MULTI CRITERIA DECISION MAKING FOR IDENTIFICATION OF OPTIMAL LOCATION FOR AQUACULTURE DEVELOPMENT

[1]P. MAHALAKSHMI, [2]A. PANIGRAHI, [3]T. RAVISANKAR, [4]J. ASHOK KUMAR, [5]B. SHANTHI

Central Institute of Brackishwater Aquaculture, (I.C.A.R), 75, Santhome High Road, R.A. Puram
Chennai
E-mail: maha@ciba.res.in; panigrahi@ciba.res.in; ravisankar@ciba.res.in; ashok@ciba.res.in drshanthi@ciba.res.in

Abstract: Identification of optimal location (aquasites) is based on the evaluation of number of sites in terms of number of criteria. In this study, twenty seven sub-criteria were categorized into five broad heads of evaluation criteria such as water (9 sub-criteria), soil (7 sub-criteria), support (4 sub-criteria), infrastructure (5 sub-criteria), and risk factor (2 sub-criteria). The priority weights for sub-criteria within the evaluation criteria under consideration were determined using the Analytical Hierarchy Process (AHP) method and subsequently, these weights were used for identifying the optimal location from a number of alternative locales based on the relative closeness values and ranks assigned to them using the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) method. Finally, the combination of TOPSIS and AHP methods constituted the methodology for identification of optimal location for aquaculture farming development. A case study application of identification of optimal location in Kalla mandal, West Godavari district, Andhra Pradesh, India, was used to illustrate the efficiency of the proposed method.
Optimal Location; Aquaculture

Key words: MCDM; TOPSIS; AHP;

I. INTRODUCTION

Aquaculture is the fast growing subsector of agriculture in India with annual growth rate of over 10 per cent. It provides cheap animal protein particularly for middle and poor classes of people. It also ensures livelihood security to one million people, either directly or indirectly. Currently the fish production in India was 8 million tonnes. While capture fish supply has remained stagnant at around 3 million tonnes since the last decade, aquaculture production has increased to 5 million tonnes and continues to grow. Though per capita fish availability was low, around 5 kg, as total population is rising fast and projected to reach 1.48 billion in the year 2030, the demand supply may have a wider gap to be filled soon. This deficit has to be overcome with aquaculture production.

The success of implementation of aquaculture projects without adverse environmental effects largely depends upon adherence to the better management practices. Especially quality of the site selected for the project plays a key role in better environmental management of aquaculture. The selection of optimal location in aquaculture system is not formulated just from one variable alone but from multiple variables [1]. Multi Criteria Decision Making (MCDM) methods provide efficient tools to deal with operation research problems with more than one criteria or objective.
Mathematical and computer models are useful for assisting the decision making process. Decision making is the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made among them. In this study, we develop a systematic, accurate, fast and practical methodology based on the combination of MCDM methods, such as Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) and Analytical Hierarchy Process (AHP), for constructing the decision process for identification of optimal location for aquaculture farming development. Statistically, the combined TOPSIS and AHP method was validated using the spearman's rank correlation.

II. MATERIALS AND METHODS

The procedural steps (Fig. 1) of the combined TOPSIS and AHP method were enlisted as below:

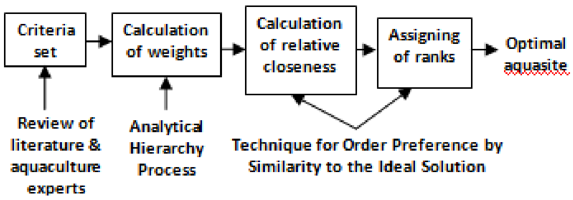

Fig. 1. Schematic representation of the combined TOPSIS and AHP method

A. Criteria set

A list of twenty seven criteria, selected by reviewing the literature and consultation with aquaculture experts were classified into five categories of evaluation criteria viz., water, soil, support, infrastructure, and risk factor. Table 1 shows the evaluation criteria and their respective sub-criteria used for the study.

B. Study area and datasets

The water, soil, support, infrastructure and risk factor related data used in this study were collected from 15 randomly selected aquasites in Kalla mandal, West Godavari district, Andhra Pradesh, India. This area was chosen purposefully in view of the concentration of aquaculture, and also as coastal aquaculture is a major economic activity in this area. The West Godavari district lies between the latitudes of $16^0 15'$ to $17^0 30'$ and the longitudes of $80^0 55'$ to $81^0 55'$.

