EVALUATION OF THE MULTIMEDIA IMPACTS OF MUNICIPAL LANDFILL SITES – THE DELPHI TECHNIQUE

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ABSTRACT

Most of the existing solid waste disposal sites in Malaysia are practising either open dumping or controlled tipping because the technology of proper sanitary landfill practice is not totally implemented. 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, and also impacts on flora and fauna including human. The contamination associated with solid waste disposal sites involved three major environmental compartments or media, i.e. the atmosphere, water and soil. This 'Cross media' or 'Multimedia' impacts phenomenon has been recognised in various countries as being of potential importance and complicated. This study discusses on the development of simple evaluation systems by using the Delphi Approach, which emphasises on the development of weightage for different parameters selected in the evaluation procedures. Environmental conditions of all closed and active disposal sites in the study area from 9 different points of view (water quality, social, gas emissions, landuse, hydrology, geology, ecotoxicology, plant ecology and chemical constituents) were assessed, which has taken into consideration 59 selected parameters. 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. The results of assessments indicated that most of the solid waste disposal sites in the study area showed relatively bad environmental conditions especially the operating or active site, i.e. Taman Beringin landfill site. 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).

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 (James, 1987; Weiss, 1977). Most of the existing solid waste disposal sites in Malaysia 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, also the impacts of the contaminants on flora and fauna including human being.

The contamination associated with solid waste disposal sites involved three major environmental compartments or media, i.e. the atmosphere, water and soil. This 'Cross media' or 'multimedia' impacts phenomenon have been recognised to cause complexity in the assessment (LaGrega et al., 1994; Asante-Duah, 1993).

The assessment of the environmental conditions from the landfill sites requires a comprehensive study that takes into account related parameters, which provide the overall perspectives of the landfill sites, not only the pollution levels such as water quality and chemical conditions, but also other factors such as the geological, hydrogeological and ecological factors. The issues that are usually used in assessing the cross media impacts of a landfill site are: water quality, hydrology, landuse, geology and geotechnics, analytical chemistry, ecotoxicology, plant ecology, landfill gases and social aspects.

2. METHODOLOGY

2.1 Study Area

The study area is the Federal Territory of Kuala Lumpur. Kuala Lumpur has the total area of 234 km^2 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 average growth rate of 2.5 percent, the area is expected to have about 3 million people by the year 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 are ten (10) dumping sites used to receive solid wastes in the study area and 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 is the only site that is still receiving wastes or still in operation during the study period, while the rest of the sites have been closed.

2.2 Identifying the Most Critical Site in terms of Overall Risks

Nine landfill sites were evaluated and assessed based on nine criteria and each criteria consist of parameters which were selected by experts in each area of the study to be assessed against each landfill site (Table 1). In this study, all the criteria are given equal weightage. However, the importance of the parameter may differ. The importance of suspended solids in the water quality criteria for example, may be different to BOD_5. In reality, each of these parameters should be given different weightage because they might not have similar level of impacts on the environment. Thus, a weightage for each of the parameter is required in order to get a more representative results.

Table 1: Lists of Specialisation / Criteria and the Parameters

No	Criteria	Parameters
1	Hydrology	Distance to river, Infiltration, Water table.
2	Water quality	BOD_5, COD, Heavy metals, Ammonia, pH, Dissolved oxygen, Suspended solids.
3	Geology & Geotechnics	Topography, Joints and Fractures, Rock type, Soil type, Hydraulic Conductivity, Groundwater level, Electrical

		resistivity of subsurface, seepage.
4	Landuse	Land settlement, Squatters, Drainage problems, Utility, Structure of buildings, open space, aesthetic, Infrastructure
5.	Landfill gas	Methane, CO, CO_2, NH_3, Freon-11, H_2S. Styrene, SO_2, Benzene, Vinyl chloride,
6	Social aspects	Health/skin, Smell, Flies, Fire/burning, Dust, Squatters, Safety.
7	Plant ecology	Plant diversity and coverage, Plant growth and Plant biomass, cover value for common species
8	Ecotoxicology	Conductivity of leachate, LC_{50}, LT_{50}.
9	Environmental & pollutants toxic chemistry (Analytical Chemistry)	Benzene, Vinyl Chloride, Ethylbenzene, 1,2-Dichloroethene, Tetrachloromethane, 1,4-Dichlorobenzene, Hg, CN, As, Pb, Se, Cr.

