

**HAZARD RATING OF
MUNICIPAL SOLID WASTE (MSW) DUMPS CONSIDERING
POTENTIAL FOR CONTAMINATION OF
AIR, SURFACE WATER AND GROUNDWATER**

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**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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POTENTIAL FOR CONTAMINATION OF
AIR, SURFACE WATER AND GROUNDWATER**

by

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Department of Civil Engineering

Submitted

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

SEPTEMBER 2016

To
my grandparents

CERTIFICATE

This is to certify that the thesis entitled “**Hazard Rating of Municipal Solid Waste (MSW) Dumps Considering Potential for Contamination of Air, Surface Water and Groundwater**” being submitted by Mr. **Amit Kumar** to the Indian Institute of Technology Delhi is a record of bonafide research work carried out by him under our supervision and guidance. The thesis work, in our opinion, has reached the standard, fulfilling the requirements for the award of Doctor of Philosophy degree.

The research report and results presented in this thesis have not been submitted, in part or full, to any university or Institute for the award of any degree or diploma.

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(AMIT KUMAR)

ASBTRACT

In India, about 80% of the waste is disposed in open dumps, making land disposal one of the most important components of solid waste management. These dumpsites have proven to be hazardous to human beings in several ways, e.g. environmental pollution due to emissions of leachate and landfill gas, damage to aircraft crash due to bird menace at waste sites, and slope failure of waste in waste dumps. As of census 2011, there are about 7000 towns in India indicating the potential number of total solid waste dumps requiring remediation and control measures. It would be almost impossible to remediate all these dumpsites at the same time. A priority list will help in ranking the sites according to their relative magnitude of hazard and remediation measures can be prioritized for the sites that need urgent action. So the study proposes new systems for hazard rating of MSW dumps considering potential for contamination of air, surface water and groundwater.

Firstly in order to understand the extent of the problem, the baseline condition of the waste dumps/sites in India was studied in terms of base area and waste height, and proximity to groundwater, surface water and communities. The information was collected by contacting all the 53 municipal corporations in India having population more than 1 million. The inputs from peer-reviewed literature and city reports were also taken. Site visits to the thirteen dump sites in six cities across India were also made to collect data.

The study evaluated existing hazard rating systems by applying them to the waste sites with continuously varying characteristics. The resulting scores for the MSW sites from these existing sites were normalized to 0-1000 scale and then assessed in terms of the scores' range and clustering index. Out of the seventeen rating systems identified from the literature, only eight systems could be adopted for further analysis as these would be applicable to non-hazardous or municipal waste sites of size in the range of interest for the present study. Out of the five systems applied for air contamination ratings, NPC performed best with a wider spread in scores of different MSW dumps. However, the clustering index had a high value of 0.70 because NPC does not consider the number of rainy days and quantity of fresh waste disposed on-site. Also NPC employs additive algorithm to aggregate their parameters by virtue of which even the substantial variations in one or two parameters do not cause any significant change in the site hazard rating. For

surface water contamination rating, seven out of the eight systems were applicable. WARM and RSS performed best amongst the seven systems. However, RSS gave scores in narrow range because it does not consider proper ranges of annual rainfall, waste quantity, distance to surface water body, soil permeability and site topography. WARM does not take into account proper range of waste quantity and gives low values for MSW and highest rating to the hazardous waste. For groundwater contamination rating, out of the eight systems applied, GW-HARAS performed best with the widest range of scores. The clustering index was low reflecting the high sensitivity of the rating system to most of the relevant parameters. However, it was not sensitive to changes in soil permeability in vadose zone and the receptor rating of GW-HARAS was usually at the top level of the scale in most of the cases. The four composite rating systems were also observed to give results clustered in a narrow range when applied to MSW dumps in the study.

In order to overcome the deficiencies of the existing systems, new systems for assessment of air contamination and surface water contamination hazard rating from MSW dumps have been proposed in the study. The study also improved an existing rating system for groundwater contamination. All the rating systems proposed in the study are based on source-pathway-receptor approach and use the numerical scale of 0- 1000. The system employs only the major site parameters that are derived based on review of case studies, literature and expert opinions. The best and worst values of the parameters are based on literature, design standards and field values. The parameters are aggregated by additive-multiplicative algorithm to determine a hazard rating from waste dumps.

