

LANDFILL POLLUTION INDEX (LPI) SYSTEM FOR LANDFILL SITES IN DEVELOPING COUNTRIES

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SUMMARY: Most of the solid waste disposal sites in Malaysia are either open dumps or controlled Landfills. The pollution levels from these sites are expected to be high. The risks associated with solid waste disposal sites involve three media, i.e. the atmosphere, water and soil. This 'Cross media' or 'Multimedia' impacts phenomenon has been recognised as being of potential importance and complicated. This study discusses the development of a new and simple evaluation system to assess the pollution levels of landfill sites. The Landfill Pollution Index (LPI) was introduced, which incorporated with 4 other sub-indices, i.e. the Environmental Degradation Index (EDI) for water quality, gas emission, chemicals in surface water and chemicals in groundwater. Active and closed landfill sites in Kuala Lumpur were assessed by using the LPI approach. The results show that Taman Beringin was the most polluted landfill with the LPI of 719.56, followed by Jinjang Utara (383.51), Paka 1 (197.66), Brickfields (128.90), Paka 2 (113.72), Sri Petaling (30.81) and Sungei Besi (17.87). For detailed evaluation, the LPI calculated was further elaborated by using the sub-indices, i.e. the EDI. The results provide information on the extent of pollution at each particular landfill site in terms of different components such as water quality, gas emission, soil and groundwater. These help the landfill operators, decision makers as well as the policy makers in giving priority to remedial or rehabilitate the environmental conditions of the landfill sites. In summary, a new evaluation system had been introduced in order to produce simple and reliable monitoring tool to evaluate the pollution levels for municipal waste landfill sites. Based on the assessment of Kuala Lumpur landfill sites, it can be concluded that the risk and pollution levels of landfill sites in Kuala Lumpur area are relatively high, but it is site-specific and varies from one landfill site to another.

1. INTRODUCTION

Landfilling is the most widely used method of solid waste disposal in the world. It has the longest history, the widest range of capabilities and in most instances, is the least expensive waste disposal method (*Weiss, 1977*). Most of the existing solid waste disposal sites in developing countries are practising either open dumping or controlled tipping because the technology of proper sanitary landfill practice is not totally implemented (*Lee and*

Sivapalasundram, 1979; Lee and Krieger, 1986; Matsufuji and Sinha, 1990). The environmental conditions from these sites are thus expected to be bad especially in terms of the contamination of soil, air, surface and underground water.

The assessment of the pollution levels from the landfill sites requires a comprehensive study that takes into account related parameters, which provide the overall perspectives of the pollution of the landfill sites. In this study, a new approach of assessing the pollution levels of landfill sites was developed, which focuses on 4 major components, i.e. water quality, gas emission, chemicals in soil and chemicals in groundwater.

Information and knowledge on the pollution levels are important to decision makers as to the consequences of any possible actions to be taken such as selecting treatment or disposal options, remediating contaminated sites and siting new facilities (*Tchobanoglous et al. 1993*). However, it should be emphasised that knowing the pollution levels is only one of many information used, and the final decisions are usually driven by political, social and economic factors.

2. METHODOLOGY

2.1 Study Area

The study area is the Federal Territory of Kuala Lumpur. Kuala Lumpur has the total area of 234 km² and it is characterised by highly populated, urbanised, and the most industrialised area in the country. As the centre of administration, industrialisation, commerce, finance and culture, Kuala Lumpur is experiencing rapid population growth. By assuming the population growth rate of 2.5 percent, the area is expected to have about 3 million people by 2020 and the waste generated is expected to increase to about 5,000 tonnes per year (*Nasir et al. 1995; Nasir et al. 1996*).

There were ten (10) dumping sites used to receive solid wastes in the study area during the study period. Out of these, seven (7) were selected for the study, i.e. Sri Petaling, Brickfields, Taman Beringin, Jinjang Utara, Sungei Besi, Paka 1 and Paka 2. Taman Beringin was the only site that was still receiving wastes or still in operation during the study period, while the rest of the sites have been closed.

2.2 Calculation of the Environmental Degradation Index (EDI) and Landfill Pollution Index (LPI)

The method developed by Battelle Columbus Laboratories was modified in this study to translate the pollution levels of landfill sites into Environmental Degradation Index (EDI) and Landfill Pollution Index (LPI), which emphasise on the development of weightage for different parameters of concerned in the evaluation. The methods of developing the weightage for parameters, evaluation of Landfill Pollution Index (LPI) and Environmental Degradation Index (EDI) are discussed below.

