

## Fuzzy Two-Stage Optimization Method Applied to Ecosystem Planning in Dongying City: Post-print

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### Abstract

Dongying City's economy is primarily dominated by the petrochemical industry, which occupies substantial land resources and generates large quantities of pollutants, exerting significant negative impacts on the sustainable development of the local ecosystem. The land transaction mechanism represents an effective planning approach that can facilitate the transformation of land use value from low to high. In practical ecosystem management planning, input parameters are subject to uncertainty due to inevitable errors and data missingness, which constrains deterministic optimization methods. This study will employ a fuzzy two-stage optimization method to address fuzzy and random uncertain information within the system; simultaneously, the transaction mechanism will be introduced into regional ecosystem planning. Through comparative analysis between transaction and non-transaction modes, land transaction volumes, ecological service values, and industrial pollutant emission levels under both modes can be obtained. The results demonstrate that the transaction mode is suitable for the current sustainable development strategy of Dongying's ecosystem; the proposed method serves as an effective tool for analyzing and processing uncertainty within systems. Furthermore, quantitative analysis can assist decision-makers in more thoroughly examining the relationship between ecological service value and economic benefits. This study explores pathways to sustainable development through the land transaction mechanism in regional ecosystems, providing feasible recommendations for local economic and ecological development.

## Full Text

# A Fuzzy Two-Stage Optimization Method for Ecosystem Planning in Dongying

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## Abstract

Dongying' s economy relies heavily on the petrochemical industry, which occupies considerable land resources and produces large quantities of pollutants, creating significant negative impacts on the sustainable development of the local ecosystem. Land trading is an effective planning method that can increase ecosystem services by encouraging their movement from low-value to high-value uses. However, inherent complexities and uncertainties exist in practical regional ecosystem management due to inevitable errors and data losses, which have placed the issue beyond the scope of conventional deterministic optimization methods. This study employs a fuzzy two-stage method to tackle fuzzy and stochastic uncertainties. A land trading mechanism was introduced to assist regional ecosystem planning. Improvements in land trading, ecological service value, and pollutant emissions have occurred under both trading and non-trading scenarios. The results show that the land trading mechanism is suitable for the regional ecosystem and sustainable development, and the proposed method is an effective tool for analyzing and dealing with uncertainties in the system. In addition, quantitative analysis can help policymakers conduct in-depth analyses of tradeoffs between ecological service value and economic benefits. This study explores a transition pathway for sustainable development through a land trading mechanism and provides suggestions for local economic and ecological development.

**Keywords:** ecosystem planning; land trading mechanism; fuzzy and stochastic uncertainties

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## 1. Current Status of Dongying' s Ecosystem

Dongying is located in the Yellow River Delta region of northern Shandong Province, serving as an important node in the Bohai Rim Economic Zone and a key component of the Shandong Peninsula urban agglomeration. It occupies a pivotal position connecting the Central Plains Economic Zone with the Northeast Economic Zone, as well as the Beijing-Tianjin-Tangshan Economic Zone with the Jiaodong Peninsula Economic Zone. The city covers a land area of 7,923 km<sup>2</sup> and relies on China' s second-largest petroleum industrial

base. However, land resources struggle to meet socio-economic development needs. Dongying's coastline stretches 412.67 km, accounting for a significant portion of Shandong's coastal length. With rapid economic development and population growth, the local government has initiated coastal land reclamation projects, converting portions of tidal flats into agricultural land and extensive aquaculture operations. The city has vigorously developed industrial zones, new towns, and large-scale infrastructure, including coastal tourism areas.

While Dongying has achieved tremendous economic progress, the local ecological environment has paid a heavy price. Large tracts of natural wetlands have been transformed into urban areas, ports, and coastal industrial parks. The soil fragmentation index has increased, and pollution has continuously degraded wetland ecosystems. Long-term discharge of industrial and agricultural wastewater has led to water pollution and eutrophication, with wetlands' ecological functions in constant decline. Due to high-intensity, high-speed land exploitation, the local ecosystem has evolved into a severely degraded area, threatening the living environment of wetland organisms. The area of beach wetlands has decreased by 1/9. Exploring rational and effective ecosystem development models is crucial for regional sustainable development.