2.3 Weighting or Ranking of Parameters - The Delphi Method

The development of a representative weightage for each parameter was based on the Delphi Method. 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:

$$V_n = \left(\sum_{i=1}^{n} S_i \right) / n$$

where: V_n = Mean of each physical 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 X from X_1 = 1st parameter to X_n = nth parameter

This process is done for all the parameters. In general, we could expect that a parameter with the least 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:

Final Weightage (FW) = TW_i / Q - for 0 to 1 basis
Final Weightage (FW) = (TW_i / Q) x 100 - for 0 to 100 basis

where:

$$Q = \sum_{i=1}^{n} (TW_I)$$

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 Application of the Weightage

The Weightage calculated for the parameters in each criteria were used to calculate the Final Score (FS) for each landfill site. The equation to calculate the final score of a landfill based on the final weightage is as follows:

$$\text{Final Score (FS)} = FW_1 + FW_2 + FW_3 + \ldots\ldots\ldots\ldots + FW_n$$

where FW_1 is the final weightage for the first parameter and FW_n is the final weightage for the nth parameter. The final score for a landfill that was obtained using this equation was from 0 to 1 or 0 to 100 (i.e. good landfill would have higher score). This means that the higher the score, the higher in terms of performance of a landfill site.

Checklists were prepared for each criteria based on the weightage obtained and these checklists were used by all the researchers to assess and evaluate the conditions of all the landfills. The percentage for Final Scores (FS) were used as the indicator to identify the most critical site for each different criteria where the site with the lowest FS is expected to be the worst.

2.5 Development of Environmental Degradation Index (EDI)

The calculation of the environmental degradation index (EDI) relied on the damage function or dose response curves for each particular pollutant. The general formula for the calculation is as follows:

$$EDI = \sum_{p=1}^{n} dp_{ji} \times wp$$

where :

p = 1 ..... n and represents the parameters relevant to the study;

dp_{ji} = the damage from each pollutant *j* resulting from the *i*th control strategy.

wp = the subjective damage weighting of each pollutant or parameter

Table 2 shows an example of the calculation of EDI for different pollutants which exceed the tolerable or threshold levels. Column 1 shows the quantities or concentration of emissions of each parameter given in lb/hr. The damage index (dp) shown in column 2 is calculated by interpolating from damage functions or dose response curves estimated for that particular pollutant.

In column 3, the weightage for the pollutants is taken directly from the data derived from the Delphi experiment and the damage potential of the pollutant is computed in column 4, which was done by multiplying column 2 and 3. The EDI is arrived at by adding the damage potentials of the pollutants, and the total scores are divided by 100 for ease of comparison.

2.6 Development of Landfill Pollution Index (LPI)

The Landfill Pollution Index (LPI) was defined as :

$$LPI = EDI_u - EDI_i$$

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.

Table 2: Example of EDI Calculation

Pollutant	Quantity (lb / hr)	Index (dp)	Weight (wp)	dp.wp
NO_x	6,900	690	48	33,120
SO_2	43,700	1,823	58	105,734
Particulates	88,320	1,853	45	83,385
Total organics	120	1.2	45	54
Suspended solids	-	-	-	
Heat	(4,600)	46	8	368
Ash	22,080	221	4	884
Total				223,545
EDI				2,235

Source: Lowe and Lewis, 1980

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

The experts from different fields of specialisation were invited to rank the parameters in their own field based on the parameters' level of importance. The rankings given by these experts were calculated based on 0 to 1 and also 0 to 100 basis using the standard method suggested in Delphi Experiment. An example of the results for the calculation of Final Weightage (FW) which were done based on 0 to 1 basis is shown in Table 3 below.

The Final Weightage (FW) calculated for each parameter was applied into equation 1 to evaluate the Final Scores (FS), which indicate the environmental conditions of the landfill sites in terms of three major concerns, i.e. environmental conditions according to individual criteria (e.g. in terms of social aspects, hydrological perspective, landuse), the overall environmental conditions and finally the pollution levels.

Table 3: Weightage of Parameters on Organic and Inorganic Pollutants

No	Parameters (X)	Average Value (V)	Temporary Weightage (TW=1.00000/V)	Weightage W = (TW / 5.56667)
1	Benzene	1.00000	1.00000	0.17964
2	Tetrachloromethane	2.00000	0.50000	0.08982
3	Vinyl chloride	3.00000	0.33333	0.05988
4	1,4–Dichlorobenzene	4.00000	0.25000	0.04491
5	Ethylbenzene	5.00000	0.20000	0.03593
6	Mercury (Hg)	1.00000	1.00000	0.17964
7	Cyanide (CN)	1.00000	1.00000	0.17964
8	Arsenic (As)	2.00000	0.50000	0.08982
9	Lead (Pb)	3.00000	0.33333	0.05988
10	Selenium (Se)	4.00000	0.25000	0.04491
11	Chromium (Cr)	5.00000	0.20000	0.03593
	TOTAL		5.56667	1.00000

The weightage used in evaluating the overall environmental conditions was different from the others. The weightage used were developed based on 0 to 100 basis instead of 0 to 10 because of the large number of parameters (i.e. 59 parameters) involved in the assessment. The development of the weightage for all the parameters in descending order is shown in Table 4 below.

