

EXTENDED STUDIES ON MATHEMATICAL MODELING OF SITE SENSITIVITY INDICES IN THE SITE SELECTION CRITERIA FOR HAZARDOUS WASTE TREATMENT, STORAGE AND DISPOSAL FACILITY

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ABSTRACT

Site selection and ranking of a suitable site for a Treatment, Storage and Disposal Facility (TSDF) earmarked for hazardous wastes is an important aspect since it covers several attributes covering site based information, physico-chemical characteristics of the hazardous wastes, and available technology for hazardous waste treatment. Guidelines are available in India to select and rank a site suitable for TSDF based on Site Sensitivity Indices (SSIs) and appropriate weightage of attributes identified for site selection. However the upper/lower limits of certain SSIs are not clearly defined in Guidelines. This is leading to an ambiguity in the usage of the methodology prescribed in the Guidelines for ranking a site for TSDF. Three mathematical models were developed earlier by these authors for eight selected attributes prescribed in the Guidelines for whom the upper/lower limits for relevant SSIs are generating ambiguity. Encouraging results were reported in that studies in predicting the SSI values. Similar approach is extended in the present study to another four attributes with an ambiguous upper/lower limits for relevant SSIs and found that the mathematical models developed are giving encouraging results in the present studies also. The Best Fit Mathematical Model (BFMM) developed based on polynomial equations is able to predict the sensitivity scale distribution accurately. Two other models viz., Overall Linear Distribution Model and Linear Interpolation Among Intervals are also developed but found that they are not as accurate as BFMM. The BFMMs developed for all the twelve attributes predict the asymptotic SSI values of 1 and 0 for all the attributes considered. The mathematical models developed are differentiating the attribute significance with regard to SSI as linear and non-linear. This information will help in understanding the significance of an attribute with respect to its sensitivity.

Keywords: TSDF, Site Sensitivity Index, Attributed Score, Regression Analysis, Mathematical model, Hazardous Waste Management.

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INTRODUCTION

The ideal industrial siting criteria prescribes that the industry should have enough land available within its premises for the treatment and disposal and or reuse/recycling of the wastes generated from it (Muralikrishna, 1995). The treatment and disposal aspects become complex while handling with hazardous wastes. Shortage of financial, administrative, and infrastructural facilities forced many industries in India (TEDDY, 1998) for not having their own treatment and disposal facilities for the hazardous wastes generated from their premises (Jeevan Rao, 1999). The treatment and disposal facilities are predominantly limited to large-scale industries (Ramakrishna and Babu, 1998). A common Treatment, Storage and Disposal Facility (TSDF) for the hazardous wastes can help such industries that are finding difficulty in providing proper treatment and disposal of their hazardous wastes. The design, land requirement, maintenance, and operation of a landfill often plays a decisive role in the site selection of TSDF. The selection of a suitable site for an effective functioning of TSDF is one of the important aspects. It depends upon several factors (Guidelines, 1991) such as waste characteristics, site characteristics, locational significance, public acceptance, and prevailing laws and regulations (Ramakrishna and Babu, 1999; Babu and Ramakrishna, 2000). Kao and Lin (1996), Siddiqui et. al. (1996), and Lakshmi, (1999) studied remote sensing applications in landfill siting. The details of several options with regard to the managerial planning, scheduling of wastes from the source of generation to the landfill, design of landfill including leachate treatment are available in literature (Babu and Ramakrishna, 2000).

The Government of India has promulgated the Hazardous Waste (Management & Handling) (abbreviated as HW (M&H)) Rules, 1989 through the Ministry of Environment and Forests (MOEF) under the aegis of Environment (Protection) Act (abbreviated as E(P) Act), 1986.