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## 2. Model Construction and Solution for the Trading Mechanism

The model comprehensively considers multiple ecological and environmental elements, including energy production and processing industries, pollutants generated from energy activities, water chemical oxygen demand (COD), ammonia nitrogen content, and wastewater discharge. The model also accounts for ecosystem service values, encompassing direct service value (reed and hay product production value) and indirect service values such as biodiversity, water conservation, and pollution purification. The objective is to maximize system benefits under a series of constraints.

### 2.1 Model Formulation

The objective function is formulated as:

$$f = \sum_i \sum_t AB_{it} \cdot PCA_{it} + \sum_m \sum_t AB_{mt} \cdot WA_{mt} - \sum_i \sum_t \sum_h p_{ith} \cdot DTC_t \cdot EXPW_{ith}$$

$$\text{where: } - AB_{it} = PC_{it} - [PC_{it} \cdot PCI_{it} \cdot SOC_t] - PC_{it} \cdot PCR_{it} \cdot TC_t + PDW_{it} \cdot PS_{it} \cdot PC_{it} \cdot SI_t - PDS_{it} \cdot PDP_{mit} \cdot PMC_t - PDSO_{it} - AB_{mt} = (PAB_t \cdot PAT_t \cdot P\beta_{mt}) + (RDB_t \cdot RDT_t \cdot R\beta_{mt}) + (WPM_{mt} \cdot PMC_t \cdot YP_{mt}) + (WPM_{mt} \cdot PMC_t \cdot YC_t \cdot YP_{mt}) + (WSO_{mt} \cdot SOC_t) + (PSA_t \cdot SA_{mt}) + (WP_{mt} \cdot ZP_{mt} \cdot ZCI_t) + (RP_{mt} \cdot V_t) + (RP_{mt} \cdot RO_t \cdot RCI_t)$$

**Parameter Definitions:** -  $f$ : System benefit -  $t$ : Planning period -  $i$ : Industrial type -  $m$ : Wetland type -  $h$ : Probability level -  $AB_{it}$ : Benefit per unit area for industry  $i$  in period  $t$  -  $AB_{mt}$ : Benefit per unit area for wetland  $m$  in period  $t$  -  $PCA_{it}$ : Planned area for industry  $i$  in period  $t$  -  $WA_{mt}$ : Planned area for wetland  $m$  in period  $t$  -  $p_{ith}$ : Probability of wastewater discharge from industry  $i$  in period  $t$  at level  $h$  -  $DTC_t$ : Economic penalty for exceeding wastewater standards in period  $t$  -  $EXPW_{ith}$ : Excess wastewater volume from industry  $i$  in period  $t$  at level  $h$  -  $PC_{it}$ : Unit area output value for industry  $i$  in period  $t$  (10 yuan/hm<sup>2</sup>) -  $PCI_{it}$ : Unit product benefit for industry  $i$  in period  $t$  -  $SOC_t$ : Solid waste treatment cost in period  $t$  -  $PCR_{it}$ : Unit product production cost for industry  $i$  in period  $t$  -  $TC_t$ : Carbon tax rate in period  $t$  -  $PDW_{it}$ : Wastewater processed per unit area for industry  $i$  in period  $t$  (t/t) -  $PS_{it}$ : Solid waste emission per unit product for industry  $i$  in period  $t$  -  $SI_t$ : Recyclable solid waste cost per unit product in period  $t$  -  $PDS_{it}$ : Solid waste processed per unit area for industry  $i$  in period  $t$  (t/t) -  $PDP_{mit}$ : Processing amount for energy industry  $i$  in period  $t$  (t/t) -  $PDSO_{it}$ : Processing amount for energy industry  $i$  in period  $t$  (t/t) -  $PAB_t$ : Hay benefit per ton from wetlands in period  $t$  -  $PAT_t$ : Hay quantity per unit area in period  $t$  (t/hm<sup>2</sup>) -  $P\beta_{mt}$ : Wetland grass percentage coefficient in period  $t$  -  $RDB_t$ : Reed benefit per ton from wetlands in period  $t$  -  $RDT_t$ : Reed quantity per unit area in period  $t$  (t/hm<sup>2</sup>) -  $R\beta_{mt}$ : Wetland reed percentage coefficient in period  $t$  -  $WPM_{mt}$ : Water purification capacity per unit area for wetland  $m$  in period  $t$  (t/hm<sup>2</sup>) -  $PMC_t$ : Wastewater treatment cost in period  $t$  -  $YP_{mt}$ : Annual tourist volume per unit area for wetland  $m$  in period  $t$  (person/hm<sup>2</sup>) -  $YC_t$ : Tourism cost per tourist in period  $t$  -  $WSO_{mt}$ : Water conservation capacity of wetland  $m$  in period  $t$  (t/hm<sup>2</sup>) -  $PSA_t$ : Animal benefit per head from wetlands in period  $t$  -  $SA_{mt}$ : Bird quantity per unit area in period  $t$  (kg/hm<sup>2</sup>) -  $WP_{mt}$ : Water quality purification capacity per unit area for wetland  $m$  in period  $t$  (t/hm<sup>2</sup>) -  $ZP_{mt}$ : Soil erosion modulus for wetland  $m$  in period  $t$  (kg/hm<sup>2</sup>) -  $ZCI_t$ : River dredging cost in Dongying in period  $t$  -  $RP_{mt}$ : Species diversity benefit per unit area in period  $t$  -  $V_t$ : Benefit per unit area for species diversity in period  $t$  -  $RO_t$ : Rainfall runoff coefficient in period  $t$  -  $RCI_t$ : Industrial oxygen production cost in period  $t$

