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CLOSURE OF MUNICIPAL SOLID WASTE DUMPS. SITE RATING FOR ODOR IMPACT

More than 60% of the waste dumps in India are within 500 m from the communities. The odor impact from these sites may be the sole criterion to prioritize these sites for closure/remediation. The existing rating systems do not consider odor impact in their assessment. A new system, proposed in the study, employs seven parameters derived from the literature review and selects their ratings based on data obtained from a survey of waste dumps in Indian cities having population more than one million and expert judgment. Application of the new system to the waste sites with continuously varying characteristics shows that the scores are spread over the full range of 0–1000 and have minimum clustering. The sensitivity analysis of the new system shows that the system exhibits medium to high sensitivity to five out of seven parameters employed in the system. The odor impact ratings for the fifteen waste dumps from the new system prioritize these dumps into three categories for remedial action and help suggesting a particular cover alternative for these dumps.

1. WASTE DUMPS – GLOBAL AND INDIAN SCENARIO

When it comes to waste disposal, landfilling and thermal treatment are the most common methods used in high-income countries in the world. For low-income countries, most of the waste is disposed in waste dumps. In India, about more than 80% of municipal solid waste (MSW) is disposed in waste dumps [1]. From amongst 7000 cities and towns having population in excess of 5000, well designed engineered landfills have started only in a dozen large metropolitan cities and disposal in open dumps continues abated.

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A study published in 2014 [2] surveyed 50 biggest waste dumps across the world. The areas of these waste dumps vary from more than 2 ha to 235 ha (Table 1). More than 60% of these waste dumps have areas less than 60 ha. The waste quantities in these dumps vary from less than a million to more than 10 million ton(s). Consequently, more than 55% of the dumps have waste quantities less than 5 million t. The waste dump site with the biggest area is reported in Reque, Peru with an area of 235 ha [2]. The second and third largest dump sites are in Surjani, Pakistan (202 ha) and Dakar, Senegal (175 ha), respectively [2].

Table 1

Site area, waste quantity and proximity to community for biggest waste dumps in the world [2] (total number of sites – 50)

Area [ha]		Quantity [million ton]		Proximity to community [m]	
Range	Percent of dump sites	Range	Percent of dump sites	Range	Percent of dump sites
0–20	41	0–1	13	0–500	29
20–40	24	1–5	45	500–2000	49
40–60	12	5–10	24	>2000	22
>60	22	>10	18		

In India, a recent study of 62 waste dumps [3] in 53 cities of population above 1 million revealed that the areas of waste dumps vary from 1 ha to 120 ha (Table 2). The largest base area in India is 120 ha for a waste dump in Mumbai. About 72% of the waste dumps in Indian cities have areas less than 20 ha and the waste quantities vary from less than a million to more than 10 million ton(s). Consequently, about 69% of the dumps have waste quantities less than 1 million t.

Table 2

Waste quantity and proximity to community for waste dumps from million plus cities of India [3] (total number of sites – 62)

Area [ha]		Quantity [million ton]		Proximity to community [m]	
Range	Percent of dump sites	Range	Percent of dump sites	Range	Percent of dump sites
0–20	72	0–1	69	0–500	62
20–40	15	1–5	23	500–2000	28
40–60	4	5–10	6	>2000	10
>60	9	>10	2		

To begin with, waste dumps are located far away from community boundaries. However, as cities and towns grow, these dumps come close to or become engulfed by local communities. As far as distance to community is concerned, across the world it varies from 100 m to 7000 m for the biggest waste dumps. About 50% of these waste dumps are located within 500 m of community [2]. In India, the distance to nearest community for these waste dumps varies from less than 500 m to more than 2000 m and more than 60% are located within 500 m of community [3] causing severe public outcry, time and again, due to bad odor and other environmental issues.

2. ODOR IMPACTS OF MSW DUMPS

The environmental impacts resulting from dumps are: groundwater contamination, odor nuisance, surface water contamination, release of greenhouse gases, fire, smoke, explosion, mosquitoes, pests and rodents, slope instability, and bird hit [4]. The recurring and hence the most important impacts amongst these are groundwater contamination, surface water contamination and odor nuisance. Remediation/closure of these dumps is inevitable in order to avoid further damage to the ecosystems.

Odors emanating from solid waste sites are the major cause of complaints from nearby population to local authorities [5]. It is very much possible that a number of common atmospheric pollutants are generally not perceived by population, even if normal exposure limit concentrations are exceeded. On the contrary, some odors are perceived far below normal exposure limit concentrations, due to the presence of odorous compounds having extremely low odor detection threshold concentration [5]. Odors cause a variety of undesirable reactions in people. These reactions vary from emotional stresses such as unease, discomfort, headaches, or depression to physical symptoms including sensory irritations, headaches, respiratory problems, nausea, or vomiting. They also lead to psychological stress and symptoms such as insomnia, loss of appetite and irrational behavior. Subirritant levels of odorants may trigger acute symptoms through non-toxicological mechanisms. These mechanisms include innate odor aversions, stress induced illness and mass psychogenic illness [6]. Depression of real estate prices in nearby areas [7] is also significant fallout of the odor. Therefore, odor nuisance may be a suitable criterion to decide the priority of closure of waste dumps.

