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Application of rank sum, TOPSIS and pair-wise comparison methods for prioritising aquaculture sites

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ABSTRACT

Prioritising aquaculture sites is done based on the evaluation of number of sites in terms of number of decision criteria. In the present study, decision criteria were categorised into six broad heads of main criteria *viz*., water, soil, support, infrastructure, input and risk factors. Each main criterion has several sub-criteria. The weights of sub-criteria were assessed by rank sum method. The relative closeness values for all the sites for each main criterion was calculated using TOPISIS (Technique for Order Preference by Similarity to the Ideal Solution) method. Moreover the main criteria weights were determined by pair-wise comparison method. Finally, the combination of rank sum, TOPSIS and pair-wise comparison methods constituted the methodology for prioritising aquaculture sites. A case study application of prioritising the aquaculture sites was used to illustrate the efficiency of the proposed method.

Keywords: Aquaculture site, Pair-wise comparisons, Prioritising, Rank sum, Relative closeness, TOPSIS

Introduction

Uncontrolled expansion of aquaculture units and the intensive farming practices adopted have brought severe stress on the surrounding environment. One of the fundamental problems of planning for the expansion of aquaculture is to accurately assess the land, water, economic and human resources available for development.

Land use allocation involves making decisions on how to use the available land to satisfy land user's needs. A decision is a choice made from two or more alternatives. Mathematical and computer models are useful for assisting the decision making process (Stagnitti and Austin, 1998). 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 present a methodology based on the combination of rank sum, TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution), which is one of the Multi Criteria Decision Making techniques, and pair-wise comparison methods for constructing the decision model for prioritising aquaculture sites. This study aimed at developing a systematic, accurate, fast and practical decision making process for prioritising aquaculture sites.

Materials and methods

Study area and data compilation

The water, soil, support, infrastructure, input and risk factor related data used in this study were collected from 10 randomly selected aquaculture farms in Dharbavembu-Narsapur Mandal in West Godavari District, Andhra Pradesh, India. This district lies between the northern latitudes of 16^0 15' to 17^0 30' and the eastern longitudes of 80^0 55' to 81^0 55'.

Criteria set

A list of criteria, selected by reviewing the available literature and in consultation with aquaculture experts were classified into six main criteria *viz*., water, soil, support, infrastructure, input and risk factor. Each main criterion has several sub-criteria. Table 1 shows the main criteria and their respective sub-criteria used for the study.

Estimation of sub-criteria weights

After identification of main criteria and its sub-criteria, a group of 50 aquaculture experts were asked to rank the set of sub-criteria within each main criterion in straight ranking method. The group's final decision was reached through majority method (Guzzo, 1982). The ranking for the tied observations were given as suggested by Kothari (2002). In the next step, the quantitative rank order was converted to qualitative weights through rank sum method (Malezewshi, 1999). Rank sum weights were calculated according to the formula:

$$w_j = (N_k - r_j + 1) \; / \; \sum_i (N_k - r_i + 1) \qquad (1)$$

where w_j is the normalised weight for the j^{th} sub-criterion, N_k is the number of sub-criteria within main

Table 1. Main criterion and related sub-criteria with weights

Main criterion*	Sub-criteria
Water (0.4489)	Salinity (0.127)
	pH (0.173)
	Total alkalinity (0.127)
	Total hardness (0.127)
	Total hardness/ Total alkalinity (0.091)
	Dissolved oxygen (0.173)
	Free NH_3-N (0.073)
	H_2S (0.055)
	Temperature (0.018)
	Transparency (0.036)
Soil (0.3576)	pH (0.233)
	Salinity (0.233)
	Clay content (0.333)
	Organic carbon (0.133)
	Available phosphorous (0.067)
Support (0.0660)	Distance to NGOs (0.667)
	Distance to university/ college (0.333)
Infrastructure (0.0543)	Distance to natural fry (0.500)
	Distance to processing plants (0.167)
	Distance to local market (0.333)
Input (0.0366)	Animal wastes (1.000)
Risk factor (0.0366)	Flood and cyclone (0.500)
	Winter rain (0.333)
	Pollution (0.167)

*Consistency ratio for main criterion weights was 0.0347
Figures in parenthesis represent corresponding weights

criterion under consideration (i = 1,2, . ., N_k) and r_j is the rank position of the sub-criterion.

