

# DMTIOLA: decision making tool for identification of optimal location for aquaculture farming development

P. Mahalakshmi · K. Ganesan · V. Venkatasubramanian

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**Abstract** Decision making tool called Decision Making Tool for Identification of Optimal Location in Aqua farming development was developed using Visual Basic programming language for identification of optimal location for aquaculture farming development. Twenty-four input criteria to the tool were categorized into six broad heads of main-criteria namely: water (10 sub-criteria), soil (5 sub-criteria), support (2 sub-criteria), infrastructure (3 sub-criteria), input (1 sub-criterion), and risk factor (3 sub-criteria). In this tool, the optimal location was identified based on the objective function, which was derived from the combination of rank sum, pair-wise comparison, and Technique for Order Preference by Similarity to the Ideal Solution methods. Based on the objective function values, alternatives (or aqua farms) were ranked in descending order in a table. In order to validate the developed tool, the same alternatives were ranked in descending order according to the observed average yield value per hectare (ha) for the last three crops. Spearman's rank correlation was used to assess the correlation between ranks obtained by the tool and ranks obtained based on average yield. It showed with 99% confidence that a significant correlation exists between ranks obtained by the tool and ranks obtained based on average yield. Developed tool appeared to be confident and robust in proof-of-concept application for aquaculture farming development in Kalla mandal with reference to shrimp farms, West Godavari district, Andhra Pradesh, India.

**Keywords** Aquaculture · Aqua farms · Decision making tool · Rank sum method · Pair-wise comparison · TOPSIS · Optimal location

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## Introduction

Aquaculture has developed into a prime industry to tap the enormous turnover of bio-energy for the benefit of mankind (Anand et al. 2011). The rapid expansion of brackish water aquaculture activities in India during the last 10 years has led a growing concern about environmental issues. The success of aquacultural projects without adverse environmental effects largely depends upon the quality of the site selected for the project. Poor site selection and uncontrolled expansion of aquaculture units and their intensive farm practices have brought stressed ecosystems, stressed culture species, decreased production, and inferior economic performance. The problem has become crucial, and the only alternative is the zoning of potential areas for shrimp cultivation (Gowda et al. 2000).

Land-use allocation involves making decisions on how to use available land to satisfy land users needs. The selection of optimal location in aquaculture system is not formulated just from one criterion alone but from multiple criteria (Ramesh and Rajkumar 1996). Multi-criteria decision making methods provide efficient tools to deal with operation research problems with more than one criterion or objective. There are many different concepts and methods for multi-criteria decision making (MCDM). Some of the potentially useful techniques are goal programming, ideal point method, multi attribute utility theory (MAUT), analytical hierarchy process (AHP), ELECTRE I-III, PROMETHEE, and cooperative game theory (Malczewski 1999). TOPSIS is one of the ideal point method developed by Hwang and Yoon (1981). It is one of the best known and most widely used methods of decision making (Wang et al. 2006). The basic concept of the TOPSIS method is that the selected alternative should have the shortest distance from the ideal solution and the longest distance from the negative ideal solution, in a geometrical sense. The TOPSIS method assumes that each criterion has a tendency of monotonically increasing or decreasing utility. Therefore, it is easy to define the ideal and the negative ideal solution (Triantaphyllou 2000).

In order to evaluate the multiple alternatives, decision making process is defined in the form of a mathematical technique for finding a maximum or minimum value of an objective function of several alternatives. Mathematical/computer models are designed in the form of decision support systems/tools for assisting the decision making process (Stagnitti and Austin 1998). The decision support system/tool is an integrated assembly of models, data, and interpretive routines and other relevant information that efficiently processes input data, runs the models, and displays the results in an easy-interpret format (George et al. 2002; Sarangi et al. 2004). Further, these tools are designed to assist the decision makers in selecting, optimal location, best alternatives from among the number of feasible alternatives (Jankowski 1995). On this premise, we develop and validate a systematic, accurate, fast, and practical decision making tool for the identification of optimal location for aquaculture farming development.