Odor is generated differently from old waste and fresh waste. The compounds of interest accrue from biodegradables and hazardous fraction of the waste. From the biodegradable fraction, the compounds of concern to odor problem are organosulfur compounds, oxygenated compounds, volatile fatty acids, amines, aromatics and halogenides [8]. The volatilization of the organic compounds from hazardous waste is the main pathway for the odorous emissions from the hazardous component of the waste [9], however the hazardous fraction is insignificant in municipal solid waste. The odor nuisance from construction and demolition (C&D) waste has been observed to be insignificant [10].

The most important parameter affecting production of gas from biodegradation is the amount of moisture infiltrated into the waste through the cover [11]. For gas generation, it is not just the total moisture content but moisture movement is also an important parameter stimulating the gas production [12]. The effect of temperature on methane production has been studied by a number of researchers [13]. However, for waste mass in landfills, at depths exceeding 2 m, the temperature was found to be independent of the ambient air temperature [14]. The temperature of the anaerobic zone may thus regulate at around the optimum of mesophilic digestion at 35 °C and hence for waste degradation in dumps, temperature may not be a controlling parameter.

A complex terrain may result in pollutant build-up due to inhibition of the pollutant dispersion. Hence, the pollutant may be confined within the low-lying areas, resulting in higher odor nuisance [15]. Aatamila et al. [16] investigated the odor annoyance from waste treatment centers in Finland and found that for the communities within 1.5–3 km of the facility, majority of the residents (57–100%) were annoyed by the odors from the waste facilities. However, within 3–5 km of the facility, much lower fraction of the population was annoyed from the odor of the facility. Other studies also report the odor nuisance from waste sites within the same distances [17].

3. SITE RATING FOR ODOR IMPACT AND CLOSURE

Government organizations in developing countries at the national level, state level, and city level are according high priority for remedial measures of MSW dumps. The professional organizations are bringing out publications to create awareness and provide guidance on the issue [2, 18]. Application of remedial measures has to be carried out in a phased manner with dumps causing larger impact receiving higher priority. A system for prioritization of sites for remedial action according to a specific hazard is an important requirement for decision-makers. As a result of proximity of these dumps to communities, control of odor and provision of aesthetic covers over these dumps receive higher priority amongst residents in comparison to control of groundwater and surface water pollution [19].

Relative hazard assessment methodologies, commonly referred to as ranking or rating systems, evaluate waste sites relative to a hypothetical base site. For the purpose of prioritization or ranking of waste disposal sites for remedial action, hazard rating systems are considered more suitable owing to their simpler and quicker methodology. Hazard rating systems are often based on structured-value approach [20]. A structured-value approach incorporates in a mathematical framework the major input factors that determine impacts and risk, but it does so in a heuristic manner. Field data and qualitative judgment are used to assign scores for different levels of the input factors, and these scores are combined mathematically to obtain an overall score for a particular potential impact. In the situations when priority setting is lone objective, and the formal risk analysis may prove time consuming and cost-intensive, the structured-value scoring methods are more suitable.

Singh et al. [21] reviewed seventeen existing hazard rating systems for ranking of hazardous and/or municipal waste sites from literature. The existing systems evaluate a hazard score for one or more hazard migration route(s), namely groundwater, surface water, air or soil. Out of these eighteen rating systems, nine systems are able to assess air contamination hazard from waste sites. However, these rating systems do not have mechanism to assess odor impact [22]. So, a new rating system for assessment of odor impact from waste dumps is need of the hour, and this study is intended at developing a relative rating system to assess odor impact potential from MSW waste sites.

4. FRAMEWORK FOR THE NEW RATING SYSTEM

The framework of the new system is derived from the hazard rating systems already developed by Singh et al. [21] and Kumar et al. [23]. For this study, source refers to a dumpsite and is characterized by parameters dealing with odor generation (Fig. 1). Pathway refers to the course followed by the odorous emissions while migrating from source to receptor, and is described by the major characteristics that govern their dispersion. Receptors are defined as nearby residents being affected by the impact.