3.1 Assessment of the Environmental Conditions

Table 5 shows the calculations of Final Scores (FS) or in other words, the environmental conditions for each landfill site. FS for individual criteria and pollution level were evaluated based on weightage of 0 to 1 basis, while FS for overall environmental conditions was calculated based on weightage of 0 to 100 basis. It can be concluded that the higher is the percentage of FS, the higher is the landfill site in terms of its performance. In other words, the lower is the percentage of FS, the more worst is the landfill's environmental conditions.

The percentage of FS that was calculated for the overall environmental conditions and pollution levels are shown in Figure 1 and Figure 2, respectively. Further descriptions and explanations of the Delphi Scores were discussed in the following sections.

Table 4: Weightage of the Overall Environmental Conditions in Descending Order

No	Parameters	Ranking	Temporary Weightage	Primary Weightage	Final Weightage
1	Benzene	1.0000	1.0000	0.0329	3.2934
2	Mercury (Hg)	1.0000	1.0000	0.0329	3.2934
3	Cyanide (CN)	1.0000	1.0000	0.0329	3.2934
4	Smell	1.0000	1.0000	0.0329	3.2934
5	Flies	1.0000	1.0000	0.0329	3.2934
6	Squatters	1.0000	1.0000	0.0329	3.2934
7	Seepage	1.0000	1.0000	0.0329	3.2934
8	Hydraulic conductivity of soil	1.0000	1.0000	0.0329	3.2934
9	Depth to saturated zone	1.0000	1.0000	0.0329	3.2934
10	Methane	1.0000	1.0000	0.0329	3.2934
11	BOD	1.0000	1.0000	0.0329	3.2934
12	Land settlement	1.0000	1.0000	0.0329	3.2934
13	Structures of buildings	1.0000	1.0000	0.0329	3.2934
14	Conductivity of leachate	1.0000	1.0000	0.0329	3.2934
15	LC50	1.0000	1.0000	0.0329	3.2934
16	LT50	1.0000	1.0000	0.0329	3.2934
17	Plant growth & biomass	1.0000	1.0000	0.0329	3.2934
18	Tetrachloromethane	2.0000	0.5000	0.0165	1.6467
19	Arsenic	2.0000	0.5000	0.0165	1.6467
20	Health / skin	2.0000	0.5000	0.0165	1.6467
21	Dust	2.0000	0.5000	0.0165	1.6467
22	Safety	2.0000	0.5000	0.0165	1.6467
23	Fractures and fissures	2.0000	0.5000	0.0165	1.6467
24	Difference In elevation (groundwater level)	2.0000	0.5000	0.0165	1.6467
25	Infiltration & vadoze zone media	2.0000	0.5000	0.0165	1.6467
26	Carbon dioxide	2.0000	0.5000	0.0165	1.6467
27	Heavy metals	2.0000	0.5000	0.0165	1.6467
28	Utility	2.0000	0.5000	0.0165	1.6467
29	Infrastructures	2.0000	0.5000	0.0165	1.6467
30	Plant diversity and coverage	2.0000	0.5000	0.0165	1.6467
31	Cover value for common species	2.0000	0.5000	0.0165	1.6467
32	Vinyl chloride /	3.0000	0.3333	0.0110	1.0978
33	Pb (lead)	3.0000	0.3333	0.0110	1.0978

