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

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ABSTRACT

With the Basel ban, imposing restrictions on Trans-boundary movement of hazardous wastes, coming into force with effect from 1.1.1998, the concept of treatment and safe disposal of hazardous wastes (HWs) assumes paramount significance. The annual HW generation in India is estimated at 0.3-0.5 million tonnes. As per the ideal industrial siting criteria in India, 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. However, very few industries in India, mostly in large scale and very few in medium scale, own proper treatment and disposal facilities. A common waste treatment and disposal facility such as treatment, storage and disposal facility (TSDF) for management of hazardous wastes generated from industries, is one of the useful options under such conditions. Few Guidelines issued by Ministry of Environment and Forests under Hazardous Wastes (Management & Handling) Rules, 1989 promulgated under Environment (Protection) Act, 1986 are available in India for selection of best site for TSDF. These guidelines may vary from country to country. A few limitations in the prevailing methodology for site selection of TSDF under Indian conditions with respect to the prediction of Site Sensitivity Indices (SSI) are observed. The present study is aimed at floating few suggestions for the accuracy improvement of the same.

A best-fit mathematical model (BFMM) is developed to accurately predict the SSI. Mathematical models are also developed for the assumption (LIAI) given in the Guidelines and another assumption (OLDM) under which the ranking of the sites may take place. The results are encouraging and revealed that, though the methodology given in the Guidelines is closely matching with the present statistical analysis, the present study is superior in terms of simplicity, reliability, accuracy and clarity over the prevailing assumptions. Moreover, the BFMMs proposed in the present study, also predict the asymptotic SSI values of 1 and 0 for all the attributes considered. The results of the second assumption (i.e., OLDM) are highly erratic and we recommend it to be discouraged from practicing it.

Key words: *TSDF, Site Sensitivity Index, Attributed Score, Regression Analysis, Mathematical Model, Hazardous Waste Management.*

INTRODUCTION

There is a growing concern all over the world for the safe disposal of hazardous wastes (HWs) generated from anthropogenic sources. They need to be disposed off in a secured manner in view of their characteristic properties such as, toxicity, corrosivity, ignitability, reactivity and persistence. Severe pollution of land, surface and ground water can be resulted if the options available (Wentz, 1995; Parsa *et al*., 1996; Chakradhar *et al*., 1999) for hazardous waste management (HWM) are not being efficiently utilized (Rama Krishna and Babu, 1999a; Rao, 1999) by the waste generators.

The reasons for the accumulation of HWs in the developing countries (Chakradhar *et al*., 1999) are attributed due to:

- The wastes generated within the country either by foreign owned/state owned or joint venture industrial units.
- The wastes generated by medium and small-scale industries.
- The wastes imported into the country.

With the Basel ban, imposing restrictions on *Trans-boundary movement of hazardous wastes,* coming into force with effect from 1.1.1998 (Bidwai, 1996), the concept of treatment and safe disposal of hazardous wastes assumes paramount significance.

As per the ideal industrial siting criteria in India, 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 (Murali Krishna, 1995). However, very few industries in India own proper treatment and disposal

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facilities (Jeevan Rao, 1999). They are predominantly limited mostly to large-scale (Capital investment greater than Rs. 5 crores) and very few to medium-scale (Capital investment between Rs. 50 lakhs and 5 crores) industries (Rama Krishna and Babu, 1998). Among the 1440 industries identified (as on 31.03.1996) in the country with a high potential for pollution, 203 industries (i.e., ~14%) are recorded as not having adequate facilities to comply with the regulatory standards for treatment and disposal of wastes (TEDDY, 1998). Financial, administrative, and infrastructural facilities are some of the limitations attributed for the above cause. A common waste treatment and disposal facility such as treatment, storage and disposal facility (TSDF) is one of the useful options under such conditions, which is advantageous in:

- ensuring safe treatment, storage and disposal of hazardous wastes.
- helping the hazardous waste generators in its near vicinity to avail the facility for its designated purpose.

