weak correlated and important equally, which were respectively weighted 0.33, 0.33 and 0.34. Correlations among four indicators for the engineering-facility theme were not significant, while the shelterbelt-density indicator was significant weak correlated to others. So weightings were separately set to 0.3, 0.2, 0.3 and 0.2, according indicator importance rank as ditch-density/shelterbelt-density > road-accessibility/field-conditions. Two indicators involved in

the production–function–sustainability theme were notably weak correlated and important equally, which were severally weighted 0.5 and 0.5. Indicator correlations between soil-microbial-activity and soil-organic-matter, gas-regulation-capacity and environmental-purification-capacity in 10 indicators for the ecology–function–sustainability theme were significant strong. So weightings were individually set to 0.174, 0.174, 0.174, 0.13, 0.13, 0.06, 0.05, 0.05, 0.043 and 0.015, relying on the importance rank as agrobiodiversity/soil-microbial activity/biodiversity > soil-and-water-conservation capacity/gas-regulation capacity/environmental-purification-capacity > wetland-proportion/semi-natural-buffer-proportion > soil-texture/soil-organic matter. Five indicators for the system-self-regulation ability theme were not prominently correlated and important equally, which were all weighted 0.2.

For the theme level, two themes related to production-resource vision were obviously weak correlated, while natural-resources were slightly more important than engineering-facility. Thus, weightings were severally set to 0.6 and 0.4. Two themes included in management vision weren't distinctly correlated, while use-intensity was a little more important than planting-structure. Therefore, weightings were separately set to 0.6 and 0.4. Three indicators were involved in system-elastic vision, which were prominently weakly correlated and equally important. Hence weightings were individually set to 0.33, 0.33 and 0.34.

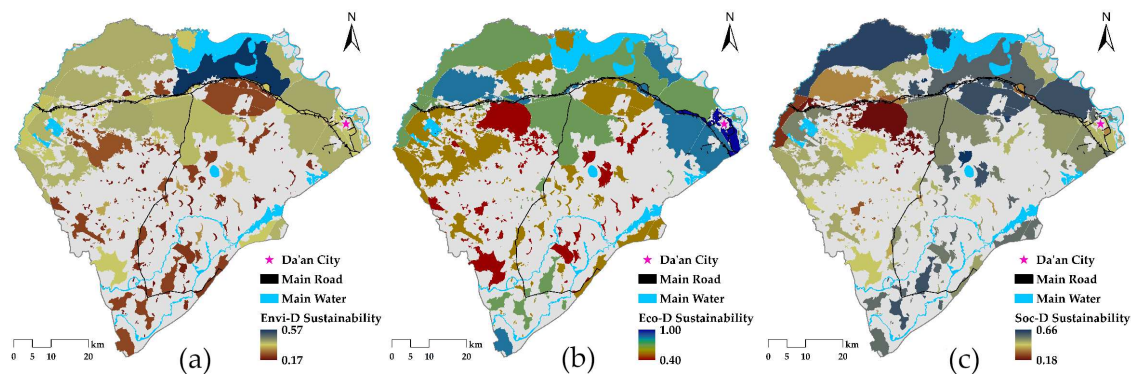
For the vision level, production-resource, management and system-elastic visions involved in Envi-D were notably weakly correlated. So weightings were severally set to 0.4, 0.35 and 0.25, by the importance rank as system-elastic > management > production-resource. Two visions included in Eco-D were significantly weak correlated and important equally, which were all weighted 0.5. Member-welfare and agro-activity-dependence visions related to Soc-D were not significantly correlated, while member-welfare was a little more important than agro-activity-dependence. So weightings were individually set to 0.7 and 0.3.

