AN EXPERT SYSTEM FOR DECISION SUPPORT OF THE TOTAL ALLOCATION OF AGRICULTURE NON-POINT SOURCE POLLUTION

A Case of Tiaoxi Watershed

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Keywords: Expert system, Non-point source, AHP; Decision support system, Waste load allocation.

Abstract: This paper develops an expert system for waste load allocation of agricultural non-point source (ES-WLAANS) to assist environment administrators in making decision in optimal solution of allocation. ES-WLAANS includes a decision model at its core which is built based on analytic hierarchy process (AHP) and a closely related database. Tiaoxi watershed is the case study area. The results showed that ES-WLAANS can enhance the efficiency of allocation of agriculture NPS pollution for environmental administrators.

1 INTRODUCTION

One watershed always covers several administrative regions. Agriculture non-point source pollution of each region has different impacts on water quality due to different pollutants emission. Waste load allocation of agriculture non-point source of river basin (WLAANS) is a scientific management method to determine the optimal pollutant abatement for each region. Therefore, it is important to decide how to allocate among these regions of a river basin.

There have been some forms of optimization models to solve the Waste Load Allocation (WLA) problem. Mostafavi and Afshar (2011) use non-dominated archiving multi-colony ant algorithm to develop WLA model. Saadatpour and Afshar (2007) presented a fuzzy WLA model. Burn et al. (2001) explored the capabilities of genetic algorithms.

Analytical Hierarchy Process (AHP) is multi-objective decision-aiding method for pollutants allocation (Li et al., 2005). However, the complexity of WLAANS and the synthesis of AHP have many problems including a mass of time, lots of human power and financial resources. It is very difficult for government to estimate pollutants abatement amount.

This paper developed an expert system for waste load allocation of agricultural non-point source (ES-WLAANS). We select COD, total nitrogen (TN), total phosphorous (TP) as pollutants and Tiaoxi Watershed as case study. ES-WLAANS is developed with Visual Basic (VB), AHP, Microsoft Access and Matrix Laboratory (MATLAB). It takes economic factor, social factor, technical factor and environmental factor into account to establish the structure of AHP for decision support system.

2 METHODS

2.1 Study Area

Tiaoxi Watershed belongs to Tai Lake basin that is located in the northwest of Zhejiang Province, China. There are 6 regions including Changxin, Huzhou, Anji, Deqing, Yuhang and Lin'an in Tiaoxi valley. Ongley et al. (2010) found that the proportion of NPS pollution to Tai lake increased remarkably in recent years and algal bloomed in the Tai Lake in 2008.

2.2 Framework of ES-WLAANS

ES-WLAANS consists of three basic components, including database, inference engine (analysis model) and interface. The basic structure of ES-WLAANS is shown in Fig.1.

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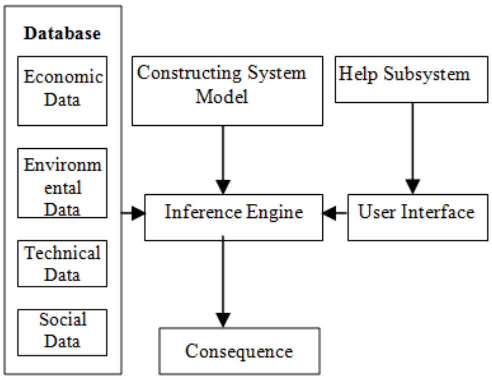

Figure 1: Architecture of the ES-WLAANS.

2.3 Modelling and Methodology

2.3.1 Allocation Index System and the Hierarchic Structure

The first step is building a proper index system for AHP. To make the allocation more acceptable for each region, the principles of fairness and efficiency were emphasized in building index system. Combining the former researches and the situation of Tiaoxi Watershed (Xiong et al., 2007), we select some representative indices: agriculture GDP, consumer price index, expenditure of science and education et al for economic factor; medical staff proportion, population density, number of personnel in agriculture et al for social factor; TN emission per cultivated area, COD emission per cultivated area, TP emission per cultivated area et al for technical factor; forest cover rate, area of paddy field, area of irrigable land, area of arid land, area of forest land et al for environmental factor.

There are 4 layers in the allocation system—objective layer, factor layer, index layer and decision layer, showed in Fig.2.