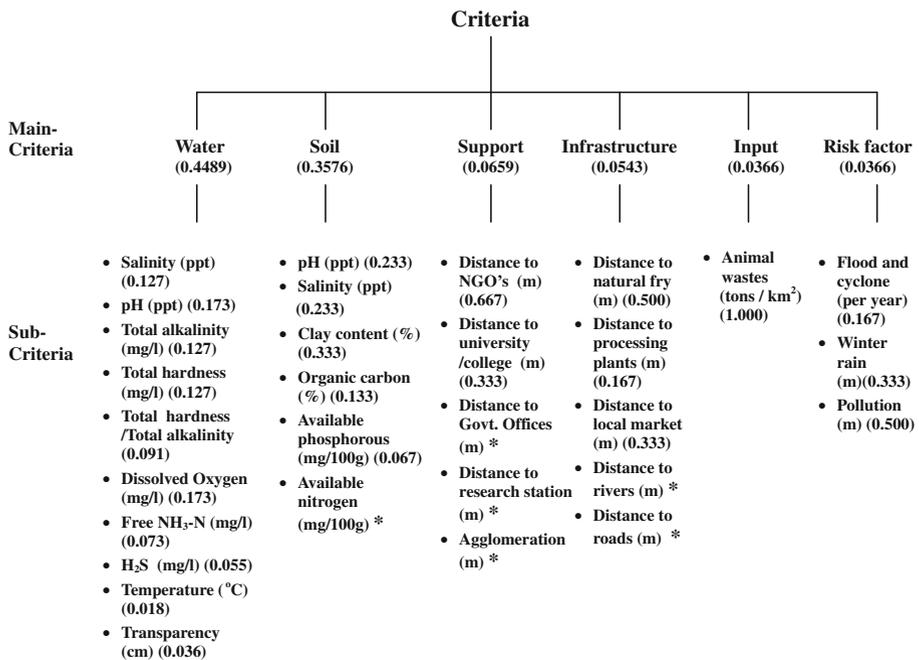
## Materials and methods

### Criteria and data sets

The key factors to be considered for selecting the optimal location in aquaculture are the availability of good quality water in abundant quantity, soil quality, salinity, temperature, pollution, exposures to flood, infrastructural facilities, and access to essential inputs and markets (Nath et al. 2000).

A list of 30 criteria was selected by reviewing the literature and consultation with experts who are all working in aquaculture field. These criteria thus selected were then classified into six categories of main-criteria namely: water (10 sub-criteria), soil (6 sub-criteria), support (5 sub-criteria), infrastructure (5 sub-criteria), input (1 sub-criterion), and risk factor (3 sub-criteria) (Fig. 1). Since all the sub-criteria may not be necessary for the decision process, it is important to identify the prime set of sub-criteria, which is a subset of the original sub-criteria. In order to identify the prime set of criteria for identifying the optimal location in aquaculture, experimental design becomes complex and difficult to manage (Mahalakshmi and Ganesan 2009). So in this study, Mahalanobis Taguchi System (MTS) (Taguchi and Jugulum 2000, 2002; Taguchi et al. 2001) was used to facilitate the selection of prime set of sub-criteria for suitable aquaculture site identification (Mahalakshmi and Ganesan 2009). The Mahalanobis Taguchi System (MTS) is a pattern recognition technology that aids in quantitative decisions by constructing a multivariate measurement scale using a data analytical method. The patterns of observations in a multidimensional system highly depend on the correlation structure of the criteria in the system (Boguslauskas and Adlyte 2010).

Out of six main-criteria, input main-criterion is having one sub-criterion such as animal waste, and also, it is considered as one of the important sub-criteria for the aquaculture system (Salam and Ross 2000). So the MTS was applied to the remaining five main-criteria namely: water, soil, support, infrastructure, and risk factor. The results of MTS along with the sub-criteria of input main-criterion (Fig. 1) showed that the 30 original sub-criteria were reduced into 24 sub-criteria (Mahalakshmi and Ganesan 2009). These reduced



\* Reduced sub-criteria by MTS method

Fig. 1 Main-criteria and their corresponding sub-criteria and weights

sub-criteria were used for the development of decision making tool for identification of optimal location for aquaculture farming development.

### Study area

The study area was Kalla mandal, West Godavari district in the state of 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 (Mahalakshmi and Ganesan 2011). The West Godavari district lies between the northern latitudes of 16° 15' to 17° 30' and the eastern longitudes of 80° 55' to 81° 55'. The water, soil, support, infrastructure, input, and risk factor related data used in this study were collected from 15 randomly selected shrimp farms from different villages such as Kalla, Kallakuru, S.C.bose, Vempadu, L.N.Puram, Kalavapudi, Elurupadu, Juvvalapalem, and Pallipalem in the study area.

### Weights of main-criteria

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  $(L \times L)$  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 main-criterion 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 positive and reciprocal matrix, that is,  $m_{ij} > 0$  and  $m_{ji} = 1/m_{ij}$  for  $\forall i, j = 1, 2, \dots, L$ . The experts have to perform  $(L/2)(L - 1)$  comparisons for a category of  $L$  main-criteria.

The identified six main-criteria namely: water, soil, support, infrastructure, input, and risk factor were presented in pairs in all possible combinations. Since six main-criteria were considered in the present study the possible pairs were fifteen. After identification of the possible pairs, judgments were established using a nine continuous scale with values from one to nine to rate the preferences for one main-criterion over the other by a group of 50 aquaculture experts, who are all working as a team, using the interview schedule. Necessary precautions were taken to ensure that the question in the schedule was unambiguous, clear, concise, complete, and comprehensive. The main purpose of the study was made clear to them, and interviews were conducted in groups. The responses obtained through the consensus (a solution that satisfies every one) method (Guzzo 1982) were entered into the pair-wise comparison matrix.

Then, the pair-wise comparison matrix was converted into a normalized pair-wise comparison matrix. This was computed by dividing each element in the matrix by its column total. Then, the relative weight vector ( $\alpha_j$ ) was calculated by the average of the elements in each row of the normalized matrix, that is, by dividing the sum of normalized scores for each row by the number of main-criteria under consideration.

In the pair-wise comparison method, if all the comparisons are perfectly consistent, then  $m_{ij} = m_{ik} m_{kj}$  (for  $i, j, k = 1, 2, \dots, L$ ) should always be true for any combination of comparisons taken from the pair-wise comparison matrix (Triantaphyllou 2000). Since the aquaculture experts weigh all main-criteria based on their own judgment, inconsistency is possible in building a weight vector. In this case, 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.

