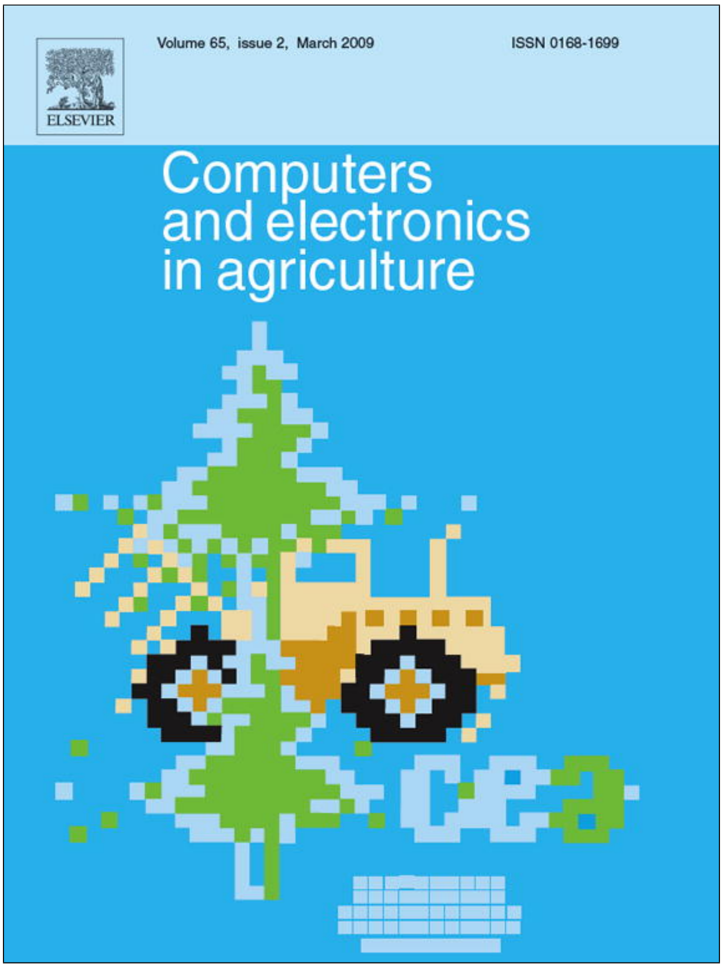
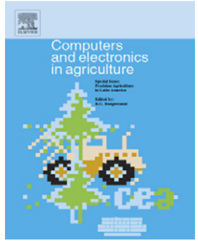

Volume 65, issue 2, March 2009
ISSN 0168-1699
ELSEVIER
Computers
and electronics
in agriculture

COMPUTERS AND ELECTRONICS IN AGRICULTURE 65 (2009) 192–197

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/compag



Mahalanobis Taguchi System based criteria selection for shrimp aquaculture development

*P. Mahalakshmi**, *K. Ganesan*

School of Computer Sciences, Vellore Institute of Technology, Deemed University, Vellore-632 014, Tamil Nadu, India

ARTICLE INFO

Article history:
Received 25 October 2007
Received in revised form
16 September 2008
Accepted 29 September 2008

Keywords:
Mahalanobis Distance
Measurement scale
Orthogonal array
Signal-to-noise ratio

ABSTRACT

Aquaculture development suitable location is not formulated from one criterion but from multiple criteria. A list of criteria was selected by reviewing the literature and consultation with aquaculture experts and then classified into five categories namely; water, soil, support, infrastructure and risk factor. Using these criteria a Mahalanobis Taguchi System (MTS) based tool was developed to facilitate the selection of prime set of criteria, which is a subset of the original criteria for suitable aquaculture site identification. Mahalanobis Distance (MD) was used for constructing a measurement scale for the aquaculture system. The principles of Taguchi method was used for screening the important criteria in the system. The information required to make an assessment was entered into the computer program. The computer program then processes the information and produces the prime set of criteria for each category. The software program is a valuable tool for the identification of prime set of criteria within each category. One can use these prime set of criteria within each category instead of all criteria for the identification of optimal location in shrimp aquaculture.