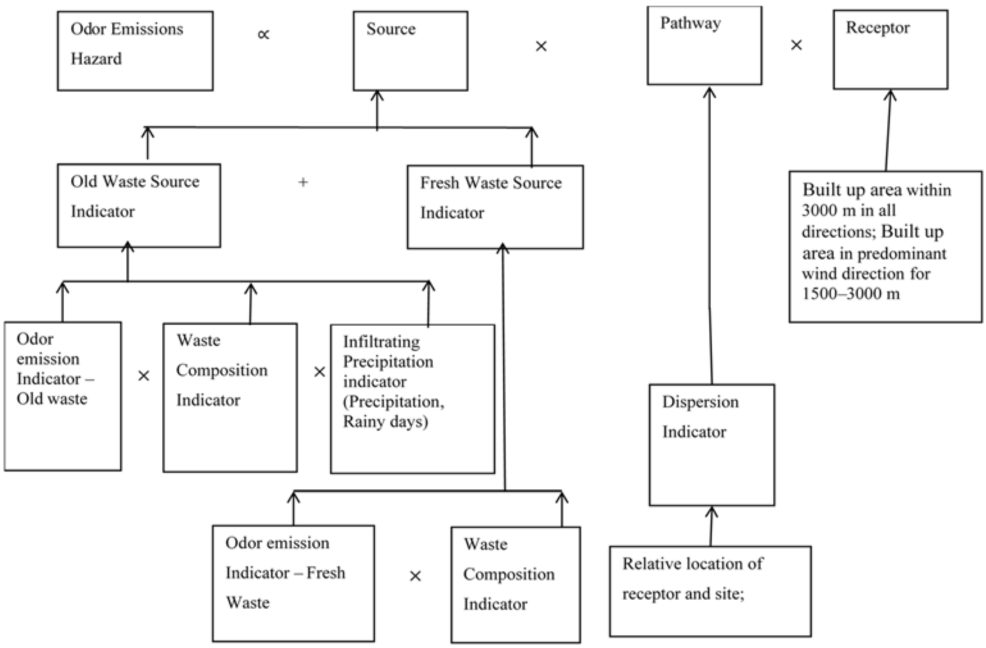

Fig. 1. Conceptual diagram for the framework of the odor impact rating system

To determine hazard rating of a waste site, source, pathway and receptor ratings are combined by a suitable scoring algorithm. Mainly three types of scoring algorithms are in use by existing rating systems: additive, multiplicative and additive-multiplicative. In general, additive algorithms exhibit the least sensitivity and multiplicative algorithms show the highest sensitivity. The sensitivity of additive-multiplicative lies in between the two [21]. The proposed system makes use of multiplicative and additive-multiplicative scoring algorithms.

For a hazard to exist, hazard chain of source, pathway and receptor should be complete. For hazard evaluation, each of the three components is based on a relative scale based on the measurement of its various characteristic parameters. In the new system, waste site rating is based on the methodology given by [21]:

$$HR \propto H_S \times H_P \times H_R$$

where HR is the hazard rating, H_S is the source rating, H_P is the pathway rating, and H_R is the receptor rating.

5. GUIDING PRINCIPLES

The evaluation of each of the three components is based on the following observations:

- The larger the quantity of waste, the greater the odorous emissions to the atmosphere are; hence the greater is the odor impact.
- A smaller waste site located in densely populated area gives an odor impact which is higher than a larger site in a remote location.
- The greater is the quantity of fresh waste disposed per day on the site, the greater are the odorous emissions; hence the greater is the odor impact.
- The larger the percentage of biodegradable fraction in MSW, the greater the odorous emissions are.
- The greater the precipitation, the greater the generation of gas and odor is; hence the greater is the odor impact.
- The lesser the dispersion of the odorous emissions, the greater the odorous nuisance is; hence the greater is the odor impact in low-lying area.
- The odor from a waste site has significant impact on population within a radius of 1.5 km. Thereafter, the impact reduces and becomes insignificant after the 3 km radius from the site.
- In the direction of the predominant wind, the impact is still significant for the population till 3 km radius.
- The denser the population within 3 km of the waste site, greater the number of people affected are; hence the greater is the odor impact.

The rating systems use parameters depending on their purpose, e.g., systems intended to assess hazardous waste sites consider toxicity of the most hazardous compound while rating systems formulated for waste dumps consider waste composition. In the present study, source rating has been considered a function of area under old waste, area under fresh waste, waste composition, rainfall and number of rainy days. Pathway rating has been considered a function of the relative location of receptor with respect to MSW site. Receptor rating has been considered a function of population density within 3 km radius of the site.

6. SYSTEM DEVELOPMENT

Source refers to the parameters affecting the quantum of odorous emissions from the waste disposed on the site. Source rating is mainly dependent on the area of waste site being used for disposal [24]. The areas under old waste and fresh waste contribute differently to the odorous emissions [17, 24]. For area of the old waste, the study assumes the total waste quantity deposited on the site as the surrogate parameter. For area under the fresh waste, the total quantity of waste received in a year is taken as the parameter as the gaseous emissions peak in a year after deposition [25].

The emissions quantity indicator denotes the relative quantity of odorous emissions from the waste. Emission quantity indicators are considered separately for the old waste and fresh waste. Source rating also considers the composition of the waste and annual rainfall received by the site.