C. Implementation

Matlab software (http://www.mathworks.com) was used to develop the combined TOPSIS and AHP decision making tool. The software has many in-built functions, for matrix calculations, which will be useful for the implementation of TOPSIS and AHP methods. We need not to write the separate routine or module for the same and also the coding part is simple and understandable for the end user.

D. Calculation of sub-criteria weights

In the present study, weights of sub-criteria under consideration were defined by pair-wise comparison method [7]. This method involves pair-wise comparisons, creating a ratio matrix. A comparison matrix R is a (L x L) matrix in which L is the number of evaluation criteria being compared. To fill the matrix R, "reference [7]" proposed the use of a one to nine scale to express the expert's preference and intensity of that preference for one element over the other. According to this scale, the available values for the pair-wise comparisons are members of the set {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}. This matrix is a positive and reciprocal matrix, that is, $r_{ij}>0$ and $r_{ji} = 1/r_{ij}$ for i, j = 1, 2, ..., L. The experts have to perform (L/2) (L-1) comparisons for a category of L evaluation criteria. The evaluation criteria identified were presented in pairs in all possible combinations. After identification of the possible pairs, judgments were established using a continuous nine scale with values from one to nine in order to rate the preferences for one sub-criterion over the other by a group of twelve aquaculture experts. The responses obtained through the geometric mean method (Wu et al., 2008), were entered into the pair-wise comparison matrix, which was then normalised.

The weight of the sub-criteria can be estimated by solving the following formula:

$$R \cdot w = \lambda_{max} \cdot w$$

(1)

Where R is the matrix of pair-wise comparison; w is the eigenvector; and λ_{max} is the largest Eigen value of R.

Since the aquaculture expert weigh all sub-criteria within the evaluation criteria under consideration based on his own judgment, inconsistency is possible in building a weight vector [9]. An index of Consistency Ratio (CR) was used to measure consistency of a pair-wise comparison matrix. The consistency ratio is designed in such a way that if $CR \leq 0.1$, the ratio indicates a reasonable level of consistency in the pair-wise comparisons; if, however, $CR > 0.1$, the values of the ratio are indicative of inconsistent judgments. In such cases, one should reconsider and revise the original values in the pair-wise comparison matrix.

E. Calculation of relative closeness and ranks

The basic concept of TOPSIS is to define the ideal solution and the negative ideal solution. The ranking of alternatives in TOPSIS is based on the relative similarity to the ideal solution, which avoids from the situation of having same similarity to both ideal and negative ideal solutions [8] (Wu et al., 2008). The calculation processes of the method used in this study were as following:

(1) Construct a decision matrix, A (a_{ij}; i = 1,2,3,…,M; j = 1,2,3,…,N, where N is the total number sub-criteria under consideration), based on all type of information available for the twenty seven sub-criteria. Each row of the decision matrix was allocated to one alternative (aquasite) and each column to one sub-criterion. Therefore, an element, a_{ij} of the decision matrix shows the performance of i^{th} alternative with respect to j^{th} sub-criterion.

(2) Calculate the normalized decision matrix, u_{ij} (i = 1,2,3,…,M; j = 1,2,3,…,N) for eliminating the influence of widely differing units and dimensions in the sub-criteria by using the following equation

$$u_{ij} = a_{ij} \Big/ \left[\sum_{i=1}^{M} a_{ij}^2 \right]^{1/2} \qquad (2)$$

(3) Construct the weighted normalized decision matrix by multiplying each column of the U with its associated weight w_j, $\sum_{j=1}^{n_k} w_j = 1$, which was accommodated from AHP method. Therefore, the weighted normalized decision matrix v_{ij} (i = 1,2,3,…,M; j = 1,2,3,…,N) was defined as

$$v_{ij} = w_j * u_{ij} \qquad (3)$$

(4) Obtain the ideal **(**best) (A^*) and negative ideal (worst) (A^-) solutions in each column using the following formulae

$$A* = \{(\max v_{ij} / j \in J), i = 1,2,\ldots\ldots\ldots, M; j = 1,2,\ldots\ldots\ldots\ldots, N\}$$
$$= \{v_{1*}, v_{2*}, \ldots\ldots\ldots\ldots, v_{N*}\} \qquad (4)$$
$$A- = \{(\min v_{ij} / j \in J), i = 1,2,\ldots\ldots\ldots, M; j = 1,2,\ldots\ldots\ldots\ldots, N\}$$
$$= \{v_{1-}, v_{2-}, \ldots\ldots\ldots\ldots, v_{N-}\} \qquad (5)$$

