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Environmental Effect Evaluation of Agricultural Production Activities Based on Analytic Hierarchy Process Model

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Abstract

This paper takes Weifang, where ecological advantage is relatively stronger than other regions in Jiaodong peninsula, as an example and establishes an index system for environmental effect evaluation of agricultural production activities in order to conduct quantitative research on the relationship between agricultural production activities and environment. Firstly, indexes are chosen under PSR framework, then extension analytic hierarchy process (AHP) is used to calculate extension interval judgment matrix on the basis of expert scoring. Calculation result is weight vectors that meet with consistency conditions and single hierarchical arrangement is practiced. The normalized results of single hierarchical arrangement are weight vectors of indexes of different hierarchies. The index system helps to formulate policies for sustainable development of economy, society and ecology, industrial restructuring and conservation and rehabilitation of ecological environment in Jiaodong peninsula.

***Keywords**: Analytic hierarchy process (AHP); Jiaodong peninsula; Agricultural production activities;Environmental effect; Evaluation*

1. Introduction

Weifang, a region in Jiaodong peninsula, has wide arable areas and rich soil resources and is one of main producing areas of high-yielding grain and cotton in Shandong. Agriculture is the dominant industry and accounts for 60% of its GDP. It is also an economic pillar for Shandong peninsula. Special geographical position endows Weifang with wet and windy climate, rich water resources, less risk of natural hazards and diversified ecological environment. However, extensive agriculture, residential lands and other human activities deteriorate the ecological environment. Ecological stress continues to increase with rapid development of agricultural and rural economy. Environmental quality in agricultural soil, water bodies (river, lake, agricultural wetlands) and atmosphere goes bad due to extensive application of chemical fertilizers, pesticides, mulching films and plant growth regulators. Therefore, research on the relationship between agricultural production activities and ecological environment by establishing an index system for environmental effect evaluation of agricultural production activities is of great significance to promote stable and sustainable development of economy, society and ecology in Weifang.

2. PSR Model of Environmental Effect Evaluation Indexes

The relationship between agricultural system and ecological environment is a typical pressure-state-response (PSR) pattern. Thus, an evaluation index system established under the PSR framework well reflects major characteristics and basic state of the environmental effect of regional agricultural production activities.

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PSR model of environmental effect evaluation indexes of agricultural production activities in Weifang is established as below based on the principles of scientificity, integrality, typical, operability, acquisitiveness and metrizability required by index selection:

Table 1. Nemerow Evaluation and Classification

<1.0	1.0~2.0	2.0~3.0	3.0~6.0	>6.0
Clear area	light pollution	moderate pollution	heavy pollution	foul pollution

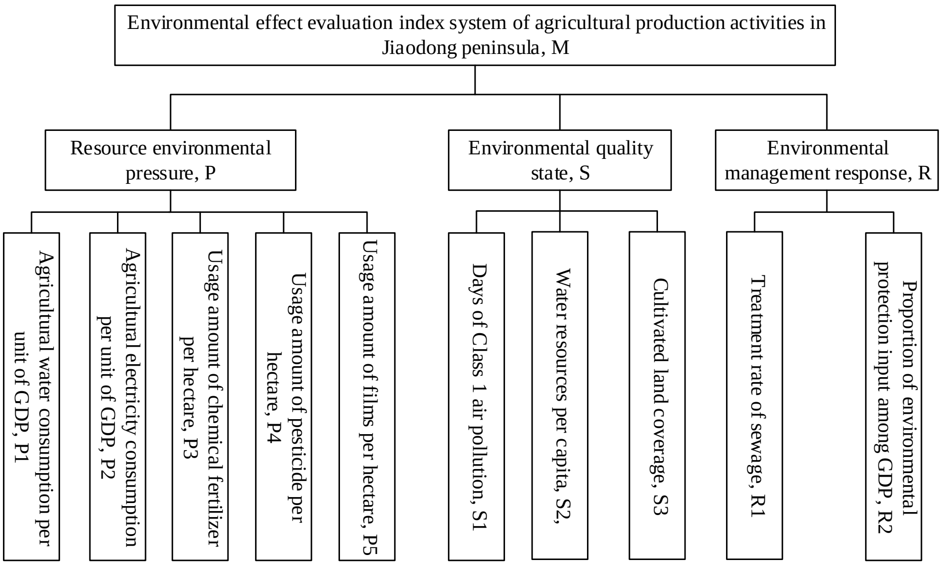

Figure 1. PSR Model of Environmental Effect Evaluation Index of Agricultural Production Activities in Weifang

