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Ecosystem Service Value Response to Different Irrigation and Drainage Practices in a Land Development Project in the Yellow River Delta

Simeng Chen and Guanghui Jiang *

Faculty of Geographic Science, Beijing Normal University, Beijing 100875, China
* Correspondence: macrophage@bnu.edu.cn; Tel./Fax: +86-135-2144-4048

Abstract: The potential for development of saline land is enormous; the concept has recently attracted great scientific attention regarding its use and development. It is especially crucial to consider the issue of ecological balance when carrying out large-scale land remediation in the Yellow River Delta region since the saline land there is rich in resources and is also typically an ecologically delicate area. In order to quantitatively estimate the value of ecosystem services under various irrigation and drainage modes, this paper uses an undeveloped land development project in the Yellow River Delta as an example, simulates five different irrigation and drainage modes, and combines the market value method and the calculation method of factor equivalents. A quantitative estimation of the ecosystem service value under different irrigation and drainage modes is carried out, exploring the impact of different irrigation and drainage modes on the ecosystem from the perspective of ecosystem service value. The findings revealed that while the "Pipeline irrigation + concealed pipe" irrigation and drainage model increased the area of cultivated land by 4.04 km^2, the overall ecological value increased by only Renminbi (RMB) 6.707 $\times$ 10^6. It is clear that only an increase in the area of cultivated land will not increase the ecological value as a whole. Through comparison, it is found that the ecological value of 'Pipeline irrigation + open ditch' irrigation and drainage pattern increases the most, which is RMB 28.405 $\times$ 10^6. It can increase the area of cultivated land and protect the ecological benefits to a greater extent, which can better meet the requirements of the current comprehensive development. The study's findings can serve as a foundation for the sustainable development of the area and the scientific selection of development in ecologically vulnerable coastal areas.

Keywords: different drainage methods; value of ecosystem services; Yellow River Delta; ecological balance; sustainable development

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1. Introduction

The development of saline land management and its comprehensive use is of considerable relevance to safeguarding the security of China's arable land and food production since coastal saline land is a valuable land reserve resource [1,2]. To protect China's arable land and food production, saline and alkaline land management and comprehensive usage are of utmost importance. The Yellow River Delta region, one of China's most significant land reserve resource areas, has more than 600,000 hectares of salinized arable land and more than 100,000 hectares of undeveloped saline land that can be converted into agricultural land.

Significant contributors to soil salinization in this area include the shallow subsurface depth, highly salinized groundwater, and intense evaporation [3,4]. The salinization of land can be prevented and improved via drainage and irrigation [5]. The success or failure of managing saline soil is directly impacted by inadequate drainage, which causes salt to accumulate [6].

Salinized farmland treatment mainly includes drainage, soil backfilling, chemical improvement, biological improvement, and other measures. The use of farmland drainage technology is still an important way to handle soil salinization. At present, the drainage methods adopted in the process of saline–alkali land improvement and treatment in China mainly include open-ditch drainage, subsurface pipe drainage, and shaft drainage [7]. Domestic and foreign scholars have done much research on drainage salt reduction [8–10]. The groundwater in the Yellow River Delta is high in salt content and shallow in depth, and the soil salinization is profound. At the same time, this area is located in a temperate continental climate zone, the precipitation is relatively concentrated, the soil in the rainy season is mostly salinized, and the land use efficiency is extremely low. It represents a typical soil salinization area. The Yellow River Delta area's drainage and salt discharge projects are still primarily based on open ditch drainage, but because concealed pipe drainage technology has a good handle on groundwater levels and land-saving benefits, it is quickly gaining in popularity and has grown to be the largest area of concealed pipe promotion and application in China [11]. Currently, there are different drainage combinations, such as "open ditch drainage" [7], "concealed pipe + open ditch drainage" [12], and "concealed pipe drainage" [13], on the field scale of various development projects in the area. The drainage standard can be improved using concealed pipe drainage technology, which is based on open ditch drainage and is the fastest-growing technology in this field [5]. In the process of treating saline–alkali soil, canal water conveyance and canal-lining technology are still widely used for irrigation, and pipeline irrigation has also advanced quickly due to the region's growing water constraints from the Yellow River.

Land remediation has had a variety of effects on the spatial patterns of natural ecosystems and ecosystem services while promoting regional economic and social advantages [14,15]. Land remediation has significantly altered land use patterns and the accompanying ecosystem services in China [16], making it one of the largest coordinated human operations to alter land use patterns and impact terrestrial ecosystems [17]. Ecological land remediation has entered a crucial phase of theoretical innovation and practical application, as a result of the ongoing promotion of ecological civilization construction and the transformation of multifunctional land management [18].

An urgent scientific issue is how to utilize and apply the theoretical framework of ecosystem service functions to scientifically and impartially assess the changes in ecosystem service values that are brought about by land remediation activities [19], but there are still no methods that have been proven to be effective in the real world for identifying and evaluating agro-ecosystem service functions [20]. Many studies have been conducted in China [15,21–23], based on changes in ecosystem service function gains and losses in land remediation projects or administrative areas before and after remediation; however, comparative studies on ecosystem service function responses under various remediation technology measures are lacking. This makes it difficult to evaluate and choose ecologically based remediation technologies. One of the crucial types of land rehabilitation is the development and management of saline land. The land use structure of the project area after management, as well as the area occupied by the field road system, will be directly impacted by the development and management of saline land if different irrigation and drainage design schemes are adopted. This, in turn, will inevitably affect the spatial distribution pattern and service function of the ecosystem after management, and result in corresponding ecological and environmental effects [24].