A new system for Air contamination hazard rating has been proposed after studying five existing rating systems and empirical odour impact assessment models. The improvements have been made in considering the effects of total area under waste, relative contribution of old waste and fresh waste for odorous effects, number of rainy days and relative location of receptor with respect to waste dump. The new system is significantly better than the existing systems on account of high sensitivity and low clustering index.

A new system for surface water contamination hazard rating has been proposed after studying seven existing systems. Improvements have been made in considering the effects of site topography, distance to surface water body, soil permeability and annual rainfall.

The clustering indices for existing systems ranged from 0.67 to 0.80, which improved to 0.18 for the new system. The new system displays significant sensitivity for eight parameters out of the total nine parameters. In contrast, significant sensitivity was observed only in maximum four parameters for existing systems i.e. in case of ERPHRS only. In other cases, sensitivity was lower.

The existing system, GW-HARAS has been improved for groundwater contamination rating by incorporating influence of changes in soil permeability. Pathway rating was revised to make the system more sensitive to changes in soil permeability by introducing the step function for vadose zone indicator. The modified system was found to be better than the existing system on account of higher sensitivity to soil permeability and groundwater use type.

Subsequent to development of the individual rating systems, a suitable aggregation function had to be decided to aggregate the three individual ratings into a composite hazard rating and priority for closure. Thirteen aggregation functions were first tested for ambiguity and eclipsity. The functions free from ambiguity and eclipsity were then analyzed using clustering index. The root mean square function giving a low clustering index was then selected for composite hazard rating. However, it does not adequately address the issue of priority for closure. Consequently a new category based aggregation approach has been proposed in the study and found to be outperforming other functions in determining the site priority for closure.

Finally the new/modified aggregation functions were applied to ten waste dumps selected from Indian cities to determine their individual and composite hazard rating scores. For the case studies, comparison with existing systems shows that the scores from the new system classify these ten waste dumps distinctly as compared to those from the existing systems. Also the suitability of closure alternative for these ten waste dumps has been determined using the new/modified hazard rating systems.

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Notations

Symbol	Definition
A_{fresh}	: Area under fresh waste
A_{old}	: Area under old waste
B	: Biodegradable waste fraction (%)
BS_b	: Best value of Facility Base Slope (%)
BS_f	: Value of Facility Base Slope (%) at the site
BS_w	: Worst value of Facility Base Slope (%)
C	: Construction and demolition waste fraction (%)
$C_{m,weighted}$: Weighted value of methane potential of the waste
D_b	: Best value of waste depth for methane generation
DSW_i	: Indicator for distance to the surface water body
D_w	: Worst value of waste depth for methane generation
$E_{qi,fresh}$: Odorous emissions indicator of fresh waste
$E_{qi,old}$: Odorous emissions indicator of old waste
FBS_i	: Indicator for Facility Base Slope
FF_i	: Facility flow indicator
GS_b	: Best value of intervening ground slope (%)
GS_f	: Value of intervening ground slope (%) at the site
GS_w	: Worst value of intervening ground slope (%)
$Gu_{i,j}$: indicator for jth groundwater user category
H	: Hazardous waste fraction (%)
$H_{i,GHG}$: Waste height indicator for GHG emissions rating
$H_{p,GHG}$: Pathway rating for GHG emissions hazard

$H_{p,GW}$: Pathway rating for groundwater contamination hazard
$H_{p,SW}$: Pathway rating for surface water contamination hazard
$H_{R,GHG}$: Receptor rating for GHG emissions hazard
$H_{R,GW}$: Receptor rating for groundwater contamination hazard
$H_{R,SW}$: Receptor rating for surface water contamination hazard
HR_{Air}	: Total hazard rating for a hazard
HR_{comp}	: Composite hazard rating
HR_{GHG}	: Hazard rating for GHG emissions
HR_{GW}	: Hazard rating for groundwater contamination
HR_i	: hazard rating for the i th hazard
$HR_{i,BBB}$: hazard rating for the i th hazard when all the parameters are at their best value
HR_{odr}	: Hazard rating for odour emissions
HR_{SW}	: Hazard rating for surface water contamination
$HS_{,GHG}$: Source rating for GHG emissions hazard
$HS_{,GW}$: Source rating for groundwater contamination hazard
$H_{s,odr}$: Source rating for odour emissions hazard
$H_{s,odr,fresh}$: Source rating for odour emissions hazard due to fresh waste
$H_{s,odr,old}$: Source rating for odour emissions hazard due to old waste
$HS_{,SW}$: Source rating for surface water contamination hazard
IGS_i	: Indicator for intervening ground slope
I_{pi}	: Infiltrating precipitation indicator for groundwater and surface water contamination hazard rating
$I_{pi,GHG}$: Infiltrating precipitation indicator for GHG emissions rating