1. Introduction

Aquaculture is emerging as a prime industry to tap the enormous turnover of bioenergy for the benefit of mankind. Close to 20% of all seafood consumed is now produced by aquaculture and global demand for aquaculture products was 22–24 million matric tonnes in the year 2000, a 14–24% increase since 1990 (Chamberlain and Rosenthal, 1995). India's present population is projected to hit 1.48 billion in the year 2030 leaving a wider gap in the supply demand stand (Brown et al., 1997). This gap has to be fulfilled with aquaculture production.

Uncontrolled expansion of aquaculture units and their intensive farm practices have brought severe stress on the surrounding environment. At present shrimp farming areas are rapidly expanding horizontally due to the increasing demand of shrimps in the international markets. This rapid expansion of shrimp farming areas in the recent years is not following the ways of proper planning and management. A key factor in improving the environmental management of aquaculture is to develop methods of optimizing site selection for aquaculture.

The selection of optimal location in aquaculture system is not formulated just from one criterion but from multiple criteria (Ramesh and Rajkumar, 1996). Since all the criteria may not be necessary for the decision process, it is important to identify the prime set of criteria, which is a subset of the original criteria. In order to identify the prime criteria, experimental design becomes complex and difficult to manage. In this study, an alternative new approach is identified to the experimental design, the Mahalanobis Taguchi System (MTS) based decision tool. The purpose is MTS-based criteria selection for suitable shrimp farming area identification.

* *Corresponding author*. Present address: Central Institute of Brackishwater Aquaculture (I.C.A.R), 75 Santhome High Road, R.A. Puram, Chennai-600 028, Tamil Nadu, India. Tel.: +91 44 2461 6948; fax: +91 44 2461 0311.
E-mail address: maha_ciba@yahoo.com (P. Mahalakshmi).
0168-1699/$ – see front matter
doi:10.1016/j.compag.2008.09.003

2. Materials and methods

This section discusses the study area, decision criteria and its suitability ratings, normal and abnormal observations, and MTS framework. In presenting the framework, an outline of the method as used was provided.

2.1. *Study area*

The study area was Nellore district in the state of Andhra Pradesh, India. This district was selected because coastal aquaculture is a major economic activity in these areas. The Nellore district area is about 13,076 km^2. This district lies between the latitude of 13°37′–15°51′ and the longitude of 79°15′–80°15′ (Fig. 1).

2.2. *Decision criteria and its suitability ratings*

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

A list of criteria was selected by reviewing the literature and consultation with researchers who are all working aquaculture field. These criteria thus selected were then classified into five categories namely: water, soil, support, infrastructure and risk factor. The suitability ratings for the identified criteria for shrimp culture were drawn from different literatures with slight modification to suit the Indian environment based on the opinion of 25 researchers who are working in the aquaculture field. The group final decision was reached through majority (Guzzo, 1982). The criteria and its suitability ratings of shrimp are depicted in Table 1. The suitablity ratings are given in three categories: (a) "Suitable", if the corresponding criterion favorable for designated use and no unusual construction, design, management or maintenance will be required in the identified site for the designated use; (b) "Moderately", if the corresponding criterion not favorable for designated use and special attention will be required in the identified site for the designated use; (c) "Severe", if the corresponding criterion unfavorable for designated use and the identified site may be useful for the designated purpose due to the major reclamation and modification in design, management or maintenance, but it may not be economically feasible to use a site with one or more unsuitable limitations.

2.3. *Normal and abnormal observations*

The data used in this study were collected from 52 randomly selected shrimp farms including normal and abnormal obser-