#### 4.2. Composite Assessment of Indicator System

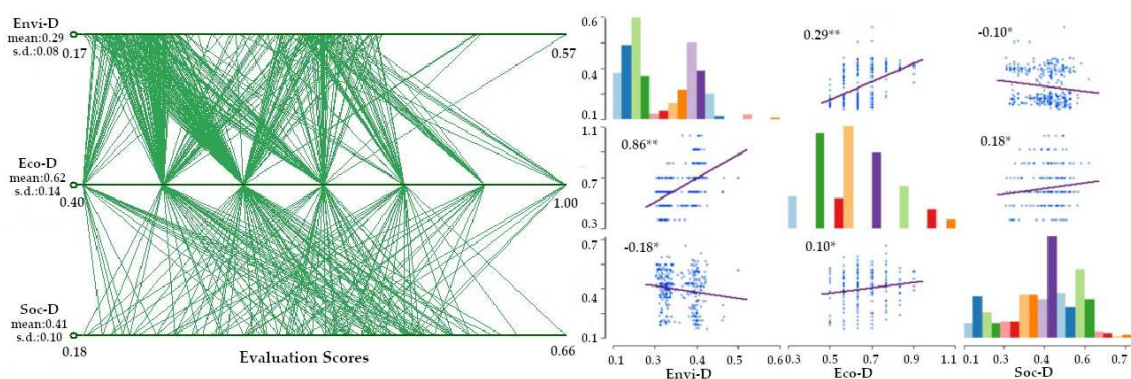
The final evaluation result of HFSAF was 3D Evaluation Scores, corresponding to Envi-D, Eco-D, and Soc-D. Spatial distribution of all smallholder farmland systems' 3D Evaluation Scores is shown in Figure 4. Envi-D scores were generally not high, with significantly piecewise aggregation of space. Scores of partial smallholder farmland systems in south-central, south, east-central and west-central were lower, while others in north-central near waters were significantly higher. Eco-D scores had a wide range and high spatial variability, without significant spatial aggregation. Scores of fractional smallholder farmland systems in east and west which located around main traffic lines were significantly higher, while others in south-central with lack of traffic were lower. Soc-D scores were generally high and had senior spatial variability, without significant spatial aggregation. Scores of partial smallholder farmland systems in central, north-central, north-east, north-west and south were higher, while others in west-central, west and south-west were lower. From parallel coordinate axis mapping and cross scatter plot shown in Figure 5, Envi-D and Eco-D, Eco-D and Soc-D were significantly positive correlated, while Envi-D and Soc-D were significantly negative correlated.

Another statistical analysis of evaluation results was made in this paper, taking townships as units. Evaluation scores of each town were used to represent average scores of smallholder farmland systems in each town. Statistical information of all townships' 3D Evaluation Scores (see Figure 6a) revealed significant spatial differences existed among 3 dimensions. Scores of Envi-D and Eco-D had similar spatial patterns, while Eco-D was different from them. Envi-D scores were generally lower. Scores of township 2, 4, 7, 9, 10, 12, 15, and 18 were below-average scores. These townships were mainly located in the south of east–west axis and covered most of south, south-east and south-west, having high spatial consistency with a main distribution area of saline-alkali. For Eco-D, scores were widely general. Nine townships with scores less than average score are Township 2, 4, 6, 7, 9, 10, 12, 14, and 18. These townships were mainly situated in the south of east–west axis and the west of north–south axis, far away from the center or main traffic arteries. Scores of Soc-D were universally

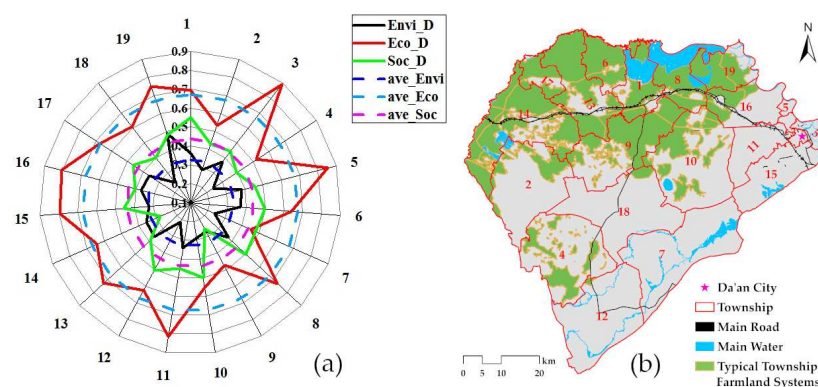
lower. Scores of townships 2, 4, 9, 13, 14, 16, and 18 were inferior to the average score. These townships were mainly found in middle, northwest-middle and south-west, distributing in sparsely populated areas. Then townships 1 and 19 with 3D high scores, townships 10 and 14 with 3D general scores and township 4/9 with 3D lower scores (see Figure 6b) were taken as typical townships to carry out multi-level refinement analysis of results.



**Figure 4.** Spatial distribution of all smallholder farmland systems' 3D Evaluation Scores in Da'an City: (a) Envi-D; (b) Eco-D; (c) Soc-D.