No	Parameters	Ranking	Temporary Weightage	Primary Weightage	Final Weightage
34	Fire / burning	3.0000	0.3333	0.0110	1.0978
35	Rock type	3.0000	0.3333	0.0110	1.0978
36	% of sand and gravel	3.0000	0.3333	0.0110	1.0978
37	Sulphur dioxide	3.0000	0.3333	0.0110	1.0978
38	Drainage problems	3.0000	0.3333	0.0110	1.0978
39	1,4-dichlorobenzene	4.0000	0.2500	0.0082	0.8234
40	Selenium (Se)	4.0000	0.2500	0.0082	0.8234
41	Electrical resistivity of subsurface	4.0000	0.2500	0.0082	0.8234
42	Topography	4.0000	0.2500	0.0082	0.8234
43	Hydrogen sulphide	4.0000	0.2500	0.0082	0.8234
44	Ammonia	4.0000	0.2500	0.0082	0.8234
45	Aesthetic	4.0000	0.2500	0.0082	0.8234
46	Ethylbenzene	5.0000	0.2000	0.0066	0.6587
47	Chromium (Cr)	5.0000	0.2000	0.0066	0.6587
48	Vinyl chloride (gas)	5.0000	0.2000	0.0066	0.6587
49	pH	5.0000	0.2000	0.0066	0.6587
50	Squatters	5.0000	0.2000	0.0066	0.6587
51	Open space	5.0000	0.2000	0.0066	0.6587
52	Styrene	6.0000	0.1667	0.0055	0.5489
53	Suspended solids (SS)	6.0000	0.1667	0.0055	0.5489
54	Benzene	7.0000	0.1429	0.0047	0.4705
55	Dissolved Oxygen (DO)	7.0000	0.1429	0.0047	0.4705
56	Freon-11	8.0000	0.1250	0.0041	0.4117
57	COD	8.0000	0.1250	0.0041	0.4117
58	Ammonia	9.0000	0.1111	0.0037	0.3659
59	Carbon monoxide	10.0000	0.1000	0.0033	0.3293
	TOTAL		30.3635	1.0000	100.0000

3.2 Environmental Conditions According to Individual Criteria

The calculations of weightage for evaluation of individual criteria were carried out based on 0 to 1 basis. The Final Score (FS) identified for each different criteria shows the most risky landfill site in terms of different criteria. For examples, Taman Beringin Landfill Site was identified as the most risky or critical site in terms of landuse perspective; on the other hand, Brickfields Landfill Site was identified to be most critical or risky from hydrological point of view (refer to Table 5).

3.3 The Overall Environmental Conditions

All information about each site were gathered and assessed using the Delphi Method in order to identify the worst landfill site by combining the score of all parameters in each criteria. The weightage for all 59 parameters involved were developed based on 0 to 100 basis using the Delphi Method. The results show the combination of the importance of all parameters with the assumption that all the criteria are equal in terms of their importance.

The results of the overall assessments are shown in Figure 2 and we can conclude that Taman Beringin landfill site is the worst landfill site in terms of its environmental conditions, followed by Jinjang Utara, Brickfields, Paka 2, Paka 1, Sungei Besi, and Sri Petaling.

It is important to emphasis here that the overall worst site is not necessary the most polluted site since the identification of the most critical site have taken into account various aspects or criteria in addition to the pollution aspects. It is also important to emphasis that the landfill sites which are not ranked as the worst are not necessarily safe or critical from the environmental perspective.

3.4 Environmental Conditions in Terms of Pollution Level

In terms of pollution level, the landfill sites are assessed or investigated based on three major criteria, i.e. water quality, landfill gas and chemical pollutants (organic and inorganic pollutants in soils and groundwater).

Based on the assessment results, it can be concluded that the most polluted landfill site in the study area was Taman Beringin followed by Jinjang Utara and Paka 1. The pollution level at Taman Beringin was significant in terms of water quality, chemical pollutants in soils and groundwater as well as gas emissions.

Table 5: Final Scores of Landfill Sites (%)

Landfill Sites	Final Scores (FS) in %										
	Hydrology	Water Quality	Geology and Geotechnics	Landuse	Landfill Gases	Social Aspects	Plant Ecology	Ecotoxicology	Analytical Chemistry	Overall Criticality	Pollution Level
Taman Beringin	64.29	**7.55**	**13.40**	**1.13**	**0.00**	**23.80**	**30.00**	**0.00**	89.94	**29.02**	**48.11**
Jinjang Utara	64.29	33.31	14.04	20.00	100.00	**23.80**	60.00	20.00	90.42	46.92	79.56
Sungai Besi	50.00	NA	31.06	24.86	99.28	39.31	80.00	NR	96.29	62.14	97.32
Sri Petaling	57.14	76.06	26.17	46.36	100.00	62.07	70.00	NR	98.08	68.61	93.77
Brickfields	**14.29**	NA	47.23	31.76	73.14	53.80	70.00	NR	**86.59**	56.56	84.21
Paka 1	28.57	50.24	45.53	36.65	100.00	43.11	80.00	NR	90.00	60.31	83.43
Paka 2	57.14	67.78	37.23	38.54	93.38	28.97	80.00	NR	91.92	59.45	86.71