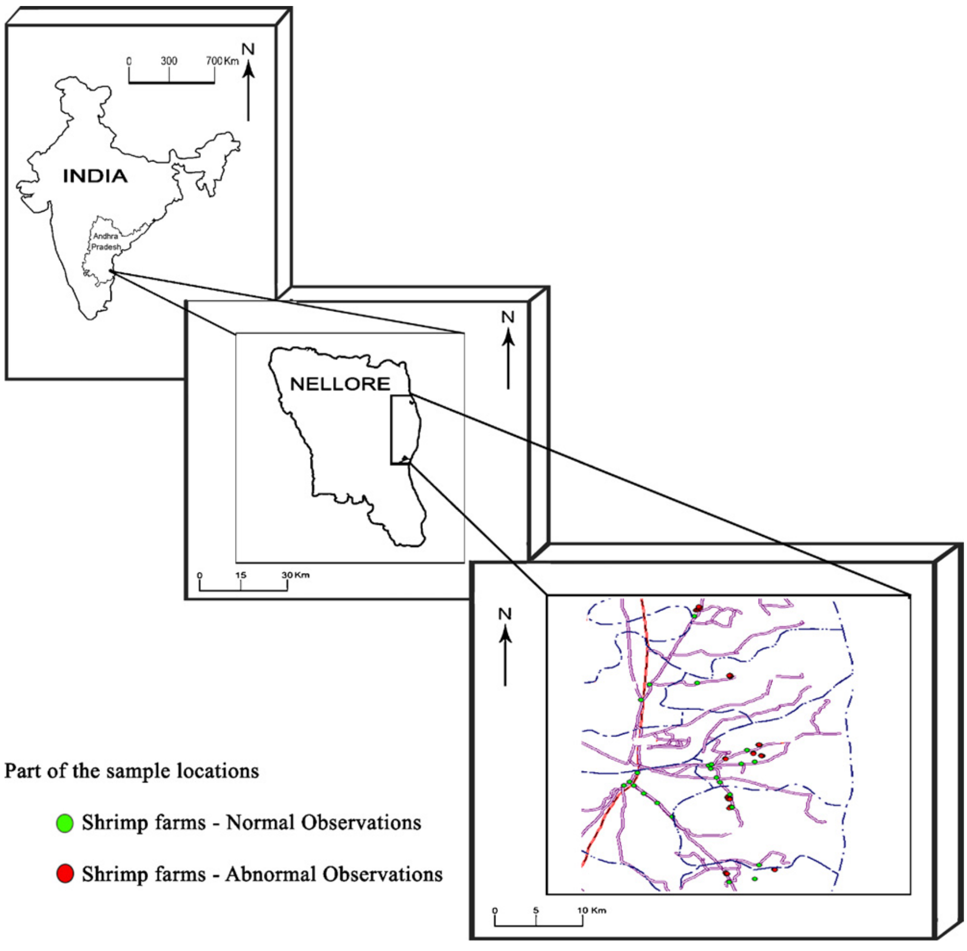


Fig. 1 – Location map.

Table 1 – Criteria (before and after application of MTS) and its suitability ratings of shrimp.