**Figure 5.** Relationships among 3D evaluation scores of all smallholder farmland systems in Da'an City.

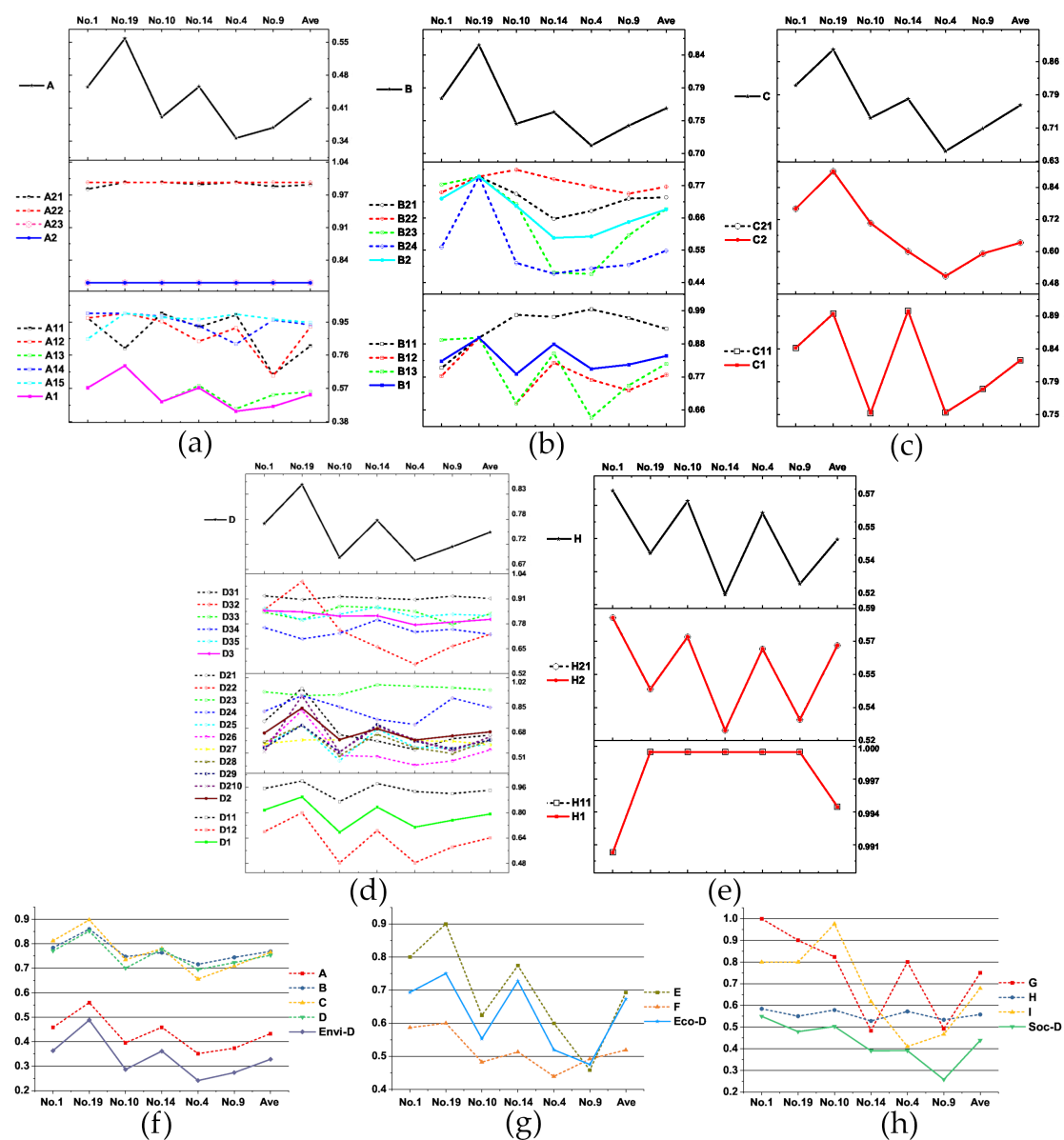


**Figure 6.** All townships' 3D evaluation scores' statistical information and six typical townships' smallholder farmland systems in Da'an City: (a) all townships' 3D evaluation scores' statistical information; (b) townships distribution of Da'an City and six typical townships' smallholder farmland systems; No.-Township: 1-Anguang Town, 2-Chagan Town, 3-Municipal District, 4-Dagangzi Town, 5-Dalai Village, 6-Fengshou Town, 7-Haituo Village, 8-Honggangzi Town, 9-Lesheng Village, 10-Liangjiazi Town, 11-Lianhe Village, 12-Longzhao Town, 13-Shaoguozen Village, 14-Sheli Town, 15-Sikeshu Village, 16-Taishan Town, 17-Xinailimengguzu Village, 18-Xinpingan Town, 19-Yueliangpao Town.