The overuse and irrational usage of coastal-zone land have been a significant issue and are a threat to China's ecological security [25]. In order to increase the overall value of ecosystem services in coastal areas, it is crucial to carry out land development and remediation in the environmentally vulnerable coastal area of the Yellow River Delta and to choose ecologically oriented development and management strategies. This article selects the Yellow River Delta region and the Dongying City Hekou District Beili land development project as the object. It simulates five different irrigation and drainage designs, including "Irrigation channel + open ditch", "Pipeline irrigation + open ditch", "Irrigation channel + open ditch + concealed pipe", "Irrigation channel + concealed pipe" and "Pipeline irrigation + concealed pipe”, and then examines how the land use structure changes under each design scheme.

2. Materials and Methods

2.1. Overview of the Study Area

The project area (37°59′28″–38°00′20″ N, 118°17′48″–118°20′28″ E), which encompasses five administrative villages and covers an area of 4.63 km^2, is situated in the Hekou District of Dongying City. These villages are Shuanghe, Xingxing, Beili, Dongfeng, and Xinli of Xindu Town. The project area has a broad, flat topography, located in the Yellow River's present alluvial plain, and has a northern temperate semi-humid continental climate. The deep soil has a significant salt content (4‰) as a result of the soil formation process of seawater impregnation. Land-use types are typically broken down into four groups, based on the present state of land use in the project area: arable land, forest land, other agricultural land, and unused land. Arable land includes both dry and wet ground, while other agricultural land also contains hardened channels, open drainage ditches, hardened roads, and vegetative roads. Saline land makes up the remaining area. The use of different land use types is shown in Table 1.

Table 1. Use of different land use types in the project area.

Land Use Type	Usage
Dry land	Fields growing xerophytic crops from natural precipitation without irrigation
Watered land	Fields with water guarantee and irrigation facilities are used to plant economic crops such as cotton.
Harding channels	Field irrigation and drainage channels using concrete as a base
Guttering	Diversion of low-lying catchment water to soil ditches outside crop fields and roadbeds
Hardened Road	Used for cargo transportation, vehicle traffic, etc.
Packway	Mostly distributed in the field, more for daily farming and so on

2.2. Data Sources

The basic data in this paper are from the current land-use map of the project area (Figure 1), local survey data, and statistical data, such as the statistical yearbook of Dongying City. Other data, such as crop prices and planting areas, are from the official website of EPS data (accesses on 15 April 2022), the Statistical Yearbook of China (2020), and the compilation of national agricultural product cost-benefit data.

2.3. Design Simulations for Different Irrigation and Drainage Modes

This paper establishes five irrigation and drainage modes: “Irrigation channel + open ditch”, “Pipeline irrigation + open ditch”, “Irrigation channel + open ditch + concealed pipe”, “Irrigation channel + concealed pipe”, and “Pipeline irrigation + concealed pipe”, by the land-use change characteristics of the project area and prior planning experience. The specific scheme is shown in Table 2. Figure 2 is the simulation distribution diagram of five modes.

2.4. Calculation of Ecosystem Services Value

The system of ecosystem service value proposed by Costanza is currently primarily used in the evaluation of ecological values [26]. Xie Gaodi et al. [27] improved Costanza's system, which was based on a questionnaire survey and study, to increase the accuracy of the computation of ecosystem service value. The ecosystem service functions in the project area were divided into production, ecological, and life aspects for assessment in this paper, based on the types of terrestrial ecosystem service values in China that have been proposed by Xie Heights, combined with the functional characteristics of farmland ecosystems. The ecological function includes six aspects of biodiversity maintenance value, gas regulation value, climate regulation value, hydrological regulation value, environmental purification value, and maintaining soil value. The production function only takes into account the production of agricultural products. The life function is chosen as characterized by landscape aesthetics (Table 3).