Since landfill is the final waste disposal option (Tchobanoglous *et al*., 1993), its design, maintenance and operation often play a **decisive** role in the site selection of TSDF (Rama Krishna and Babu, 1999b). However, few externalities such as land usage, water pollution from leachate, air pollution deducting net energy recovery, residue disposal, transportation of waste etc. can decide the best suitable treatment/disposal option (Chung and Poon, 1997) for solid waste management. Considering such externalities, for example, landfilling resulted in a lower external cost (HK$ 288 per tonne of solid waste) than incineration (HK$ 365.7 per tonne of solid waste) for its use as treatment/disposal of solid waste. The multi-factor spatial analysis and Geographical Information Systems are reported to be applicable for landfill siting (Kao and Lin, 1996; Siddiqui *et al*, 1996). But, leachate and gas generation (predominantly methane) from landfills is one of the typical problems encountered from landfills. Prediction of leachate quality from landfill is difficult due to its various features such as age of landfill and phase of waste decomposition (Tchobanoglous *et al*, 1993). However mathematical models are available for estimation of leachate quality from a landfill (Kouzeli-Kastri *et al*, 1999). The treatment technology for leachate generated from landfills is also available (Zolten, 1991; Tchobanoglous *et al*, 1993). Recent studies (during 1994-1999, some of which are discussed below) concentrated on improving the anaerobic decomposition of waste and hence the methane generation from the landfill. One of the encouraging results was reported at recycling the leachate (Anex, 1996) into the waste cell while considering the prevention of potential leakage through the liner as a result of recycling. Another study indicated at using lime-stabilized sludge as landfill cover material (Rhew and Barlaz, 1995). Scheduling of the wastes from the source of generation to the landfill disposal site, after segregating the recyclable and reusable wastes, involve a lot of complex managerial options. Mathematical tools are effectively used to solve such difficulties. Long-term scheduling of disposal and diversion options in a regional integrated solid waste management system is studied (Everett and Abhijit, 1996; Modak and Everett, 1996) using linear programming model. This model is capable of handling multiple communities, landfills & incinerators and can incorporate the possible implementation of numerous collection and diversion options such as recycling and composting programs. Managerial options for optimal planning in solid waste management systems such as recycling, suitability of material market and their subsequent economic impacts are studied (Chang and Wang, 1996) using fuzzy programming. While, cost-effectiveness and workload constraints in the optimization of solid waste collection, recycling treatment and disposal systems is studied (Chang *et al*, 1997) using systems analysis through non-linear programming and integer programming. Mathematical tools can also be effectively used to decide (Minor and Jacobs, 1994) the optimal allocation of the site for landfill disposal based on various parameters pertaining to the shape of the site, wastes to be disposed, cost factor etc. However, more than one unit operation may be employed for the treatment and disposal of wastes at TSDF. The site selection options for TSDF are based on minimization of few aspects on the receptors and the pathways through which the waste is likely be transported (Lakshmi, 1999). However the options for site selection of TSDF vary from country to country (Salim *et al*, 1995).

A thorough and critical examination of the above literature revealed that, though landfill is one of the treatment/disposal options at TSDF, the site selection criteria for a TSDF depends upon few other aspects as well, pertaining to receptors and pathways of likely waste movement. The results of the above studies, however, are useful in planning for effective solid waste management at TSDF considering various complex managerial options. In this context, the Guidelines prescribed by the Apex Regulatory agency in the country is the only option for selecting a suitable site for TSDF. However, a few limitations in the prevailing methodology prescribed for Indian conditions for site selection of TSDF are observed. The present study is aimed at floating few suggestions for the improvement of the same pertaining to reliability, accuracy, simplicity and clarity which, none of the previous reported studies attempted.