### 4.3. Multi-Level Refinement Analysis

Partial statistic information of six typical townships' multi-level scores is shown in Figure 7. Hierarchical relations of economic-benefit/economic-stability/member-welfare/agro-activity dependence visions' indicator systems were perspicuous, so relevant refinement analysis was omitted. The trend of Envi-D scores in typical townships was consistent with ecological-security, production-resource, management and system-elastic visions, which was dominantly affected by ecological-security while less affected by the other three visions. The tendency of ecological-security vision was in keeping with soil-environment-quality theme highly, while landscape-environment-quality theme had teeny spatial variability. Variation and score range of soil-environment-quality theme were identified with soil-PH indicator highly, while spatial variability of other indicators under the same theme was smaller. Thus, soil-PH was a key indicator to restrict Envi-D sustainability.



**Figure 7.** Partial statistic information of 6 typical townships' multi-level scores in Da'an City: (a) multi-level scores of A vision; (b) multi-level scores of B vision; (c) multi-level scores of C vision; (d) multi-level scores of D vision; (e) multi-level scores of H vision; (f) multi-level scores of Envi-D; (g) multi-level scores of Eco-D; (h) multi-level scores of Soc-D.



The trend of Eco-D scores was in accord with economic-benefit vision extremely but less influenced by economic-stability vision. Because spatial variability of economic-stability was weak. Economic-benefit and average-annual-output were respectively the only themes and indicators involved in economic-benefit vision. Hence, average-annual-output played an almost decisive role in economic-benefit vision and Eco-D sustainability.

Tendency and score range of Soc-D scores were greatly consistent with agro-product-quality and member-welfare vision, less affected by agro-activity-dependence vision. The trend of agro-product-quality vision was in keeping with agro-product-character theme highly, while spatial variability of the agro-product-security theme was poor. Main-nutrient-content was a single indicator related to the agro-product-character theme, hence agro-product-quality vision's change could be approximately decided by the main-nutrient-content indicator. Member-welfare vision could be almost determined by the per-capita-income indicator, by a similar principle to the main-nutrient-content indicator. From analysis above, main-nutrient-content and per-capita-income were pivotal indicators to constraint Soc-D sustainability.

For six typical townships, no distinct constraints could affect the agriculture sustainability of Township 1/19. Agriculture sustainability of Township 10 was limited by the soil environment to the greatest extent, such as soil PH and salinization. Nutrient content of agro-product was the core that must be considered in the agriculture sustainability of township 14. Restrictive factors on agriculture sustainability of townships 4 and 9 were relatively complex, including soil environment, agro-production efficiency, etc. Besides, agro-product quality was another important factor in the agriculture sustainability of township 9. The results above were corresponding to the set criteria of the indicator system and consistent with the actual situation of the research area.

#### 4.4. Overall Discussion

In this paper, HFSAF was constructed and applied to the sustainability assessment of smallholder farmland systems in Da'an City. At farmland system level, the spatial distribution of HFSAF results showed improvement of social sustainability required certain sacrifices from environmental sustainability, and vice versa. The difficulty of achieving three-dimensional sustainability equilibrium was to find a balance point between environment and social development, and assistance of economy means was required in this process. Further, statistical analysis at the township level indicated: (1) Envi-D sustainability was in line with local prominent agro-status (soil salinization problem, etc.). Townships with inferior Envi-D should be strengthened in targeted environmental restoration and ecological remold, such as saline-alkali land improvement technology; (2) Eco-D sustainability was in accordance with the expectation of agro-production as the world-famous golden corn-belt and Chinese commodity grain base. Townships at lower Eco-D scores were supposed to be intensified in the construction of infrastructures and multi-center economic radial circle, to increase ties among townships. Advanced agro-technologies and equipment should be introduced to increase crop yields steadily and comprehensively; (3) Soc-D sustainability was closely related to important agro-practice carried out in local area (organic agriculture, healthy production capacity, etc.) and was consistent with the social situation that farmers' income could deeply affect enthusiasm and durability of agro-production. Townships that scored lower in Soc-D should be reinforced in government macro-control (agro-employment, fiscal subsidies, etc.) and production environment improvement (formula fertilization, etc.).

