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Landfill Hazard Assessment Model Based on the Analytic Hierarchy Process

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位階分析過程에 근거한 매립지 유해성 평가 모형

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요 약

본 연구에서는 침출수를 비롯한 매립지의 각종 오염물질 배출로 수자원이 오염되어 피폭체의 피해가 빈발하는 문제를 해결하기 위해서, 매립지의 상대적 유해성을 평가하여 한정된 환경관리 예산의 합리적 배분을 위한 우선순위를 결정할 수 있는 의사결정 지원도구로서 LHR(Landfill Site Hazard Ranking)모형을 개발했다. LHR모형은 多要素意思決定 기법에 정성적 危害性 평가기법을 접맥시켜 주관적 가중치를 모형에 반영한 價値內在化 모형이다.

LHR모형은 피폭체의 주요 피폭경로를 지하수 이동경로와 지표수 이동경로로 보았으며, 각 이동경로별로 누출 가능성, 폐기물 특성 및 피폭체 특성으로 요소범주를 3종류로 구분하여 폐기물의 독성이나 매립량같은 특성이 매립지의 수리지질학적 요소 및 자연지리적 요소에 의해 결정되는 오염물질의 누출 가능성을 통해 매립지 주변의 지역주민과 취약한 수생태계 같은 피폭체에 끼치는 매립지의 유해성을 상대적으로 평가했다. 그리고 LHR모형에서는 매립지 유해성을 공기 이동경로 및 사회경제적 측면에서도 평가하기 위해 매립지 이격거리별 토지이용 형태의 유해성을 평가했다. 그리고 각 평가요소별 가중치는 位階分析過程의 雙對比較法에 의하여 할당했으며, 민감도 분석으로 LHR모형을 검증했다.

주요어 : 매립지 유해성, 지하수 오염, 취약성, 위해성 평가

I. Introduction

Hazardous contaminants generated from landfill could deteriorate receptors through multiple media such as groundwater, surface water, air and soil. Therefore, the adequate management of abandoned and uncontrolled landfills is requisite to safeguard human health and natural environments against hazardous substances.[1][2] However, the government budget for remediation is restricted. To cope with this dilemma, a relative ranking of landfill hazards seems to be indispensible for the determination of priorities for the rational allocation of the limited resources.[3]

Resource allocation for landfill remediation is an issue in Korea, as well as abroad. Often, decision-makers do not have financial or personnel resources to use data intensive ranking/assess-