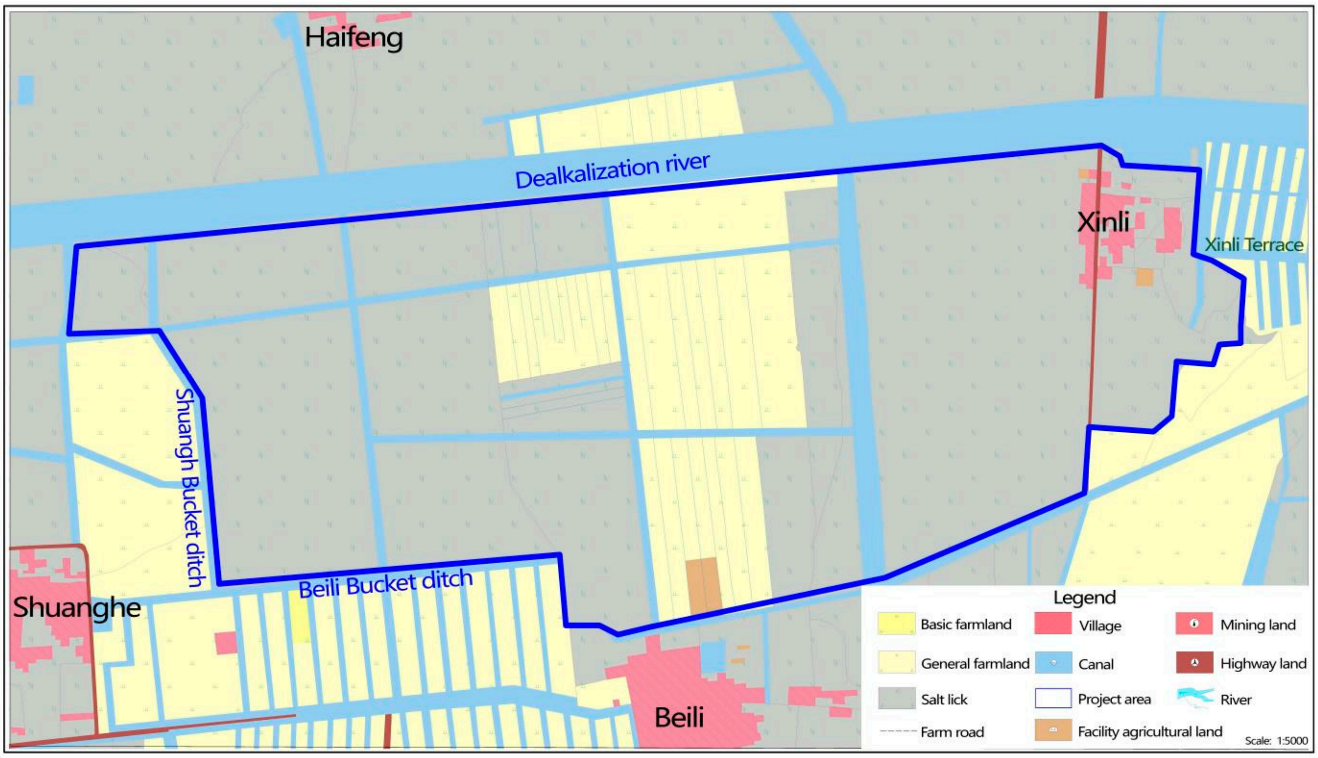

Figure 1. Current land-use map of the project area.

Table 2. Design options for different irrigation and drainage modes.

Irrigation and Drainage Patterns	Water Conveyance System	Design Solutions Drainage System	Comprehensive Width of Field
Irrigation channel + open ditch	Hardened branch canal, bucket canal, agricultural canal	Branch ditches, bucket drains, farm drains	50 m
Pipeline irrigation + open ditch	Branch pipe, bucket pipe, agricultural pipe	Branch ditches, bucket drains, farm drains	50 m
Irrigation channel + open ditch + concealed pipe	Hardened branch canal, bucket canal, agricultural canal	Concealed pipe, farm drains	100 m
Irrigation channel + concealed pipe	Hardened branch canal, bucket canal, agricultural canal	Concealed pipe	100 m
Pipeline irrigation + concealed pipe	Branch pipe, bucket pipe, agricultural pipe	Concealed pipe	100 m

Table 3. Classification of ecosystem functions in the project area.

Category	Ecosystem Service Value	Evaluation Methodology
Production	Production function value	Market Value Method
Ecology	Biodiversity maintenance value, gas regulation value, climate regulation value, hydrological regulation value, environmental purification value, maintaining soil value	Equivalent factor method
Life	Landscape aesthetic value	Equivalent factor method

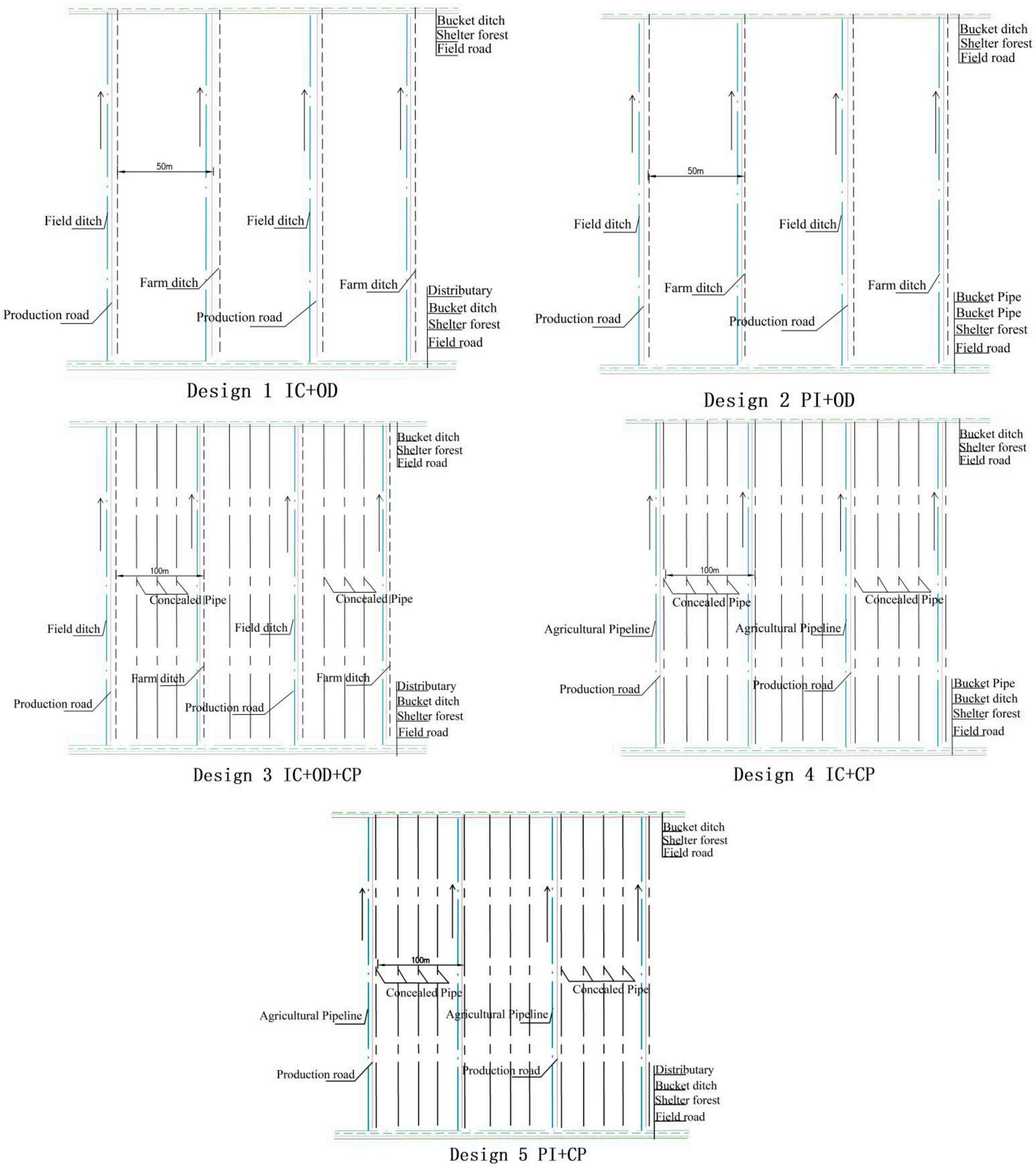

Figure 2. Design schematics for various irrigation and drainage techniques.