HAZARDOUS WASTE MANAGEMENT – INDIAN APPROACH

According to a OECD (Organization for Economic Co-operation and Development) study, the annual HW generation in India is estimated at 0.3-0.5 million tonnes (Chakradhar *et al.*, 1999). The Government of India has promulgated the Hazardous Waste (Management & Handling) Rules (HW (M&H)) in 1989 through the Ministry of Environment and Forests (MOEF) under the aegis of Environment (Protection) Act [E(P) Act], 1986. Under the HW (M&H) Rules, the hazardous wastes are divided into 18 categories. Moreover, the role and responsibilities of the waste generator, state/central pollution controls boards and state Government is clearly defined. In order to encourage the effective implementation of these rules, the MOEF has further brought out the Guidelines for HW (M & H) Rules in 1991 (Maudgal, 1995; Rama Krishna and Babu, 1999b) giving the technical details of the principles of HWM covered under the HW (M&H) Rules, 1989.

However, the selection of a suitable site for an effective functioning of TSDF is the key aspect and depends upon several factors such as waste characteristics, site characteristics, public acceptance and prevailing laws & regulations. The facility siting should also incorporate the protection of human health, environment and property values in a community. Few more aspects are also involved (Rama Krishna and Babu, 1999b) pertaining to the ideal site selection for TSDF, based on its locational significance. Though the selection of an ideal site confirming with the above factors is a difficult task, few Guidelines are available (Guidelines, 1991) in India for selection of best site for the same purpose. They are summarized below (Rama Krishna and Babu, 1999b):

- General evaluation -considering various features of the region/site such as climate, ecology, landuse, logistics, topography, soil properties, aesthetics etc.- is mainly used as an initial screening criteria to eliminate certain sites without much consideration into their complicated technical aspects. This is analogous to the heirarchy of decisions made in selecting a best process by screening out the available thousands of process alternatives (Douglas, 1988).
- The sites that are highly sensitive such as seismic risk zones, national parks/sanctuaries, coastal flood hazard areas and wetlands etc. are identified and eliminated using constraint mapping. Remote sensing applications can be used for the same purpose. The short-listed sites are ranked using Site Sensitivity Indices developed for the purpose. Thirty four attributes pertaining to four different categories such as, *Receptor related; Pathway related; Waste characteristics related and Waste management practice related*, are identified and the impact of TSDF on them is graded on a four-level sensitivity scale ranging from *0 to 1 (0.0-0.25, 0.25-0.5, 0.5-0.75,* and *0.75-1.0).* The values of the site sensitivity index (SSI) *0* (zero) to *1* indicates very low to very high sensitivities respectively. Each of the 34 attributes are given weights totaling to 1000 points, depending on their significance in the four different categories. The individual weights when multiplied with the corresponding SSI of the site will give the attributed score. The decision on the ranking of the site depends on the summation of the attributed scores with the site having the least score given the first priority for selection.
- Environmental Impact Assessment (EIA) studies are to be conducted for the site(s) zeroed on in the ranking process. Though the public opinion is considered as part of EIA studies, their acceptance will also be collected by means of various awareness programmes. The State Government or a person authorized by it will make the final decision pertaining to the site identified for TSDF as per the Guidelines to HW (M&H) Rules issued by the MOEF (from time to time).

After examining the technical aspects covered in the Guidelines under Indian conditions for the management and handling of hazardous wastes (Guidelines, 1991), a typical layout of TSDF is developed and is given in Fig. 1. As can be seen from the figure, the hazardous waste at TSDF can be:

- pre-treated to render it less hazardous;
- incinerated for volume reduction;
- safely disposed in a secured landfill and the leachate generated from the landfill is collected, treated and disposed as per the local regulatory standards.

The movement of vehicles carrying the hazardous wastes is regulated through properly located entry and exit points. The site is aptly fenced and greenbelt is raised to attenuate the pollutant emissions and conceal the site from the public as well due to aesthetic considerations. The design of a landfill depends upon various aspects such as quantity and quality of the waste to be disposed off, topographical features of the site etc. (Tchobanoglous et al, 1993). The landfill may be designed either as one unit (denoted by landfill) or more than one unit (denoted by Extensions-I & II as optional) as shown in Fig.1.