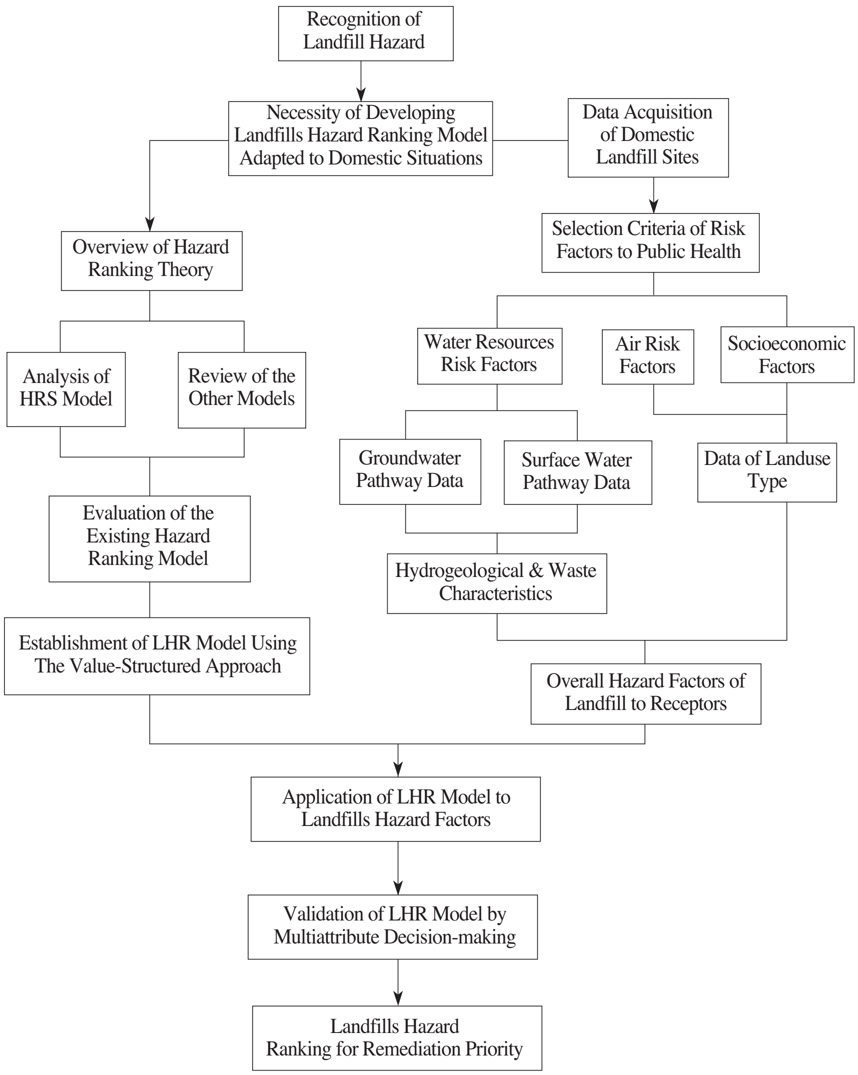

Figure 1. The Schema of LHR Formulation

ment tool. There is a need for a hazard assessment screening tool that cost-effectively makes use of readily available or easily obtained information, and includes the uncertainties that are inherent in the input data to arrive at a final hazard score[4]. The methodology proposed uses multi-attribute ranking techniques to combine the available, often conflicting, site data into a final overall site hazard level.

For the above-mentioned purpose, this study developed the Landfill Hazard Ranking Model (LHR). LHR is a value-structured model which reflects subjective weights.[5] LHR is a landfill assessment model which combines the multi-attribute decision-making(MADM) theory with the qualitative risk assessment methodology[6]. LHR structure is grounded on analytic hierarchy process(AHP) which applies pairwise comparisons.[7] The sensitivity analysis which estimates the effect of the variation of individual factors conditions and weights was attempted for the verification of LHR logic.

LHR is a desk-top evaluation method of existing site-specific data designed to determine whether a landfill deserves further measures. It is the scoring system to assess the relative threat associated with actual or potential release of hazardous substances. However, it does not repre-