## 2.2 Constraints

**Land Resource Allocation Constraint:** Land resource allocation affects regional economic, ecosystem, and societal sustainable development. This constraint ensures that the sum of land allocation across industries does not exceed the total planned area.

$$PCA_{it} + WA_t \leq TA_t, \forall t$$

where  $TA_t$  is the total planned area in period  $t$ .

**Water Environment Constraint:** The water environment system is a crucial ecosystem component. Once wastewater discharge exceeds the self-purification

capacity, it affects the entire ecosystem. This constraint primarily limits pollutant emissions to ensure wetland ecosystems can process pollutants.

*Wastewater discharge limit:*

$$(PW_{ith} \cdot PC_{it} - PDW_{it}) \cdot PCA_{it} \geq EXPW_{ith}, \forall i, t, h$$

$$(PW_{ith} \cdot PC_{it} - PDW_{it}) \cdot PCA_{it} - EXPW_{ith} \leq (1 - \mu) \cdot SW_{it}, \forall i, t, h$$

where  $PW_{ith}$  is wastewater discharge per unit product for industry  $i$  in period  $t$  at probability  $p_{ith}$  (t/t),  $SW_{it}$  is the wastewater discharge quota for industry  $i$  in period  $t$ , and  $\mu$  is the percentage reduction allowed for industrial wastewater discharge.

*Total water resources constraint:*

$$PC_{it} \cdot PCA_{it} + PDW_{it} \cdot PCA_{it} \cdot PF_{it} \cdot (1 - GW_t) \leq CSW_t + \sum_m WP_{mt} \cdot WA_{mt}, \forall t$$

where  $PF_{it}$  is water consumption per unit product for industry  $i$  in period  $t$  (t/t),  $GW_t$  is the water reclamation rate from treatment plants in period  $t$  (%), and  $CSW_t$  is the total water resources in period  $t$  (10<sup>8</sup> t).

*Wastewater treatment capacity constraint:*

$$\sum_i (PW_{ith} \cdot PC_{it} - PDW_{it}) \cdot PCA_{it} \leq \sum_m WP_{mt} \cdot WA_{mt} + TPC_t, \forall t$$

where  $TPC_t$  is the annual treatment capacity of municipal wastewater plants in period  $t$ .

*COD constraint:*

$$\sum_i PCOD_{it} \cdot (PW_{it} \cdot PC_{it} - PDW_{it}) \cdot PCA_{it} \leq TCOD_t + \sum_m SCOD_{mt} \cdot WCOD_t \cdot WA_{mt}, \forall t$$

where  $PCOD_{it}$  is COD content per unit wastewater for industry  $i$  in period  $t$  (kg/t),  $TCOD_t$  is the allowed industrial COD discharge in period  $t$  (kg),  $SCOD_{mt}$  is COD removal rate by wetland  $m$  in period  $t$  (%), and  $WCOD_t$  is COD purification amount by wetlands in period  $t$  (kg/m<sup>3</sup>).

*Ammonia nitrogen constraint:*

$$\sum_i PNH_{it} \cdot (PW_{it} \cdot PC_{it} - PDW_{it}) \cdot PCA_{it} \leq TNH_t + \sum_m SNH_{mt} \cdot WNH_t \cdot WA_{mt}, \forall t$$

where  $PNH_{it}$  is ammonia nitrogen content per unit wastewater for industry  $i$  in period  $t$  (kg/t),  $TNH_t$  is the allowed ammonia nitrogen discharge in period  $t$

(kg),  $SNH_{mt}$  is ammonia nitrogen removal rate by wetland  $m$  in period  $t$  (%), and  $WNH_t$  is ammonia nitrogen purification amount by wetlands in period  $t$  (kg/m<sup>3</sup>).