(5) In this study, N dimensional Euclidean (or straight-line) distance method was applied to measure the separation distances of each alternative to the ideal solution (S_{i*}) and negative ideal solution (S_{i-}). These were represented by

$$S_{i*} = [\sum_j (v_{ij} - v_{j*})^2]^{1/2}, i = 1,2,\ldots\ldots\ldots, M \qquad (6)$$

$$S_{i-} = [\sum_j (v_{ij} - v_{j-})^2]^{1/2}, i = 1,2,\ldots\ldots\ldots, M \qquad (7)$$

(6) The relative closeness with respect to ideal solution was calculated for each alternative by

$$C_{i*} = S_{i-} / S_{i*} + S_{i-}, i - 1,2,\ldots\ldots,M \quad (8)$$

where $0 \leq C_{i*} \leq 1$, that is, an alternative i is closer to the ideal solution as C_{i*} approaches to 1.

(7) The optimal alternative was identified based on the ranking according to the descending order of relative closeness, C_{i*}. The alternative with the highest value of C_{i*} was the optimal alternative, next highest value of C_{i*} was the second optimal alternative and so on.

F. Validation of the TOPSIS-AHP method

After collecting the required information from the study area, aquasites were ranked first by the combined TOPSIS and AHP method (X) and then the same aquasites were ranked by observed average yield value per hectare (ha) for the last three crops (Y). The ranking for the tied observations were given as in the method suggested by "reference [10]". The Spearman's rank correlation was used to test the significance of the correlation between the ranks obtained by the combined TOPSIS and AHP method and ranks obtained based on average yield. The cutoffs used correspond to a level of significance of alpha (α) equal to 0.01. The Spearman's rank correlation coefficient (ρ) is defined as [12]

$$\rho = 1 - \left(\frac{6 \sum d^2}{n(n^2 - 1)} \right) \quad -1.00 < \rho \leq +1.00 \qquad (9)$$

Where n is the number of items that are to be correlated; and d is the difference in the ranks assigned to a particular item.

In this study, the value of Spearman's rank correlation coefficient (ρ) was compared with the critical value of ρ for a dataset with 15 samples and alpha equal to 0.01 (a confidence level of 99 percent). The hypothesis for validation was defined as

H_0 (Null hypothesis, ρ = 0): There is no rank order correlation between ranks obtained by the combined TOPSIS and AHP method and ranks obtained based on average yield.

H_1 (Alternative hypothesis, $\rho \neq 0$): Positive rank order correlation exists between ranks obtained by the combined TOPSIS and AHP method and ranks obtained based on average yield.

H_0 is rejected if the value obtained for ρ is greater than the critical value of ρ .

III. RESULTS AND DISCUSSION

A. Weights of sub-criteria

The weights of sub-criteria within the evaluation criteria under consideration were determined using the relative scores assigned by the experts in the pair-wise comparison matrix. The weight for the sub-criteria was calculated by the procedures given in the methodology section. The weights of sub-criteria within the evaluation criteria under consideration were given in Table 1. The respective weights of the 9 sub-criteria for water were SC1 (0.123), SC2 (0.193), SC3 (0.179), SC4 (0.114), SC5 (0.089), SC6 (0.154), SC7 (0.060), SC8 (0.048), SC9 (0.040). The respective weights of the 6 sub-criteria for soil were SC10 (0.181), SC11 (0.124), SC12 (0.181), SC13 (0.120), SC14 (0.135), SC15 (0.135) and SC16 (0.123). The respective weights of the 4 sub-criteria for support were SC17 (0.141), SC18 (0.358), SC19 (0.320) and SC20 (0.181). The respective weights of the 5 sub-criteria for infrastructure were SC21 (0.177), SC22 (0.335), SC23 (0.086), SC24 (0.189) and SC25 (0.214). The respective weights of the 2 sub-criteria for risk factor were SC26 (0.333) and SC27 (0.667). The value of CR for sub-criteria within the evaluation criteria under consideration were less than the allowed value of CR (≤0.1), indicating the fact that there was a good consistency by the experts while assigning values in the pair-wise comparison matrix.