Note: The Highest Risk Level for Different Categories (Figure in bold)

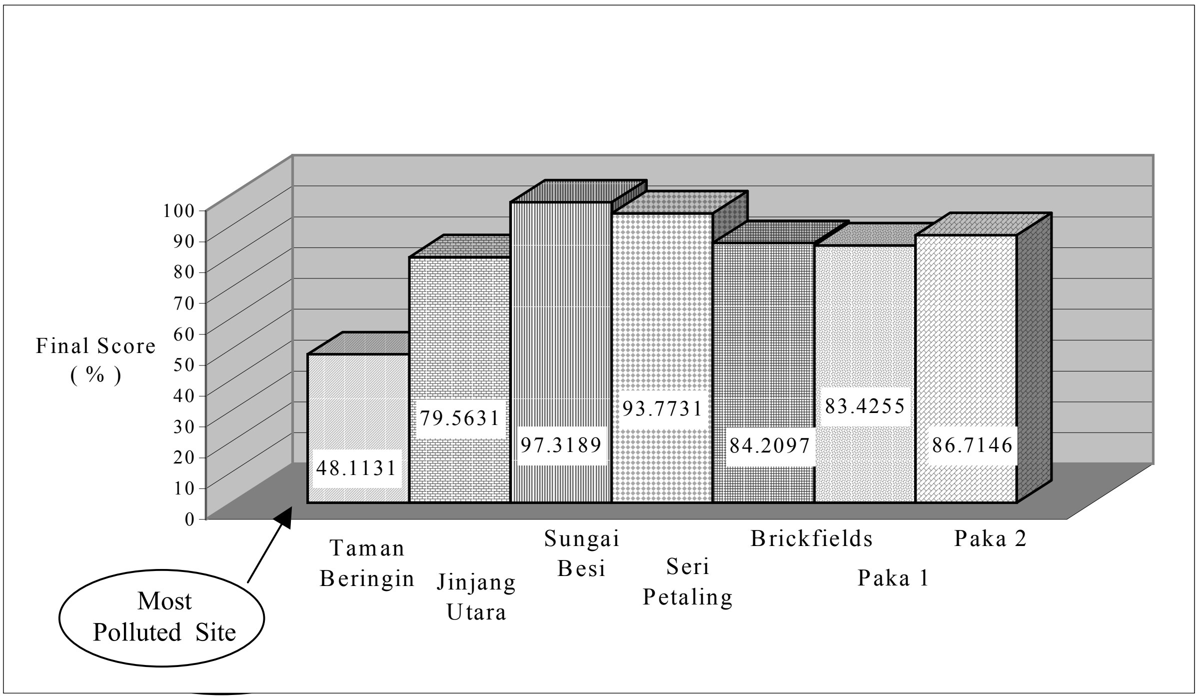

Figure 1: Final Score (%) for Landfill Sites in Terms of Pollution Level

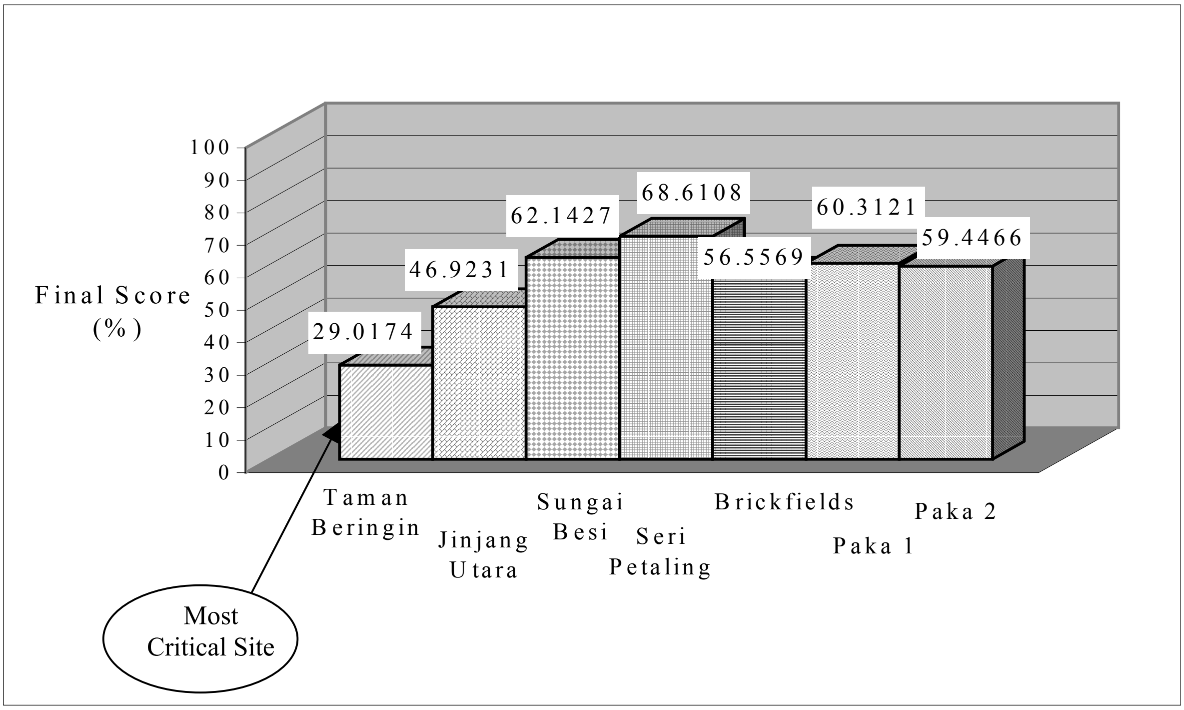

Figure 2: Final Score (%) for Landfill Sites in Terms of Overall Environmental Conditions

3.5 Development of Weightage Dose-Response Relationships

The weightage and dose response equations obtained by using the Delphi Method were summarised in Table 6 below.

Table 6: Summary of the Dose Response Equations

No.	Parameters	Weightage	Dose Response Equations
Water Quality Parameters			
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
Gas Emission Parameters			
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 = 3.1531 x
13	Benzene	0.4705	y = 723.4x
14	Ammonia	0.3659	y = 1.3249x
15	Carbon Monoxide (CO_2)	0.3293	y = 1.2385x
Chemical Parameters in Soil			
16	Benzene	3.2934	y = 642.34x
17	1,2-dichloroethane	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
Chemical Parameters in Groundwater			
21	Benzene	3.2934	y = 4000x
22	1,2-dichloroethane	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)

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 are 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 are excluded in the study because these chemicals were not detected in the samples in the study area.

3.6 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 7.

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 were used as
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 7: Data Used as Threshold Limit Values in the Study

Parameters	Threshold Limit Values	Intervention Values	Unit	Sources
BOD (w)	20	50	mg/L	A
COD (w)	50	100	mg/L	A
Cr (w)	0.05	0.05	mg/L	A
Pb (w)	0.1	0.5	mg/L	A