i_s	: Infiltration score
k_b	: Best value of soil permeability (m/sec)
k_f	: Value of soil permeability (m/sec) at the site
k_i	: Indicator for soil permeability
k_w	: Worst value of soil permeability (m/sec)
L	: Vadose zone thickness (m)
LI_i	: Leachate intercept indicator
n	: Number of individual hazard ratings
O_{ci}	: Odour containment indicator
OF_i	: Overland flow indicator
O_{pi}	: Odour dispersion indicator
P	: annual precipitation in millimeters
$PD_{1500,i}$: Indicator for built-up area within 1500m of the site
$PD_{1500-3000,i}$: Indicator for built-up area within 1500-3000m of the site
P_s	: Precipitation score
$PWD_{1500-3000,i}$: Indicator for predominant wind direction for built-up area within 1500-3000m of the site
SF_{GHG}	: Scaling factor for GHG emissions rating
SF_{GW}	: Scaling factor for groundwater contamination hazard
SF_{odr}	: Scaling factor for odour emissions rating
SF_{SW}	: Scaling factor for surface water contamination hazard
SG_i	: indicator for subsoil or groundwater
Su_i	: highest indicator amongst the surface water user categories
V_i	: Vadose zone indicator

WBT_i	: indicator for type of surface water body
WC_i	: Waste composition indicator for groundwater and surface water contamination hazard rating
$WC_{i,GHG}$: Waste composition indicator for GHG emissions rating
$WC_{i,odr}$: Waste composition indicator for odour emissions rating
W_{cover}	: Rating of a cover type for infiltration potential
w_{DSW}	: Relative weightage for distance to the surface water body
w_{FBS}	: Relative weightage for Facility Base Slope
w_i	: Weightage for the i th hazard
w_{IGS}	: Relative weightage for intervening ground slope
w_k	: Relative weightage for soil permeability
W_q	: Waste quantity in tons
W_{qi}	: Waste quantity indicator for groundwater and surface water contamination hazard rating
$W_{qi,GHG}$: Waste quantity indicator for GHG emissions rating

ACRONYMS AND ABBREVIATIONS

Abbreviation/Acronym	Definition
C&D	: Construction & Demolition
COD	: Chemical Oxygen Demand
CPCB	: Central Pollution Control Board
DOD	: Department of Defense
DOE	: Department of Energy
DPM	: Defense Priority Model
ERPHRS	: Environmental Repair Program Hazard Ranking System
GW	: Groundwater
HARM	: Hazard Assessment Rating Methodology
HDPE	: High Density Polyethylene
HR-FCP	: Hazard Ranking using Fuzzy Composite Programming
HRS	: Hazard Rating System
HW	: Hazardous Waste
ISM	: Indiana Scoring Model
KDG	: Kodungaiyur Dumping Ground
LCRS	: Leachate Collection & Removal System
MOEF	: Ministry of Environment & Forest
MSW	: Municipal Solid Waste
NCAPS	: National Corrective Action Prioritization System
NCS-2008	: National Classification System (revised in 2008)
NPC	: National Productivity Council
PDG	: Perungudi Dumping Ground
RASCL	: Risk Assessment for Small and Closed Landfills
RCRA	: Resource Conservation and Recovery Act

RSS	: Risk Screening System
SRAP	: Standardized Risk Assessment Protocol
SWLID	: Surface Water Leachate Interception Drain
TDS	: Total Dissolved Solids
TOC	: Total Organic Carbon
US	: United States
USEPA	: United States Environmental Protection Agency
VOC	: Volatile Organic Compound
WARM	: Washington Ranking Method
XOCs	: Xenobiotic Organic Compounds