3. AHP

Index weight is critical to establishing index system and to the accuracy of evaluation results. AHP is a simple, flexible and practical multi-criteria method for making decisions in quantitative research on qualitative questions. But when comparing two principles or two indexes, single quantitative value cannot accurately reflects artificial judgment. In addition, AHP judgment matrix is hard to pass consistency check in case of more than one index. However, extension AHP introduces extension interval numbers that can avoid ambiguity of artificial judgment. Moreover, extension interval judgment matrix does not require consistency check.

Step 1: Specifying extension judgment matrix

In the model shown in Figure 1, for the target layer M, two of n principles in criterion layer are compared and the extension interval number $a_{ij} = < a_{ij}^{-}, a_{ij}^{+} >$ denotes relative importance of every two principles. Then an extension interval judgment matrix is built as follows: $A = (a_{ij})_{n\times n}$. It can be known that A is a positive reciprocal matrix as $a_{ij} = \frac{1}{a_{ji}} = < \frac{1}{a_{ij}^{+}}, \frac{1}{a_{ij}^{-}} >, a_{ii} = 1$.

Step 2: Calculating overall extension judgment matrix

Assume the number of decision makers joining in the specification of matrix is T and the extension interval judgment matrix of target layer M is $A = (a_{ij})_{n\times n}$.

$a_{ij}{}^{t} = < a_{ij}{}^{-t}, a_{ij}{}^{+t} >$ denotes the extension interval number given by the expert t. Then the formula $A_{ij} = \frac{1}{T} \otimes (a_{ij}{}^{1} + a_{ij}{}^{2} + \cdots a_{ij}{}^{T})$ can be used to obtain the overall extension interval number. The overall extension judgment matrix for indexes in criterion layer can be calculated in the same way.

Step 3: Calculating weight vectors

Weight vectors that meet with consistency conditions can be calculated through following three steps for the overall extension interval judgment matrix $A = (A^{-}, A^{+})$ in the target layer M :

(1) Calculate normalized eigenvector with positive component x^{-} and x^{+} for the maximum eigenvalue of $A^{-} = (a_{ij}{}^{-})_{n \times n}, A^{+} = (a_{ij}{}^{+})_{n \times n}$ respectively;

(2) Calculate $m^{-} = \sqrt{\sum_{j=1}^{n} \frac{1}{\sum_{i=1}^{n} a_{ij}{}^{-}}}, m^{+} = \sqrt{\sum_{j=1}^{n} \frac{1}{\sum_{i=1}^{n} a_{ij}{}^{+}}}$;

(3) weight vector $S = (S_1, S_2, \cdots, S_n) = (m^{+}x^{-}, m^{-}x^{+})$

Step 4: Single hierarchical arrangement

The formula $V(S_i \geq S_j) = \frac{2(S_i^{+} - S_j^{-})}{(S_j^{+} - S_j^{-}) + (S_i^{+} - S_i^{-})}$ is used to calculate the value of $V(S_i \geq S_j)$. If $\forall i, j = 1, 2, \cdots, n; i \neq j, V(S_i \geq S_j) > 0$, then $W_j = 1, W_i = V(S_i \geq S_j)$, $i, j = 1, 2, \cdots, n$, $i \neq j$, where W_i denotes the single ordering weight value of principle i to target layer and the normalized result is $W_M = (W_1, W_2, \cdots, W_n)^T$, which denotes the single ordering weight vector of principle layer to target layer M .

Similarly, two indexes in principle index are compared to specify extension interval judgment matrix P , S and R . Then the step 2, 3 and 4 are repeated to get single ordering weight vector of target layer to principle layer, namely W_P , W_s and W_R .