**Reclamation Intensity Constraint:** Reclamation intensity represents the scale and intensity of coastal reclamation within a certain area, expressed as reclamation area per unit coastline length. The constraint limits reclamation intensity to  $10 < TR < 20$ , indicating relatively low reclamation pressure.

$$\frac{\sum_i PCA_{it} + \sum_m WA_{mt}}{CL_t} \leq (1 - TR_t), \forall t$$

where  $CL_t$  is coastline length (km) and  $TR_t$  is the reclamation intensity coefficient.

**Vegetation Coverage Constraint:** Vegetation coverage is an important indicator reflecting vegetation resources and greening levels.

$$\sum_i (PFR_t \cdot PCA_{it}) \leq \sum_m (P\beta_{mt} + R\beta_{mt}) \cdot WA_{mt}, \forall t$$

where  $PFR_t$  is industrial land vegetation coverage in period  $t$  (%) and  $R\beta_{mt}$  is wetland reed percentage coefficient in period  $t$  (%).

**Wetland Water Demand Constraint:** Wetland water demand refers to the minimum water capacity required to maintain basic wetland functions.

$$\sum_m (1 - \alpha_m) \cdot RP_{mt} \cdot WA_{mt} \geq \sum_m \min, \forall t$$

where  $\alpha_m$  is the moisture retention coefficient for wetland  $m$ .

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### 3. Model Parameter Selection

Data were obtained from field investigations, government reports, and relevant literature [16-20]. Within the study area, available water resources include surface water, seawater desalination, and recycled water. Water resource reserves remain stable during the planning period. The second period's municipal wastewater treatment capacity will increase proportionally year-over-year. According to Dongying's ecological construction master plan, stricter standards will be set during the planning period, limiting emissions per million yuan of revenue. All data were sourced from the Dongying 12th Five-Year Plan, Dongying Ecological City Construction Master Plan, and Dongying Statistical Yearbook.

Input data for chemical, petroleum processing, and oilfield industries are provided in Table 1, while model input data for constructed wetland service values are derived from ecosystem service value assessments (2003-2020).

Industrial product production and prices

Benefits of constructed wetlands

#### 4. Model Solution

The fuzzy two-stage model is formulated as:

$$\max f = \sum_j c_j x_j - \sum_j \sum_h p_h e_{jh} y_{jh}$$

Subject to:

$$\begin{aligned} \sum_j a_{rj} x_j &\geq b_r, \quad r = 1, 2, \dots, R \\ \sum_j t_{jh} y_{jh} &\geq \sum_j a_{rj} x_j + \omega_h, \quad r = 1, 2, \dots, R; h = 1, 2, \dots, H \\ x_j &\geq 0, \quad j = 1, 2, \dots, J \\ y_{jh} &\geq 0, \quad j = 1, 2, \dots, J; h = 1, 2, \dots, H \\ \lambda_k &\geq 0, \quad k = 1, 2, \dots, K \end{aligned}$$

where  $x_j$  represents first-stage decision variables determined before random variable realization, and  $y_{jh}$  represents second-stage decision variables under random variable  $\omega_h$  with probability  $p_h$ . Parameters  $p_i > 0$  and  $q_i > 0$  are penalty coefficients that can be selected based on practical scenarios [21]. Terms  $a_{rj}$  and  $b_r$  are fuzzy sets.

The key to solving fuzzy linear programming models is defuzzification. This study employs superiority and inferiority measures to convert the fuzzy model into a deterministic model, reducing the number of additional constraints and variables compared to traditional methods. The superiority measure defines the degree to which fuzzy set  $\tilde{P}$  is superior to  $\tilde{Q}$ , while the inferiority measure defines the degree to which  $\tilde{P}$  is inferior to  $\tilde{Q}$ . This approach quantifies the relationship between fuzzy parameters directly, replacing traditional defuzzification, ranking, or discrete segmentation methods to simplify computation and enhance practical applicability.