Guidelines are available (Guidelines, 1991) in India for selection of a best site suitable with respect to all the factors described previously. The State Government or a person authorized by it will make the final decision pertaining to the site identified for the TSDF as per the Guidelines of HW (M&H) Rules issued by MOEF (from time to time). The short-listed sites that are identified by the standard procedures (Guidelines, 1991; Lakshmi, 1999; Ramakrishna and Babu, 1999; Babu and Ramakrishna, 2000) are ranked using Site Sensitive Indices (SSIs) developed for the purpose. The value of SSI is graded on a four-level *linear* scale of sensitivity ranging from 0 (very low sensitivity) to 1 (very high sensitivity). Thirtyfour attributes pertaining to Receptor related; Pathway related; Waste characteristics related; and Waste management practices related are identified that are causing an impact on site selection of TSDF. Each of these attributes are given weights totaling to 1000 points depending on their significance in their respective categories. The attributed score is calculated by multiplying the individual weights of the attribute with the corresponding score of SSI. The site with the least sum of the attributed score is chosen as best site for TSDF.

SIGNIFICANCE OF THE PRESENT STUDY

The Guidelines (Guidelines, 1991) prescribed four different categories of attributes for ranking a site for TSDF as briefly discussed above. The Pathway- and Receptor- related attributes are site specific and based on primary and secondary sources. The attributes related to waste characteristics and waste management practices deal with physico-chemical properties of the wastes and available technology for the treatment of wastes. A thorough examination of the attributes given in these four categories show that the upper and lower limits for few attributes are not clearly defined, which may lead to error in the prediction of SSI and hence the attributed score. Babu and Ramakrishna (2000) have developed mathematical models for predicting the

SSI values for the eight selected attributes pertaining to the Pathway- and Receptor- related categories and got encouraging results. After examining the description given for the attributes in the other two categories, it is noticed that, the upper/lower limits are not clearly defined for four attributes related to waste characteristics and waste management practices. The details of these four attributes are given in Table-1, which show that the sensitivity scale distribution in the ranges of 0.0-0.25 & 0.75-1.0 is not clearly defined for the attribute description. It is also observed that the overall distribution of sensitivity scale for the attributes is linear for few attributes and non-linear for the other attributes. It is decided to apply the methodology given by Babu and Ramakrishna (2000) to the four selected attributes pertaining to the categories of Waste characteristics and waste management practices related and develop the mathematical models to overcome the limitations of these attributes as mentioned above.

Table-1

METHODOLOGY

The methodology adopted by Babu and Ramakrishna (2000) is considered in the present study and is given as follows:

- The data given in the Guidelines (Guidelines, 1991) is taken as reference for the entire analysis.
- The analysis is carried out taking each attribute, case by case.
- Regression analysis is carried out to find out the Best Fit Mathematical Model (BFMM) suitable for the data points of each attribute.
- An analysis is carried out for all the data points by considering Linear Interpolation Among the Intervals (LIAI) specified in the Guidelines.

- An additional analysis is also carried out for cross-checking by considering an Overall Linear Distribution Model (OLDM) of all the data points.
- The above three analyses viz., BFMM, LIAI, and OLDLM are compared and conclusions are drawn.

RESULTS AND DISCUSSION

The BFMM is developed for each of the four attributes selected for the present study by considering all the data points given in Guidelines (Guidelines, 1991) for each attribute. Polynomial equations are found to be a best fit for the four attributes considered. The details of the BFMM are given in Table-2. It is to be noted from Table-1 that, for the SSI value of 0.25, 0.50, & 0.75 a clear limit of the description is given for each of the four attributes. For a SSI value in the range of 0.0-0.25 and 0.75-1.0, the upper/lower limit of the attribute description is not clearly mentioned. Hence, arbitrary variables are chosen for each attribute in the SSI range of 0.25-0.50 & 0.50-0.75 for error estimation. The SSI value is estimated for the arbitrary variables by each of the three models and is given in Table-3. As is evident from Table-3, the SSI values predicted by the three models for two of four attributes viz., Radioactivity and Ignitability are perfectly matching except for a couple of data points due to the rounding-off of the SSI values at four digits after decimal. However, a little variation is observed in the SSI values predicted by the three models for the other two attributes. This indicates that, out of the four attributes listed in Table-3, the distribution of the attribute significance in each of the four SSI intervals is linear for the first two attributes and non-linear for the remaining two attributes. The SSI values are predicted using all the three models for the description of the attributes given in Guidelines (Guidelines, 1991). The predicted values are plotted in Figs. 1 & 2. The BFMM being representing a best fit follows the trend of attribute significance. The OLDLM gives only the best