2.4.1. Calculation of Production Value

The total value of agricultural production function under various irrigation and drainage modes in the project area was calculated using the following formula, based on the calculation method of the agricultural food production service function presented by Xie Gaodi et al. [28]:

$$E_p = S \times \sum_{i=1}^{n} \frac{m_i p_i q_i}{M} \quad (1)$$

where E_p is the total economic value of the production service function of farmland in the project area (RMB/km^2); S is the cultivated area of the project area under different irrigation and drainage patterns (km^2); i is the type of crops grown; m_i is the planted area of i crops (km^2); p_i is the national average price of i crops (RMB/kg); q_i is the yield per unit area of i crops (kg/km^2); M is the total planted area of crops.

Cotton, corn, and wheat are the primary crops today and will remain so after the proposed development in the project area. The production value of the project area under various irrigation and drainage modes is determined using the aforementioned method, with reference to the national agricultural market prices in 2020.

2.4.2. Calculation of Ecological and Life Values

The value equivalent factor approach was employed to determine the ecological value of the project area by calculating the ecological function value of various types of land, in conjunction with the actual land use in the project area. The equivalent value of watered land in the project area was calculated using the benchmark of ecosystem service value equivalents per unit area, as proposed by Xie Gaodi. The hardened channels had water periods of only 15 to 30 days per year, and the rest were bare concrete surfaces, in accordance with the equivalent value assigned to the construction land by An Sven et al. [29]. The value of the ecosystem services offered by hardened channels was calculated based on actual conditions. Open drainage ditches in the project area are always used for water storage; their ecological value is measured based on the water surface. Unused land is salty and can be compared to the equivalent desert and bare land. The majority of the vegetation in the project area is mixed coniferous; the increase in forest land following remediation is based on the coniferous equivalent of the second-class classification in a first-class forest. The ecosystem service value of the vegetation road surface is calculated using bare land, while the ecological value of the hardened road surface is determined using construction land. The aesthetic value of the landscape was chosen as an indicator to evaluate the living value of the project area because the natural landscape created by the plant community can be physically and mentally enjoyable, can provide an aesthetic landscape, and may also potentially be used for recreation and gain cultural and artistic value. The equivalent factor approach is also used to determine the aesthetic value of the landscape in the project area. The final unit area ecosystem services value equivalent factor results are shown in Table 4.

Table 4. Equivalent factor of ecosystem service value per unit area.

Land Use Type	The Equivalent Weight Factor of ESV						
	Biodiversity Maintaining	**Gas Conditioning**	**Climate Control**	**Hydrological Regulation**	**Clean-Up Operation**	**Soil Conservation**	**Landscape Aesthetic**
Watered land	0.17	0.89	0.465	1.495	0.135	0.52	0.075
Dry land	0.13	0.67	0.36	0.27	0.10	1.03	0.06
Hardened channels	0.01	0.06	0.01	0.02	0.01	0.01	0.01
Guttering	2.55	0.77	2.29	102.24	5.55	0.93	1.89
Hardened Road	−0.01	0.04	0.01	0.02	0.01	0.01	0.02
Packway	0.02	0.02	0	0.03	0.10	0.02	0.01
Woodland	2.60	2.35	7.03	3.51	1.99	2.86	1.14
Saline–alkali land	0.07	0.065	0.05	0.12	0.205	0.075	0.03

The ecological service value of a unit farmland ecosystem in Dongying City in 2020 was calculated using 1/7 of the market value of the grain yield of cotton, corn, and wheat, the main crops in the city, as the standard for farmland ecological service value. The correction coefficient [30] was then used to correct the equivalent value of the ecosystem services of different land types.

2.5. Ecological Value Sensitivity

The ecological value sensitivity (C_s) is a measure of the dependence of the total value of ecosystem services on the value coefficient. When $C_s > 1$, this means that the value of ecosystem services is elastic, while when $C_s < 1$, this means that the value of ecosystem services is inelastic. The specific formula is:

$$C_s = \left| \frac{\left(V_g - V_f\right)/V_f}{\left(C_{v \cdot g} - C_{v \cdot f}\right)/C_{v \cdot f}} \right| \quad (2)$$

where C_s is the sensitivity of ecological value, C_v is the ecological service value coefficient, V is the total value of ecosystem services, and f and g are the value of ecosystem services before and after the adjustment of value coefficients.

2.6. Statistical Methods of Various Land-Use Types

According to the design scheme of each irrigation and drainage mode in Figure 2, the ArcGIS software is used to draw the design diagram of the different mode project areas, and the mask extraction tool in the software is used to identify different land use types in the project area. According to the extraction results, the geometric area of each land-use type layer is calculated. In the drawing process, the width of the hardened channel is the width of the channel base, while the width of the drainage ditch is selected as the width of the upper mouth of the drainage ditch, which can more accurately calculate the final occupied area of the hardened channel and the drainage ditch.

3. Results and Analysis

3.1. Analysis of Land Use Changes in Different Irrigation and Drainage Modes

The land-use structure of the project area was created and simulated in accordance with the various irrigation and drainage modes, and the land use in each mode is depicted below (Table 5).

Table 5. Land use of different irrigation and drainage patterns. Unit: km^2.