Hg (w)	0.005	0.05	mg/L	A
Mn (w)	0.2	1.0	mg/L	A
SS (w)	50	100	mg/L	A
CO_2 (g)	5,000	5,000	ppm	B
SO_2 (g)	2.0	2.0	ppm	B
H_2S (g)	10.0	10.0	ppm	B
Vinyl Chloride (g)	5.0	5.0	ppm	B
Styrene (g)	50.0	50.0	ppm	B
Benzene (g)	10.0	10.0	ppm	B
Ammonia (g)	25.0	25.0	ppm	B
CO (g)	25.0	25.0	ppm	B

Benzene (s)	0.05	1.00	mg/kg	C
Vinyl Chloride (s)	0.001	0.10	mg/kg	C
Ethylbenzene (s)	0.05	50.0	mg/kg	C
Hg (s)	0.3	10.0	mg/kg	C
CN (s)	1.0	-	mg/kg	C
As (s)	29	55	mg/kg	C
Pb (s)	85	530	mg/kg	C
Cr (s)	100	380	mg/kg	C
Benzene (gw)	0.0002	0.03	mg/L	C
Tetrachloromethane (gw)	0.00001	-	mg/L	C
Vinyl Chloride (gw)	0.00001	0.0007	mg/L	C
Ethylbenzene (gw)	0.0002	0.15	mg/L	C
Hg (gw)	0.00005	0.00003	mg/L	C
CN (gw)	0.005	-	mg/L	C
As (gw)	0.01	0.06	mg/L	C
Pb (gw)	0.015	0.075	mg/L	C
Cr (gw)	0.001	0.03	mg/L	C

Notes: Source A = Environmental Quality Act (1974)
Source B = ACGIH (1995)
Source C = Environmental Impact Assessment Guidelines for Groundwater and/or Surface Water Supply Projects (1996)

According to the method recommended by *Asante-Duah (1993),* if toxicity data such as the threshold values is not available for a particular parameter, decision can be made to exclude the parameter from the evaluation procedure. In this study, there were 9 parameters which were decided to be excluded from the EDI evaluation procedure because no toxicity data was available or exist for these parameters, namely methane and freon-11 gases, 1,4-dichlorobenzene and selenium in both soil and groundwater. For water quality parameters, DO and ammonia nitrogen were excluded because no specific threshold limits were found in Malaysia. pH value was also excluded from the evaluation because the standards provides a range of pH values and no specific pH value could be used as the limit.