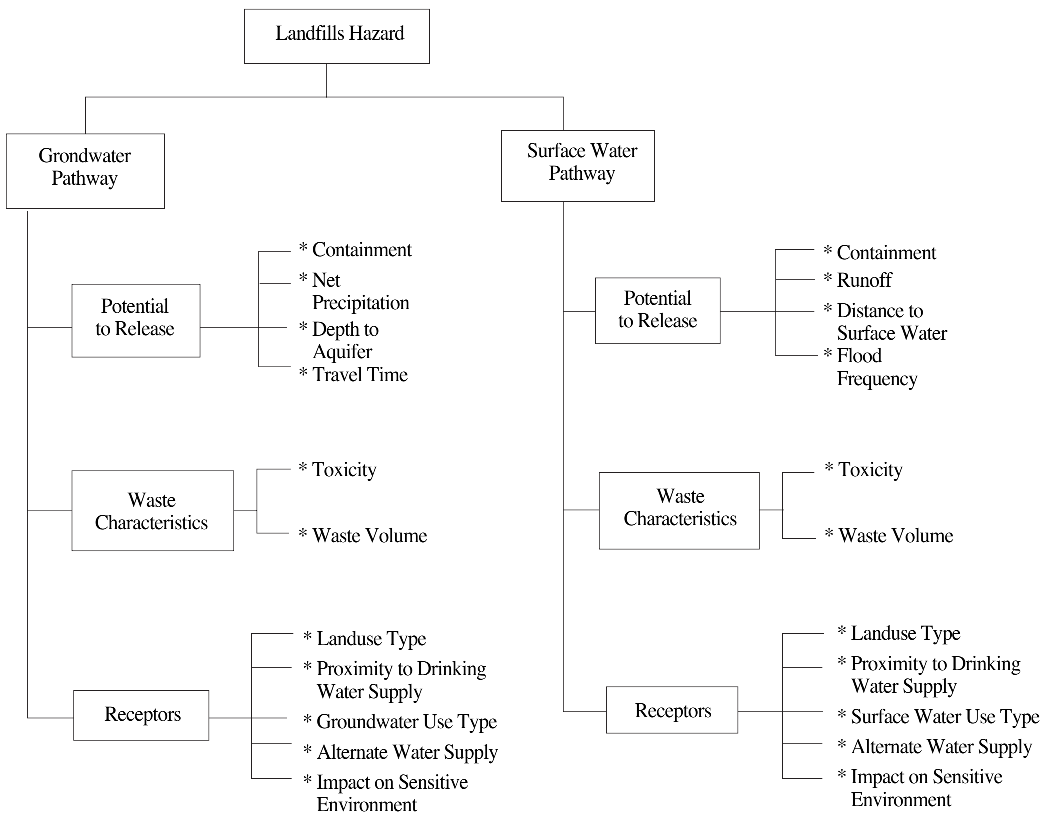

Figure 2. Hierarchical Structure of LHR

sent a specified level of risk, but could be used as a screening-level indicator of the threatened release. LHR is not a detailed risk assessment, just a screening tool.

LHR is for the relative ranking of landfill hazard which is mainly based on the characteristics of vulnerability in water resources. Further, it aims at the prompt and cost-effective assessment of landfill hazard by available site-specific data. The above-mentioned scope and methodology of this study are schematized in Figure 1 and Figure 2.

II. Methodology

1. Scoring Procedure of LHR

The investigation of uncontrolled landfills with traditional methods is time-consuming and expensive. There is a need for a screening system that uses thorough but inexpensive data to estimate the potential hazards from a landfill site. The system proposed could be used for the evaluation of those landfills seemed to be potentially hazardous by a preliminary assessment procedure, thus determining which landfills should receive immediate measures for further investigation.

This paper presents a methodology to assess the environmental and public health hazard posed by an unregulated landfill whose available data is imprecise, uncertain, and subjective. The assessment structure was based on such that hazard indicator values which are relatively easy to obtain or estimate, thus not requiring in-depth calculations or costly data-collection procedures.

The LHR was developed to evaluate the potential for environmental and health hazards created by uncontrolled hazardous waste landfills. The LHR is intended to serve as a uniform scoring procedure for the consistent technical evaluation of landfills across geographical location, waste type, and facility characteristics. The LHR is constructed using a structured value analysis approach. It has both multiplicative and additive capacity for facility evaluation.

The LHR structure consists of evaluating groundwater migration and surface water migration pathways. Theses pathways are selected as the means of leachate or contaminant movement, thus creating possible health and environmental hazards. The pathways are subdivided into categories which contain a number of factors to be scored.

The LHR site score(S) is the result of an evaluation of two pathways : ground water migration(S_{gw}), surface water migration(S_{sw}). Scores are first calculated for the individual pathways and then combined for the site using the following root-mean-square equation to determine the overall LHR site score, which ranges from 0 to 100 ; 100 being a highly hazardous situation.

Each pathway score is the product of three "factor categories" : likelihood of release, waste characteristics, and receptors. (① Likelihood of release is a measure of the likelihood that a waste has been or will be released to the environment. ② Waste characteristics factor category includes the following factors : hazardous waste quantity, toxicity, and as appropriate to the pathway or threat being evaluated, mobility, persistence, and/or bioaccumulation potential. ③ The types of receptors evaluated include the following: individual, human population, resources, sensitive environments.)