Type of Irrigation and Drainage	Land Use Type								Total
	Arable Land		Other Agricultural Land				Woodland	Unused Land	
	Watered Land	Dry Land	Hardening Channels	Guttering	Hardened Road	Packw-ay	Arbor Land	Saline Land	
Raw data	0	1.17	0	0.37	0	0.13	0.002	2.96	4.63
Design 1	3.06	0	0.30	0.90	0.10	0.18	0.09	0	4.63
Design 2	3.35	0	0	0.90	0.10	0.18	0.09	0	4.63
Design 3	3.56	0	0.17	0.63	0.10	0.09	0.09	0	4.63
Design 4	3.87	0	0.17	0.31	0.10	0.09	0.09	0	4.63
Design 5	4.04	0	0	0.31	0.10	0.09	0.09	0	4.63

Under the five irrigation and drainage patterns, the forest land and unused land underwent the largest overall changes in terms of land-use type. The area of forest land increased from 0.002 km^2 before becoming 0.09 km^2 after development, and the area of unused land decreased from 2.96 km^2 to 0 after remediation, when all unused land was converted into usable land. The "Design 5" mode is the most effective model for increasing arable land when compared to other irrigation and drainage methods because it reduces the need for hardened channels and so results in a significant increase in the amount of arable land. The traditional "Design 1" mode needs to occupy more topsoil area than other modes, so the cultivated land area is the least among the five irrigation and drainage modes, at only 3.06 km^2, while the hardened channel, drainage ditch, and other agricultural land types are the opposite, accounting for the highest proportion. This is because the traditional "Design 1" mode requires more topsoil area for open ditches than other modes. The "Design 2" model significantly increases the size of open drainage ditches and dirt roads, while significantly decreasing the area occupied by hardened channels, compared to the "Design 3" and "Design 4" modes. The farmed land only covers 3.35 km^2.

3.2. Value Changes for Ecosystem Services under Various Irrigation and Drainage Methods

The final calculation results are displayed in Table 6. The ecosystem service values of the "Design 2" and "Design 1" modes, at RMB 46.585 $\times$ 10^6 and RMB 45.798 $\times$ 10^6, respectively, are much greater than those of the other three modes. The "Design 4" drainage type has the lowest ecosystem service value, at only RMB 24.429 $\times$ 10^6. The most significant element of the overall ecosystem service value, from the perspective of various functional values, is the ecological value. The largest amount of arable land is provided by "Design 5", which also has the highest production value. "Design 2" has the highest ecological value, which is RMB 40.585 $\times$ 10^6. The "Design 1" irrigation and drainage model expands the area of woodland on the original land type while maintaining the original number of ecological open ditches, increasing the production value and ecological value.

Table 6. Value of ecosystem services under different irrigation and drainage patterns. Unit: RMB10^6.

Type of Irrigation and Drainage	Ecosystem Service Value			Total	Value Added
	Production Value	Ecological Value	Life Value		
Raw data	1.796	16.09	0.295	18.18	
Design 1	4.841	40.249	0.707	45.798	27.618
Design 2	5.256	40.615	0.714	46.585	28.405
Design 3	5.635	29.931	0.539	36.104	17.924
Design 4	6.132	17.945	0.342	24.419	6.239
Design 5	6.393	18.148	0.346	24.887	6.707

The pattern of change in ecosystem service value of arable land is not consistent with the trend of changes in arable land area, according to the change in the ecosystem service value of each land-use type under various irrigation and drainage systems. Most arable land area was expanded by the "Design 5" irrigation and drainage method; however, the overall ecosystem value was low, and the ecosystem service value only increased by RMB 6.707 $\times$ 10^6. Even though the "Design 1" irrigation and drainage model improved the least amount of arable land, it had a far higher gain in ecosystem service value than "Design 5", coming in at RMB 27.617 $\times$ 10^6. The " Design 2 " irrigation and drainage model offers the biggest gain in ecosystem service value, which is RMB 28.405 $\times$ 10^6. The original ecological open agricultural ditch is kept for its ecological value. The three irrigation and drainage techniques of "Design 3", "Design 4", and "Design 5" have increased the area of arable land, but they are insufficient to balance the growth of hardened channels and the decline of vegetation roads. Therefore, despite a growth in the amount of cultivated land, the value of ecosystem services, as a whole, did not improve.

3.3. Sensitivity Analysis

In order to calculate the sensitivity index of the ecosystem service value of the project area under five irrigation and drainage modes, the ecological value coefficients of cropland, forest land and other agricultural land were adjusted up- and downward by 50%. After that, the overall ecosystem service value change caused by the change in the ecosystem service value of the land type was calculated (Table 7).

Table 7. Changes in the project area's sensitivity indices (CS) of ecosystem service values under five different forms of irrigation and drainage.

Irrigation and Drainage Patterns	Land-Use Type					
	Watered Land	Hardened Channels	Guttering	Hardened Road	Dirt Road	Arbor Land
Design 1	0.097	0.000	0.886	0.000	0.000	0.016
Design 2	0.105	0.000	0.878	0.000	0.000	0.016
Design 3	0.151	0.000	0.826	0.000	0.000	0.022
Design 4	0.274	0.000	0.688	0.000	0.000	0.037
Design 5	0.283	0.000	0.681	0.000	0.000	0.036

According to the results in the table, the sensitivity index (CS) for each type of land use under the five irrigation and drainage modes ranged from 0.000 to 0.886, with a total value of less than 1. This shows that the ecosystem service value in the project area is inelastic to the corrected ecosystem service value equivalent coefficient; that is, the corrected ecosystem service value equivalent coefficient is consistent with the actual situation in the project area, and the calculation results have a high degree of confidence. The calculated results have strong confidence; the adjusted Ecosystem Service Value Equivalent Coefficient is compatible with the project area's current state. The ecosystem service value (ESV) of hardened channel, hardened road, and plain road is around zero, suggesting that the ecological service value equivalency coefficient (VC) of these three land use types has little influence on the ecosystem service value. Conversely, the CS of the open drainage ditch is the greatest among all land types, demonstrating that the accuracy of VC is the most essential factor for the calculation of ESV.