2.3.2 Dimensionless Evaluation Factors

There are different units among these indices, so it is essential to make all factors non-dimensional-normalized for better comprehensive analysis (Xiong et al., 2007). There are negative and positive factors. Positive factors were advantageous to WLA such as forest cover rate, and negative factors were disadvantageous to WLA such as emission of pollutants per cultivated area. Therefore, the positive factors should be dimensionless with equation (1) and negative factors should be dimensionless with equation (2):

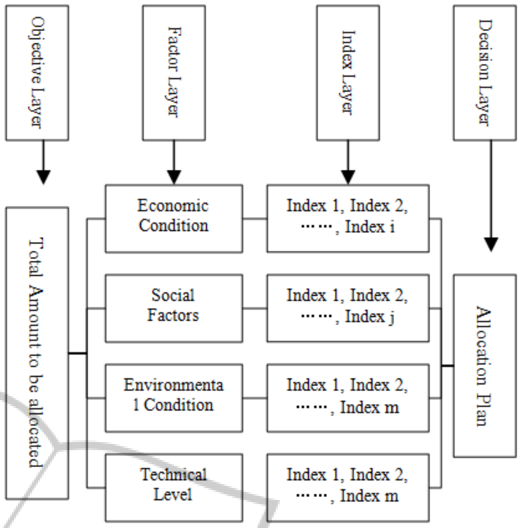

Figure 2: Frame of AHP of waste load allocation.

$$x'_i = \frac{x_i - x_{i\min}}{x_{i\max} - x_{i\min}} \times 100 \tag{1}$$

$$x'_i = \left(1 - \frac{x_i - x_{i\min}}{x_{i\max} - x_{i\min}}\right) \times 100 \tag{2}$$

where i is index, x_i is original value, $x_{i\max}$ and $x_{i\min}$ are the maximum and minimum value.

2.3.3 Indices Weights Estimation

The first layer was broken down into four layers including economic layer, social layer, environmental layer and technical layer to establish the pair-wise comparison matrix. The pair-wise comparisons are done in terms of which element dominates the other (Xiong et al., 2007). The matrix was expressed with A=$(a_{ij})_{4\times4}$.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \tag{3}$$

We can assign the value of element in the matrix as follows: if social factor is more important than economic factor, the value of a_{ij} can be assigned greater than 1. At the same time, the value that is less than 1 means less important than another and if the value of 1 means that the two factors have equal importance. This study selects MATLAB to calculate the eigenvalue and eigenvector of the pair-wise comparison matrix. Members of the eigenvector represent corresponding weights of the indices. Weights of indices in the lower lay can also be obtained with the same method.

2.3.4 Rate of Decision Layer Estimation

Based on the weight of each index, we can calculate the synthetic evaluation value of each unit by the following formulas.

$$V_i^{'} = V_1 + V_2 + V_3 + V_4 \tag{4}$$

$$V_j = W_j \times \sum_{k=1}^{n} u_k \times w_k \tag{5}$$

where i is the unit to be allocated, j and k are index type in the first layer and lower layer, $V^{'}$ is the synthetic evaluation value, V is the evaluation value of the first layer, W and w are the weight of the index in the first layer and lower layer, u is the value of the index in the lower layer.

Finally, we can calculate the rate of WLA for each unit based on the synthetic value (equation (6)) :

$$T_i = P_i - L \times \frac{V_i^{'}}{\sum_{k=1}^{n} V_k^{'}} \tag{6}$$

where i is the unit to be allocated, T is the amount of pollutant to be reduced, P is the total amount of pollutant, L is the total environmental capacity added by all the units.

2.4 Database

Microsoft Office Access has two distinguishing characteristics what are Microsoft Jet Database Engine and Graphical User Interface which render it suitable for developing the database.

2.5 Implementation of ES-WLAANS

ES-WLAANS is implemented by VB which is an advanced programming language characterized by visualization, object-oriented and event-driven (Liu and Lu, 2010). Owing to the complexity of model calculation for AHP, this system selects MATLAB to support the calculation. Though MATLAB has the advantage of data process and graph plot, it is weak in functional interface. Fortunately, Visual Basic can call dynamic link library compiled by MATLAB so that the system easily integrates advantages of AHP and MATLAB (Zhou et al., 2004).