Estimation of main criteria weights

In the present study, weights of main criteria under consideration were defined by pair-wise comparison method (Saaty, 2000). This method involves pair-wise comparisons, creating a ratio matrix. A comparison matrix M is a (L x L) matrix in which L is the number of main criteria being compared. To fill the matrix M, Saaty (2000) 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, *i.e.*, $m_{ij}>0$ and $m_{ji} = 1/m_{ij}$ for " i, j = 1, 2, ..., L. The experts have to perform (L/2) (L-1) comparisons for a category of L main criteria.

The main criteria identified were presented in pairs in all possible combinations. Since six main criteria were considered in the present study, the possible pairs are fifteen. 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 main criterion over the other by a group of 50 aquaculture experts. The responses obtained through the consensus (a solution that satisfies every one) method (Guzzo, 1982), were entered into the pair-wise comparison matrix, which was then normalised

Then the pair-wise comparison matrix was converted to normalised pair-wise comparison matrix by dividing each element in the matrix by its column total. Then the relative weight vector (a_j) was calculated by the average of the elements in each row of the normalised matrix, *i.e.*, by dividing the sum of normalised scores for each row by the number of main criteria under consideration. Since the aquaculture expert weighs all elements based on his own judgment, inconsistency is possible in building a weight vector. 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 < 0.1, the ratio indicates a reasonable level of consistency in the pair-wise comparisons; if, however, CR $\geq$ 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.

Estimation of relative closeness

TOPSIS method (Malczewski, 1999) was used for calculating the relative closeness values for all the sites for each main criterion. The basic principle is to construct a decision matrix for each main criterion whose elements reflect the characteristics of a given set of choice possibilities determined by a given set of their sub-criteria (Triantaphyllou and Sanchez, 1997). If sites are denoted as S_i (for i = 1, 2, . . ., M sites), main criteria as E_k (for k = 1, 2, 3. . ., L main criteria) and sub-criteria as C_j (for j = 1, 2, . . ., N_k) where N_k is the number of sub-criteria within E_k, it is assumed that for each sub-criterion C_j, the decision maker has to determine its weight, w_j, $\sum_{j=1}^{N_k} w_j = 1$.

After constructing the decision matrix a_{ij} (for i = 1, 2, 3 . . . M and j = 1, 2 . . . N_k), the importance of site S_i in terms of sub-criterion C_j was evaluated for each main criterion iteratively using the following steps:

Step 1: Elements of the decision matrix (a_{ij}) were expressed as u_{ij} in a ratio scale as $0 \leq u_{ij} \leq 1$ for eliminating the widely differing numerical sizes of the sub-criteria, by using similar triangular method (Mahalakshmi *et al.,* 2006).

	Sub-criteria within E_k				
	C_1	C_2	C_3	......	C_{NK}
Sites	W_1	W_2	W_3	......	W_{NK}
S1	a_{11}	a_{12}	a_{13}	......	a_{1NK}
S2	a_{21}	a_{22}	a_{23}	......	a_{2NK}
S3	a_{31}	a_{32}	a_{33}	......	a_{3NK}
.	.	.	.		.
.	.	.	.		.
S_M	a_{M1}	a_{M2}	a_{M3}	......	a_{MNK}

Fig. 1. Decision matrix for each main criterion

Step 2: Weighted normalised decision matrix (v_{ij}) was calculated by :

$$v_{ij} = w_j * u_{ij} \text{ where } i = 1, 2, 3... M \text{ and } j = 1, 2... N_k. \quad (2)$$