Sub-criteria (before MTS)	Suitability ratings			Notation for implementation	Sub-criteria (after MTS)
	Suitable	Moderate	Unsuitable		
Water					
Salinity (ppt)-Brackishwater	[15, 25]	(5, 15) or (25, 35)	≤5 or ≥35	W1	Salinity (ppt)-Brackishwater
pH (ppt)	[6.5, 8.5]	(5, 6.5) or (8.5, 10)	≤5.0 or 10.0	W2	pH (ppt)
Total alkalinity (mg/l)	[50, 200]	(20, 50) or (200, 500)	≤20 or ≥500	W3	Total alkalinity (mg/l)
Total hardness (mg/l)	[50, 200]	(20, 50) or (200, 500)	≤20 or ≥500	W4	Total hardness (mg/l)
Total hardness/total alkalinity	1	(0.5, 1)	≤0.5 or ≥	W5	Total hardness/total alkalinity
Dissolved oxygen (mg/l)	[5, 10]	(2, 5) or (10, 15)	≤2 or ≥15	W6	Dissolved oxygen (mg/l)
Free NH_3-N (mg/l)	≤0.1	(0.1, 1.0)	≥1.0	W7	Free NH_3-N (mg/l)
H_2S (mg/l)	[0, 0.1]			W8	H_2S (mg/l)
Temperature (°C)	[28, 33]			W9	Temperature (°C)
Transparency (cm)	[30, 60]	(15, 30) or (60, 120)	≤15 or ≥120	W10	Transparency (cm)
Soil					
pH (ppt)	[6.5, 9.0]	(4.5, 6.5)	≤4.5 or ≥9.0	S1	pH (ppt)
Salinity (ppt)	[8, 26]	(4, 8) or (26, 37)	≤4 or ≥37	S2	Salinity (ppt)
Clay content (%)	≥35	(18, 35)	≤18	S3	Clay content (%)
Organic carbon (%)	[1.5, 2.5]	(0.5, 1.5)	≤0.5 or ≥2.5	S4	Organic carbon (%)
Available nitrogen (mg/100 g)	[50, 75]	(25, 50)	≤25 or ≥75	S5	–
Available phosphorous (mg/100 g)	[4, 6]	(3, 4)	≤3 or ≥6	S6	Available phosphorous (mg/100 g)
Support					
Distance to NGOs (m)	≤5000	(5000, 15,000)	≥15,000	SU1	Distance to NGOs (m)
Distance to govt. offices (m)	≤3000	(3000, 10,000)	≥10,000	SU2	–
Distance to research station (m)	≤5000	(5000, 15,000)	≥15,000	SU3	–
Agglomeration (m)	≤1000	(1000, 3000)	≥3000	SU4	–
Distance to university/college (m)	≤5000	(5000, 15,000)	≥15,000	SU5	Distance to university/college (m)
Infrastructure					
Distance to natural fry (m)	≤3000	(3000, 12,000)	≥12,000	I1	Distance to natural fry (m)
Distance to processing plants (m)	≤3000	(3000, 10,000)	≥10,000	I2	Distance to processing plants (m)
Distance to rivers (m)	[500, 1000]	(1000, 4000)	≤500 or ≥4000	I3	–
Distance to roads (m)	≤2000	(2000, 5000)	≥5000	I4	–
Distance to local market (m)	≤1000	(1000, 3000)	≥3000	I5	Distance to local market (m)
Risk factor					
Flood and cyclone (per year)	0	1	≥1	R1	Flood and cyclone (per year)
Winter rain (m)	≤200	(200, 350)	≥350	R2	Winter rain (m)
Pollution (m)	≥4000	(2000, 4000)	≤2000	R3	Pollution (m)

vations (Fig. 1). The normal group, called Mahalanobis Space (MS), was constructed based on observations on 40 farms, which do not have the value of any criteria in the severe rating condition, that is, the value of criteria either in suitable or moderate ratings. The abnormal group was constructed based on 12 farms, which have the value of criteria in the severe rating condition.

2.4. *Implementation*

Matlab software (http://www.mathworks.com) was used to develop the MTS-based decision tool. The software has many in-built functions, such as transpose of matrix and inverse of matrix, which will be useful for the study. We need not write the separate routine or module for the same and also the coding part is simple and understandable for the end user.

2.5. *Mahalanobis Taguchi System*

The selection of prime set of sub-criteria for each main criterion was computed iteratively using the following steps (Taguchi and Jugulum, 2000, 2002; Taguchi et al., 2001).

2.5.1. *Construct a measurement scale with MS as the reference*

The first step for the construction of measurement scale was the collection of normal observations and then normalized these observations using mean and standard deviation obtained from the normal observations. Mahalanobis Distances (MDs) corresponding to all these observations were computed using inverse of correlation matrix method (Taguchi et al., 2001).

$$MD_j = D_j^2 = \frac{1}{k} Z_{ij}^T C^{-1} Z_{ij} \quad (1)$$

where Z_i is the normalized vector obtained by normalizing the values of X_i ($i = 1, 2, 3, \ldots, k$)

$$Z_{ij} = \frac{X_{ij} - \bar{X}_i}{S_i}, \quad i = 1, 2, \ldots, k; \quad j = 1, 2, \ldots, n \quad (2)$$

$$\bar{X}_i = \frac{\sum_{j=1}^{n} X_{ij}}{n_i} \quad (3)$$

where X_{ij} is the value of ith sub-criteria in jth observation.

$$S_i = \sqrt{\frac{\sum_{j=1}^{n} (X_{ij} - \bar{X}_i^2)}{n-1}} \quad (4)$$

where S_i is the standard deviation of ith sub-criteria, k is the number of sub-criteria, n is the number of observations, T is the transpose of the normalized vector and C^{-1} is the inverse of the correlation matrix.