2.3 Weighting or Ranking of Parameters - Delphi Approach

The development of a representative weightage for each parameter was based on the Delphi Method. The Delphi Experiment are originated through the work of Dalky and Helmer (1963) and is commonly used in setting a weightage for a group of parameters or variables (e.g. pollutant) especially in developing an index such as the Malaysia Air Pollution Index (*Lai, 1997*) and The National Sanitation Foundation's Quality Index (NSF WQI).

The procedure involved a selection of a group of experts and each of these individuals was asked to rank the parameters according to their importance from a fixed number of weighting

units, and then through second round of feedback asking them to revise their response toward a group mean (Lowe and Lewis, 1980; Turner and O’riordan, 1982; Richey et al., 1985).

Based on the scores given by each expert, a representative weightage for each selected physical parameter can be obtained. In the survey, the experts were asked to rate the importance of each physical parameter ranging from the scale of ‘1’ if that parameter is the most significant to the scale of ‘10’ if the parameter is the least important. The raw data given by the experts were evaluated as follows (Low, 1995; Lai, 1997):

The average score for each parameter is evaluated as follows:

$$V_n = \frac{\sum_{i=1}^e S_i}{e} \quad (1)$$

Where:

V_n = Average score of each parameter from $n = 1$ for the 1st parameter to $n = n$ for the nth parameter;

S_i = Score that an expert i put on the importance of parameter;

e = Total number of experts.

This process is done for all the parameters. In general, we could expect that a parameter with the least average score is the most critical or important. In other word, the lower is the average score, the more critical is the parameter. The average score for each parameter was then used to evaluate the ‘temporary weights’, which were evaluated using the following formula:

$$\text{Temporary weight (TW)} = V_m / V_i$$

Where:

V_m = The lowest mean value among the parameters or the base data in which other parameter are to be compared with;

V_i = Mean of each physical parameter where $i = 1$ for the 1st parameter and $i = n$ for the nth parameter.

The evaluation of the final weightage is as follows:

$$\text{Final Weightage (FW)} = TW_i / Q \quad \text{- for 0 to 1 basis} \quad (3)$$

$$\text{Final Weightage (FW)} = (TW_i / Q) * 100 \quad \text{- for 0 to 100 basis} \quad (2)$$

Where :

$$Q = \sum_{i=1}^n TW_i \quad (4)$$

Q = Total of all temporary weightage.

TW_i = Temporary weightage of each parameter from $i = 1$ for the 1st parameter to $i = n$ for the nth parameter.

The main application of the ‘Temporary Weights’ is to seek a set of weights for all the parameters which would add up to 1 or 100.

2.4 Environmental Degradation Index (EDI)

The calculation of the Environmental Degradation Index (EDI) relies on the dose response curves for each particular pollutant. The general formula for the calculation is as follows:

$$EDI = \sum_{p=1}^n dp_{ji} \cdot wp \quad (5)$$

Where :

$p= 1 \dots n$ and represents the parameters relevant to the study;

dp_{ji} = the damage from each pollutant j resulting from the i th control strateg;

wp = the subjective damage weighting of each pollutant or parameter.

2.5 Landfill Pollution Index (LPI)

The Landfill Pollution Index (LPI) was defined as :

$$LPI = EDI_u - EDI_i \quad (6)$$

Where :

EDI_u = Environmental Degradation Index for parameters exceeded the tolerable levels (uncontrolled cases);

EDI_i = The environmental degradation index for parameters at tolerable levels (controlled cases).

In this study, EDI_u is assumed to represents the current actual condition of landfill site, while EDI_i represents the lowest limit or the tolerable point. Thus, the LPI obtained in the study is actually a value showing the pollution levels exceeding the tolerable limit of landfill sites.

According to *Hansson (1997)*, the toxicological database is insufficient for most substances, and the scientific interpretation of toxicological data is complex and controversial. All dose-response relationships used in the study were based on the common assumption, i.e. “linear extrapolation to zero” method for establishing exposure guidance values (*Wilson, 1997*). For cases where the damage functions or dose-response curves are not available for certain parameters, decisions can be made to exclude the parameters from the evaluation or to estimate the curves from that of similar compounds (*Asante-Duah, 1993*).