The source rating in the case of odor emissions rating is proposed as:

$$H_{s,\,\mathrm{odr}} = H_{s,\,\mathrm{odr,\,old}} + H_{s,\,\mathrm{odr,\,fresh}} \tag{1}$$

$$H_{s,\,\mathrm{odr,\,old}} = E_{qi,\,\mathrm{old}} \times W_{ci,\,\mathrm{odr}} \times I_{pi,\,\mathrm{gas}} \tag{2}$$

$$H_{s,\,\mathrm{odr,\,fresh}} = E_{qi,\,\mathrm{fresh}} \times W_{ci,\,\mathrm{odr}} \tag{3}$$

where, $H_{s,\,\mathrm{odr}}$ is the total source rating for odor generation, $H_{s,\,\mathrm{odr,\,old}}$ – source rating from old waste, $H_{s,\,\mathrm{odr,\,fresh}}$ – source rating from fresh waste, $E_{qi,\,\mathrm{old}}$ – emissions quantification indicator for old waste (Table 3), $E_{qi,\,\mathrm{fresh}}$ – emissions quantification indicator for fresh waste (Table 4), $W_{ci,\,\mathrm{odr}}$ – waste composition indicator for odor (Table 5), $I_{pi,\,\mathrm{gas}}$ – infiltrating precipitation indicator for gas (Table 6). The indicator for fresh waste does not include precipitation because the incoming waste in developing countries is laden with moisture [25] and does not need extra moisture for waste degradation during the first year.

Table 3

Indicator for old waste quantity ($E_{qi,\text{ old}}$)

Waste quantity [million t]	Rating
0.2–1	600
1–2	650
2–3	700
3–4	750
4–5	800
5–6	850
6–7	900
7–8	950
>8	1000

Based on expert judgment.

Table 4

Indicator for fresh waste ($E_{qi,\text{ fresh}}$)

Fresh waste (t/day)	Rating
0–300	125
300–600	150
600–900	175
900–1200	200
1200–1500	225
1500–1800	250
1800–2100	275
2100–2400	300
2400–2700	325
2700–3000	350

Based on expert judgment.

Table 5

Waste composition indicator (W_{ci})

Biodegradable fraction, %	40–50	50–60	60–70	70–80
Rating	0.85	0.90	0.95	1

Based on expert judgment.

The waste composition indicator for odor is based on the fraction of biodegradable waste present in the waste. It varies between 0.85 and 1 for the waste having fraction of biodegradables components between 40 and 80%.

The infiltrating precipitation indicator for gas indicates the fraction of rainfall infiltrating into the waste. Moisture movement in a landfill may be stimulated by rainfall events. To account for moisture movement inside the waste, number of rainy days in a year has been taken as a surrogate parameter. Infiltrating precipitation indicator varies between 0.65 and 1.25.

Table 6

Infiltrating precipitation indicator for gas ($I_{pi,\,\mathrm{gas}}$)[a]

Annual rainfall [mm]	Number of rainy days			
	10–40	40–80	80–120	120–160
100–400	0.65	0.70	0.70	0.70
400–800	0.70	0.75	0.85	0.85
800–1200	0.70	0.80	0.95	1.05
1200–1600	0.70	0.85	1.05	1.15
1600–2000	0.70	0.90	1.15	1.25

Based on expert judgment.

The maximum value of the source rating is limited to 1000 for a municipal waste site.

Pathway refers to the emissions control by the cover systems installed, if any and the dispersion of the odorous emissions before it reaches the receptor by the relative location of waste site with respect to receptor. The pathway rating is proposed as:

$$H_{p,\,\mathrm{odr}} = OD_i \times C_{gi} \tag{4}$$

where, OD_i is the odor build-up indicator, C_{gi} – gas emissions control by the cover type installed. As the waste dumps do not have any cover installed, the value of C_g will remain 1.0.

The odor build-up indicator indicates the dispersion of the odor in the atmosphere between site and receptor, due to topography. In case a waste site and nearby receptors are situated in a low-lying area, the odor impact is maximum as the odorous emissions get trapped in the low-lying area. On the contrary, when the site is situated on an elevated area, then it would result into the odor impact being minimized on the nearby receptors. Three scenarios have been postulated for the dispersion: (i) the worst scenario – receptor and waste dump are co-located in a low-lying area (ii) the best scenario – waste dump is located higher than the receptor (iii) in-between scenario – waste dump is located at plain ground along with the receptors. The values of odor build-up indicator for various scenarios vary between 0.6 and 1 (Table 7).

Receptor refers to the population of human beings in the near vicinity of a waste site. Odor regulations in a number of countries consider the population density in determination of odor impact [26]. The new system assumes that the receptor rating depends on population density within 3000 m of the waste site. The proposed system considers population density around the waste site in terms of built-up area within 0–1500 m and

1500–3000 m of the site. For the distance of 1500–3000 m, it also takes into account the presence of receptor in the direction of predominant wind [17].

Table 7

Odor dispersion indicator for various types of dispersion scenarios (OD_i)

Dispersion scenario (relative location of dump with respect to receptor)	Odor dispersion indicator
Worst scenario (low-lying)	1
In-between scenario (plain ground)	0.9
Best scenario (elevated)	0.6

Based on expert judgment.