Each of the three factor categories contains a set of factors that are assigned numerical values. The procedure of obtaining LHR score is as follows ;

$$S = \sqrt{((S_{gw}^2+S_{sw}^2)/2)} \quad \text{<Eq. 1>}$$

$$S_{gw} = (LR_{gw} \times WC_{gw} \times RT_{gw})/SF_{gw} \quad \text{<Eq. 2>}$$

$$S_{sw} = (LR_{sw} \times WC_{sw} \times RT_{sw})/SF_{sw} \quad \text{<Eq. 3>}$$

S = LHR site score

S_{gw} = Hazard Score of Groundwater Migration Pathway
S_{sw} = Hazard Score of surface water Migration Pathway
LR_{gw} = Likelihood of Release Factor Category Value in Groundwater Pathway

Table 1. Groundwater Migration Pathway Scoresheet

Factor Categories and Factors	
Likelihood of Release to an Aquifer	Maximum Value
1. Observed Release	170
2. Potential to Release	
2a. Containment	66
2b. Net Precipitation	12
2c. Depth to Aquifer	6
2d. Travel Time	36
2e. Potential to Release [lines 2a+2b+2c+2d]	120
3. Likelihood of Release (Higher of lines 1 and 2e)	170
Waste Characteristics	
4. Toxicity/Mobility	a
5. Hazardous Waste Quantity	a
6. Waste Characteristics	90
Receptors	
7. Potential for Impact on Humans	
7a. Proximity	160
7b. Substitutability	25
7c. Groundwater Use	65
7d. Landuse	100
7e. Potential for Impact on Humans (lines 7a+7b+7c+7d)	350
8. Potential for Impact on Environment	270
9. Receptors (Lines 7e + 8)	620
Groundwater Migration Pathway Score	
10. Pathway Score (lines 3 × 6 × 9/94,860)	100

Where, a : Maximum value applies to waste characteristics category

Table 2. Surface Water Overland/Flood Migration Component Scoresheet

Factor Categories and Factors	Maximum Value
Likelihood of Release	
1. Observed Release	160
2. Potential to Release by Overland Flow	
2a. Containment	70
2b. Runoff	30
2c. Distance to surface water	20
2d. Potential to Release by Overlandflow (lines 2a + 2b + 2c)	120
3. Potential to Release by Flood	
3a. Containment	60
3b. Flood Frequency	30
3c. Potential to Release by Flood (lines 3a + 3b)	90
4. Potential to Release (lines 2d + 3c, subject to a maximum of 120)	120
5. Likelihood of Release (higher of lines 1 and 4)	160
Waste Characteristics	
6. Toxicity/Persistence	a
7. Hazardous Waste Quantity	a
8. Waste Characteristics	70
Receptors	
9. Potential for Impact on Humans	310
9a. Proximity	140
9b. Substitutability	20
9c. Surface Water Use	60
9d. Landuse	90
9e. Potential for Impact on Humans (lines 9a + 9b + 9c + 9d)	310
10. Potential for Impact on Environment	250
11. Receptors (Lines 9e + 10)	560
Surface Water Threat Score	
13. Surface Water Threat Score (lines 5 × 8 × 11/62,720)	100

Where, a : Maximum value applies to waste characteristics category

WC_{gw} = Waste Characteristics Factor Category Value in Groundwater Pathway
RT_{gw} = Receptors Factor Category Value in Groundwater Pathway
SF_{gw} = Scaling Factor in Groundwater Pathway
LR_{sw} = Likelihood of Release Factor Category Value in Surface Water Pathway
WC_{sw} = Waste Characteristics Factor Category Value in Surface Water Pathway
RT_{sw} = Receptors Factor Category Value in Surface Water Pathway
SF_{sw} = Scaling Factor in Surface Water Pathway

The ranking procedure for a given site begins by assigning a numerical value to each factor within a given category. Each of these numerical values is derived from a weighting multiplier, which reflects the relative importance of the system assigned to each factor within a category, to derive a factor score. All scores obtained within one category are added or multiplied to derive a total score for that category. Table 1 and Table 2 outline the specific calculation procedure of groundwater and surface water migration pathway respectively.