3. RESULTS AND DISCUSSION

3.1 Development of Weightage for Selected Parameters

Parameters that were suggested and selected by the experts to be considered in the Delphi evaluation, i.e. the water quality parameters, gas emission parameters and chemical parameters in groundwater and soil are shown in Table 1 below. By following the standard Delphi evaluation method, experts from different fields of specialisation were invited to rank the parameters in their own field based on the parameters’ level of importance. The Final Weightage (FW) evaluated for each parameter is also shown in Table 1 below. Generally, we could conclude that the higher is the FW of the parameter, the more important or significant is the parameter in terms of its contribution to the pollution on the environment.

3.2 Development of Dose-Response Relationships

The dose response equations obtained by using the Delphi Method were also summarised in Table 1. The damage functions or dose-response relationships were determined for all the parameters of three criteria in indicating the pollution levels of landfill sites. The development of the dose-response curves for all relevant parameters were carried out based upon the results of checklists on the conditions of all landfill sites. Based on the method recommended by USEPA, the model used for the dose-response assessment was a linear model where the responses at high level doses were extrapolated to low doses by a straight line to the origin (0) except for some

“special” parameters such as pH and dissolved oxygen (DO) which give different styles of responses against the doses. The dose-response relationships for some parameters were excluded in the study because these chemicals were not detected in the samples in the study area.

Table 1 - Summary of the Weightage and Dose Response Equations Developed

No.	Parameters	Final Weightage	Dose Response Equations
<i>Water Quality Parameters</i>			
1	BOD	3.2934	$y = 1.1928x$
2	COD	0.4117	$y = 0.0742x$
3	Chromium (Cr)	0.6467	$y = 2109.6x$
4	Lead (Pb)	0.6467	$y = 0.998x$
5	Mercury (Hg)	0.6467	$y = 150.4x$
6	Suspended Solids (SS)	0.5489	$y = 0.1914x$
7	Manganese (Mn)	0.6467	$y = 35.917x$
<i>Gas Emission Parameters</i>			
8	Carbon Dioxide (CO ₂)	1.6467	$y = 0.00008x$
9	Sulphur Dioxide (SO ₂)	1.0978	$y = 0.002x$
10	Hydrogen Sulphide (HS)	0.8234	$y = 0.0002x$
11	Vinyl Chloride (VC)	0.6587	$y = 3.4349x$
12	Styrene	0.5489	$y = 3.1531x$
13	Benzene	0.4705	$y = 723.4x$
14	Ammonia	0.3659	$y = 1.3249x$
15	Carbon Monoxide (CO ₂)	0.3293	$y = 1.2385x$
<i>Chemical Parameters in Soil</i>			
16	Benzene	3.2934	$y = 642.34x$
17	Vinyl Chloride	1.0978	$y = 533.44x$
18	Ethylbenzene	0.6587	$y = 250.11x$
19	Lead	1.0978	$y = 0.1688x$
20	Chromium	0.6587	$y = 0.1129x$
<i>Chemical Parameters in Groundwater</i>			
21	Benzene	3.2934	$y = 4000x$
22	Vinyl Chloride	1.0978	$y = 3888.9x$
23	Ethylbenzene	0.6587	$y = 2985.1x$
24	Lead	1.0978	$y = 69.778x$
25	Chromium	0.6587	$y = 422.09x$
26	Arsenic	1.6467	$y = 289.44x$

Notes: x = Concentrations of pollutants (Dose);
 y = Damage (Response)

3.3 Threshold Limits for Parameters

Threshold Limit Values (TLVs) or maximum exposure level of the parameters were gathered from various sources such as the American Council of Government Industrial Hygienists (ACGIH), Environmental Protection Agency (EPA), National Institute of Occupational Safety and Health (NIOSH), US Occupational Health and Safety Administration (OSHA), the World Health Organization (WHO) and the Air Quality Guidelines for Europe. It is difficult to have the threshold limits values for all parameters in different media of pollution such as groundwater, soil and surface water from a single source. In this study, threshold limits values from various sources were used. The threshold limit values used in this study are summarised in Table 2.