The receptor rating is proposed as:

$$H_{R,\text{odr}} = PD_{0\text{–}1500} + PD_{1500\text{–}3000} \times D_i \tag{5}$$

where PD_i is the indicator for the population density within 0–1500 m and 1500–3000 m distance around the waste site in all directions. D_i is the indicator for the presence of built-up area in the direction of predominant wind direction.

Table 8

Indicators for receptor rating of the odor impact rating

Receptor indicator	Rating
Built up area within 0–1500 m ($PD_{0\text{–}1500}$) in all directions, %	
5–20%	0.35
20–50%	0.55
>50%	0.75
Built up area within 1500–3000 m ($PD_{1500\text{–}3000}$) in all directions	
5–20%	0.15
20–50%	0.20
>50%	0.25
Indicator for predominant wind direction (D_i)	
Receptors in predominant wind direction within the distance of 1500–3000 m (yes/partly/no)	1.0/0.85/0.70

Based on expert judgement.

If the built-up area is less than 5%, the receptor indicator will be 0.1 for 0–1500 m as well as for 1500–3000 m.

The population density within 0–1500 m and 1500–3000 m of the landfill site are defined by the percentage of the built-up area within the area with more than 50% being dense, from 20 to 50% indicating medium, and less than 20% indicating sparse density of population. The ratings, based on expert judgment, differ on the basis of population density and distance from the waste site (Table 8).

The overall impact rating similar to [21] is proposed as:

$$HR_{\mathrm{odr}} = \frac{H_{s,\ \mathrm{odr}} H_{p,\ \mathrm{odr}} H_{r,\ \mathrm{odr}}}{SF_{\mathrm{odr}}} \times 1000 \tag{6}$$

The scaling factor, SF_{odr}, is equal to the product of the source, pathway, and receptor ratings of a waste disposal site having all its parameters at the worst values. The function of scaling factor is to bring the value of rating to a predefined scale (i.e., 0–1000 in the present study). All the existing rating systems use scaling factor to convert the ratings to a specific scale [21]. The value of scaling factor, SF_{GHG}, is equal to 1. The maximum value of odor impact rating is limited to 1000. The best and worst values of different parameters are shown in Table 9.

Table 9

The best and worst values of site parameters for the odor impact rating system

System No.	Waste site parameter	Best value	Worst value
1	waste quantity, million t	≤0.2	≥8
2	annual rainfall, mm	≤100	≥2000
3	number of rainy days	≤10	≥160
4	fresh waste disposed, t/day	0	≥1000
5	biodegradable waste fraction, %	≤40	≥80
6	dispersion scenario	best (elevated)	worst (low-lying)
7	population density (within 1500 m and 1500–3000 m)	Nil (<5% of built-up area)	high (>50% of built-up area)

7. VALIDATION OF THE PROPOSED SYSTEM

The proposed system has been validated by considering three criteria: range of resulting scores, clustering index and sensitivity analysis. The performance of the rating systems can be measured in terms of spread in the value of the scores for the waste sites with continuously varying characteristics (from the best to worst scenario) [21]. Another indicator for performance measurement is the clustering index, a parameter for measuring uniformity of spread of scores across the range between the minimum and maximum possible value of the scores [23]. Sensitivity analysis of the system indicates the response of the system to the variation in the values of the individual parameters.

The new rating system was applied to a set of waste sites having continuously varying characteristics (Table 10). Sites from HAC-1 to HAC-6 have continuously varying characteristics making these sites increasingly potentially hazardous in terms of odor impact. The area and waste heights used for the waste sites are based on a country-wide survey of waste dumps from million-plus cities of India [23]. The values for rainfall are based on the ranges of annual rainfall employed by the existing rating systems [21, 27]. The dispersion scenario varies from the best to worst, i.e., waste site located at an elevation with respect to receptors in the best scenario and, for the worst scenario, waste site and receptors are co-located in a low-lying area. Receptor scenarios indicating various levels of population density are taken from the conditions existing around the waste dumps in India.

Table 10

Characteristics of waste sites with continuously varying characteristics for determination the odor impact rating from the new rating system

Parameter	Site					
	HAC-1	HAC-2	HAC-3	HAC-4	HAC-5	HAC-6
Landfill area, ha	5	10	15	20	25	30
Landfill height above ground, m	5	10	15	15	20	20
Fresh waste disposed, ton/day	0.0	300	600	1200	1500	2000
Biodegradable fraction, %	40	50	60	70	75	80
Rainy days	30	40	50	60	60	100
Annual rainfall, mm	500	750	1000	1000	1250	1500
Cover type	none					
Dispersion scenario	elevated		plain	low-lying		
Built-up area, within 3000 m	sparse	sparse	medium	medium	dense	dense
Receptors present in prominent wind direction	no				yes	

The scores given by the new system are in the range of 97–1000 (Table 11, Fig. 2), which is practically the full range of the system. Furthermore, the ratings of the source, pathway and receptor continuously increase with the change in site characteristics. The set of scores obtained for the waste sites from the new system are also assessed using clustering index [23]. The clustering index is an indicator of the spread of results over the full-scale; a lower value indicates better spread. The clustering index for the scores from the new system is 0.15 on a scale of 0–1. This low value of the clustering index further corroborates the fact that the scores are spread evenly over the entire scale of 0–1000 and the new system responds to the changes in site conditions.