Calculation of sub-criteria weights

After identification of main-criteria and their sub-criteria, a group of 50 aquaculture experts were asked in groups to rank the set of sub-criteria within each main-criterion in straight ranking method using interview schedule. The group’s final decision was reached through the majority method (Guzzo 1982). The ranking for the tied observations were given as in the method suggested by Kothari (2004, pp 293, 308). In the tied observations, if the group of experts has given the same preference to the two sub-categories then the average rank for the two sub-categories were calculated, and this average rank has given to both the sub-categories. This ensures that the sum of the ranks is equal across all sub-criteria.

In the next step, the quantitative rank order was converted to qualitative weights using rank sum method (Malczewski 1999), which can be defined by

$$w_j = (N_k - r_j + 1) / \sum_i (N_k - r_i + 1) \tag{1}$$

where  $w_j$  is the normalized weight for the  $j$ th sub-criterion,  $N_k$  is the number of sub-criteria within the main-criterion under consideration ( $i, j = 1, 2, \dots, N_k$ ), and  $r_j$  is the rank position of the  $j$ th sub-criterion. Each sub-criteria was weighted  $(N_k - r_j + 1)$  and then normalized by the sum of all weights, that is,  $\sum_i (N_k - r_i + 1)$ .

Calculation of relative closeness

TOPSIS method (Hwang and Yoon 1981; Malczewski 1999) was used for calculating the relative closeness values for all the alternatives 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). Consider there are  $M$  alternatives (or aqua farms) and  $L$  main-criteria. Here alternatives are denoted as  $A_i$  (for  $i = 1, 2, \dots, M$ ), main-criteria as  $E_k$  (for  $k = 1, 2, 3, \dots, L$ ), and sub-criteria as  $C_j$  (for  $j = 1, 2, \dots, N_k$ ) where  $N_k$  is the number of sub-criteria within  $E_k$  (Fig. 2) Assume that for each sub-criterion  $C_j$  the decision maker has to determine its weight,  $w_j$ , with the condition that

$$\sum_{j=1}^{N_k} w_j = 1 \tag{2}$$

Furthermore, it is also assumed that the decision maker has determined  $a_{ij}$  (for  $i = 1, 2, 3, \dots, M$  and  $j = 1, 2, \dots, N_k$ ); the importance of alternatives  $A_i$  in terms of sub-criterion  $C_j$ .

After constructing the decision matrix, it was evaluated for each main-criterion iteratively using the following steps:

*Step 1* Elements of the decision matrix ( $a_{ij}$ ) were expressed as unidimensional decision matrix,  $u_{ij}$  ( $i = 1, 2, 3, \dots, M; j = 1, 2, 3, \dots, N_k$ ) in a ratio scale as  $0 \leq u_{ij} \leq 1$  for

**Fig. 2** Characteristics of each main-criterion in the form of decision matrix

Alternatives	<u>Sub-criteria within <math>E_k</math></u>					
	$C_1$	$C_2$	$C_3$	.....	$C_{Nk}$	
$A1$	$W_1$	$W_2$	$W_3$	.....	$W_{Nk}$	
$A2$	$a_{11}$	$a_{12}$	$a_{13}$	.....	$a_{1Nk}$	
$A3$	$a_{21}$	$a_{22}$	$a_{23}$	.....	$a_{2Nk}$	
$A3$	$a_{31}$	$a_{32}$	$a_{33}$	.....	$a_{3Nk}$	
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	
$A_M$	$a_{M1}$	$a_{M2}$	$a_{M3}$	.....	$a_{MNk}$	

eliminating the widely differing numerical sizes of the sub-criteria, by using similar triangular method (Mahalakshmi and Ganesan 2006).

*Step 2* Weighted normalized unidimensional decision matrix  $v_{ij}$  ( $i = 1, 2, 3 \dots, M; j = 1, 2, 3 \dots, N_k$ ) was constructed by multiplying each value of the column by the corresponding weight. So, the weighted normalized decision matrix was defined as

$$v_{ij} = w_j * u_{ij} \tag{3}$$

*Step 3* The best and worst value in each column were identified and two sets of these values were created across all columns named as positive ideal solution ( $A^*$ ) and negative ideal solution ( $A^-$ ), respectively. These were defined as

$$A^* = \{(\max v_{ij}/j \in J), i = 1, 2, \dots, M\} \\ = \{v_{1^*}, v_{2^*}, \dots, v_{Nk^*}\} \tag{4}$$

$$A^- = \{(\min v_{ij}/j \in J), i = 1, 2, \dots, M\} \\ = \{v_{1^-}, v_{2^-}, \dots, v_{Nk^-}\} \tag{5}$$

where  $J = (j = 1, 2, 3, \dots, N_k)$

*Step 4* In this study,  $N_k$  dimensional Euclidean (or straight-line) distance method was applied to measure the separation distances of each alternative to the positive ideal solution ( $S_{i^*}$ ) and negative ideal solution ( $S_{i^-}$ ). These were represented by

$$S_{i^*} = \left[ \sum_j (v_{ij} - v_{j^*})^2 \right]^{1/2} \tag{6}$$

$$S_{i^-} = \left[ \sum_j (v_{ij} - v_{j^-})^2 \right]^{1/2} \tag{7}$$

where  $i = 1, 2, \dots, M$

*Step 5* Finally, the relative closeness with respect to positive ideal solution was calculated for each alternative by

$$C_{i^*} = S_{i^-} / S_{i^*} + S_{i^-} \tag{8}$$

where  $0 \leq C_{i^*} \leq 1$  and  $i = 1, 2, \dots, M$ .