In this paper, efforts were made to improve limitations mentioned in the introduction, basing on some international universal sustainability assessment frameworks: (1) for limited applicability of existing frameworks to China and other MSE areas, RISE [14] was put forward in accordance with agriculture sustainability requirements of UN millennium development goals. Sustainability of farms was assessed by measuring the state and driving force from ecological-economic-social dimensions. RISE has been successfully tested in 15 countries, including China, but long time has passed. Relevant tests couldn't demonstrate RISE's regional universality to China, because they only

took individual farms as examples. SAFA [17] was a global framework for evaluating agricultural value chain's sustainability from management-environment-economy-society dimensions, with certain applicability to China. But the indicator system was complex and the feasibility of regional extension was limited. Results of the global framework were rather macroscopic, and would be more detailed with more practical guiding significance if SAFA was improved by regional agricultural characteristics. In this study, the connotation of international sustainable agriculture was sinicized to bring up the concept of a healthy farmland system to guide the construction of HFSAF. HFSAF's frame structure grew out of SAFA, referencing the latter in hierarchy setting, multi-scale aggregation process and some core indicators. It was indicated that the evaluation process and results of HFSAF could reflect multi-level sustainability of smallholder farmland systems reasonably and comprehensively; (2) for the relatively brief construction process of indicator system, most objectives of existing frameworks were related to development policies of UN/EU, such as INSPIA [13]. Evaluation objects were comparative uniform and assessment criteria were mostly parallel listed. Thus, the hierarchy and composition of INSPIA's major structure were clear. No strict theoretical principle was referenced in a specific indicator setting, while indicators were mainly accumulated and filtered from existing extensive works (SAFA [17], SOSTARE [20], SAEMETH [18], etc.). A general overlap was in specific indicators of existing international universal frameworks above. A multi-level aggregation method of indicator system was single, without detailed exploration. In this study, the hierarchy of HFSAF referred to existing frameworks, but further considered complex relationships between evaluation criteria. Inter-level and intra-level relationships of indicator systems were systematically combed, and basic indicators were determined by combining regional practice and multidisciplinary theories effectively. Compared to existing international frameworks/studies, HFSAF has advantages in the realization of indicators' connotation, change of physical meaning to statistical characteristics and objective quantitative, and logicity keeping of indicator system. In addition, a combination of SBM-WSM-CMM was introduced to the multi-level polymerization process of HFSAF, so that interpretation of evaluation results was improved. In the future, the indicator system of HFSAF will be flexibly adjusted with demand change of sustainable agriculture.

## 5. Conclusions

Following conclusions were obtained in this paper: (1) an agriculture sustainability assessment framework, which is suitable for Chinese smallholder farmland systems with three dimensions, nine visions, 15 themes, 40 basic indicators, has been established by combining Chinese MSE characteristics with international research experience; (2) HFSAF can be used for plantation farmland systems in MSE areas with limited agro-resource supplies to reveal the weak links of agriculture sustainability; (3) trade offs in smallholder farmland systems' 3D sustainability are existing in study region, taking Eco-D as link to balance Envi-D and Soc-D; (4) soil salinization, agro-production efficiency, member well-being and agro-product quality are critical restriction factors for smallholder farmland systems' sustainability, which is in line with agro-production facts of the study region; (5) HFSAF is a broad framework, it can be used to solving specific regional problems basing on parameter adjustment, such as weightings.

Compared to the existing studies, HFSAF is more applicable to Chinese agriculture conditions and has been improved in the logicity of indicator system, the scientificity of element selection and the reliability of indicator preparation. HFSAF can be used to assist targeted decision-making and remould of regional agriculture, accelerate the optimal allocation of resources and promote the construction of sustainable agriculture in MSE regions like China.

**Author Contributions:** Y.L. designed the study and participated in all phases. C.Z. contributed the direction of the idea and made detailed revisions. J.M. helped on detailed revisions. W.Y. provided guidance and improving suggestions. L.G. and P.L. helped on revisions. All authors gave their approval of the version submitted for publication.