It can be seen that MD in Eq. (1) was obtained by scaling (that is by dividing with k) the original MD. Since MDs were used to define the normal group we called this group as Mahalanobis Space. Mahalanobis Space is a database for the normal group consisting of mean vector, standard deviation vector, and inverse of the correlation vector (Taguchi and Jugulum, 2000). This Space provides a reference point for the measurement scale. According to MTS theory the average value of MDs is one for all the observations in MS (Taguchi et al., 2001).

2.5.2. *Validating the measurement scale*

The accuracy of the scale was justified by measuring the MDs of the known abnormal observations. The data from abnormal observations were normalized using mean and standard deviation obtained from the normal observations. The MDs were obtained for the abnormal observations using the correlation matrix of normal observations in Eq. (1). After calculating MDs, the average MD for the normal observations was compared with abnormal observations. The higher values of MDs for the abnormal group validate the accuracy of the measurement scale.

According to the MTS theory, the MD of abnormal observations will be larger than the MD of normal observations if this is a good scale. Otherwise, one has to re-sample or find new sub-criteria to build the MS again.

2.5.3. *Identification of the prime set of sub-criteria*

In this step, prime set of sub-criteria was identified using orthogonal arrays (OAs) and signal-to-noise (S/N) ratios. The suitable OA was selected depending on the total degrees of freedom required to study the individual sub-criteria. The number of degrees of freedom is one less than the number of levels associated with the sub-criterion (Antony and Antony, 2001). The individual 'k' sub-criteria under study were assigned to the first 'k' columns of the identified OA (Taguchi, 1987). Level 1 in the identified OA column represents the presence of a sub-criterion and level 2 represents the absence of that sub-criterion. Inside an OA, every row represents the experimental combination of a run.

Using the sub-criteria combinations in the identified OA, MDs for the known abnormal observations were obtained using Eq. (1). From the MDs a larger-the-better S/N ratio was obtained for the qth run using the formula (Taguchi et al., 2001).

$$\frac{S}{N}\ \text{ratio} = -10\log_{10}\left[\left(\frac{1}{t}\right)\sum_{i=1}^{t}\frac{1}{MD_i^2}\right] \quad j = 1, 2, \ldots, t \quad (6)$$

where t is the number of sub-criteria present for a given combination of the experimental run.

An average S/N ratio was calculated for each sub-criterion at level 1 and level 2. Subsequently, gain in S/N ratio values were calculated as:

$$\text{Gain} = \left(\text{average of } \frac{S}{N} \text{ ratio}\right)_{\text{level 1}} - \left(\text{average of } \frac{S}{N} \text{ ratio}\right)_{\text{level 2}} \quad (7)$$

If the gain is positive, keep the sub-criterion; if not then exclude it, for the next step.

2.5.4. *Confirmation run*

A confirmation run was conducted with the prime set of sub-criteria identified from the previous step. The reduced

Table 2 – MDs range of normal and abnormal group for each main criterion.

MDs (range and average)	Water	Soil	Support	Infrastructure	Risk factor
Normal					
Range	0.3655–1.4305	0.4962–1.7949	0.1002–2.8624	0.1471–2.2818	0.2709–3.02796
Average	0.9475	0.9583	0.9436	0.9410	0.9977
Abnormal (all sub-criteria)					
Range	54.9894–325.8896	11.7431–27.913	5.4683–196.5499	5.9123–12.9733	9.9476–25.3095
Average	165.28	18.8027	100.9772	9.2736	16.7423
Abnormal (prime set of sub-criteria)					
Average	85.9437	21.58344	244.7575	12.4950	7.6588

Table 3 – $L_{12}(2^{11})$ OA and average response for larger-the-better S/N ratios (water).