Apparently, an alternative  $A_i$  is closer to the positive ideal solution as  $C_{i^*}$  approaches to 1.

### Calculation of an objective function

As multiple criteria are considered, the final objective function gives the ultimate weightage considering all the criteria. First, relative closeness matrix  $R$  ( $C_{ij}$ ;  $i = 1-M$  and  $j = 1-L$ ) of order  $M \times L$  for  $M$  alternatives and  $L$  main-criteria was constructed using  $L$  relative closeness vectors of order  $M \times 1$ . Then, an objective function was constructed by using the criteria weights and relative closeness values. In this study, objective function ( $OF_i$ ) ( $i = 1, 2, 3, \dots, M$ ) for each alternative was defined by

$$OF_i = \sum_j C_{ij} \alpha_j \quad (9)$$

where  $C_{ij}$  is the relative closeness to the positive ideal solution of the  $i$ th alternative with respect to the  $j$ th main-criterion and the weight  $\alpha_j$  is a normalized weight for the given main-criterion under consideration, so that  $\sum \alpha_j = 1$ . The weights represent the relative importance of the main-criteria.

### Best alternatives

After calculating the objective function for each alternative, it was ranked according to the descending order of values of objective function, the alternative with the highest value of objective function was the best alternative, next highest value of objective function was the second best alternative and so on.

### Implementation

A framework, which sought to identify the optimal location for aquaculture farming development, is conceptualized in the previous sections and presented as a decision making tool using the interactive controls and algorithms of Visual Basic (VB) 6.0 programming language. The nested If ... Then ... Else construct was extensively used as an interpretive algorithm for the generation of alternative decisions using the input information. Pop-up windows, button controls, and mouse driven events were used for designing the Graphic User Interface (GUI) of the decision making tool.

### Validation of the decision making tool

After collecting the required information from the study area, first alternatives were ranked by decision making tool ( $X$ ) developed for this purpose, and then, the same alternatives were ranked by observed average yield value per hectare (ha) for the last three crops ( $Y$ ).

The Spearman's rank correlation (Bansiya and Davis 2002; Neter et al. 1996) was used to test the significance of the correlation between the ranks obtained by the tool and ranks obtained based on average yield. It provides a nonparametric significance test that works well with ranked data without precise proportional scaling and can be used to detect relationships other than linear ones. The cutoffs used correspond to a level of significance of alpha ( $\alpha$ ) equal to 0.01.

If  $E_1$  and  $E_2$  are two independent evaluations of 'n' number of items that are to be correlated, then the values of  $E_1$  and  $E_2$  are ranked (either increasingly or decreasingly) from 1 to 'n' according to the relative size within the evaluations. For each  $E_1$  and  $E_2$  pair in the relative rankings, the difference in the ranks 'd' is computed. The sum of all the  $d^2$ s,

denoted by  $\sum d^2$  is used to compute Spearman's rank correlation coefficient ( $\rho$ ) using the following formula (Bansiya and Davis 2002)

$$\rho = 1 - \left( \frac{6 \sum d^2}{n(n^2 - 1)} \right) - 1.00 < \rho \leq + 1.00 \quad (10)$$

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

$H_0$  (Null hypothesis,  $\rho = 0$ ): There is no rank order correlation between ranks obtained by the tool and ranks obtained based on average yield.

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

In this study, to reject  $H_0$  is to say that there is a rank order relationship between ranks obtained by the tool and ranks obtained based on average yield at Kalla mandal.  $H_0$  is rejected if the value obtained for  $\rho$  is greater than the critical value of  $\rho$  (Neter et al. 1996).

## Results and discussion

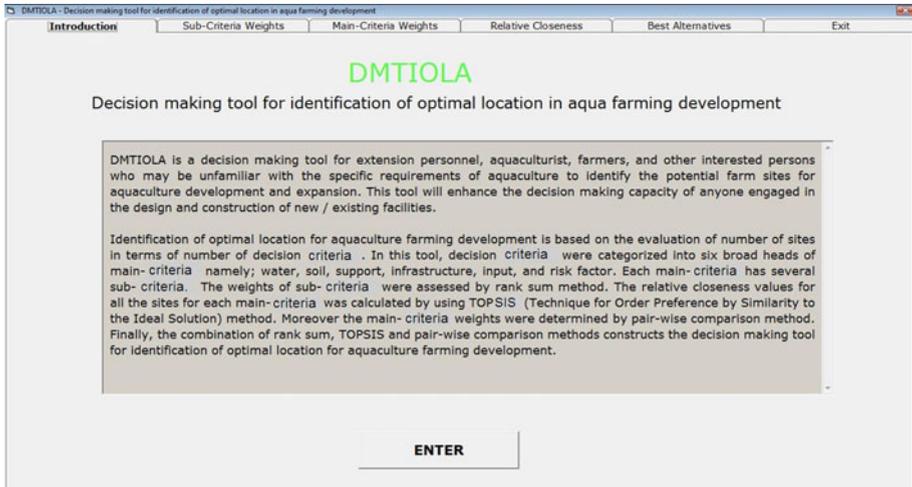
### Software requirements and its availability

DMTIOLA (Decision Making Tool for Identification of Optimal Location in Aqua farming development) is a decision making tool that allows the user to enter data for identification of optimal location for aquaculture farming development through an interactive dialogue screen. The tool runs on a platform of Windows 95<sup>TM</sup> or above, is user-friendly, and is best viewed at a screen resolution of 1,366 by 768 pixels. The first executable (setup file) version of DMTIOLA is freely available from the corresponding author. The prospective/interested user should contact the author for a copy of the tool for non-commercial purposes.