**Funding:** This research was supported by National Key R&D Program of China (2017YFF0206801-2).

**Acknowledgments:** Thanks for research assistance from Dehai Zhu, Jianyu Yang, Hongju Li, Jinyou Li, Changzhi Wang and Fan Xu. Insightful and constructive comments of the anonymous reviewers are appreciated.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Brown, L.R. *Who Will Feed China*; World Watch Institute: Washington, DC, USA, 1995.
2. Brundtland, G.H.; Khalid, M.; Agnelli, S.; Al-Athel, S. *Our Common Future*; World Commission on Environment and Development: New York, NY, USA, 1987.
3. United Nations. *United Nations Sustainable Development Goals*; The United Nations Conference on Sustainable Development: Rio de Janeiro, Brazil, 2012.
4. Colglazier, W. Sustainable development agenda: 2030. *Science* **2015**, *349*, 1048–1050. [[CrossRef](#)] [[PubMed](#)]
5. Tanaka, D.; Krupinsky, J.; Merrill, S.; Liebig, M.; Hanson, J. Dynamic cropping systems for sustainable crop production in the northern Great Plains. *Agron. J.* **2007**, *99*, 904–911. [[CrossRef](#)]
6. Martínez-Castillo, R. Sustainable agricultural production systems. *Rev. Tecnol. Marcha* **2016**, *29*, 70–85.
7. Andersen, E.; Baldock, D.; Bennett, H.; Beaufoy, G.; Bignal, E.; Bouwer, F.; Elbersen, B.; Eiden, G.; Giodeschalk, F.; Jones, G. *Developing a High Nature Value Farming Area Indicator: Final Report*; Wageningen Environmental Research: Wageningen, The Netherlands, 2004.
8. Wenju, Y.; Huaizhi, T.; Mengyin, L.; Jinme, F. “13th Five-Year” land improvement plan: Ecological good land construction in a prominent position. *Rural Work Bull.* **2015**, *7*, 32–34.
9. Ministry of Natural Resources of the People’s Republic of China. *Rules of Well-Facilitied Farmland Construction (GB/T30600)*; MNR: Beijing, China, 2014. (In Chinese)
10. Liding, C.; Bojie, F. Farm ecosystem management and control of nonpoint source pollution. *Environm. Sci.* **2000**, *21*, 98–100.
11. Yanqing, C. *A Cultivated Land Quality Evaluation Method Based on Multi-Scale Indicators’ System in Grid Environment*; China Agricultural University: Beijing, China, 2015.
12. Pengshan, L. *Integrated Ecological Assessment of Farmland System and Trade-Offs Analysis of Functions*; China Agricultural University: Beijing, China, 2017.
13. Trivino-Tarradas, P.; Gomez-Ariza, M.R.; Basch, G.; Gonzalez-Sanchez, E.J. Sustainability assessment of annual and permanent crops: The Inspia model. *Sustainability* **2019**, *11*, 738. [[CrossRef](#)]
14. Hani, F.; Braga, F.S.; Stampfli, A.; Keller, T.; Fischer, M.; Porsche, H. RISE, a tool for holistic sustainability assessment at the farm level. *Int. Food Agribus. Manag. Rev.* **2003**, *6*, 78–90.
15. Zahm, F.; Viaux, P.; Vilain, L.; Girardin, P.; Mouchet, C. Assessing farm sustainability with the IDEA method—From the concept of agriculture sustainability to case studies on farms. *Sustain. Dev.* **2008**, *16*, 271–281. [[CrossRef](#)]
16. Van Passel, S.; Meul, M. Multilevel and multi-user sustainability assessment of farming systems. *Environ. Impact Assess. Rev.* **2012**, *32*, 170–180. [[CrossRef](#)]
17. Food and Agriculture Organization of the United Nations. *SAFA. Sustainability Assessment of Food and Agriculture Systems. TOOL. User Manual Beta Version 2.1.50*; FAO: Rome, Italy, 2014.
18. Peano, C.; Tecco, N.; Dansero, E.; Girenti, V.; Sottile, F. Evaluating the sustainability in complex agri-food systems: The SAEMETH framework. *Sustainability* **2015**, *7*, 6721–6741. [[CrossRef](#)]
19. Van Cauwenbergh, N.; Biala, K.; Biolders, C.; Brouckaert, V.; Franchois, L.; Ciudad, V.G.; Hermy, M.; Mathijs, E.; Muys, B.; Reijnders, J. SAFE—A hierarchical framework for assessing the sustainability of agricultural systems. *Agric. Ecosyst. Environ.* **2007**, *120*, 229–242. [[CrossRef](#)]
20. Paracchini, M.L.; Bulgheroni, C.; Borreani, G.; Tabacco, E.; Banterle, A.; Bertoni, D.; Rossi, G.; Parolo, G.; Origgi, R.; De Paola, C. A diagnostic system to assess sustainability at a farm level: The SOSTARE model. *Agric. Syst.* **2015**, *133*, 35–53. [[CrossRef](#)]
21. De Luca, A.I.; Falcone, G.; Stillitano, T.; Iofrida, N.; Strano, A.; Gulisano, G. Evaluation of sustainable innovations in olive growing systems: A life cycle sustainability assessment case study in southern Italy. *J. Clean. Prod.* **2018**, *171*, 1187–1202. [[CrossRef](#)]
22. Król, A.; Księżak, J.; Kubińska, E.; Rozakis, S. Evaluation of sustainability of maize cultivation in Poland: A prospect Theory—PROMETHEE approach. *Sustainability* **2018**, *10*, 4263. [[CrossRef](#)]