Table 1. Evaluation criteria and its sub-criteria and weights

Evaluation criteria and its sub-criteria	Weights for the sub-criteria	Consistency Ratio
Water (C1)		
• Temperature (SC1)	0.123	0.087
• pH (SC2)	0.193	
• Salinity (SC3)	0.179	
• Transparency (SC4)	0.114	
• TSS (SC5)	0.089	
• Dissolved Oxygen (SC6)	0.154	
• Free ammonia (SC7)	0.060	
• Nitrate-N (SC8)	0.048	
• H_2S (SC9)	0.040	
Soil (C2)		
• pH (0SC10)	0.181	0.074
• Calcium carbonate (SC11)	0.124	
• Organic carbon (SC12)	0.181	
• Textural class (SC 13)	0.120	
• Available phosphorous (SC14)	0.135	
• Available nitrogen (SC15)	0.135	
• Electrical conductivity (SC16)	0.123	
Support (C3)		
• Distance to NGO's (SC17)	0.141	0.051
• Distance to Govt. Offices (SC18)	0.358	
• Distance to research station (SC19)	0.320	
• Distance to university /college (SC20)	0.181	
Infrastructure (C4)		
• Distance to processing plants (SC21)	0.177	0.04
• Distance to rivers (SC22)	0.335	
• Distance to roads (SC23)	0.086	
• Distance to local market (SC24)	0.189	
• Distance to hatcheries (SC25)	0.214	
Input (C5)		
Flood and cyclone (SC26)	0.333	0
Nearby area pollution (SC27)	0.667	

B. Identification of optimal (best) aquasites

First the decision matrix was constructed based on the data collected from 15 aquasites in Kalla mandal, West Godavari district. In the dataset, twenty six sub-criteria were obtained as quantitative information and one sub-criteria namely textural class was obtained as prescribed linguistic words such as 'sandy clay', 'sandy clay loam', 'clay loam' or others. While constructing the decision matrix these linguistic words were converted into quantitative information by using the rules: IF (textural class is equal to 'sandy clay' or 'sandy clay loam' or 'clay loam') THEN textural class = 1; OTHERWISE textural class = 0. As all the sub-criteria for identifying the optimal aquasites were having different units and dimension, their values in the decision matrix were first normalized using the equation (2) and then the values in the normalized decision matrix and sub-criteria weights determined using AHP were multiplied using equation (3) to yield the weighted normalized decision matrix. The ideal (best) and negative ideal (worst) solutions were calculated using equations (4) and (5), respectively. Using equations (6) and (7), the separation measures of each alternative from the ideal and negative ideal solutions were computed. Relative closeness of each alternative was calculated using equation (8). Now, the alternatives for identification of optimal aquasites were arranged in descending order according to their relative closeness value. From Table 3, final ranking of the aquasites was S2-S14-S9-S8-S3-S11-S7-S10-S4-S13-S6-S5-S12-S1-S15.

Table 2. Results of combined TOPSIS and AHP method and observed average yield of three crops

Alternatives (aquasites)	Predicted values by combined TOPSIS and AHP methods		Observed values by average yield of three crops	
	Relative closeness	Rank	Average yield (tons)	Rank
S1	0.341	14	1.4	12
S2	0.668	1	3.5	3
S3	0.554	5	2.5	7
S4	0.529	9	2.2	8.5
S5	0.472	12	2	10
S6	0.498	11	1	14
S7	0.549	7	2.2	8.5
S8	0.559	4	4	1.5
S9	0.565	3	4	1.5
S10	0.532	8	2.6	6
S11	0.552	6	3	5
S12	0.461	13	1.7	11
S13	0.519	10	1.2	13
S14	0.583	2	3.2	4
S15	0.310	15	0.7	15

The ranking pattern obtained by the observed average yield value per ha for last three crops was given in Table 2. It showed that there was slight change in the ranks obtained by the combined TOPSIS and AHP method and ranks obtained based on the observed average yield. In both methods, alternative, S15, (rank 15) was identified as last rank. Spearman's rank correlation coefficient (ρ) was computed for the dataset of Kalla mandal. The value of the ρ obtained in this correlation was 0.896. The critical value of ρ for a dataset with 15 samples and alpha (α=0.01) is 0.654 according to "reference [13]". As the value of ρ obtained from the spearman's rank correlation was greater than the critical value of ρ, the null hypothesis was rejected. Therefore, the correlation between ranks obtained by the combined TOPSIS and AHP methods and ranks obtained based on average yield was significant (a confidence level of 99 percent), meaning that this combined method is reliable for identification of optimal location for aquaculture farming development.

CONCLUSIONS

The study has demonstrated that the combined TOPSIS and AHP method is capable and computationally easy to identify the optimal aquasite from a finite set of alternatives. The developed methodology for identification of best aquasites in the presence of multiple criteria may contribute to the improvement of decision making for planners and aqua farmers for their farming development. These would greatly minimise environmental, social and economic impacts due to the orderly and planned development of aquaculture for its sustainability by using the advanced methods namely TOPSIS and AHP in the presence of multiple variables.

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