Fig.1

SIGNIFICANCE OF THE PRESENT STUDY

The four different categories as discussed earlier consist of 7, 10, 8 and 9 attributes leading to a total of thirty-four attributes. Each of the attributes has four options for the prediction of sensitivity due to TSDF (Guidelines, 1991). A close examination of these options has resulted in the following observations:

- The upper and lower limits for few attributes are not clearly defined.
- The sensitivity scale distribution for some of the selected attributes is not clear, and also non-linear when overall distribution is considered.
- The error/ambiguity in the prediction of SSI could lead to erratic ranking of the site designated for TSDF.

Out of the four categories of the attributes considered for the present computation of SSI:

- The attributes related to waste characteristics such as toxicity, reactivity, corrosivity etc., depend upon the physico-chemical properties of the waste.
- The characteristics related to waste management practice such as leachate treatment, use of liners etc., depend upon the available technology.
- The attributes of the above two categories (waste characteristics related and waste management practice related) are independent of the site though, the SSI depends on these two categories as well in the site selection.

However, the other two categories namely, the receptor related and pathway related attributes are site specific and based on the primary & secondary data sources. The overall ranking is thus very sensitive to the attributes of these two categories. Hence, a small error in the prediction of SSI at early stages could lead to a wrong selection of relatively unfavorable site(s). We focus our attention to eight attributes in the present study (see Table-1) based on the observations discussed above. From the Table, it can be seen that, the upper limit of all the eight attributes and lower limit of six of the eight attributes is not clearly defined. For example, the upper and lower limits of the first and last options (viz., greater than 5000 m and less than 1000 m) for the attribute, distance to nearest drinking water source, are not clearly defined. The distribution of sensitivity scale is also not clearly stated in this particular case, though the tendency is to interpolate within the limits assuming a linear distribution. The present study highlights this ambiguity and offers a solution using *statistical analysis* with all the necessary justifications.

Table-1

METHODOLOGY

Based on the objective and significance of the study, the following methodology is adopted:

- The data given in 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. Additional points are also generated by plotting graphs wherever necessary, for accurate fitting.
- An analysis is carried out by considering Linear Interpolation Among the Intervals (LIAI) specified in the Guidelines for all the data points.
- 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 OLDM are compared and conclusions are drawn.

RESULTS AND DISCUSSION

While carrying out the analysis, the BFMM is developed using the data points given for each attribute. The coefficients of the BFMMs for all the eight attributes considered are given in Table-2. Arbitrary variables are chosen for each attribute for error estimation and the corresponding SSI is predicted using the developed mathematical models. The SSI for each arbitrary variable is multiplied with the corresponding weightage allotted for the attribute to calculate the attributed score. The exercise is repeated for the OLDM using the same arbitrary variables in the calculation of attributed scores. Linear equations are developed among the data points for each attribute under the LIAI analysis. The SSI is calculated for above arbitrary variables and the corresponding attributed score is estimated as mentioned above. The comparison of the three mathematical models considered in the study viz., BFMM, LIAI and OLDM for four of the eight attributes, is shown in Figures 2(a), 2(b), 3(a) & 3(b) respectively. From the figures, it can be noticed that, for all the four attributes, the lines corresponding to

BFMM (non-linear) and LIAI model (linear) have close agreement with each other. However, the OLDM can be seen deviating from these two models indicating its relative erratic assumption for prediction of SSI. Similar trends are observed for the other attributes as well. The results of the comparative study are given in Table-3. The value of SSI and attributed scores are rounded-off to the nearest second digit. From the Table, it can be noticed that, the results of the OLDM for the data points are highly deviating (error range: -19.72% to 72.41% for the arbitrary variables considered) from those obtained from BFMM results. The standard deviation (SD_1) of this error calculation for each attribute ranged from 2.2173 to 29.8315 with respect to the arithmetic mean of error. Eleven data points out of thirty-two (i.e., 34%) arbitrary data points generated for the analysis exceeded ± 10% error. The 95%ile value for the positive and negative errors is 25.93% and –11.94% respectively. The high values of SD_1 and 95%ile error indicate the results for prediction of SSI using OLDM is not reliable. The standard deviation (SD_2) for the results from BFMM and OLDM is calculated with respect to the expected value (Babu, 1993; Rama Krishna and Babu, 1999b) and given in Table-4. From the Table, it can also be observed that, the BFMM is more accurate than OLDM.