The overall distribution trend is the same, from small to large, followed by hardened roads, plain soil roads, arboreal forest land, irrigated land, and open drainage ditches. However, the impact degree of various land use types will vary, as seen from the perspective of the order change in sensitivity indexes of different land use types in each irrigation and drainage mode (Figure 3). The three modes of "Design 1," "Design 2," and "Design 3" each have a higher sensitivity index for open drainage ditches, with the mode of "Design 1" having the highest index at 0.886. This means that the entire ecosystem service value coefficient of the project area will grow or decrease by 88.6 percent for every 1 percent change in the corresponding coefficient of ecosystem service value of an open drainage ditch.

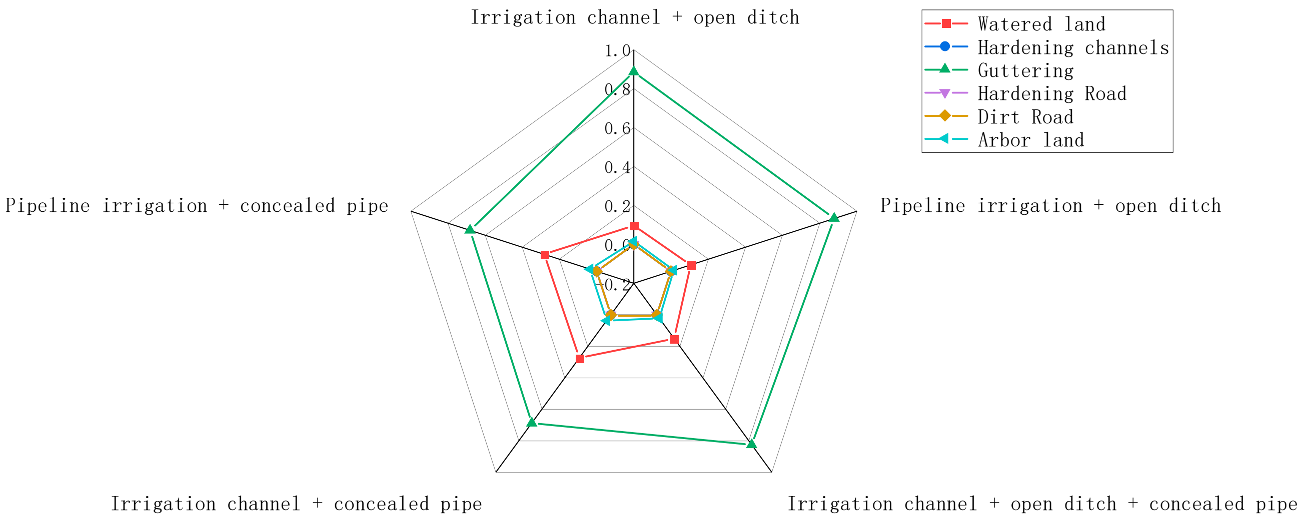

Figure 3. Comparison of sensitivity indices for each land-use type under different irrigation and drainage patterns.

4. Discussion

In the current process of improving saline–alkali land, the improvement methods adopted are different according to the actual conditions of each project area [31–33]; however, the project implementation and research focus mainly on the improvement effect of different modes on the drainage and salt discharge of saline–alkali land [34,35]. There is a lack of comparative research on the impact of the different irrigation and drainage modes used in the improvement process regarding ecological value. The five irrigation and drainage modes designed in this paper are some of the more common ways to improve saline–alkali land through drainage and irrigation. The comparative analysis of the ecological value of different modes fills the gap in research to a certain extent and provides a basis for the selection of irrigation and drainage in the process of saline–alkali land improvement in the future. The patterns provide a reference.

The ongoing discussion concerning land use and ecosystem service value is mostly conducted for a finished project or the entire region [36,37]. This article chooses five distinct irrigation and drainage modes for simulation, based on an underdeveloped project area, and computes the ecosystem service value for each option. The findings demonstrate that merely pursuing an increase in the cultivated land area throughout the process of developing underused land would not raise the ecosystem service value in a manner that is commensurate. The influence of various land types on the value of ecosystem services should be taken into account when making a thorough selection since this serves as a guide for selecting design schemes that are appropriate. The project area's land ecosystem service value was previously estimated by roughly dividing the different land types; here, the ultimate overall value evaluation will be different. For instance, the ecological service value of agricultural hardened open ditches is not explicitly provided, but the ecosystem service value of field roads is directly categorized under other land categories [38,39]. Field roads in this paper are split into plain soil roads and hardened roads for assessing the value of ecosystem services. According to the real situation and the equivalent of building land, the fields' open hardened ditches are assigned.

A single parameter's increase in the area of cultivated land cannot cause its corresponding ecological value to increase synchronously, which is something that needs to be taken into account as part of the goal of increasing cultivated land and meeting the demand for land for social and economic development. This paper makes use of the comparable table of ecosystem service value per unit area proposed by Xie Gaodi for the terrestrial environment in China. Although it has been updated to reflect Shandong Province's current circumstances, the value of each ecosystem service has not been further clarified. The issue of spatial disparities has not been included in research on the shift in ecosystem service value; this is an area that needs to be expanded upon in future studies.