23. Smyth, A.; Dumanski, J. *FESLM: An International Framework for Evaluating Sustainable Land Management*; FAO: Rome, Italy, 1993.
24. Van Ittersum, M.K.; Ewert, F.; Heckelei, T.; Wery, J.; Olsson, J.A.; Andersen, E.; Bezlepikina, I.; Brouwer, F.; Donatelli, M.; Flichman, G. Integrated assessment of agricultural systems—A component-based framework for the European Union (SEAMLESS). *Agric. Syst.* **2008**, *96*, 150–165. [\[CrossRef\]](#)
25. Ripoll-Bosch, R.; Díez-Unquera, B.; Ruiz, R.; Villalba, D.; Molina, E.; Joy, M.; Olaizola, A.; Bernués, A. An integrated sustainability assessment of mediterranean sheep farms with different degrees of intensification. *Agric. Syst.* **2012**, *105*, 46–56. [\[CrossRef\]](#)
26. Rigby, D.; Woodhouse, P.; Young, T.; Burton, M. Constructing a farm level indicator of sustainable agricultural practice. *Ecol. Econ.* **2001**, *39*, 463–478. [\[CrossRef\]](#)
27. Nambiar, K.; Gupta, A.; Fu, Q.; Li, S.; Biophysical, chemical and socio-economic indicators for assessing agriculture sustainability in the Chinese coastal zone. *Agriculture Ecosystems and Environment* **2001**, *87*, 209–214. [\[CrossRef\]](#)
28. Pacini, C.; Lazzerini, G.; Migliorini, P.; Vazzana, C. An indicator-based framework to evaluate sustainability of farming systems: Review of applications in Tuscany. *Ital. J. Agron.* **2009**, *4*, 23–40. [\[CrossRef\]](#)
29. Van Passel, S.; Nevens, F.; Mathijs, E.; Van Huylenbroeck, G. Measuring farm sustainability and explaining differences in sustainable efficiency. *Ecol. Econ.* **2007**, *62*, 149–161. [\[CrossRef\]](#)
30. Bohanec, M.; Cortet, J.; Griffiths, B.; Žnidaršič, M.; Debeljak, M.; Caul, S.; Thompson, J.; Krogh, P.H. A qualitative multi-attribute model for assessing the impact of cropping systems on soil quality. *Pedobiologia* **2007**, *51*, 239–250. [\[CrossRef\]](#)
31. Gómez-Limón, J.A.; Sanchez-Fernandez, G. Empirical evaluation of agriculture sustainability using composite indicators. *Ecol. Econ.* **2010**, *69*, 1062–1075. [\[CrossRef\]](#)
32. Dantsis, T.; Douma, C.; Giourga, C.; Loumou, A.; Polychronaki, E.A. A methodological approach to assess and compare the sustainability level of agricultural plant production systems. *Ecol. Indic.* **2010**, *10*, 256–263. [\[CrossRef\]](#)
33. Lebacqz, T.; Baret, P.V.; Stilmant, D. Sustainability indicators for livestock farming. A review. *Agron. Sustain. Dev.* **2013**, *33*, 311–327. [\[CrossRef\]](#)
34. Van Asselt, E.; Van Bussel, L.; Van der Voet, H.; Van der Heijden, G.; Tromp, S.; Rijgersberg, H.; Van Evert, F.; Van Wagenberg, C.; Van der Fels-Klerx, H. A protocol for evaluating the sustainability of agri-food production systems—A case study on potato production in peri-urban agriculture in The Netherlands. *Ecol. Indic.* **2014**, *43*, 315–321. [\[CrossRef\]](#)
35. Boyle, P.; Hayes, M.; Gormally, M.; Sullivan, C.; Moran, J. Development of a nature value index for pastoral farmland—A rapid farm-level assessment. *Ecol. Indic.* **2015**, *56*, 31–40. [\[CrossRef\]](#)
36. Lynch, J.; Donnellan, T.; Finn, J.A.; Dillon, E.; Ryan, M. Potential development of Irish agriculture sustainability indicators for current and future policy evaluation needs. *J. Environ. Manag.* **2019**, *230*, 434–445. [\[CrossRef\]](#)
37. Slätmo, E.; Fischer, K.; Röös, E.J.S.R. The framing of sustainability in sustainability assessment frameworks for agriculture. *Sociol. Rural.* **2017**, *57*, 378–395. [\[CrossRef\]](#)
38. Meul, M.; Van Passel, S.; Nevens, F.; Dessein, J.; Rogge, E.; Mulier, A.; Van Hauwermeiren, A. MOTIFS: A monitoring tool for integrated farm sustainability. *Agron. Sustain. Dev.* **2008**, *28*, 321–332. [\[CrossRef\]](#)
39. Wenju, Y.; Mengyin, L.; Huaizhi, T. Improving the quality of arable land focuses on building healthy production capacity. *China Land* **2015**, *3*, 22–23.
40. Xingqing, Y. Evolution track, the policy choice of getting rid of the dilemma and changing the mode of agricultural development in China. *Reform* **2016**, *6*, 22–39.
41. Dalsgaard K. Defining soil quality for a sustainable environment. *Geoderma* **1995**, *66*, 163–164. [\[CrossRef\]](#)
42. Food and Agriculture Organization of the United Nations. *Current World Fertilizer Trends and Outlook to 2015*; FAO: Rome, Italy, 2013; Volume 5.
43. Li, Q.; Su, Q.; Zhao, Y.; Yun, W.-J.; Sun, L.; Li, W.-Y.; Li, T.-J. Exploration of the evaluation system and method for agriculture land health in Suburb based on land productivity. *Geogr. Geo-Inf. Sci.* **2008**, *24*, 70–74.
44. Food and Agriculture Organization of the United Nations. *Global Soil Health Indicators and Assessment*; FAO: Rome, Italy, 2011.
45. Ministry of Nature Resources of the Republic of China. *Specification of Land Quality Geochemical Evaluation Chinese National Standard Agency (DZ/T 0295-2016)*; MNR: Beijing, China, 2016. (In Chinese)