4. Environmental Effect Evaluation of Agricultural Production Activities based on PSR-EAHP in Weifang

Two experts compared any two of three principles and got following extension judgment matrix:

Table 2. Expert Scoring Table on Extension Interval Judgment Matrix of Principles to Target M

M	P	S	R	P	S	R
P	$<1,1>$	$<1.5,2>$	$<1.1,1.2>$	$<1,1>$	$<2,3>$	$<1,2>$
S	$<1/2, 2/3>$	$<1,1>$	$<5/9, 5/7>$	$<1/3, 1/2>$	$<1,1>$	$<1/2, 2/3>$
R	$<5/6, 10/11>$	$<1.4,1.8>$	$<1,1>$	$<1/2, 1>$	$<1.5,2>$	$<1,1>$

he formula is used to calculate the overall extension interval judgment matrix of target layer), $A^{-}=(a_{ij}^{-})_{3\times 3}=\begin{pmatrix} 1 & 1.75 & 1.05 \\ 5/12 & 1 & 19/36 \\ 2/3 & 1.45 & 1 \end{pmatrix}$, $A^{+}=(a_{ij}^{+})_{3\times 3}=\begin{pmatrix} 1 & 2.5 & 1.6 \\ 7/12 & 1 & 29/42 \\ 21/22 & 1.9 & 1 \end{pmatrix}$

,

for A^{-}, 令 $M_i^{-}=\sqrt[3]{\prod_{i=1}^{3} a_{ij}^{-}}$, $M^{-}=\sum_{i=1}^{3} M_i^{-}$, normalized eigenvector with positive component for the maximum eigenvalue of matrix A^{-} ($x^{-}=\left(\frac{M_1^{-}}{M^{-}},\frac{M_2^{-}}{M^{-}},\frac{M_3^{-}}{M^{-}}\right)=\left(\frac{1.2248}{2.8172},\frac{0.6036}{2.8172},\frac{0.9888}{2.8172}\right)=(0.4348,0.2143,0.3510)$,

similarly, for A^{+}, when $M_i^{+}=\sqrt[3]{\prod_{i=1}^{3} a_{ij}^{+}}$, $M^{+}=\sum_{i=1}^{3} M_i^{+}$, normalized eigenvector with positive component for the maximum eigenvalue of matrix A^{+}) $x^{+}=\left(\frac{M_1^{+}}{M^{+}},\frac{M_2^{+}}{M^{+}},\frac{M_3^{+}}{M^{+}}\right)=\left(\frac{1.5874}{3.5454},\frac{0.7385}{3.5454},\frac{1.2195}{3.5454}\right)=(0.4477,0.2083,0.3440)$。

when： $m^{-}=\sqrt{\sum_{j=1}^{n}\frac{1}{\sum_{i=1}^{n} a_{ij}^{-}}}=1.0517, m^{+}=\sqrt{\sum_{j=1}^{n}\frac{1}{\sum_{i=1}^{n} a_{ij}^{+}}}=0.9397$, then weight vector $S=(S_1,S_2,\cdots,S_n)=(m^{+}x^{-},m^{-}x^{+})$, where $S_1=<0.4086,0.4952>$, $S_2=<0.2014,0.2304>$, $S_3=<0.3298,0.3805>$。

Then it comes to single hierarchical arrangement. The formula $V(S_i\geq S_j)=\frac{2(S_i^{+}-S_j^{-})}{(S_j^{+}-S_j^{-})+(S_i^{+}-S_i^{-})}$ can be used to calculate $W_2=1$, $W_1=V(S_1\geq S_2)=5.0830$, $W_3=V(S_3\geq S_2)=4.4944$, and the normalized result is the single hierarchical arrangement of principle layer to target layer $W_M=(0.4806,0.0945,0.4249)$. Three components of W_M is the weight coefficient of resource environmental pressure, environmental quality state and environmental management response.

Repeat above steps to get the single ordering results of each principle to its principle layer, as shown in following three tables:

Table 3. Expert Scoring and Single Hierarchical Arrangement of Extension Interval Judgment Matrix of Principle P to Target M

P	P1	P2	P3	P4	P5
P1	$<1,1>$	$<2,2.5>$	$<1.2,1.3>$	$<1.1,1.2>$	$<5/9,2/3>$
P2	$<2/5,1/2>$	$<1,1>$	$<1/2,2/3>$	$<5/11,2/3>$	$<2/5,1/2>$
P3	$<10/13,5/6>$	$<1.5,2>$	$<1,1>$	$<1,1.2>$	$<1/2,5/9>$
P4	$<5/6,10/11>$	$<1.5,2.2>$	$<5/6,1>$	$<1,1>$	$<5/11,1/2>$
P5	$<1.5,1.8>$	$<2,2.5>$	$<1.8,2>$	$<2,2.2>$	$<1,1>$
P1	$<1,1>$	$<1.5,2>$	$<1,1.5>$	$<1,1.8>$	$<2/5,1/2>$