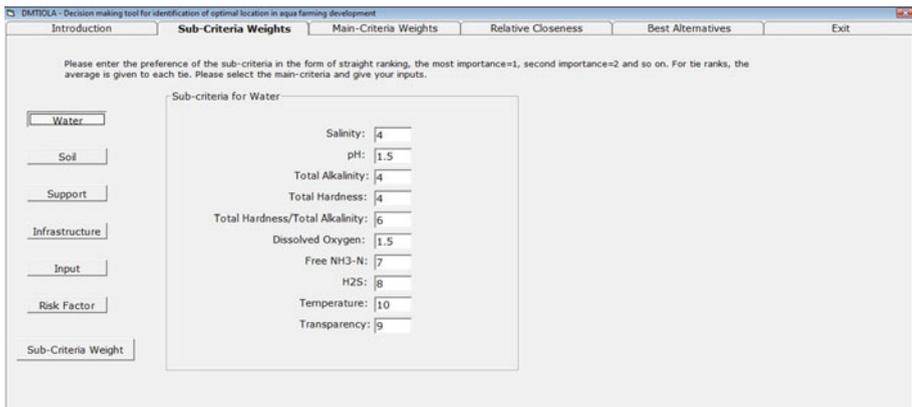
### Software operations

The opening screen of DMTIOLA is shown in Fig. 3. It gives a brief introduction of the tool. The 'ENTER' button prompts the user to navigate into the tool. There are five modules supported in this tool, presented as tabs, named as Sub-Criteria Weights, Main-Criteria Weights, Relative Closeness, Best Alternatives, and Exit. All the modules are linked in a Visual Basic 6.0 environment. The 'Sub-Criteria Weights' module consists of six input buttons, one for each main-criterion, named as 'Water', 'Soil', 'Support', 'Infrastructure', 'Input', and 'Risk Factor', and one output button named as 'Sub-Criteria Weight'. User can select each input button and enter the rank as value for each sub-criterion according to straight ranking method. The input screen of 'Sub-Criteria Weights' module for water main-criterion is illustrated in Fig. 4. Once the user has completely given the inputs for all the sub-criteria in each input button, then the user can press the 'Sub-Criteria Weight' button to get the sub-criteria weights for each main-criterion (Fig. 5).

'Main-Criteria Weights' module displays a comparison matrix along with the explanation of Saaty scale (1–9). In this matrix, the tool fixes the diagonal elements as 1, and the user can enter the inputs in the upper-triangular entries. When the user enters the input in



**Fig. 3** Opening screen of decision making tool for identification of optimal location in aqua farming development (DMTIOLA)



**Fig. 4** Input screen of ‘Sub-Criteria Weights’ module for water main-criterion

any upper-triangular entry in the matrix, immediately the reciprocal of that value is displayed automatically in its corresponding lower-triangular entry (Fig. 6). This module also displays a ‘View Weights’ button. Clicking the ‘View Weights’ button, open a new frame to display the main-criteria weights along with the CR value and its description (Fig. 7).

In the ‘Relative Closeness’ module, user has to give the number of alternatives (more than one) to be considered for identification of optimal location. Suppose, if the user has given the number of alternatives as 1 then the tool will display the message ‘Please enter 2 or more sites’. After confirming the number of alternatives as more than one by clicking the ‘Ok’ button, the input and output control buttons are displayed. The number of rows in the input screen for each main-criterion is constructed based on the number of alternatives given by the user. This module consists of six input buttons, one for each main-criterion, named as ‘Water’, ‘Soil’, ‘Support’, ‘Infrastructure’, ‘Input’, and ‘Risk Factor’, and one