2. Determination of Weights for Each Factors

The methodology proposed uses multi-attribute decision-making(MADM) techniques to combine the available, often conflicting, landfill data into a final overall landfill hazard level. The selected MADM technique is composite programming which incorporates analytic hierarchy process(AHP) and pairwise comparison.

The basic AHP(Analytic Hierarchy Process) model involves obtaining values scores for each alternatives for each of multiple attributes and then combining the scores by weighting them by

Table 3. AHP Structure of LHR

Landfill Hazard (5th-Level)	Pathways (4th-Level)	Factor Categories (3rd-Level)	Factor Categories (2nd-Level)	Factors (1st-Level)
LHR	GW	LR	OR	OR
			PR	CT
				TT
				NP
				DA
		WC	WC	WC
		RT	TH	GP
				GL
				GU
				GA
			TE	TE
	SW	LR	OR	OR
			OV	VC
				RF
				DS
			FL	FC
				FF
		WC	WC	WC
		RT	TH	SP
				SL
				SU
				SA
			TE	TE

LR : Likelihood of Release
WC : Waste Characteristics
RT : Receptors
TH : Potential for Impact on Humans
OR : Observed Release
TE : Potential for Impact on Environments
PR : Potential to Release
GP : Proximity to Drinking Water Source
CT : Containment Facility
TT : Travel Time
NP : Net Precipitation
DA : Depth to Aquifer
GL : Landuse Type
GA : Alternate Drinking Water Supply
GU : Type of Groundwater Use Except Drinking Water
FL : Potential to Release by Flood
VC : Containment Facility
RF : Runoff
FC : Containment Facility
DS : Distance to surface water
FF : Flood Frequency
SP : Proximity to Drinking Water Source
SL : Landuse Type
SA : Alternate Drinking Water Supply
SU : Surface Water Use Type
OV : Potential to Release by Overlandflow

scaling constants that specify the importance of each attribute. The AHP procedure involves a step-by-step regrouping of a set of various basic indicators to form a single indicator.

The AHP structure developed for landfill site assessment contained 23 factors as first-level indicators, 11 as second-level indicators, 6 as third-level indicators, 2 as fourth-level indicators, and 1 as the final indicator (shown in Table 3). The landfill hazard potential was included to determine if a site is releasing contaminants via the two pathways. The indicators were selected based on their ability to use available, inexpensive and easily obtained data.

A major advantage of AHP in landfill assessment is its flexibility. As more information becomes available, the structure can be modified to include the additional information. To determine weighting multipliers of indicators in AHP structure, a pairwise comparison was applied to indicators. In a pairwise comparison, the “agreed upon” numbers are the following. Given elements A and B ; if

A and B are equally important, insert 1

A is weakly more important than B, insert 3

A is strongly more important than B, insert 5

A is demonstrably or very strongly more important than B, insert 7

A is absolutely more important than B, insert 9

in the matrix in position (A, B) where the row of A meets the column of B

The numerics of 2, 4, 6, 8 can be used as an intermediate values to reflect a compromise. After completing a matrix of pairwise comparison, weights of evaluation factors are decided by the following method. As shown in Table 4 - Table 6, divide the elements of each column by the sum of that column(i.e., normalize the column) and then add the elements in each resulting row and divide this sum by the number of elements in the row.

Table 4. Pairwise Comparison Matrix of Groundwater Factor Categories

Factor Categories	TH	TE	OR	PR	WC	Weights
TH	1	2	2	3	3	0.35
TE	1/2	1	2	3	3	0.27
OR	1/2	1/2	1	2	2	0.17
PR	1/3	1/3	1/2	1	2	0.12
WC	1/3	1/3	1/2	1/2	1	0.09

Table 5. Pairwise Comparison of Factors of Potential to Release

Factors	CT	TT	NP	DA	Weights
CT	1	3	6	8	0.55
TT	1/3	1	5	7	0.30
NP	1/6	1/5	1	3	0.10
DA	1/8	1/7	1/3	1	0.05