## 5. Results Analysis Under Trading Mode

This study generates different land trading volumes based on the trading mechanism. During the planning period, land transactions occur between industrial land (chemical industry, petroleum processing) and wetland ecosystems (grassland and lakes). As ecosystem service functions and industrial wastewater discharge permits change, land trading schemes adjust accordingly. Positive values represent seller market land quantities, while negative values represent buyer market land quantities.

The total trading volume in the first period is 1,099.7 hm<sup>2</sup>, and 1,102.9 hm<sup>2</sup> in the second period. The oilfield and petroleum industries are the primary participants, accounting for the majority of land transactions. This is mainly because energy industries have relatively high pollutant emissions and greater ecosystem impacts. To protect local ecosystem sustainability, energy industry land areas must continuously decrease, requiring a transition to new ecological industrial development models characterized by high land use efficiency and low pollution emissions.

Wetland ecosystems provide both direct and indirect values, delivering tangible and intangible benefits to human life and development. Different ecosystem service values include water conservation, soil retention, and nutrient regulation. Results indicate that water conservation value accounts for the dominant proportion of total wetland ecosystem service value. Wetlands achieve water conservation through soil pores and groundwater connections, which also enhances soil retention functions. Different wetland types show similar ecological values. In the first period, water conservation benefits from marsh and constructed wetlands are ¥4.04×10 and ¥4.08×10 respectively. In the second period, ecosystem service values increase to ¥4.12×10 and ¥4.02×10 respectively.

After introducing the land trading mechanism, local development trends favor wetland protection. Under the trading mechanism, wetland planning areas continuously expand while their service values increase. The oilfield industry accounts for the main land retirement area, while chemical and petroleum processing industries occupy smaller proportions. As wetland planning areas increase, their economic benefits continuously improve, with water conservation value dominating total ecosystem service value. This land allocation pattern favors regional ecosystem sustainable development.

[Figure 1: see original paper] Results of traded land area

[Figure 2: see original paper] Ecosystem service values of wetlands

## 6. Comparison and Discussion

Figure 3 shows land planning areas for industrial zones and wetlands under trading and non-trading mechanisms. Land allocation differs significantly between scenarios. Industrial planning areas under the non-trading scenario exceed those under the trading scenario, while wetland planning areas show the opposite pattern. Wetland area expansion provides additional ecological service values, directly slowing ecosystem degradation.

Industrial production is the primary source of wastewater discharge. However, excessive discharge causes irreversible ecosystem impacts. Figure 4 shows excess wastewater discharge under different scenarios. Trading mode results are substantially lower than non-trading mode. Under the trading scenario, wastewater discharge from oil and oilfield industries remains within regulatory standards. As emission standards become stricter (from low to high levels), discharge quantities increase, indicating that stringent requirements constrain industrial wastewater discharge. The trading mechanism positively impacts wastewater reduction.

[Figure 3: see original paper] Planning areas for industry and wetland

[Figure 4: see original paper] The amount of sewage emission

Ammonia nitrogen (NH<sub>3</sub>-N) emissions primarily originate from the chemical industry, plastics, and rubber production. Trading mode emissions are significantly lower than non-trading mode. For the energy industry, wastewater discharge is relatively low. These results reveal that local chemical and manufacturing industries have high wastewater discharge, while energy processing industries have relatively low discharge. Comparing land allocation and industrial pollutant discharge between trading and non-trading modes demonstrates the advantages of the trading mode, which reduces both COD and ammonia nitrogen emissions while expanding wetland areas.

[Figure 5: see original paper] The amount of COD and NH<sub>3</sub>-N emissions

The proposed method offers clear advantages in handling uncertainty and policy analysis, particularly when uncertainties appear as fuzzy and stochastic parameters. Traditional fuzzy programming methods introduce numerous additional constraints and variables with complex, time-consuming calculations. The superiority-inferiority measure approach reduces these constraints and simplifies computation. For ecological benefit accounting, this study uses simulated market methods to calculate ecosystem service values, helping decision-makers quantitatively analyze economic values of different ecosystem services and comprehensively consider ecological factors in planning.

## 7. Conclusions

This study applies a fuzzy two-stage optimization method to regional ecosystem planning. The algorithm improves upon traditional fuzzy programming issues by integrating ecosystem service value assessment into the optimization model. Quantitative analysis of ecological values, land management, and environmental issues helps decision-makers plan ecosystems more accurately and reasonably.