5. Conclusions

The paper simulates five different irrigation and drainage modes, based on an undeveloped land development project in the Yellow River Delta. The modes are "Design 1 (Irrigation channel + open ditch)", "Design 2 (Pipeline irrigation + open ditch)", "Design 3 (Irrigation channel + open ditch + concealed pipe)", "Design 4 (Irrigation channel + concealed pipe)", and "Design 5 (Pipeline irrigation + concealed pipe)". The paper also uses the market value method and the unit area equivalent method to determine the respective ecosystem service values, based on various land use conditions.

(1) The corresponding land-use structures are developed from the five simulated irrigation and drainage modes. The conventional "Design 1" irrigation and drainage style takes up the most surface space, while other agricultural land makes up the majority of this area. Among them, the "Design 5" model occupies less surface area and can provide the most cultivated area. After development, there is no more undeveloped terrain.

(2) The ecosystem service value under the five irrigation and drainage modes of "Design 1", "Design 2", "Design 3", "Design 4", and "Design 5" in the study area is calculated us-

ing the market value method and equivalent factor method. The results show that the overall value has increased and is, respectively, RMB 45.798 $\times$ 10^6, RMB 46.585 $\times$ 10^6, RMB 36.104 $\times$ 10^6, RMB 24.419 $\times$ 10^6 and RMB 24.887 $\times$ 10^6. Comparative analysis reveals that the "Design 2" option has the highest ecosystem service value. This model combines a classic open agricultural ditch with underground pipeline irrigation to optimize the ecological value, while maintaining the cultivable land area. The most significant increase in the cultivated land area cannot considerably raise the total ecological value because "Design 5" only has a small impact on the rise of ecosystem service value.

(3) The open drainage ditch and irrigated land have relatively high ecological value sensitivity indices that significantly affect the value coefficient of ecosystem services. The ranking of the ecological value sensitivity index for each land type is unaffected significantly by the various irrigation and drainage methods. The ecological value sensitivity index of irrigated land has grown in comparison in "Design 5" and "Design 4", whereas the ecological value sensitivity index of the open drainage ditch has somewhat dropped.

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References

1. Hu, Q.; Zhao, Y.; Hu, X.; Qi, J.; Suo, L.; Pan, Y.; Song, B.; Chen, X. Effect of saline land reclamation by constructing the "Raised Field -Shallow Trench" pattern on agroecosystems in Yellow River Delta. *Agric. Water Manag.* **2022**, *261*, 107345. [CrossRef]
2. Xu, C.; Dong, Y.; Lu, J.; Zhang, Y.; Cheng, M.Q.; Cheng, M.Y.; Ma, J. Research Progress of Soil Improvement and Soil Resources Utilization of Coastal Saline-alkaline Land in China. *World For. Res.* **2020**, *33*, 68–73.
3. Guan, Y.; Liu, G.; Liu, Q.; Ye, Q. The Study of Salt-affected Soils in the Yellow River Delta Based on Remote Sensing. *J. Remote Sens.* **2001**, *5*, 46–52.
4. Yang, J.; Yao, R. Spatial Variability ofSoil Water and Salt Characteristics in the Yellow River Delta. *Sci. Geogr. Sin.* **2007**, *27*, 348–353.
5. Zhao, L.; Heng, T.; Yang, L.; Xu, X.; Feng, Y. Study on the Farmland Improvement Effect of Drainage Measures under Film Mulch with Drip Irrigation in Saline–Alkali Land in Arid Areas. *Sustainability* **2021**, *13*, 4159. [CrossRef]
6. Mitra, S.P.; Shanker, H. Formation of alkali soils by neutral salt solutions. *Soil Sci. Plant Nutr.* **1957**, *3*, 145–147. [CrossRef]
7. Zhang, K.; Ma, H.; Meng, C.; Li, Z.; Wang, K. Effects of Ditch Drainage on Soil Salinity in Salinized Jujube Field. *Bull. Soil Water Conserv.* **2018**, *38*, 307–312.
8. Ghumman, A.R.; Ghazaw, Y.M.; Niazi, M.F.; Hashmi, H.N. Impact assessment of subsurface drainage on waterlogged and saline lands. *Environ. Monit. Assess.* **2011**, *172*, 189–197. [CrossRef]
9. Haj-Amor, Z.; Bouri, S. Subsurface Drainage System Performance, Soil Salinization Risk, and Shallow Groundwater Dynamic Under Irrigation Practice in an Arid Land. *Arab. J. Sci. Eng.* **2019**, *44*, 467–477. [CrossRef]
10. Heng, T.; Wang, Z.; Li, W.; Zhang, J.; Yang, B. Impacts of Diameter and Depth of Drainage Pipes in Fields under Drip Irrigation on Soil Salt. *Acta Pedol. Sinica.* **2018**, *55*, 111–121.
11. Pan, T.; Wang, S.; Fu, T.; Liu, J.; Han, L. Development history, present situation, and the prospect of subsurface drainage technology in China. *Chin. J. Eco-Agric.* **2021**, *29*, 633–639.
12. Chen, W.; Wang, W.; Liu, Z.; Zhang, L.; Yin, C.; Ni, L. Parameters Design and Its Application of Subsurface Pipe Drainage Engineering in Yellow River Delta. *Yellow River* **2020**, *42*, 145–149.
13. Yang, Y.; Bu, F.; Luo, W. Experimental Research on the Irrigation and Drainage Model Conversion Project in the Yellow River Delta. *Yellow River* **2012**, *34*, 103–105.
14. Turner, K.G.; Odgaard, M.V.; Bøcher, P.K.; Dalgaard, T.; Svenning, J. Bundling ecosystem services in Denmark: Trade-offs and synergies in a cultural landscape. *Landsc. Urban Plan.* **2014**, *125*, 89–104. [CrossRef]
15. Wang, J.; Yan, S.; Guo, Y.; Li, J.; Sun, G. The effects of land consolidation on the ecological connectivity based on ecosystem service value: A case study of Da'an land consolidation project in Jilin province. *J. Geogr. Sci.* **2015**, *25*, 603–616. [CrossRef]
16. Zhou, Z.; Liu, D.; Sun, Y.; He, J. Predicting joint effects of multiple land consolidation strategies on ecosystem service interactions. *Environ. Sci. Pollut. Res.* **2022**, *29*, 37234–37247. [CrossRef]