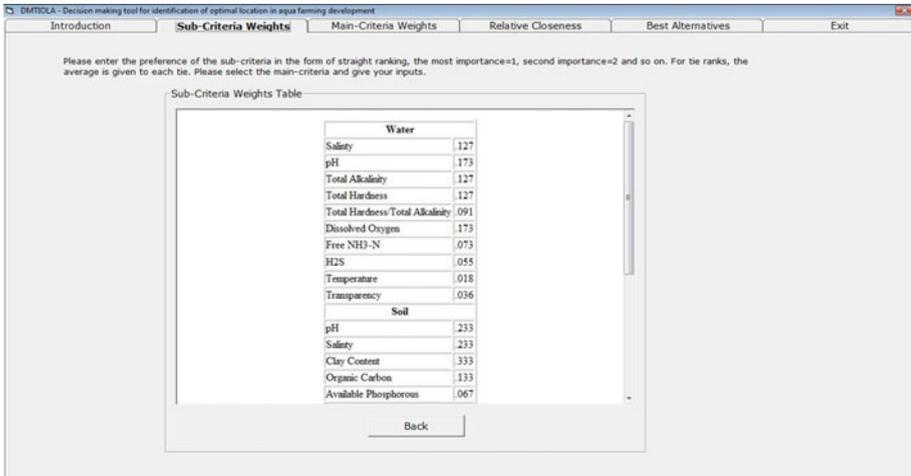


Fig. 5 Output screen displays weights of sub-criteria for each main-criterion

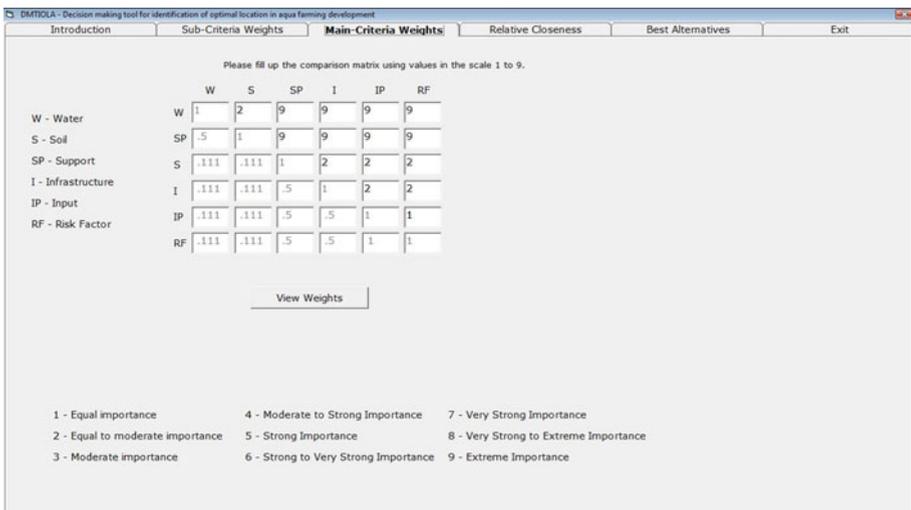
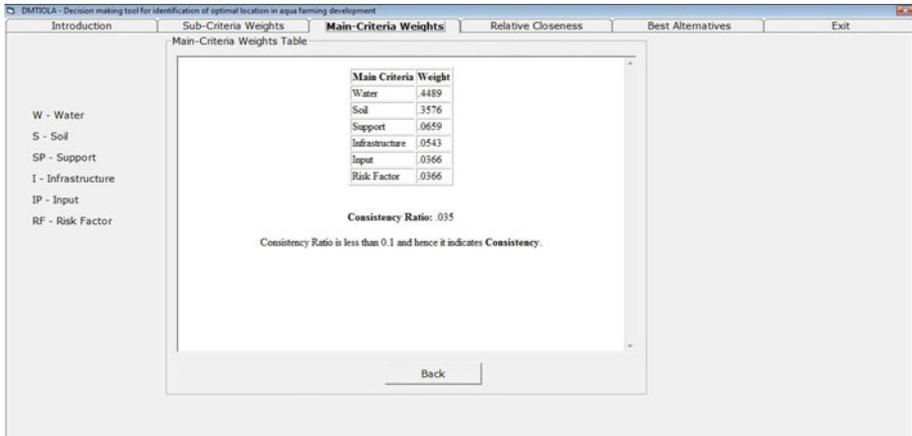


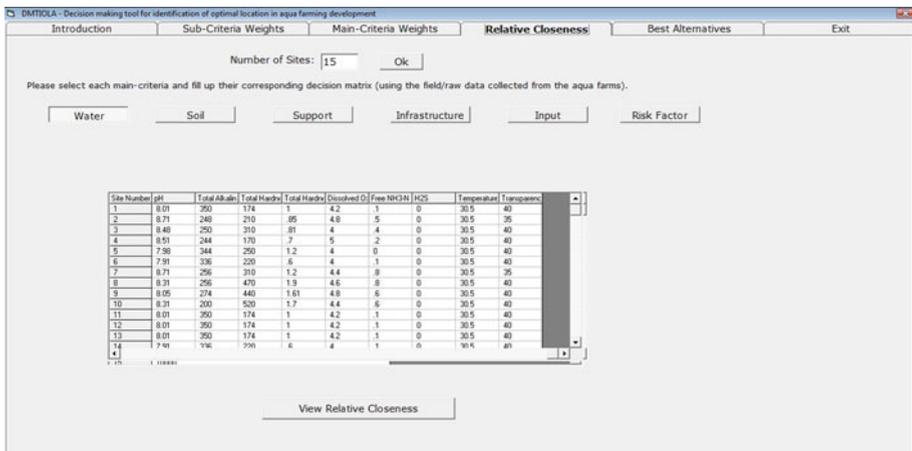
Fig. 6 Pair-wise comparison matrix along with the Saaty scale in the ‘Main-Criteria Weights’ module

output button named as ‘View Relative Closeness’. User has to select each input button and enter the values, which were collected from the farms, in the displayed input screen. The input screen for the water main-criterion is shown in Fig. 8.

In this module, for the calculation of relative closeness values, the sub-criteria weights for each main-criterion are automatically entered from the ‘Sub-Criteria Weights’ module. When the user enters the values for each main-criteria and clicks the ‘View Relative Closeness’ button, the relative closeness values of all the alternatives for each main-criterion are automatically calculated using TOPSIS method and displayed in a new frame (Fig. 9).