To explore sustainable regional ecosystem development pathways, this study introduces a cross-industry trading mechanism where wetlands act as buyers. Model solutions quantitatively compare land allocation between trading and non-trading modes. Results show that: 1. Trading mode yields higher ecological benefits than non-trading mode 2. Land allocation under trading mode tends to expand wetland areas and reduce industrial zones 3. Wastewater discharge is significantly reduced through the trading mechanism 4. Local chemical and manufacturing industries have high wastewater discharge, while energy processing industries have relatively low discharge 5. Wetland ecosystems play a crucial role in local sustainable development, with water conservation capacity representing the highest proportion of ecosystem service value

Rational planning of industrial land and wetland areas is significant for local economic development and ecological protection. The proposed method provides an effective tool for analyzing and handling system uncertainties.

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## References

- [1] Valuation of ecosystem services in China. Mountain city green space ecosystem planning: A case study of Changshou District, Chongqing. *Journal of Nanjing Forestry University (Natural Sciences Edition)*, 2015, 37(9): 1740-1746.
- [2] Green space system planning in Xi' an Chan-Ba Ecological District. *Journal of Suzhou University of Science and Technology (Engineering and Technology Edition)*, 2013, 26(3): 62-66.
- [3] Prato T. Multiple attribute Bayesian analysis of adaptive ecosystem management. *Ecological Modelling*, 2000, 133(3): 181-193.
- [4] Hein L, van Koppen K, de Groot R S, van Ierland E C. Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics*, 2006, 57(2): 209-228.
- [5] Green space system planning in Xi' an Chan-Ba Ecological District. *Urban Studies*, 2009, 3(4): 58-61.
- [6] Muscolo A, Panuccio M R, Mallamaci C, Sidari M. Biological indicators to assess short-term soil quality changes in forest ecosystems. *Ecological Indicators*, 2014, 45: 416-423.

- [7] Ahmed S, Tawarmalani M, Sahinidis N V. A finite branch-and-bound algorithm for two-stage stochastic integer programs. *Mathematical Programming*, 2004, 100(2): 355-377.
- [8] Complexity analysis of ecosystem dynamics. *Nankai University Journal (Natural Science Edition)*, 2009, 42(2): 99-104.
- [9] Research progress on the relationship between ecosystem complexity and stability based on soil food webs. *Acta Ecologica Sinica*, 2014, 34(9): 2173-2186.
- [10] Haddad K, Egodawatta P, Rahman A, Goonetilleke A. Assessing uncertainty in pollutant wash-off modelling via model validation. *Science of the Total Environment*, 2014, 497-498: 578-584.
- [11] Roy P O, Azevedo L B, Margni M, van Zelm R, Deschênes L, Huijbregts M A J. Characterization factors for terrestrial acidification at the global scale: A systematic analysis of spatial variability and uncertainty. *Science of the Total Environment*, 2014, 500-501: 270-276.
- [12] Cai Y P, Huang G H, Yang Z F, Tan Q. Identification of optimal strategies for energy management systems planning under multiple uncertainties. *Applied Energy*, 2009, 86(4): 480-495.
- [13] Wu X Q, Gao M, Wang D, Wang Y, Lu Q S, Zhang Z D. Framework and practice of integrated coastal zone management in Shandong Province, China. *Ocean & Coastal Management*, 2012, 69: 58-67.
- [14] Ecosystem health assessment of the Tarim River Basin based on analytic hierarchy process. *Resources Science*, 2009, 31(9): 1535-1544.
- [15] Landscape pattern changes and cumulative environmental effects of coastal wetlands in southern Laizhou Bay. *Chinese Journal of Ecology*, 2009, 28(12): 2437-2443.
- [16] Dongying Municipal People' s Government. *Dongying City Master Land Use Plan (1996-2010)*. Dongying Municipal People' s Government, 2000.
- [17] Dongying Municipal People' s Government. *Dongying Statistical Yearbook*. Dongying Municipal Bureau of Statistics, 2013.
- [18] Dongying Municipal People' s Government. *Dongying 12th Five-Year Plan*. Dongying Municipal People' s Government, 2011.
- [19] Dongying Municipal People' s Government. *Dongying Ecological City Construction Master Plan (2003-2020)*. Dongying Municipal People' s Government, 2004.
- [20] Dongying Municipal Bureau of Statistics. *Dongying Statistical Yearbook*. Dongying Municipal People' s Government, 2014.

[21] Van Hop N. Solving fuzzy (stochastic) linear programming problems using superiority and inferiority measures. *Information Sciences*, 2007, 177(9): 1977-1991.

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