Table 6. Pairwise Comparison of Factors of Receptors

Factors	GP	GL	GU	GA	Weights
PD	1	5	7	9	0.46
LU	1/5	1	4	8	0.29
GU	1/7	1/4	1	4	0.18
GA	1/9	1/8	1/4	1	0.07

III. Validation and Sensitivity Analysis of LHR

As a result of sensitivity analysis, as shown Table 7 and Table 8, LHR composite scores are largely influenced by some factors following sequential order such as waste volume, proximity to sensitive environments, containment facilities,

Table 7. Test Conditions for Sensitivity Analysis

Conditions	Factors	Original Status	New Status
A	Containment	No Liner	Double Liner
B	Net Precipitation	Greater than 70cm/yr	0 cm/yr
C	Depth to Aquifer	Less than 1.5m	Greater than 30m
D	Travel Time	Hydraulic Conductivity : > 10^{-3}cm/sec, Vadose Zone : < 1.5m	Hydraulic Conductivity : < 10^{-7}cm/sec, Vadose Zone : >30m
E	Waste Toxicity	Highly Toxic	Less Toxic
F	Waste Volume	Large Quantity	Small Quantity
G	Proximity to Drinking Water Supply	< 500m	2km to 3km
H	Alternate Drinking Water Supply	Not Available	Available
I	Groundwater Use Type	Recreational	Domestic Use Except Drinking Water
J	Landuse Type	Residential < 300m	Industrial > 2km
K	Runoff	Drainage Area : > $5km^2$, Coarse-textured Soil	Drainage Area : < $0.1km^2$, Fine-textured Soil
L	Distance to Surface Water	< 50m	> 2km
M	Flood Frequency	Floods Annually	>500-year Floodplain
N	Distance to Sensitive Habitats	< 500m	> 6km

Table 8. Sensitivity Analysis

Factor	Scores Based on New Status for Conditions														
Categories	Control	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Groundwater Pathway														
LR	120	61	109	115	85	120	120	120	120	120	120	120	120	120	120
WC	90	90	90	90	90	72	45	90	90	90	90	90	90	90	90
RT	620	620	620	620	620	620	620	476	598	562	530	620	620	620	377
Sgw	70.59	35.88	64.12	67.65	50.00	56.47	35.29	54.19	68.08	63.98	60.34	70.59	70.59	70.59	42.92
	Surface Water Pathway														
LR	120	93	120	120	120	120	120	120	120	120	120	90	102	93	120
WC	70	70	70	70	70	56	35	70	70	70	70	70	70	70	70
RT	560	560	560	560	560	560	560	434	542	560	480	560	560	560	335
Ssw	75.00	58.13	75.00	75.00	75.00	60.00	37.50	58.13	72.59	75.00	64.29	56.25	63.75	58.13	44.87
	Overall LHR Score														
S_{LHR}	72.83	48.30	69.77	71.42	63.74	58.26	36.41	56.19	70.37	69.71	62.35	63.82	67.26	64.66	43.91

distance from drinking water supplies, and waste toxicity.

The relative hazard ranking of landfills evaluated by LHR, as shown Table 9 - Table 10, is not influenced by weights change of individual factors. Therefore, LHR seems to be a credible model to determine priorities of landfill remediation based on the vulnerability of water resources.

IV. Case Study

It is estimated there are about 2,000 hazardous waste disposal facilities across South Korea.