P	P1	P2	P3	P4	P5
P2	$<1/2, 2/3>$	$<1,1>$	$<5/6, 1>$	$<2/3, 1>$	$<1/3, 1/2>$
P3	$<2/3, 1>$	$<1, 1.2>$	$<1,1>$	$<1, 1.1>$	$<1/2, 2/3>$
P4	$<5/9, 1>$	$<1, 1.5>$	$<10/11, 1>$	$<1,1>$	$<5/11, 1/2>$
P5	$<2, 2.5>$	$<2,3>$	$<1.5, 2>$	$<2, 2.2>$	$<1,1>$
single hierarchical arrangement $W_P = (0.1720, 0.0256, 0.1709, 0.1294, 0.5021)$					

Table 4. Expert Scoring and Single Hierarchical Arrangement of Extension Interval Judgment Matrix of Principle S to target M

S	S1	S2	S3	S1	S2	S3
S1	$<1,1>$	$<2, 2.5>$	$<3, 3.5>$	$<1,1>$	$<2,3>$	$<2, 2.5>$
S2	$<2/5, 1/2>$	$<1,1>$	$<1.5, 1.8>$	$<1/3, 1/2>$	$<1,1>$	$<1.5, 2>$
S3	$<2/7, 1/3>$	$<5/9, 2/3>$	$<1,1>$	$<2/5, 1/2>$	$<1/2, 2/3>$	$<1,1>$
single hierarchical arrangement $W_S = (0.6841, 0.2715, 0.0444)$						

Table 5. Expert Scoring and Single Hierarchical Arrangement of Extension Interval Judgment Matrix of Principle R to Target M

R	R1	R2	R1	R2
R1	$<1,1>$	$<1/3, 1/2>$	$<1,1>$	$<2/5, 1/2>$
R2	$<2,3>$	$<1,1>$	$<2, 2.5>$	$<1,1>$
single hierarchical arrangement $W_R = (0.0964, 0.9036)$				

To sum up, environmental effect evaluation index system of agricultural production activities based on PSR-EAHP is shown in the table as follows:

Table 6. Environmental Effect Evaluation Index System of Agricultural Production Activities based on PSR-EAHP

target layer	principle layer		index layer	
	sequence	weight	sequence	weight
M	*P*	0.4806	P1	0.1720
			P2	0.0256
			P3	0.1709
			P4	0.1294
			P5	0.5021
	S	0.0945	S1	0.6841
			S2	0.2715
			S3	0.0444
	R	0.4249	R1	0.0964
			R2	0.9036

Research results show that experts pay more attention to resource environmental pressure (48.06%) and environmental management response (42.49%) than to environmental quality state, which coincides with the status quo of Weifang. First, people have been aware of the serious environmental pollution caused by agricultural production activities. Environmental quality can be only improved at source by reducing emission of pollutants. Second, more efforts should be done to strengthen environmental management, for example increasing environmental protection input and reducing hazard of pollutants. However, little attention is paid to environmental quality state (9.45%) because it will gradually turn better with decreasing resource environmental pressure and stronger environmental management. Among pressure indexes, usage amount of agricultural films per hectare has the largest weighted value. Due to the great harm of plastic film residues in soil, there are cultivated lands being abandoned every year. Thus it draws attention of experts. However, usage amount of pesticides per hectare, usage amount of chemical fertilizers per hectare and agricultural water consumption per unit of GDP have similar weighted values, though the weighted value of agricultural water consumption per unit of GDP is bit higher due to serious water shortage in recent years in Weifang. Among state indexes, experts pay most attention to days of Class 1 air pollution, which indicates that agricultural production activities have significant influence on air pollution in the region. It is followed by water resources per capita. Agricultural production activities consume a large quantity of water, which results in decreasing water resources per capita. Among response indexes, weight of environmental protection input among GDP is relatively large, showing that people has been aware of the fact that properly increased environmental protection inputs are material prerequisite for solving environment problems.

5. Conclusions

This paper employs extension AHP to determine the weighted values of environmental effect evaluation index system of agricultural production activities. Judgment matrix in AHP is replaced by extension interval judgment matrix to avoid consistency check and validate the normalized results of each hierarchical index weights. The method is easy to calculate, understand and operate. It can also ensure the reliability of index system and of certain practical values to environmental effect evaluation of agricultural production activities in similar regions.

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