17. Wang, J.; Zhong, L. Literature Analysis on Land Consolidation Research in China. *China Land Sci.* **2016**, *30*, 88–97.
18. Liu, C.; Xue, S.; Wu, Y. Ecological environmental effects of land consolidation: Mechanism of action and application. *Chin. J. Appl. Ecol.* **2019**, *30*, 685–693.
19. Wang, Y.; Yan, S.; Yu, L.; Zhang, Y. Evaluation of ecosystem service value and strategies for ecological design in land consolidation: A case of land consolidation project in Da'an City, Jilin Province, China. *Chin. J. Appl. Ecol.* **2014**, *25*, 1093–1099.
20. Soloviy, I.; Kuryltsiv, R.; Hernik, J.; Kryshenyk, N.; Kuleshnyk, T. Integrating Ecosystem Services Valuation into Land Use Planning: Case of the Ukrainian Agricultural Landscapes. *Forests* **2021**, *12*, 1465. [CrossRef]
21. Chen, Q. The Environment Impact Assessment of Land Consolidation Based on the Theory of Ecosystem Service Value. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *170*, 22027. [CrossRef]
22. Wang, Y.; Zhao, S. Valuing the ecosystem service losses from land reclamation by contingent valuation in Zhoushan, China. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *675*, 12036. [CrossRef]
23. Luo, Y.; Yu, R.; Han, G.; Wang, W.; Hu, J.; Xie, Y.; Liao, D. Evaluation of Landscape Pattern Changes and Ecological Effects in Land Reclamation Project of Homestead in Hilly and Mountainous Regions of Southwest China. *J. Agric. Resour. Environ.* **2015**, *32*, 429–435.
24. Zhao, W.; Min, M.; Li, J. Regulation of Ecosystem Services in Land Consolidation Regions. *Resour. Sci.* **2013**, *35*, 1415–1422.
25. Zhang, Y.; Chen, R.; Wang, Y. Tendency of land reclamation in coastal areas of Shanghai from 1998 to 2015. *Land Use Policy* **2020**, *91*, 104370. [CrossRef]
26. Robertcostanza, R.R.G.S. The value of the world's ecosystem services and natural capital. *Ecol. Econ.* **1998**, *25*, 3–15.
27. Xie, G.; Zhang, C.X.; Zhang, C.S.; Xiao, Y.; Lu, C. The value of ecosystem services in China. *Resour. Sci.* **2015**, *37*, 1740–1746.
28. Xiao, Y.; Xie, G.; An, K. Economicvalue of ecosystem services in Mangcuo Lake drainage basin. *Chin. J. Appl. Ecol.* **2003**, *14*, 676–680.
29. An, S.; Ma, C.; Hua, Y.; Li, C. Analysis of Ecosystem Service Value Profit and Loss Under the Oasis Development Model of Ecological Fragile Area in the Upper Yellow River—A Case Study Hongsibu District Ningxia. *Res. Soil Water Conserv.* **2022**, *29*, 1–8.
30. Xie, G.; Xiao, Y.; Zhen, L.; Lu, C. Study on ecosystem servicesvalue of food production in China. *Chin. J. Eco-Agric.* **2005**, *13*, 10–13.
31. Wang, C.; Zhang, W.; Gao, Z. Research Progress of Saline Alkali Land Improvement Technology in Bayan Nur City. *Agric. Technol. Equip.* **2021**, *3*, 49–51.
32. Wang, Y.; Tian, S.; Zuo, Z. Research of Desalting Effect of Improved Undeground Drainage Pipe in Saline-Alkali Soli of NingXia. *J. Ningxia Univ.* **2021**, *42*, 456–462.
33. Yan, X.; Zhang, J.; Yang, Z.; Zhu, X. Present Situation and Improvement Measures of Saline-alkaline Land in Qaidam Basin. *Agric. Technol.* **2020**, *40*, 18–20.
34. Geng, Q.; Yan, H.; Yang, J.; Zhang, J.; Chen, Y. Evaluation for Soil Improvement Effect of Open Ditch and Concealed Drainage Engineering on Saline Alkali Land Development. *Chin. J. Soil Sci.* **2019**, *50*, 617–624.
35. Li, J.; Ye, S.; Niu, Y. Research on the Effect of Different Models on Soil Environmental Improvement in Saline-alkali Land. *China Rural. Water Hydropower* **2018**, *9*, 193–198.
36. He, L.; Li, C.; Jia, Q. Profi t and Loss Analysis on Ecosystem Services Value Based on Land Use Change in Coastal Land. *Ecol. Econ.* **2016**, *32*, 14–18.
37. Su, M.; Wu, J. Impact of Comprehensive Land Consolidation Rehabilitation on Ecosystem Services: A Case Study of Shazai Island, Jiangmen, Guangdong Province. *Trop. Geogr.* **2021**, *41*, 159–166.
38. Jiang, B.; Lu, X. Study on the Value Profit and Loss of Regional Ecological Service in Different Types of Land Consolidation Projects—Empirical Comparison Based on the Scale of Project, County and City. *Hubei Soc. Sci.* **2018**, *33*, 42–50.
39. Zhou, X.; Feng, Y.; Luo, W.; Jia, W.; Yang, J.; Li, H. Comparing two ecosystem service evaluation methods of the ecological benefits from a land consolidation project at a township level: A case study in Sanxing Town, Jintang County of Sichuan Province. *Acta Ecol. Sin.* **2020**, *40*, 1799–1809.