Table 9. Weights of Factors for Five Different Trials

Type		Factor Categories	Factors	Weights				
				Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
GW		TH	PD	0.160	0.263	0.244	0.055	0.047
			LU	0.100	0.136	0.171	0.032	0.027
			GU	0.065	0.056	0.075	0.021	0.012
			GA	0.025	0.025	0.050	0.015	0.018
		TE	TE	0.270	0.220	0.220	0.080	0.078
		OR	OR	0.170	0.140	0.120	0.249	0.410
		PR	CT	0.066	0.047	0.044	0.049	0.036
			TT	0.036	0.031	0.016	0.082	0.138
			NP	0.012	0.009	0.006	0.028	0.059
			DA	0.006	0.003	0.004	0.017	0.022
		WC	WC	0.090	0.070	0.050	0.372	0.153
	Sum	-	-	1.000	1.000	1.000	1.000	1.000
SW		TH	PD	0.140	0.212	0.140	0.035	0.017
			LU	0.090	0.122	0.217	0.020	0.043
			SU	0.060	0.080	0.063	0.010	0.008
			SA	0.020	0.056	0.100	0.013	0.011
		TE	TE	0.250	0.220	0.160	0.058	0.063
		OR	OR	0.160	0.130	0.130	0.219	0.334
		FL	FC	0.060	0.020	0.045	0.077	0.056
			FF	0.030	0.040	0.015	0.038	0.170
		OV	VC	0.070	0.058	0.048	0.055	0.047
			RF	0.030	0.015	0.022	0.087	0.115
			DS	0.020	0.007	0.010	0.026	0.020
		WC	WC	0.070	0.040	0.050	0.362	0.116
	Sum	-	-	1.000	1.000	1.000	1.000	1.000

Where, Trial 1 : Weights for LHR in this Study
Trial 2 : Weights for Human are higher than Trial 1
Trial 3 : Weights for Human are higher than Trial 1
Trial 4 : Weights for Waste Characteristics are higher than Trial 1
Trial 5 : Weights for Likelihood of Release are higher than Trial 1
GW : Groundwater Pathway
SW : Surface Water Pathway

Approximately 1,500 of these are abandoned or uncontrolled sites that require immediate attention to prevent serious degradation of the environment. This paper attempts : (1) To demonstrate the use of the LHR scoring procedures ; (2) to test the sensitivity of several of the scoring factors associated with the ranking methodology.

LHR was applied to distinctive landfill sites in central Korea, which were equipped with adequate site-specific data, such as Nanjido Landfill, Metropolitan Landfill, and Hwasung Landfill. Nanjido Landfill is an open dump site located in wetlands adjacent to the Han river which runs through Seoul city. The Metropolitan Landfill is a very large sanitary landfill located in marine clay soil reclaimed from the Yellow Sea coast, and Hwasung Landfill for disposal of specific hazardous waste is located about 50km southwest of Seoul.

As shown in Table 12 - Table 13, the result of

Table 10. LHR Scores for Trial 2 and Trial 3

Landfill	Trial 1 (Original)		Trial 2		Trial 3	
Nanjido	GW	LR = 170	GW	LR = 140	GW	LR = 120
		WC = 90		WC = 70		WC = 50
		RT = 330		RT = 427		RT = 463
	SW	LR = 160	SW	LR = 130	SW	LR = 130
		WC = 70		WC = 40		WC = 50
		RT = 311		RT = 341		RT = 399
	Composite	54	Composite	56	Composite	60
Kimpo	GW	LR = 58	GW	LR = 39	GW	LR = 35
		WC = 72		WC = 56		WC = 40
		RT = 320		RT = 451		RT = 485
	SW	LR = 109	SW	LR = 68	SW	LR = 67
		WC = 56		WC = 32		WC = 40
		RT = 236		RT = 275		RT = 351
	Composite	19	Composite	16	Composite	18
Hwasung	GW	LR = 40	GW	LR = 26	GW	LR = 24
		WC = 45		WC = 35		WC = 25
		RT = 277		RT = 381		RT = 435
	SW	LR = 54	SW	LR = 40	SW	LR = 36
		WC = 35		WC = 20		WC = 25
		RT = 291		RT = 311		RT = 356
	Composite	7	Composite	6	Composite	7

Where, Trial 1 : Weights for LHR in this Study
Trial 2 : Weights for Human are higher than Trial 1
Trial 3 : Weights for Human are higher than Trial 1
GW : Groundwater Pathway
SW : Surface Water Pathway
Composite : LHR Composite Score of Groundwater Pathway and Surface Water Pathway