Sensitivity analysis reflects the variation induced in the output, i.e., hazard rating of a site by changes in the input parameters. The process of sensitivity analysis involves assuming a base case of a waste site and, then recording the changes in hazard ratings of the base case in response to a specified change in individual parameters. The observed change in hazard rating of base case is evaluated in percent and forms the sensitivity of a rating system to a particular parameter.

Table 11

Odor impact ratings for waste sites with continuously varying characteristics from the new rating system

Rating	Site					
	HAC-1	HAC-2	HAC-3	HAC-4	HAC-5	HAC-6
Source rating	357	518	637	760	905	1000
Pathway rating	0.60	0.60	0.90	1.00	1.00	1.00
Receptor rating	0.46	0.49	0.73	0.73	0.80	1.00
Odor impact rating	97	152	415	551	724	1000

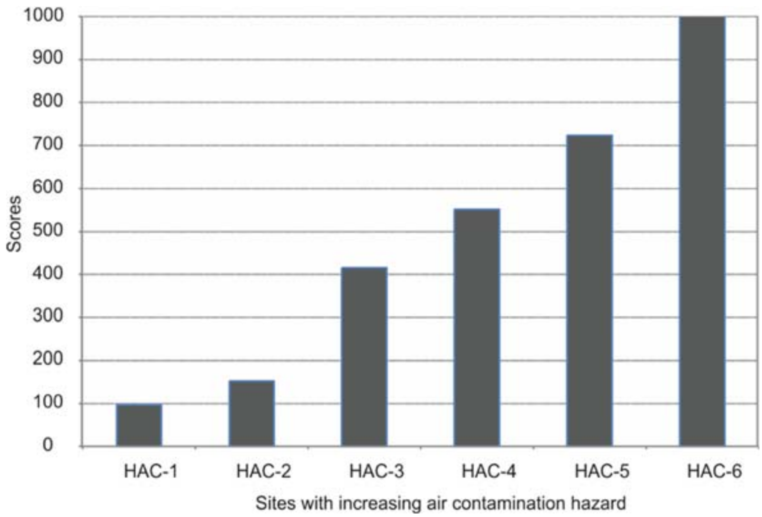

Fig. 2. Odor impact ratings for waste sites with continuously varying characteristics from the new rating system

To perform sensitivity analysis, a site having values of all the parameters, as provided in Table 12, was assumed as the base case. The values for six parameters, i.e., the site area, waste height, quantity of fresh waste disposed/day, biodegradable fraction, rainy days and annual rainfall were varied by ±50%. The remaining two parameters i.e. dispersion scenario and receptor were varied from their best to worst values. For variation in each parameter, the respective change in odor impact rating was recorded (Table 13). The system is most sensitive to the changes in receptors' scenario. The total change is about 115% in the impact rating score, when the receptor scenario changes from the best to worst. A number of researchers emphasized the importance of population density in odor impact assessment [5, 26].

Table 12

Parameters of the base case for sensitivity analysis of the new rating system

System No.	Waste site parameter	Base case value
1	waste quantity, million t	1
2	annual rainfall, mm	550
3	rainy days	55
4	biodegradable waste, %	60
5	fresh waste disposed, t/day	500
6	dispersion scenario	middle scenario (plain ground)
7	population density (within 1500 m)	medium (20–50% built-up area)
8	population density (within 1500–3000 m)	medium (20–50% built-up area)

Table 13

Results of the sensitivity analysis of the new rating system

Base case scenario		Best and worst values for the parameter (change as percent of full range)	Resultant hazard score[a] (% change) New system		Total change [%]
Site parameter	Value		Rating	Change [%]	
Waste quantity million t	1	a) 0.5 (–50%)	339	–6.1	6.1
		b) 1.5 (50%)	361	0.0	
Fresh waste disposed/day	500	a) 250 (–50%)	347	–4.1	8.2
		b) 750 (50%)	376	4.1	
Biodegradable fraction	60	a) 30 (–50%)	323	–10.5	15.8
		b) 90 (50%)	380	5.3	
Rainy days	55	a) 28 (–50%)	304	–15.9	37.1
		b) 83 (50%)	438	21.2	
Annual rainfall, mm	550	a) 275 (–50%)	323	–10.6	15.9
		b) 825 (50%)	381	5.3	
Dispersion scenario	plain ground[b]	a) elevated	241	–33.3	44.4
		b) low-lying	401	11.1	
Best/worst receptor	medium (20–50% built-up area)[b]	a) sparse	107	–70.3	115.2
		b) dense	524	44.9	

[a]Score for the base case – 361.
[b]Determining percent change of the value is not possible.