fit of a linear model and may have a deviation from BFMM and can vary from attribute to attribute. This is clearly evident on comparing Fig. 1 with Fig. 2 while, LIAI is a fit that is modeled considering linearity between the SSI intervals. The trend of the results from LIAI model may or may not closely follow the BFMM trend. The variation of results from LIAI and BFMM could be very little but it again depends upon the resemblance of the attribute significance within the SSI interval with respect to the overall non-linear trend of attribute significance distribution. This is evident on comparison of Fig. 2(a) and Fig. 2(b).

Table-2

Table-3

Fig. 1

Fig. 2

From Table-3 and Figs. 1 & 2 it is evident that, the mathematical models developed are differentiating the attribute significance with regard to SSI as linear and non-linear. This information will help in understanding the significance of an attribute with respect to its sensitivity.

In order to understand the variation of the above predicted values of SSI, Standard Deviation (SD_1) with respect to the expected value (i.e., 0.25, 0.50, & 0.75) is calculated (Babu, 1993; Ramakrishna and Babu, 1999) for each attribute and is given in Table-4. The SD_1 value for the results of BFMM is zero for all the attributes (see Table-4) and the SD_1 value for the results of OLDMM ranging from 0.05126-0.1336 are also encouraging. This information clearly indicates that BFMM could accurately predict the trend of attribute significance for the four attributes considered in the present study while the other models could predict the same with little error.

Table-4

The attributed scores based on SSI and weightage (Lakshmi, 1999) given for a particular attribute are used (Guidelines, 1991) in the ranking of a site for TSDF. The attributed scores are calculated using the predicted SSI values of all the arbitrary variables (see Table-3) and the weightages for three of the four attributes viz., Radioactivity, Ignitability, and Volatility and given in Table-5. The data indicates that the SSI predictions and hence attributed scores are perfectly matching for two of the three attributes viz., Radioactivity and Ignitability. The resemblance in the trends of all the three models for the above two attributes can be observed in Fig. 3(a) & 3(b). A marginal deviation in the attributed scores in accordance with the predicted SSI values given by the three models is observed for Volatility, the third attribute. This deviation is distinctly visible in Fig. 4 where the non-linear trend of attribute significance is showing a large variation in the trend patterns of the three models. An additional data point can be observed in Figs. 3 & 4 for the attributed scores using LIAI model. This additional point joins the data points in the range of 0.25-0.50 with that in the range of 0.50-0.75. This is like a *link* connecting the two assumed linear portions within the SSI ranges and gives physical interpretation of LIAI model. The results of the attribute scores calculated using the SSI values predicted by the three models are compared for the deviation in the results for the same SSI value. Keeping the SSI value and hence the attributed score calculated using BFMM as reference and the deviation of SSI predicted using LIAI and OLDM over BFMM is calculated in terms of Standard Deviation (SD_2) (see Table-6). The SD_2 is calculated with respect to the mean of the deviations for the results of difference between LIAI & BFMM; OLDM & BFMM. The data given in Table-6 show that the deviation of the attributed scores predicted by the LIAI with respect to BFMM is

lesser (SD_2 : 0.259915) than that predicted using OLDLM with respect to BFMM (SD_2 : 0.421609) for Volatility and almost similar (approximately zero) with respect to the other two attributes.

Table-5

Fig. 3

Fig. 4

Table-6

The information with regard to the weightage of the fourth attribute i.e., hazardous waste quantity per annum is not available in literature (Lakshmi, 1999) and hence attributed score is not calculated. However, the SSI values and hence attributed score can be calculated for a given description of this attribute using the BFMM developed (see Table-2).