Run	1 (W1)	2 (W2)	3 (W3)	4 (W4)	5 (W5)	6 (W6)	7 (W7)	8 (W8)	9 (W9)	10 (W10)	11
1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	2	2	2	2	2	2
3	1	1	2	2	2	1	1	1	2	2	2
4	1	2	1	2	2	1	2	2	1	1	2
5	1	2	2	1	2	2	1	2	1	2	1
6	1	2	2	2	1	2	2	1	2	1	1
7	2	1	2	2	1	1	2	2	1	2	1
8	2	1	2	1	2	2	2	1	1	1	2
9	2	1	1	2	2	2	1	2	2	1	1
10	2	2	2	1	1	1	1	2	2	1	2
11	2	2	1	2	1	2	1	1	1	2	2
12	2	2	1	1	2	1	2	1	2	2	1
Level 1	15.3424	15.5052	15.9630	15.3200	15.7005	15.6429	16.0740	15.8727	16.0590	14.2493	
Level 2	14.3802	14.2174	13.7596	14.4026	14.0221	14.0797	13.6485	13.8499	13.6636	15.4733	
Gain	0.9621	1.2878	2.2033	0.9175	1.6785	1.5632	2.4255	2.0228	2.3954	−1.2240	

measurement scale was constructed using the prime set of sub-criteria identified and then MDs corresponding to the abnormal observations were obtained using Eq. (1). In the next step, the average MD based on the abnormal observations obtained with prime set of sub-criteria identified was compared to that obtained from all the sub-criteria originally used. If the average MD of abnormal group with prime set of sub-criteria identified was lower than that of all the sub-criteria, retain the excluded sub-criteria also in the prime set of sub-criteria identified; if not then consider only the sub-criteria which were identified as prime set from the previous step, for the prediction of future observations.

Table 4 – $L_8(2^7)$ OA and average response for soil, support, and infrastructure.

Run	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

	Sub-criteria					
	(S1)	(S2)	(S3)	(S4)	(S5)	(S6)
Soil						
Level 1	8.3538	8.0795	10.5344	8.2307	7.4301	8.1429
Level 2	7.3371	7.6114	5.1565	7.4602	8.2608	7.5480
Gain	1.0166	0.4682	5.3778	0.7705	−0.8307	0.5949

	Sub-criteria				
	(SU1)	(SU2)	(SU3)	(SU4)	(SU5)
Support					
Level 1	13.2238	11.6154	11.3544	11.8034	13.6409
Level 2	10.7311	12.3395	12.6005	12.1515	10.3141
Gain	2.4926	−0.7241	−1.2461	-0.3480	3.3268

	Sub-criteria				
	(I1)	(I2)	(I3)	(I4)	(I5)
Infrastructure					
Level 1	9.7749	8.6041	7.5980	7.3057	9.5403
Level 2	7.2316	8.4024	9.4084	9.7008	7.4661
Gain	2.5433	0.2017	−1.8104	−2.3951	2.0742

Table 5 – $L_4(2^3)$ OA and average response for larger-the-better S/N ratios (risk factor).

Run	1 (R1)	2 (R2)	3 (R3)
1	1	1	1
2	1	1	1
3	1	2	2
4	1	2	2
Level 1	10.9501	10.1701	8.2293
Level 2	6.9392	7.7192	9.6599
Gain	4.0109	2.4509	−1.4306

3. Results and discussion

With the help of 40 normal observations, the MDs corresponding to all these observations were computed for each main criterion. Mahalanobis Space was defined for each main criterion with the help of the MDs obtained for 40 observations. The data from the 12 abnormal observations were normalized using mean and standard deviation obtained from the 40 normal observations. The MDs corresponding to all these observations were estimated for each main criterion. Table 2 gives the MDs range of normal and abnormal group with their corresponding average value for each main criterion. It was seen that the average MD for the normal observations for each main criterion was close to the theory of MTS. Since the MDs of abnormal for each main criterion have higher distances, the measurement scale was considered as good.