Table 2 - Data Used As Threshold Limit Values In The Study

Parameters	Media	Threshold Limit Values	Intervention Values	Unit	Sources
BOD	Water	20	50	mg/L	A
COD	Water	50	100	mg/L	A
Chromium (Cr)	Water	0.05	0.05	mg/L	A
Lead (Pb)	Water	0.1	0.5	mg/L	A
Mercury (Hg)	Water	0.005	0.05	mg/L	A
Manganese (Mn)	Water	0.2	1.0	mg/L	A
Suspended Solids (SS)	Water	50	100	mg/L	A
Carbon Dioxide (CO ₂)	Gas	5,000	5,000	ppm	B
Sulphur Dioxide (SO ₂)	Gas	2.0	2.0	ppm	B
Hydrogen Sulphide (H ₂ S)	Gas	10.0	10.0	ppm	B
Vinyl Chloride	Gas	5.0	5.0	ppm	B
Styrene	Gas	50.0	50.0	ppm	B
Benzene	Gas	10.0	10.0	ppm	B
Ammonia	Gas	25.0	25.0	ppm	B
Carbon Monoxide (CO)	Gas	25.0	25.0	ppm	B
Benzene	Soil	0.05	1.00	mg/kg	C
Vinyl Chloride	Soil	0.001	0.10	mg/kg	C
Ethylbenzene	Soil	0.05	50.0	mg/kg	C
Mercury (Hg)	Soil	0.3	10.0	mg/kg	C
Cyanide (CN)	Soil	1.0	-	mg/kg	C
Arsenic (As)	Soil	29	55	mg/kg	C
Lead (Pb)	Soil	85	530	mg/kg	C
Chromium (Cr)	Soil	100	380	mg/kg	C
Benzene	Groundwater	0.0002	0.03	mg/L	C
Tetrachloromethane	Groundwater	0.00001	-	mg/L	C
Vinyl Chloride	Groundwater	0.00001	0.0007	mg/L	C
Ethylbenzene	Groundwater	0.0002	0.15	mg/L	C
Mercury (Hg)	Groundwater	0.00005	0.00003	mg/L	C
Cyanide (CN)	Groundwater	0.005	-	mg/L	C
Arsenic (As)	Groundwater	0.01	0.06	mg/L	C
Lead (Pb)	Groundwater	0.015	0.075	mg/L	C
Chromium (Cr)	Groundwater	0.001	0.03	mg/L	C

Notes: Source A = Environmental Quality Act (1974)

Source B = ACGIH (1995)

Source C = EIA Guidelines for Groundwater and/or Surface Water Supply Projects (1996)

The threshold limit values for chemicals in soil and groundwater were referred to the Malaysian Environmental Impact Assessment Guidelines for Groundwater and/or Surface Water Supply Projects developed by Department of Environment Malaysia. For water quality parameters, Standards B of the Environmental Quality Act (EQA) Regulations, 1974 were used as the threshold limit values.

For gas emissions, the threshold limit values developed by the American Council of Governmental Industrial Hygienists (ACGIH) were used. The values used for comparison of gas emission parameters were the Time-Weighted Average (TLV-TWA) values, i.e. the average concentration for a normal 8-hours workday and a 40-days workweek, to nearly all workers that may be repeatedly exposed.

Table 4 - EDI Calculations for Threshold Limit Values

Parameters	Unit	Threshold Limits	Index (dp)	Weights (wp)	dp.wp
BOD (w)	mg/L	20.0000	23.8560	3.2934	78.5674
COD (w)	mg/L	50.0000	3.7100	0.4117	1.5274
Cr (w)	mg/L	0.0500	105.4800	0.6467	68.2139
Pb (w)	mg/L	0.1000	0.0998	0.6467	0.0645
Hg (w)	mg/L	0.0050	0.7520	0.6467	0.4863
Mn (w)	mg/L	0.2000	7.1834	0.6467	4.6455
SS (w)	mg/L	50.0000	9.5700	0.5489	5.2530
CO ₂ (g)	ppm	5,000.0000	4.000E-01	1.6467	6.587E-01
SO ₂ (g)	ppm	2.0000	4.000E-03	1.0978	4.391E-03
H ₂ S (g)	ppm	10.0000	2.000E-03	0.8234	1.647E-03
Vinyl Chloride (g)	ppm	5.0000	1.717E+01	0.6587	1.131E+01
Styrene (g)	ppm	50.0000	1.577E+02	0.5489	8.654E+01
Benzene (g)	ppm	10.0000	7.234E+03	0.4705	3.404E+03
Ammonia (g)	ppm	25.0000	3.312E+01	0.3659	1.212E+01
CO (g)	ppm	25.0000	3.096E+01	0.3293	1.020E+01
Benzene (s)	mg/kg	0.0500	32.1170	3.2934	105.7741
Vinyl Chloride (s)	mg/kg	0.0010	0.5334	1.0978	0.5856
Ethylbenzene (s)	mg/kg	0.0500	12.5055	0.6587	8.2374
Pb (s)	mg/kg	85.0000	14.3480	1.0978	15.7512
Cr (s)	mg/kg	100.0000	11.2900	0.6587	7.4367
Benzene (gw)	mg/L	0.0002	0.8000	3.2934	2.6347
Vinyl Chloride (gw)	mg/L	0.0000	0.0389	1.0978	0.0427
Ethylbenzene (gw)	mg/L	0.0002	0.5970	0.6587	0.3933
As (gw)	mg/L	0.0100	2.8944	1.6467	4.7662
Pb (gw)	mg/L	0.0150	1.0467	1.0978	1.1490
Cr (gw)	mg/L	0.0010	0.4221	0.6587	0.2780