The results obtained in the present study are compared with those reported by Babu and Ramakrishna (2000) for other selected attributes prescribed in the Guidelines (Guidelines, 1991) for ranking of TSDF and the observations are summarized as follows:

- The attribute significance of all the eight attributes considered in the previous study are show non-linear trends while only two of the four attributes considered in the present study are showing non-linear trends.
- Low values of SD_1 are obtained for the results using BFMM (0.0297 to 8.0659×10^{-6} in the previous study to zero in the present study).
- The SD_1 values reported (0.0557 to 0.5842) for the results using OLDLM in the previous study are slightly higher than that arrived (zero to 0.1338) in the present study.
- The SD_2 values calculated for the deviation of the attributed scores predicted by the LIAI with respect to BFMM is lesser (0.259915) than that predicted using OLDLM with respect to

BFMM (0.421609) for one attribute and almost similar (approximately zero) with respect to the other two attributes.

- The *link* point or the additional point (see Figs. 3 & 4 in the present study) in the LIAI model is found to be useful in understanding the attribute significance in both the studies.
- Accuracy is improved on estimation of SSI using the proposed BFMM over the assumed LIAI and OLDM of the data points.

The above observations reveal that, the mathematical models can be used to understand the trends of attribute significance. The mathematical models developed can be used to predict the sensitivity scale distribution for the selected attributes from all the four categories involved in the selection of a suitable site for the TSDF viz., Receptor-; Pathway-; Waste characteristics-; and Waste Management practices-related attributes. Out of the three models developed, the BFMM developed is giving encouraging results for the twelve attributes considered in both the studies. The BFMM is particularly useful in predicting the upper/lower limits of SSI in the ranges of 0.0-0.25 and 0.75-1.0. It is *superior* in terms of *accuracy, simplicity, clarity, and reliability* to the other two assumptions of calculating the SSI values.

SUMMARY AND CONCLUSIONS

Three mathematical models are developed based on the successful methodology reported in literature (Babu and Ramakrishna, 2000) for four selected attributes pertaining to the categories of Waste characteristics and waste management practices, to overcome the limitations of these attributes with regard to their use in the site selection of TSDF. The results arrived in the present study are compared with those reported in the literature for eight other attributes also used in the site selection of TSDF. It is found that the mathematical models developed are giving encouraging results for all the twelve attributes considered. BFMM is found to be superior over

the other two developed models, LIAI and OLDM in predicting the sensitivity scale distribution of all the twelve attributes. BFMM is thus proved to be advantageous in terms of accuracy, simplicity, clarity, and reliability in the prediction of SSI values required for the ranking of the site in the site selection process of a TSDF.

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Fig. 1. Comparison of Site Sensitivity Index (SSI) prediction using BFMM, LIAI, and OLDMM for various attributes.

- (a) SSI vs. Radioactivity
- (b) SSI vs. Ignitability

Fig. 2. Comparison of Site Sensitivity Index (SSI) prediction using BFMM, LIAI, and OLDMM for various attributes.

- (a) SSI vs. Volatility
- (b) SSI vs. Hazardous waste quantity per annum

Fig. 3. Comparative attribute scores of the three models.

- (a) Attributed score vs. Radioactivity
- (b) Attributed score vs. Ignitability

Fig. 4. Comparative attributed scores of the three models – Attributed score vs. Volatility

Table-2 Regression analysis based Best Fit Mathematical Models (BFMMs) developed for the selected attributes

S.No.	Attribute	BFMM	Coefficient of BFMMs
1	Radioactivity	$y = a + bx$	$a = 0.125;$ $b = 0.125.$
2	Ignitability	$y = a + bx$	$a = 0.928571;$ $b = - 0.00714286.$
3	Volatility	$y = a + bx + cx^2$	$a = 0.248825;$ $b = 0.0117553;$ $c = -6.83335 \times 10^{-5}.$
4	Hazardous waste quantity per annum	$y = a + bx + cx^2$	$a = 0.154762;$ $b = 0.000392857;$ $c = -4.7619 \times 10^{-8}.$

Table-4 Comparison of Best Fit Mathematical (BFMM) and Overall Linear Distribution (OLDM) Models

S.No.	Attribute	Standard Deviation (SD₁)	
		BFMM	OLDM
1	Radioactivity	0	0
2	Ignitability	0	0
3	Volatility	0	0.1338
4	Hazardous waste quantity per annum	0	0.0513

Table-6 Comparison of Overall Linear Distribution (OLDM) and Linear Interpolation Among Intervals (LIAI) models with Best Fit Mathematical Model (BFMM).