**Fig. 7** Output screen displays the weights of main-criteria along with the consistency ratio value and its description



**Fig. 8** Input screen for the water main-criterion in ‘Relative Closeness’ Module

The results of ‘Main-Criteria Weights, and ‘Relative Closeness’ modules are entered as input for the ‘Best Alternatives’ module. Once the user completely entered the information in the ‘Sub-Criteria Weights’, ‘Main-Criteria Weights’, and ‘Relative Closeness’ modules, then the user clicks the ‘View Best Alternatives’ button in the ‘Best Alternatives’ module for getting the final output in a tabular form (Fig. 10). Ranks are assigned to the alternatives based on the descending order of values of objective function.

In this tool, output screen for the ‘Sub-Criteria Weights’, ‘Main-Criteria Weights’, ‘Relative Closeness’, and ‘Best Alternatives’ modules has a vertical scroll bar that allows the user to view all details of the output by pressing the up or down arrows. In addition, the user can move to the main page of ‘Sub-Criteria Weights’, ‘Main-Criteria Weights’, and ‘Relative Closeness’ modules by either clicking on the ‘Back’ button in its corresponding output screen (Figs. 5, 7, 9) or by clicking its corresponding tab. The user can change or

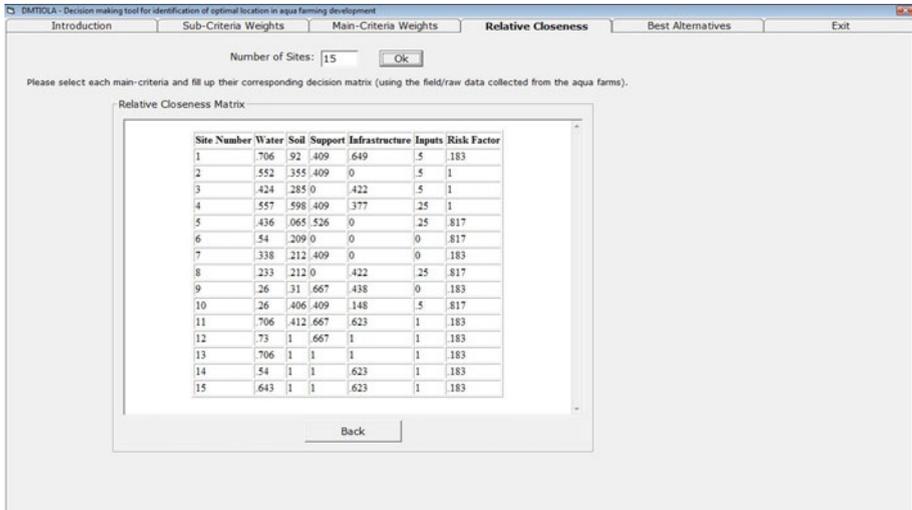


Fig. 9 Output screen displaying the relative closeness values for each main-criterion

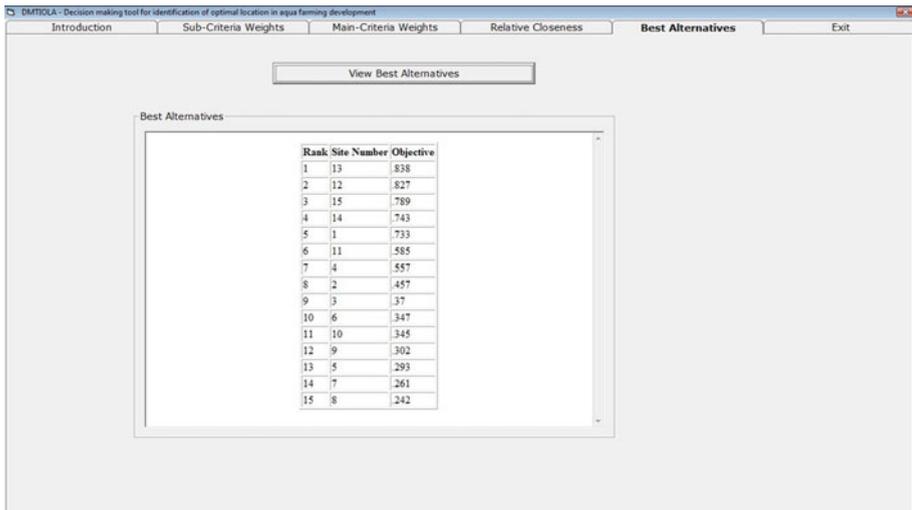


Fig. 10 Output screen displaying the best alternatives

clear the value of the criteria at any time by backspacing. The ‘Exit’ module is used to allow the user to quit from the tool.

Case study results and tool validation

Based on the expert’s opinion (discussed in the section ‘Study area’ and ‘Weights of main-criteria’), the weights of main-criteria and sub-criteria calculated using the tool are shown in Figs. 1, 5, and 7. The main-criterion weights are 0.4489, 0.3576, 0.0659, 0.0543, 0.0366, and 0.0366 for water, soil, support, infrastructure, input, and risk factor, respectively. This

means that water is the most important criterion followed by soil, support, infrastructure, input, and risk factor. The criteria weights for input and risk factor are same. The result shows that the consistency ratio is 0.035 (Fig. 7), which is less than the threshold value 0.1. The ratio indicates that the comparisons of main-criteria are perfectly consistent. This implies that the weights of main-criteria are suitable for this study.