Step 3: The positive ideal solution (A*) and negative ideal solution (A^-) were calculated by :

$$A^* = \{ (\max v_{ij} / j \in J) \ i = 1, 2 .... M\}$$
$$= \{v_{1*}, v_{2*}, ..., v_{Nk*}\} \quad (3)$$
$$A^- = \{ (\min v_{ij} / j \in J) \ i = 1, 2 .... M\}$$
$$= \{v_{1-}, v_{2-}, ..., v_{Nk-}\} \quad (4)$$

where $J = \{j = 1,2,3 ....., N_k\}$

Step 4: N_k dimensional Euclidean (or straight-line) distance method is applied to measure the separation distances of each site to the positive ideal solution (S_{i*}) and negative ideal point (S_{i-}). This is represented by:

$$S_{i*} = [\sum_j (v_{ij} - v_{j*})^2]^{1/2} \quad (5)$$

$$S_{i-} = [\sum_j (v_{ij} - v_{j-})^2]^{1/2} \quad \text{where } i = 1, 2, ..., M \quad (6)$$

Step 5: Finally the relative closeness with respect to positive ideal solution was calculated for each site by:

$$C_{i*} = S_{i-} / S_{i*} + S_{i-} \quad \text{where } 0 \leq C_{i*} \leq 1 \text{ and } i = 1, 2, ..., M. \quad (7)$$

Prioritising aquaculture sites

Relative closeness matrix (C_{ij}; i = 1 to M and j =1 to L) was formed using the relative closeness vectors (C_{i*}) of all the main criteria obtained from the TOPSIS method. Aquaculture sites were prioritised using the formula:

$$P_i = \alpha_j C_{ij+} \alpha_j \quad (8)$$

Sites were ranked according to the descending order of P_i,

Results and discussion

The main criterion weights obtained are 0.4489, 0.3576, 0.0660, 0.0543, 0.0366, and 0.0366 for water, soil, support, infrastructure, input, and risk factor respectively (Table 1). This means that water is the most important criterion followed by soil, support, infrastructure, input and risk factor. The criterion weights for input and risk factor are same. The result shows that the consistency ratio was 0.0347, which was less than the threshold value of 0.1. The ratio indicates that comparisons of each main criterion were perfectly consistent. This implies that the weights of main criteria were suitable for prioritising the aquaculture sites.

Table 2 presents the relative closeness values of all the main criteria for each site estimated using TOPSIS method. It also shows the P_i value and rank of each site. The result revealed that, site 4 was identified as the most preferred (rank 1), followed by sites 3 and 1 (rank 2 and 3 respectively). The worst three sites were 6, 5 and 8 (rank 8, 9 and 10 respectively). The best three sites of relative closeness values for each main criterion were close to the positive ideal point. Therefore, sites 4, 3, and 1 were easily acceptable as best sites to all decision makers.

Table 2. Relative closeness, P_i value and rank for each site in the study area

Site No.	Water	Soil	Support	Infrastructure	Input	Risk factor	P_i	Rank
1	0.502	0.720	0.334	0.576	0.333	0.699	0.574	3
2	0.554	0.409	0.334	0.623	0.333	0.601	0.485	5
3	0.746	0.613	0.334	0.623	0.167	0.999	0.653	2
4	0.732	0.998	0.334	0.350	0.667	0.699	0.777	1
5	0.242	0.218	1.000	0.000	1.000	0.699	0.315	9
6	0.405	0.375	0.000	0.000	0.167	0.699	0.347	8
7	0.476	0.635	0.000	0.438	0.333	0.169	0.483	6
8	0.242	0.378	0.000	0.000	0.667	0.832	0.299	10
9	0.500	0.495	0.667	0.000	0.000	0.302	0.457	7
10	0.245	0.838	1.000	0.376	0.333	0.169	0.514	4

Though in the worst sites, input and risk factor were close to the positive ideal point, the remaining main criteria were close to negative ideal point. Therefore, sites 6, 5, and 8 were confirmed as worst sites by all decision makers. The results predicted as best from this method were partly verified by the existing farms in the area. However there was some variation among the predicted and actual locations possibly due to weighting method used and the different factors employed in the method.

The study has demonstrated that the combination of rank sum, TOPSIS and pair-wise comparison methods are useful for prioritising aquaculture sites, based on the decision criteria for development of the aquaculture industry. This method will enhance the decision making capacity of anyone engaged in design and construction of new/existing facilities. The study result suggests that this methodology has sufficient predictive power to help extension personnel, aquaculturists, land-use managers, farmers, and other interested persons who may be unfamiliar with the specific requirements of aquaculture, to prioritise potential farm sites for aquaculture development and expansion.

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