S.No.	Attribute	Standard Deviation (SD ₂) between the attributed scores predicted by	
		OLDM & BFMM	LIAI & BFMM
1	Radioactivity	0	0
2	Ignitability	0	0.0016
3	Volatility	0.4216	0.2600

Table-3 Comparison of SSI predicted values using the three models developed

S.No.	Attribute	Arbitrary variable, x	SSI		
			BFMM	OLDM	LIAI
1	Radioactivity	1.5	0.3125	0.3125	0.3125
		2.5	0.4375	0.4375	0.4375
		3.5	0.5625	0.5625	0.5625
		4.5	0.6875	0.6875	0.6875
2	Ignitability	80	0.3571	0.3571	0.3572
		70	0.4286	0.4286	0.4286
		50	0.5714	0.5714	0.5714
		40	0.6429	0.6429	0.6429
3	Volatility	10	0.3595	0.3501	0.3490
		15	0.4098	0.3809	0.3990
		40	0.6097	0.5349	0.5714
		60	0.7081	0.6580	0.6654
4	Hazardous waste quantity per annum	500	0.3393	0.3345	0.3335
		700	0.4226	0.4054	0.4168
		1300	0.5850	0.5615	0.5750
		1600	0.6614	0.6466	0.6500

Table-5 Comparison of attributed scores using the three models

S.No.	Attribute	Weightage, points	BFMM	Arbitrary variable, x	SSI due to BFMM	Attributed score due to BFMM	Attributed score due to OLDM	Attributed score due to LIAI model
<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>	<i>(6)</i>	<i>(7) = (3) x (6)</i>	<i>(8)</i>	<i>(9)</i>
1	Radioactivity	30	1 st degree polynomial	1.5	0.3125	9.375	9.375	9.375
				2.5	0.4375	13.125	13.125	13.125
				3.5	0.5625	16.875	16.875	16.875
				4.5	0.6875	20.625	20.625	20.625
2	Ignitability	20	1 st degree polynomial	80	0.3571	7.142	7.142	7.142
				70	0.4286	8.572	8.572	8.572
				50	0.5714	11.428	11.428	11.428
				40	0.6429	12.858	12.858	12.858
3	Volatility	15	2 nd degree polynomial	10	0.3595	5.393	5.252	5.235
				15	0.4098	6.147	5.714	5.985
				40	0.6097	9.146	8.024	8.571
				60	0.7081	10.622	9.870	9.981

Table-1 Details of selected attributes considered in the present study

S.No.	Attribute description	Category of attribute	Site Sensitivity Index (SSI)			
			0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
1	Radioactivity	Waste characteristics related	At or less than back-ground level	1 to 3 times background level	3 to 5 times background level	Over 5 times background level
2	Ignitability	Waste characteristics related	Flash point greater than 95 ⁰ C	Flash point of 60 ⁰ to 95 ⁰ C	Flash point of 25 ⁰ to 60 ⁰ C	Flash point less than 25 ⁰ C
3	Volatility	Waste characteristics related	Vapor pressure less than 0.1mm Hg.	Vapor pressure of 0.1 to 25mm Hg.	Vapor pressure of 25 to 78mm Hg.	Vapor pressure greater than 78mm Hg.
4	Hazardous waste quantity per annum	Waste Management Practice related	Upto 250 tonnes	250 to 1000 tonnes	1000 to 2000 tonnes	Greater than 2000 tonnes