Table 11. LHR Scores for Trial 4 and Trial 5

Landfill	Trial 1 (Original)		Trial 4		Trial 5	
Nanjido	GW	LR = 170	GW	LR = 249	GW	LR = 410
		WC = 90		WC = 372		WC = 153
		RT = 330		RT = 113		RT = 101
	SW	LR = 160	SW	LR = 219	SW	LR = 334
		WC = 70		WC = 362		WC = 116
		RT = 311		RT = 71		RT = 94
	Composite	54	Composite	54	Composite	61
Kimpo	GW	LR = 58	GW	LR = 74	GW	LR = 99
		WC = 72		WC = 298		WC = 122
		RT = 320		RT = 109		RT = 95
	SW	LR = 109	SW	LR = 184	SW	LR = 250
		WC = 56		WC = 290		WC = 93
		RT = 236		RT = 53		RT = 75
	Composite	19	Composite	21	Composite	24
Hwasung	GW	LR = 40	GW	LR = 64	GW	LR = 94
		WC = 45		WC = 186		WC = 77
		RT = 277		RT = 102		RT = 89
	SW	LR = 54	SW	LR = 73	SW	LR = 128
		WC = 35		WC = 181		WC = 58
		RT = 291		RT = 67		RT = 84
	Composite	7	Composite	7	Composite	9

Where, Trial 1 : Weights for LHR in this Study
Trial 4 : Weights for Waste Characteristics are higher than Trial 1
Trial 5 : Weights for Likelihood of Release are higher than Trial 1
GW : Groundwater Pathway
SW : Surface Water Pathway
Composite : LHR Composite Score of Groundwater Pathway and Surface Water Pathway

Table 12. LHR Scores of Landfill Sites

Factor Categorie \ Landfill Site		Nanjido	Kimpo	Hwa-sung
Ground-water Pathway	Likelihood of Release	170	58	40
	Waste Characteristics	90	72	45
	Receptors	330	320	277
	Pathway Score	53	14	5
Surface Water Pathway	Likelihood of Release	160	109	54
	Waste Characteristics	70	56	35
	Receptors	311	236	291
	Pathway Score	56	23	9
Landfill Site Hazard Score		55	19	7

LHR scoring is as follows ; Nanjido Landfill 54, Metropolitan Landfill 19, and Hwasung Landfill 7. These LHR scores imply just the relative hazard ranking, not the absolute risk of landfill.

V. Conclusions

The procedure developed in this paper is a screening method for landfill assessment, not an alternative to a full-scale evaluation. It is, however, a relatively quick and inexpensive method of

Table 13. Ranking Criteria for Landfill Hazard

Type		Degree of Hazard	Factor Categories			LHR Score
			LR	WC	RT	
Path-way	Ground-water	EH	170	90	620	100
		VH	120	72	440	40
		GH	95	54	288	16
		GS	20	18	86	0
		VS	10	9	63	0
	Surface Water	EH	160	70	560	100
		VH	120	56	395	42
		GH	95	42	252	16
		GS	35	14	107	1
		VS	18	7	57	0
Overalll Score		EH		-		100
		VH		-		41
		GH		-		16
		GS		-		1
		VS		-		0

Where, EH : Extremely Hazardous VH : Very Hazardous
SH : Slightly Hazardous SS : Slightly Safe VS : Very Safe

determining the potential hazards. The methodology can be extended to rank several sites relative to each other.

LHR was applied to distinctive landfill sites in central Korea, which were equipped with adequate site-specific data, such as Nanjido Landfill, Metropolitan Landfill, and Hwasung Landfill. The result of LHR scoring is as follows ; Nanjido Landfill 54., Metropolitan Landfill 19., and Hwasung Landfill 7. These LHR scores imply just the relative hazard ranking, not the absolute risk of landfill.

As a result of sensitivity analysis, LHR composite scores are largely influenced by some factors following sequential order such as waste volume, proximity to sensitive environments, containment facilities, distance from drinking water supplies, and waste toxicity. The relative hazard ranking of landfills evaluated by LHR is not influenced by weights change of individual factors. Therefore, LHR seems to be a credible model to determine priorities of landfill remediation based on the vulnerability of water resources.

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