The other parameters for which the system shows high sensitivity (more than 30% change in impact rating) are the dispersion scenario and rainy days. The total change in odor impact rating is about 44% when the value of dispersion scenario changes from the best to the worst value. A number of studies emphasize the importance of dispersion scenario [15] in affecting the dispersion of gaseous emissions. The sensitivity for rainy days comes out to be 37%, suggesting the importance of moisture movement in gas generation in the waste [12].

The change in hazard rating is about 16% for ±50% variation in annual precipitation as well as for the waste composition. Moisture availability in waste mass has been known to stimulate the gas production [11]. The waste composition has been known to affect the relative composition of landfill gas from the waste [8].

The changes in the hazard rating with respect to variations in waste quantity and fresh waste disposed are 6.1% and 8%, respectively. Although the quantities of old waste are much larger as compared to the fresh waste at a site, the emissions from fresh waste per unit area are much higher than the old waste [24].

8. RESULTS. APPLICATION TO 15 WASTE DUMPS

To evaluate the performance of the new system, fifteen MSW dumps were selected from India and other developing countries (Tables 14, 15). All the dump sites are uncontrolled, do not have any covers and liners and are currently in operation except the one, i.e., dump A which is no longer operational. The site areas vary from less than 10 ha to more than 200 ha. The new system was applied to these fifteen dumps to determine their odor impact rating (Tables 16, 17, Fig. 3).

Table 14

Site characteristics of the MSW dumps from Indian cities

Parameter	Dump									
	A	B	C	D	E	F	G	H	I	J
Region of India	Central		Western	South		Eastern	Western	North		
Landfill area, ha	8	21.5	28	81	81	21.4	120	16.2	13	29.8
Landfill height, m	16	5	24	8	6.4	24	15	32	48	32
Fresh waste disposed, t/day	0	800	2000	2600	2300	3500	4000	1800	600	2500
Biodegradable fraction	43	48	43	41	41	51	43	50	40	61
C&D waste	20	20	20	20	20	30	20	16	20	16
Annual rainfall, mm	950	1050	803	1200	1200	1650	2400	721	721	721
No. of rainy days	70	72	59	120	120	115	80	61	61	61
Dispersion scenario	plain									
Built up area (within 1500 m), %	5–20	20–50			>50	<5	20–50	>50	20–50	>50
Built up area (1500–3000 m), %	5–20	>50				5–20				>50
Receptors in the predominant wind direction	no			yes		no	yes	partly	no	yes

Table 15

Site characteristics of the MSW dumps in other countries [2]

Parameter	Dump				
	K	L	M	N	O
City, country	Ibaden, Nigeria	Dandora, Kenya	Surjani, Pakistan	Lahore, Pakistan	Santo Domingo, Dominican Republic
Landfill area, ha	14	53	202	25.5	128
Landfill height, m	4	56	10.6	33	17
Fresh waste disposed, t/day	115	2355	380	1590	3870
Biodegradable fraction	50	70	50	67	61
C&D waste	12	8	15	6	8
Annual rainfall, mm	1120	926	237	630	1370
No. of rainy days	94	89	36	71	110
Dispersion scenario	plain				
Built up area (within 1500 m), %	>50	>50	<5	20–50	<5
Built up area (1500–3000 m), %	>50	>50	<5	20–50	5–20
Receptors in the predominant wind direction	yes				

Table 16

Odor impact ratings of the MSW dumps from Indian cities by using the new system

Rating	Dump									
	A	B	C	D	E	F	G	H	I	J
Source	442	567	791	1000	1000	1000	1000	808	675	1000
Pathway	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Receptor	0.46	0.80	0.73	0.80	1.00	0.21	0.75	1.00	0.69	1.00
Odor impact	181	408	516	720	900	185	675	727	419	900

A majority of the waste dumps show high score (above 500) indicating that bad odor is a significant problem in vicinity of waste dumps in these cities. The odor impact ratings of dumps E, J and L are the highest amongst these nine dumps. These dumps are situated in densely populated areas, receive more than 2000 t of fresh waste every day and receive medium to high rainfall. Dumps A and M have the lowest ratings of 166 and 153, respectively. Dump A is a smaller and abandoned waste dump located in a sparsely populated area. Although dump M is the second largest waste dump in the world [2] in terms of site area, still it has the low rating because of its location in an area with insignificant population within the vicinity of 1500 m as well as 1500–3000 m. Additionally, the site also receives scanty rainfall.