3 APPLICATION OF ES-WLAANS

3.1 Selecting Index for AHP

According to the present situation of Tiaoxi Watershed, we select 18 indices in the lower layer shown in Fig.3.

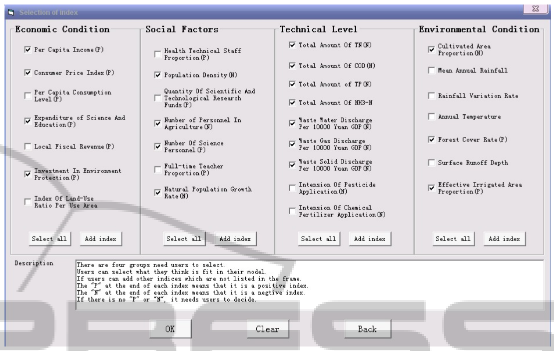

Figure 3: Frame of AHP of waste load allocation.

3.2 Data Input Interface

As showed from GUI of data input in the Fig.4, users can input the pair-wise comparison matrix and kinds of data such as pollutants emission, local environmental capacity and data of each index.

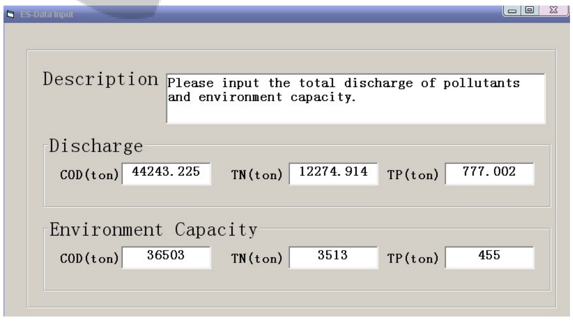

Figure 4: The GUI of data input.

4 RESULTS AND DISCUSSION

Fig.5 shows the result estimated with ES-WLAANS. From figure 5, we can see that Changxing has the worst result which requires reduction of 9575.2 ton of COD, 4056 ton of TN and 223.45 ton of TP followed by Anji which needs reduction of 6005.2 ton of COD, 2406.2 ton of TN and 85 ton of TP. As for Deqing, the required reduction of TP is 87.81 ton just less than Changxing, but COD, 251.5 ton, and TN, 623 ton, are the second least except Lin'an which needn't be reduced anymore. Besides,

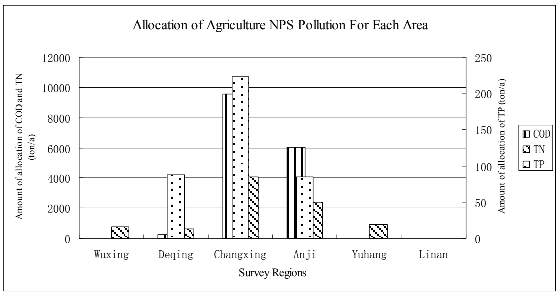

Figure 5: Result of allocation for each area.

Wuxing and Yuhang have the similar condition that reduction of TN for Wuxing is 767.6 ton and reduction of TN for Yuhang is 926.9 ton. COD and TP in both Wuxing and Yuhang needn't be reduced like Lin'an.

5 CONCLUSIONS

ES-WLAANS is a modelling expert decision support system that assists decision-makers in local environmental administration selecting an optimal solution for reduction proportion of pollutants from agriculture NPS among survey regions. Compared with other model or system, it has own feature which are showed in the table.1.

Table 1: Comparison with other decision support systems.

System/ Model	Manual/ computerized	Index number	Expert
ES-WLAANS	C	Flexible	Not
Delphi-AHP	M	18	Need
Input-output analysis (Ni et al., 2001)	M	21	Need
Linear programming (Deng et al., 2010)	M	6	Need

The characteristic of ES-WLAANS is listed as following:

1. It can provide user-friendly interface for operators without special training such as mastering MATLAB or AHP.
2. When ES-WLAANS is applied in other watershed, users can select any index they need.
3. ES-WLAANS can give pollutants abatement scenarios of agriculture non-point source in each administrative region.

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