3.7 Calculation of the Environmental Degradation Index (EDI)

An example of the EDI calculation for parameters exceeding the threshold limits for Taman Beringin Landfill is shown in Table 8 below. For EDI_i calculation or the control cases, which has taken into account all the threshold limits and target values, the results are tabulated in Table 9. It is important to emphasise that the EDI_i for each different landfill will have different values based on the total number of parameters exceeded the threshold or limit values. For Taman Beringin case, there were 16 parameters exceeded the thresholds and the total EDI_i evaluated was 179.58.

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 Gaussion 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.

Table 8: EDI Calculations for Taman Beringin Landfill Site Parameters

Parameters	Unit	Actual Conditions	Index (dp)	Weights (wp)	dp.wp	Exceeded Limits
BOD (w)	mg/L	84.6000	100.9109	3.2934	332.3399	Y
COD (w)	mg/L	1,594.0000	118.2748	0.4117	48.6937	Y
Cr (w)	mg/L	0.0530	111.8088	0.6467	72.3068	Y
Pb (w)	mg/L	100.4390	100.2381	0.6467	64.8240	Y
Hg (w)	mg/L	0.6700	100.7680	0.6467	65.1667	Y
Mn (w)	mg/L	2.8000	100.5676	0.6467	65.0371	Y
SS (w)	mg/L	413.0000	79.0482	0.5489	43.3896	Y
CO_2 (g)	ppm	1.440E+02	0.0115	1.6467	0.0190	N
SO_2 (g)	ppm	3.410E+01	0.0682	1.0978	0.0749	Y
H_2S (g)	ppm	1.888E+02	0.0378	0.8234	0.0311	Y
Vinyl Chloride (g)	ppm	2.427E-03	0.0083	0.6587	0.0055	N
Styrene (g)	ppm	5.457E-02	0.1721	0.5489	0.0944	N
Benzene (g)	ppm	1.252E-05	0.0091	0.4705	0.0043	N
Ammonia (g)	ppm	2.004E-03	0.0027	0.3659	0.0010	N
CO (g)	ppm	0.000E+00	0.0000	0.3293	0.0000	N
Benzene (s)	mg/kg	0.0450	28.9053	3.2934	95.1967	N
Vinyl Chloride (s)	mg/kg	0.0430	22.9379	1.0978	25.1812	Y
Ethylbenzene (s)	mg/kg	0.0500	12.5055	0.6587	8.2374	N
Pb (s)	mg/kg	95.3000	16.0866	1.0978	17.6599	Y
Cr (s)	mg/kg	77.1000	8.7046	0.6587	5.7337	N
Benzene (gw)	mg/L	0.0050	20.0000	3.2934	65.8680	Y
Vinyl Chloride (gw)	mg/L	0.0040	15.5556	1.0978	17.0769	Y
Ethylbenzene (gw)	mg/L	0.0070	20.8957	0.6587	13.7640	Y
As (gw)	mg/L	0.0000	0.0000	1.6467	0.0000	N
Pb (gw)	mg/L	0.6160	42.9832	1.0978	47.1870	Y
Cr (gw)	mg/L	0.0740	31.2347	0.6587	20.5743	Y
EDI						**899.17**

Table 9: 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_2S (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

3.8 Development of Landfill Pollution Index (LPI)

Based on the results of EDI_u (actual conditions) and EDI_i (Threshold limit values) calculations, the Landfill pollution Index (LPI) for the landfill sites were obtained, and summarised in Table 10.

Table 10: 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

From the results of LPI calculations, 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.

4. CONCLUSION

The development of simple evaluation systems based on Delphi approach to assess the environmental conditions and pollution levels of landfill sites has been achieved in order to provide a more simple and meaningful system in assessing the pollution levels and environmental conditions of landfill sites in terms of different criteria, the overall as well as the pollution level.

The Landfill Pollution Index (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 in providing 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.