Table 17

Odor impact ratings of the MSW dumps
from other countries by using the new system

Rating	Dump				
	K	L	M	N	O
Source	603	1000	653	900	1000
Pathway	0.90	0.90	0.90	0.90	0.90
Receptor	1.00	1.00	0.17	0.75	0.25
Odor impact	543	900	100	608	225

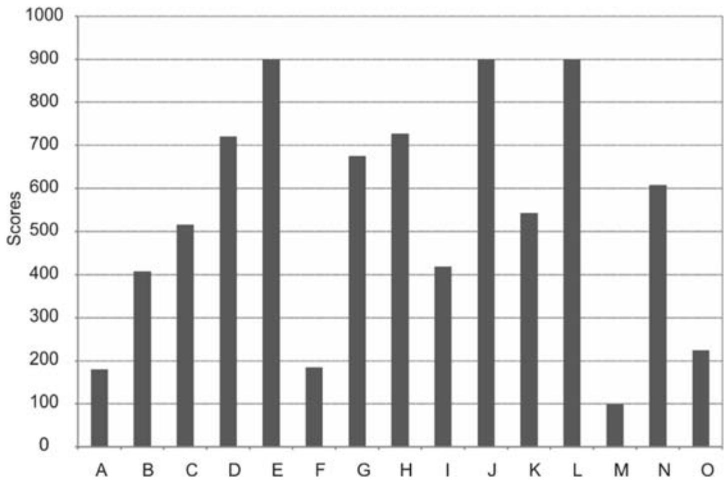

Fig. 3. Odor impact ratings of the fifteen waste dumps using the new system

Dumps B and I with the impact ratings of 408 and 419, respectively, are two sites having ratings in the middle range of 250–500. These sites have from medium to high waste quantities, receive medium quantity of waste and from medium to high annual rainfall. Within 0–1500 m of the sites, the built-up area is within 20–50% and there are no receptors in predominant wind direction.

9. PRIORITIZATION AND RESPONSE LEVELS FOR CLOSURE OF WASTE DUMPS

The odor impact ratings can be used to prioritize these waste dumps for remedial action and also to prescribe the cover type to be installed on the site. The waste dumps can be prioritized according to their scores: site requiring attention immediately (hazard rating more than 500), site requiring attention in short-term (hazard rating between 250 and 500), site requiring attention in long-term (hazard rating between 0 and 250).

The odor impact ratings can also be used to suggest a closure alternative. Four different alternatives of the cover system are proposed:

- regrade and a cover with local soil for odor rating of 0–250,
- regrade and a cap with a multilayer cover of clay soil with compost windows for odor rating of 250–500,
- regrade and a cap with a multilayer cover of clay soil and a geomembrane with compost windows for odor rating of 500–750,
- regrade and a cap with a multilayer cover of clay soil and a geomembrane with active gas collection and a flaring/utilization system for odor rating of 750–1000.

Amongst the fifteen waste dumps studied, nine dumps have score more than 500 and should be accorded immediate priority for remediation. Out of these, three dumps (E, J, and L) with ratings more than 750 may be capped with a clay soil and geomembrane cover with active gas collection system. The remaining six waste dumps having scores in the range of 500–750 may be installed with a multilayer cover of clay soil and a geomembrane with compost windows.

Two dumps (B and I) in the medium range (250–500) represent short-term priority for remediation. These two dumps may be capped with a multilayer cover of clay soil with compost windows. The dumps requiring attention in the long-term are dumps A, F, M and O which may be installed with a local soil cover.

10. CONCLUSIONS

The study focuses on waste dumps in developing countries having conditions similar to Indian ones. A system has been developed on the basis of data from cities having population in excess of 1 million. Following are the conclusions from the study:

- In India, more than 60% of the waste dumps are located within 500 m of the communities. Across the world in developing countries, about 50% of the biggest waste dumps are situated within 500 m of the communities.
- As a consequence to the closer vicinity between waste dumps and communities, odor impact becomes very important in the hierarchy of hazards and hence can be used as a sole criterion for prioritizing these waste dumps for closure.
- Existing rating systems for site prioritization do not have mechanism to assess relative odor impact, so a new system is required for assessment of relative odor impact from waste dumps.
- A new system for prioritization of waste dumps has been proposed in the study. The new system employs seven parameters, i.e., waste quantity, quantity of fresh waste

disposed/day, biodegradable waste fraction, annual rainfall, rainy days/year, dispersion scenario and population density within 3 km of the site.

- When applied to the municipal waste sites with continuously varying conditions, the new system gives scores in the range of 90-1000 with a very low clustering index of 0.15. The sensitivity analysis of the new system reveals that the new system is most sensitive to the changes in receptors' scenario. The system also exhibits high sensitivity to dispersion scenario and number of rainy days, and medium to low sensitivity to waste quantity, fresh waste disposed/day, biodegradable waste fraction and annual rainfall.
- Fifteen waste dumps from developing countries were selected for determining their priority of closure and cover system required for abating the odor impact. The ratings from the new system help categorizing these waste dumps into three distinct categories for closure/remediation. The odor impact ratings from the new system also assist in prescribing the cover type for these waste dumps.

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