Table –2

Fig.s 2(a), 2(b), 3(a) & 3(b)

Table –3

Table –4

The results of the LIAI analysis are also giving erratic values (error range: -13.43% to 13.79% for the arbitrary variables considered) compared to those obtained from BFMM analysis. It is to be noticed that, only three data points out of the 32 arbitrary data points (i.e., 10%) generated for the LIAI analysis exceeded an error of ± 10%. The 95%ile value for the positive and negative errors is 6.12% and –5.63% respectively. The standard deviation (SD_1) of this error calculation for each attribute ranged from 0.61 to 8.44 with respect to the arithmetic mean of error. The low values of SD_1 and 95%ile error indicate the reliability of its results for prediction of SSI. Considering the above reasons, LIAI model appears to be in *close* agreement with the BFMM.

From the above observations, it is understood that, the variation of the error (%) in the attributed scores calculated using LIAI and OLDM with respect to BFMM is very large (-19.72% to 72.41%). This can result in projecting relatively unfavorable sites for their selection as TSDF. To illustrate this aspect, the variation of arbitrary variable (x) considered in the study with the attributed score for each attribute is calculated using all the three models (BFMM, LIAI & OLDM) and presented in Figures 4(a), 4(b), 5(a) & 5(b) respectively. It may be noted that, an additional point for LIAI is included in Fig.s 4 & 5 (i.e., 5 points for LIAI as against 4 points each for BFMM and OLDM respectively). It is to be remembered that, the LIAI model is developed based on the linear interpolation among the data points (see Fig.s 2 & 3) prescribed by the Guidelines for predicting the SSI. For comparison of the error in the prediction of attributed score, two arbitrary variables in each of the two linear models of LIAI for each attribute are chosen. The attributed score as shown in Fig.s 4 & 5 corresponds to those four arbitrary variables. The additional point of LIAI model reflects the critical point that can be considered as a "*link*" between the two linear models of LIAI for each attribute. The attributed score predicted to the left and right of these linear models of LIAI are linear as per the definition of LIAI model. This is clearly illustrated in the Fig.s 4 & 5. A small error in the attributed scores calculated using LIAI or OLDM can yield significant deviations with respect to those calculated from BFMM, since the SSI is multiplied with the weightage of the corresponding attribute. This enhances the error **significantly** and can be clearly seen in Fig.s 4 & 5. Similar trends are observed for the other attributes as well.

Fig.s 4(a), 4(b), 5(a) & 5(b)

It may be noted that, the BFMM developed for each attribute predicts the asymptotic SSI values of *1* and *0* for the corresponding variable respectively. For example, in the case of the attribute, distance to nearest drinking water source, the SSI values of *1* and *0* (i.e., upper and lower limits) correspond to a distance of *0 (zero)* m and *7100* m (i.e., variables) respectively. This is the additional advantage offered by BFMM of the present study, which is not included in the LIAI model (Guidelines, 1991). An overall examination of results summarized in Tables 3 and 4 and Figures 2 to 5 reveal that, the BFMM option is **superior** in terms of accuracy, simplicity, clarity, and reliability to the other two assumptions. In addition, the SSI can be easily predicted using the developed BFMMs, which are expressed in the form of polynomial equations.

ADVANTAGES OF THE PRESENT STUDY

The advantages that can be achieved from the present study are summarized below:

- Appropriate BFMMs (best-fit mathematical models) for prediction of SSI for each attribute are developed.
- Accuracy improvement on estimation of SSI using the proposed BFMM over the assumed linear interpolation among the intervals of the data points.
- The upper and lower limits for prediction of SSI can be clearly identified.
- The erratic prediction of SSI can be minimized. This is important in order to avoid an improper representation of attributed scores (on the same basis) for ranking of available sites. It may project relatively unfavorable sites to be a better option.
- The standard deviation (SD_1) for the data points considered under each attribute using the proposed BFMMs is very low (0.0297 to 8.0659×10^{-6}).