There are many orthogonal arrays in Taguchi's method; however, in this study, $L_{12}(2^{11})$ (Table 3), $L_8(2^7)$ (Table 4), and $L_4(2^3)$ (Table 5) OAs were selected for the identification of the prime set of sub-criteria from their corresponding main criteria with minimum number of sub-criteria combinations. In Tables 3–5, "1" (or level 1) represents including the sub-criterion and "2" (or level 2) excluding the sub-criterion. An average S/N ratio was obtained for each sub-criterion at level 1 and level 2. Subsequently, gain in S/N ratio was calculated by the difference between the average S/N ratio value at level 1 and level 2 (Tables 3–5).

From Table 3, it is clear that in water the nine sub-criteria such as: W1, W2, W3, W4, W5, W6, W7, W8 and W9 have positive gains. That means these sub-criteria have higher average responses when they are part of the system (level 1). Hence these sub-criteria were considered to be useful for confirmation run. A similar interpretation was true for the rest of the main criteria in Tables 4 and 5.

A confirmation run was conducted for each main criterion with their corresponding prime set of sub-criteria identified. MDs corresponding to the normal and abnormal observations were obtained using Eq. (1). Comparisons of average MD for normal and abnormal group for each main criterion were given in Table 2. It can be observed from Table 2 that all the main criteria, except water and risk factor, have higher value of average MD based on the abnormal group (obtained with only their corresponding prime sub-criteria identified as useful) compared to that obtained from all the sub-criteria originally used. This shows that, we only need to collect the samples for soil, support, and infrastructure from their corresponding prime set of sub-criteria, to identify the optimal location in aquaculture. The results also revealed that, in water and risk factor, the abnormals have lower average MD with their corresponding prime set of sub-criteria combinations. Therefore, the sub-criterion transparency and pollution cannot be reduced from water and risk factor respectively for future observations (Table 2). Table 1 shows the results of MTS algorithm, that is, the required set of sub-criteria in each main criterion for aquaculture development.

4. Conclusion

A simple-to-use MTS-based decision tool that assists for the selection of important criteria which will be useful for the identification of optimal location for aquaculture development has been developed. One can use the MTS-based tool in aquaculture system without the knowledge of statistics. If the discrimination is performed alone by an individual criterion, it may produce a misleading result. The proposed MTS decision tool combines all criteria into an MD index with considering the correlation among all criteria. The proposed decision tool can be easily adapted to other closely related industries such as agriculture and environmental engineering. This tool is also useful for demonstration and training purposes.

REFERENCES

Antony, J., Antony, F.J., 2001. Teaching the Taguchi method to industrial engineers. Work Study 50, 141–149.

Brown, L.R., Flavin, C., Hilari, F., Abramovitz, J., Bright, C., Gardner, G., Mc Ginn, A., Rennder, M., Roomdman, D.M., Starke, I., 1997. State of the World: A World Watch Institute on Progress toward a Sustainable Society. W.W. Norton & Company, New York.

Chamberlain, G., Rosenthal, H., 1995. Aquaculture in the next centaury, opportunities for growth, challenges of sustainability. World Aquaculture 26, 21–25.

Guzzo, RA., 1982. Improving Group Decision under Multiple Criteria. Spring-Verlag, Germany.

Nath, S.S., Bolte, J.P., Ross, L.G., Aguilar-Manjarez, J., 2000. Applications of Geographical Information Systems (GIS) for spatial decision support in aquaculture. Aquacultural Engineering 23, 233–278.

Ramesh, R., Rajkumar, R., 1996. Coastal aquaculture site selection and planning in Tamil Nadu using Remote Sensing and GIS. Asian-Pacific Remote Sensing and GIS Journal 9, 39–49.

Taguchi, G., 1987. System of Experimental Design. Dearborn, Michigan, and White Plain. ASI Press and UNIPUB-Kraus International Publications, New York.

Taguchi, G., Jugulum, R., 2000. New Trends in Multivariate Diagnosis. Sankhyā: The Indian Journal of Statistics 62, 233–248.

Taguchi, G., Jugulum, R., 2002. The Mahalanobis-Taguchi Strategy. John Wiley and Sons Press, New York.

Taguchi, G., Chowdury, S., Wu, Y., 2001. The Mahalanobis-Taguchi System. McGraw-Hill Press, New York.