46. Bünemann, E.K.; Bongiorno, G.; Bai, Z.; Creamer, R.E.; De Deyn, G.; de Goede, R.; Fleskens, L.; Geissen, V.; Kuyper, T.W.; Mäder, P.; et al. Soil quality—A critical review. *Soil Biol.* **2018**, *120*, 105–125. [[CrossRef](#)]
47. Chen, L.; Fu, N.; Zhao, W. Source-sink landscape theory and its ecological significance. *Acta Ecol. Sin.* **2006**, *26*, 1444–1449.
48. Ministry of Environmental Protection of the people's Republic of China. *Soil Environmental Quality-Risk Control Standard for Soil Contamination of Agriculture Land (GB15618-2018)*; MEP: Beijing, China, 2018. (In Chinese)
49. Ministry of Environmental Protection of the People's Republic of China. *Environmental Quality Evaluation Standards for Farmland of Edible Agricultural Products (HJ/T 332-2006)*; MEP, China Environmental Science: Beijing, China, 2006. (In Chinese)
50. Lv, Y.; Yun, W.; Zhang, C.; Zhu, D.; Yang, J.; Chen, Y. Multi-characteristic comprehensive recognition of well-facilitated farmland based on TOPSIS and BP neural network. *Trans. Chin. Soc. Agric. Mach.* **2018**, *49*, 196–204.
51. Van der Werf, H.M.; Petit, J. Evaluation of the environmental impact of agriculture at the farm level: A comparison and analysis of 12 indicator-based methods. *Agric. Ecosyst. Environ.* **2002**, *93*, 131–145. [[CrossRef](#)]
52. Ministry of Water Resources of the People's Republic of China. *National Professional Standards for Classification and Gradation of Soil Erosion (SL190-2007)*; China Hydraulic and Hydropower Press: Beijing, China, 2007. (In Chinese)
53. Ministry of Ecology and Environment of the People's Republic of China. *Standards for Irrigation Water Quality (GB 5084-2005)*; MEE: Beijing, China, 2005. (In Chinese)
54. Ministry of Agriculture and Rural Affairs of the People's Republic of China. *Procedural Regulation Regarding the Environment Quality Monitoring of Air in Agricultural Regions (NY/T 397-2000)*; MARA: Beijing, China, 2000. (In Chinese)
55. Ministry of Ecology and Environment of the People's Republic of China. *Technical Criterion for Ecosystem Status Evaluation (HJ 192-2015)*; MEE: Beijing, China, 2015. (In Chinese)
56. Edwards, W.; Barron, F.H. SMARTS and SMARTER: Improved simple methods for multiattribute utility measurement. *Organ. Behav. Hum. Decis. Process.* **1994**, *60*, 306–325. [[CrossRef](#)]



© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).