SUMMARY AND CONCLUSIONS

Proper treatment, storage prior to treatment or disposal and safe disposal of hazardous wastes is the need of the hour. However, the site(s) to be selected for this purpose should fulfil certain criteria. The methodology of site selection may differ from country to country. The Guidelines pertaining to the same purpose in India are considered and an attempt is made to improve upon a few aspects leading to ambiguity in the selection of a best site to be chosen as TSDF for hazardous waste management. A statistical regression analysis is carried out by developing best-fit mathematical model (BFMM) and is compared with the assumption (LIAI) under which the site is ranked as per the guidelines in India. The statistical regression analysis is also compared with another likely assumption (OLDM) under which the ranking of the sites may take place. The results are encouraging and revealed that, though the methodology given in the guidelines is *closely* matching with the present statistical analysis, the present study is superior in terms of reliability, accuracy and clarity over the prevailing assumptions. Moreover, the BFMMs proposed in the present study, also predict the asymptotic SSI values of *1* and *0* for all the attributes considered. The results of the second assumption (i.e., OLDM) are highly erratic and we recommend it to be discouraged from practicing it.

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Table-2 *Regression analysis based best-fit mathematical models (BFMMs) developed for the selected attributes*

Sr. No.	Attribute	Best-fit mathematical model (BFMM)	Coefficients of BFMMs
1	Distance to nearest drinking water source	$y = (a + bx + cx^2 + dx^3)$	$a = 1$; $b = -0.000291667$; $c = 4.5 \times 10^{-8}$; $d = -3.33334 \times 10^{-12}$
2	Distance to nearest off-site building	$y = (a + bx + cx^2)$	$a = 0.9$; $b = -0.000316667$; $c = 3.33333 \times 10^{-8}$
3	Population within 500 meters	$y = (a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gx^6 + hx^7 + ix^8 + jx^9)$	$a = -0.00436766$; $b = 0.00328853$; $c = -7.09652 \times 10^{-6}$; $d = 8.88113 \times 10^{-9}$; $e = -6.66002 \times 10^{-12}$; $f = 3.10438 \times 10^{-15}$; $g = -9.04904 \times 10^{-19}$; $h = 1059822 \times 10^{-22}$; $i = -1.55626 \times 10^{-26}$; $j = 6.36894 \times 10^{-31}$
4	Distance to nearest surface water	$y = (a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gx^6 + hx^7 + ix^8)$	$a = 1$; $b = -0.00062248$; $c = 2.77587 \times 10^{-7}$; $d = -7.02274 \times 10^{-11}$; $e = 1.03965 \times 10^{-14}$; $f = -9.20228 \times 10^{-19}$; $g = 4.79102 \times 10^{-23}$; $h = -1.35258 \times 10^{-27}$; $i = 1.59708 \times 10^{-32}$
5	Depth to groundwater	$y = (a + bx + cx^2)$	$a = 0.9$; $b = -0.0316667$; $c = 0.000333333$
6	Depth to bedrock	$y = (a + bx + cx^2)$	$a = 0.87605$; $b = -0.0439076$; $c = 0.000630252$
7	Soil permeability	$y = (a + bx + cx^2 + dx^3)$	$a = 1$; $b = -1.55952$; $c = -1.07143$; $d = 2.38095$
8	Precipitation effectiveness index	$y = (a + bx + cx^2)$	$a = -0.0716553$; $b = 0.0116374$; $c = -4.06901 \times 10^{-5}$

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

Sr. No.	Attribute	Standard deviation	
		BFMM	**OLDM**
1	Distance to nearest drinking water source	2.6940×10^{-4}	0.1370
2	Distance to nearest off-site building	8.0659×10^{-6}	0.0624
3	Population within 500 meters	0.0297	0.5842
4	Distance to nearest surface water	7.4487×10^{-4}	0.5407
5	Depth to groundwater	3.7700×10^{-6}	0.0624
6	Depth to bedrock	3.6127×10^{-6}	0.0557
7	Soil permeability	3.8150×10^{-6}	0.0729
8	Precipitation effectiveness index	1.3513×10^{-3}	0.1274