It is also important to emphasise here that the concentrations of the gas emission parameters used for calculation of LPI were simulated based on the Gaussian dispersion model, which predicts the concentrations of the emitted gases downwind from the boreholes where the gas emissions were measured. Atmospheric dispersion is only one of the environmental processes that requires modelling in a comprehensive risk assessment (*Griffiths, 1991*). The model was popularly used in describing the dispersion of the gases three-dimensionally after being released from a point source such as the boreholes (*Ujang, 1995*). In this case, the concentrations of gases reach the target in certain distance from the boreholes such as the residents around the landfill areas could be estimated before it can then be compared with the threshold limit values.

3.5 Development of Landfill Pollution Index (LPI)

Based on the results of EDI_u (actual conditions) and EDI_i (Threshold limits) calculations, the Landfill pollution Index (LPI) for the landfill sites were obtained, and summarised in Table 5. It can be concluded that the pollution levels at Taman Beringin landfill site was the highest with the LPI of about 720. This shows that the levels of pollutants assessed at the landfill site was very much exceeded the threshold limits. Other landfill sites that were found to have high LPI values were Jinjang Utara, Paka 1 and Brickfields landfill sites.

Table 5 - Landfill Pollution Index (LPI) for Landfill Sites

Landfill Sites	EDI _u	EDI _i	LPI (EDI _u – EDI _i)
Taman Beringin	899.17	179.58	719.58
Jinjang Utara	480.35	96.84	383.51
Paka 1	302.76	105.10	197.66
Brickfields	167.21	38.32	128.89
Paka 2	211.37	97.65	113.72
Sri Petaling	41.14	10.33	30.81
Sungei Besi	18.49	0.63	17.87

3.6 Landfill Pollution Index (LPI) Calculation Software

The procedures for calculating the LPI were summarised and computed into a programme or software, which is easy to use, user friendly and it requires minimum input from the user. The programme was designed by using the Visual Basic Programming Language and was made into an application or execution file (*.EXE) in which the programme can be performed in any computers although without the Visual Basic software.

The software starts with a brief explanation of the parameters or inputs required in the LPI calculation. After the introduction, text boxes of inputs required for the LPI calculation are presented, i.e. the concentrations of water quality parameters, gas emission parameters and chemical parameters in soil and groundwater.

After the user completes the inputs, the first screen showing the results will appear and the LPI button will give results of the LPI evaluation automatically. The Landfill Pollution Index (LPI) calculated will be showed in either in red or green colour, in which red colour means that it has exceeded zero or the threshold limit for LPI and green colour indicates that it is within the threshold limits. This is also applied to the Environmental Degradation Index (EDI) displayed for each category.

4. CONCLUSION

The development of a Landfill Pollution Index (LPI) to evaluate the pollution levels of landfill sites had been introduced, which has taken into considerations all the allowable threshold limit values and dose response relationships of selected parameters. Important parameters from different point of views in assessing the pollution levels of landfill sites have been identified and quantified by using the Delphi Method, which emphasises on the development of weightage or ranking for parameters.

The LPI is able to make the status of the existing landfill sites more accessible to the landfill operator, decision-makers as well as the general public in terms of the pollution levels. This can also be useful especially as a monitoring tool and provide important information to the landfill operators and decision-makers as database in the formulation and execution of a cost-effective and efficient remediation or reclamation plan on the landfill sites.

Generally, it can be concluded that the pollution levels of landfill sites in Kuala Lumpur area are site-specific and vary from one landfill site to another. Among the seven landfill sites identified and studied in Kuala Lumpur, the active landfill site, i.e. Taman Beringin landfill site has been assessed as the most polluted site. However, the pollution levels at other landfill sites should not be taken lightly. All landfill sites in the study area were found to be facing certain levels of pollution. Special attentions should be given to those landfill sites with high level of

Environmental Degradation Index (EDI) for particular components and also where certain parameters were assessed to exceed the allowable threshold limit values.

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