The Delphi assessments determined that most of the landfill sites in the study area showed relatively bad environmental conditions especially the active site, i.e. Taman Beringin landfill site. The results also identified Taman Beringin Landfill Site as the most polluted site, in terms of gas emissions, chemical constituents and water quality. This landfill site was also the worst in terms of the overall environmental conditions, which has taken into consideration 9 different criteria with 59 selected parameters

From the view of individual criteria, Delphi assessment also identified Taman Beringin as the worst in terms of several criteria such as landuse, ecotoxicology, plant ecology, geology, water quality, gas emissions and social aspects. Other site with worst environmental conditions that were identified in the assessments was Brickfields landfill site, which was critical in terms of hydrology and chemical constituents.

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.

REFERENCES

ACGIH. 1995. *Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs)*. ACGIH Worldwide, Cincinnati. pp.133.

Asante-Duah, D. K.1993. *Hazardous Waste Risk Assessment*. Lewis Publishers, Boca Raton. pp 384.

Environmental Quality Act and Regulations. 1996. *Law of Malaysia - Details on Environmental Quality Act 1974 and Regulations Amendments from 1980 to May 1996 with Index.* MDC Publishers, Kuala Lumpur. pp.166.

Griffiths, L. F. 1991. Research requirements in major hazards risk analysis. In: *Risk Analysis*. Vol. 11(2) : 399-404.

Hansson, S. O. 1997. Critical effects and exposure limits. In: *Risk Analysis*. Vol. 17(2): 227-236.

James, D. M. 1987. Modern techniques for the development of above ground landfill site. *Waste Management*. 127(4) : 266-277.

LaGrega, M.D., P. L. Buckingham, J. C. Evans and The Environmental Resources Management Group. 1994. *Hazardous Waste Management*. McGraw-Hill International Editions, New York. pp 1146.

Lai, C. S. 1997. Thesis: *Development of A Malaysia Air Pollution Index*. Universiti Putra Malaysia, Serdang. pp.74.

Lee, T. L. and V. Sivapalasundram. 1979. Some aspects of solid waste management in Klang Valley. In : Thanh, N. C., B. N. Lohani, M. Betts, R. Bidwell and G. Tharun [Eds.] *Waste Disposal and Resource and Resource Recovery*. Asian Institute of Technology, Bangkok. pp.509-520.

Lee, Y. H. and L. Krieger. 1986. Design and operation of sanitary landfill. In: Yong, E. F. and K. K. Tan [Eds.] *Management and Utilisation of Solid Waste*. Universiti Pertanian Malaysia, Serdang. pp.203.

Low, S. M. 1995. Thesis: *Classification of Estuary by Using Physical, Chemical, Biological and Socio-economic Factors in Peninsular Malaysia*. Universiti Pertanian Malaysia, Serdang. pp 76.

Lowe, J. and D. Lewis. 1980. *The Economic and Environmental Management.* Philip and Allan Publishers Limited, Oxford. pp 222.

Matsufuji, Y. and K. Sinha. 1990. Landfill site and improvement in design for sanitary landfill in Malaysia. In: Tong, S. L. [Ed.] *Hazardous Waste Regulation and Management*. ENSEARCH, Kuala Lumpur. pp.175-199.

Nasir, M. H., Rakmi, A. R., Zamri, I., Saifullah, R. 1995. Existing solid waste management and problems in Malaysia. In*: Privatisation of Solid Waste Management in Malaysia*. Tabung Haji Technologies. Kuala Lumpur, Malaysia.

Nasir, M. H., M. K. Yusoff, W. N. Sulaiman and R. A. Rahman. 1996. Issues and problems of solid waste management in Malaysia. In: Hasan, M. N., L. A. Abdullah and I.

Komoo [Eds.]. *Proceeding of the National Review on Environmental Quality Management in Malaysia: Towards the Next Two Decades.* Institute for Environment and Development (LESTARI), UKM, Bangi. pp:179-225.

Richey, J. S., B. W. Mar and R. R. Horner. 1985. The Delphi technique in environmental assessment – 1. Implementation and effectiveness. *Journal of Environmental Management*. 21: 135 - 146.

Turner, R. K. and T. O'riordan. 1982. Project evaluation. In: *Environmental Science Method* [Eds] R. Haynes. Chapman and Hall Ltd, London. pp 372-398.

Ujang, Z. 1997. *Pengenalan Pencemaran Udara (Introduction to Air Pollution)*. Dewan Bahasa dan Pusaka, Kuala Lumpur. pp. 244.

Weiss, S. 1977. *Sanitary Landfill Technology*. Noyes Data Corporation, London. pp.300.

Wilson, J. D. 1997. So carcinogens have thresholds: how do we decide what exposure levels should be considered safe? In: *Risk Analysis*. Vol. 11(2): 1-3.