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

Sr. 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	Distance to nearest drinking water source	Receptor related	Greater than 5000 meters	2500 to 5000 meters	1000 to 2500 meters	Less than 1000 meters
2	Distance to nearest off-site building	Receptor related	Greater than 3000 meters	1500 to 3000 meters	500 to 1500 meters	Less than 500 meters
3	Population within 500 meters	Receptor related	Zero to 100	100 to 250	250 to 1000	Greater than 1000
4	Distance to nearest surface water	Pathway related	Greater than 8000 meters	1500 to 8000 meters	500 to 1500 meters	Less than 500 meters
5	Depth to groundwater	Pathway related	Greater than 30 meters	15 to 30 meters	5 to 15 meters	Less than 5 meters
6	Depth to bedrock	Pathway related	Greater than 20 meters	10 to 20 meters	3 to 10 meters	Less than 3 meters
7	Soil permeability	Pathway related	Greater than 50% clay	30% to 50% clay	15% to 30% clay	Zero to 15% clay
8	Precipitation effectiveness index	Pathway related	Less than 31	31 to 63	63 to 127	Greater than 127

Note: Precipitation Effectiveness Index is the sum of the twelve monthly rates of total monthly precipitation to total monthly evaporation. The value of the index is used to classify the regions into Wet (greater than 127), Humid (63 to 127), Sub-humid (31 to 63), Semiarid (16 to 31) and arid (less than 16).

Table-3 *Comparison of attributed scores using the three models*

Sr. No.	Attribute	Weightage, points	Best-fit mathematical model (BFMM)	Arbitrary variable, x	SSI due to best-fit	Attributed score due to BMFM	Attributed score due to OLD model	Attributed score due to LIAI model
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7) = (3) x (6)*	*(8)*	*(9)*
1	Distance to nearest drinking water source	60	3rd degree polynomial	1500 m	0.65	39.15	42.95	40.00
				2600 m	0.49	29.22	33.36	31.00
				3000 m	0.44	26.40	29.87	27.00
				4000 m	0.34	20.40	21.14	21.00
2	Distance to nearest off-site building	40	2nd degree polynomial	800 m	0.67	26.72	26.84	27.00
				1200 m	0.57	22.72	23.68	23.00
				2000 m	0.40	16.00	17.37	16.67
				2500 m	0.32	12.67	13.42	13.33
3	Population within 500 meters	80	9th degree polynomial	175	0.40	31.65	37.24	30.01
				225	0.46	36.96	37.98	36.66
				500	0.64	51.50	42.06	46.67
				750	0.71	56.41	45.78	53.34
4	Distance to nearest surface water	55	8th degree polynomial	750 m	0.66	36.45	38.42	37.81
				1250 m	0.54	29.77	37.37	30.94
				3000 m	0.39	21.19	33.68	24.33
				6000 m	0.29	15.99	27.36	17.98
5	Depth to groundwater	45	2nd degree polynomial	8 m	0.67	30.06	30.20	30.38
				12 m	0.67	25.56	26.64	25.88
				20 m	0.40	18.00	19.54	18.75
				25 m	0.32	14.25	15.10	15.00
6	Depth to bedrock	20	2nd degree polynomial	5 m	0.67	13.45	13.49	13.57
				7 m	0.60	12.00	12.33	12.14
				12 m	0.44	8.80	9.42	9.00
				16 m	0.33	6.70	7.09	7.00
7	Soil permeability	25	3rd degree polynomial	0.20 or 20%	0.66	16.61	17.04	16.67
				0.25 or 25%	0.58	14.51	15.16	14.58
				0.375or37.5%	0.39	9.75	10.45	10.16
				0.425or42.5%	0.33	8.16	8.56	8.60
8	Precipitation effectiveness index	25	2nd degree polynomial	40	0.33	8.21	8.27	8.01
				50	0.41	10.21	9.53	9.96
				80	0.60	15.00	13.30	14.16
				110	0.72	17.90	17.06	17.09