After calculating the weights of sub-criteria and main-criteria, relative closeness of all the alternatives for each main-criterion, objective function value for each alternative, and its corresponding rank (Table 1) was calculated using DMTIOLA. Table 1 showed that the alternative 13 (objective function value is 0.838) was identified as the most preferred, followed by alternatives 12 (0.827), 15 (0.789), and 14 (0.743). The worst three alternatives were 8 (0.242), 7 (0.261), and 5 (0.293). Comparing alternative 13 (rank 1) to alternative 12 (rank 2), both were having same values of relative closeness of main-criteria, except for main-criterion of support. Comparing alternative 13 to alternative 15 (rank 3) and alternative 14 (rank 4), except the relative closeness of water and support all other values of relative closeness were same. The results also revealed that alternative 13 is found to be better than the worst three alternatives (8, 7, and 5) with respect to all the relative closeness main-criteria. These results showed that all the sub-criteria in the proposed alternatives were better than the sub-criteria in the other alternatives. Therefore, alternative 1 easily became acceptable to all decision makers followed by alternatives 12, 15, and 14.

Table 2 also showed the ranking pattern obtained by the observed average yield value per hectare for last three years. Based on observed average yield, three alternatives 12, 13, and 15 were identified as best alternatives (Table 2). Tables 1 and 2 showed that there was slight change in the ranks obtained by the tool and ranks obtained based on observed

**Table 1** Relative closeness and objective function values for alternatives, and their corresponding ranks in the Kalla Mandal

Alternatives	Relative closeness values						Objective function (OF)	Rank
	Wa	So	Su	Inf	Inp	RF		
1	0.706	0.92	0.409	0.649	0.5	0.183	0.733	5
2	0.552	0.355	0.409	0	0.5	1	0.457	8
3	0.424	0.285	0	0.422	0.5	1	0.370	9
4	0.557	0.598	0.409	0.377	0.25	1	0.557	7
5	0.436	0.065	0.526	0	0.25	0.817	0.293	13
6	0.54	0.209	0	0	0	0.817	0.347	10
7	0.338	0.212	0.409	0	0	0.183	0.261	14
8	0.233	0.212	0	0.422	0.25	0.817	0.242	15
9	0.26	0.31	0.667	0.438	0	0.183	0.302	12
10	0.26	0.406	0.409	0.148	0.5	0.817	0.345	11
11	0.706	0.412	0.667	0.623	1	0.183	0.585	6
12	0.73	1	0.667	1	1	0.183	0.827	2
13	0.706	1	1	1	1	0.183	0.838	1
14	0.54	1	1	0.623	1	0.183	0.743	4
15	0.643	1	1	0.623	1	0.183	0.789	3

Wa water, So soil, Su support, Inf infrastructure, Inp input, RF risk factor

**Table 2** Ranks for alternatives based on the tool and observed average yield

	Alternatives														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Observed average yield value (tons)	3.5	2.0	1.5	2.0	0.6	0.8	0.4	0.3	1.0	0.5	3.0	4	4	2.5	4
Rank	4	7.5	9	7.5	12	11	14	15	10	13	5	1	1	6	1

average yield. In both methods, alternative 8 (rank 15) was identified as the worst alternative followed by alternative 7 (rank 14).

Spearman's rank correlation coefficient ( $\rho$ ) was computed for the validation dataset, Kalla mandal. The value of the  $\rho$  obtained in this correlation was 0.967. The critical value of  $\rho$  for a dataset with 15 samples and alpha ( $\alpha = 0.01$ ) is 0.654 according to Zar (1972). As the value of  $\rho$  obtained from the spearman's rank correlation was greater than the critical value of  $\rho$ , the null hypothesis was rejected. Therefore, the correlation between ranks obtained by the tool and ranks obtained based on average yield was significant (a confidence level of 99%), meaning that this model is reliable for identification of optimal location for aquaculture farming development.

## Conclusion

A simple-to-use decision making tool has been developed for selecting best alternatives from among a feasible set of alternatives. The tool has developed based on 24 input criteria under six broad heads of main-criteria such as water (10 sub-criteria), soil (5 sub-criteria), support (2 sub-criteria), infrastructure (3 sub-criteria), input (1 sub-criterion), and risk factor (3 sub-criteria). Other environmental/socio and economic criteria, for example, extension media contact and awareness of culture practices in aquaculture, etc., have not been considered. The presence and absence of these environmental/socio and economic criteria, may also impact on the success or otherwise of the aquaculture facility. In time, the identification of optimal location in aquaculture will be improved with incorporation of criteria currently not considered.

This tool will enhance the decision making capacity of anyone engaged in the design and construction of new/existing aquaculture farming system. The case study results suggest that this tool has sufficient predictive power to help extension personnel, aquaculturist, land-use managers, aquafarmers, and other interested persons who may be unfamiliar with the specific requirements of aquaculture to identify the optimal location for aquaculture farming development. Case study application and presented results showed that such an approach is comprehensive and relatively simple in computation. The program in VB was designed in a flexible and modular fashion, and it can be easily adapted to other closely related industries such as agriculture and animal husbandry, etc. DMTIOLA is also useful in educational and research institutions for demonstration and training purposes.

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