2012 2nd International Conference on Environmental and Agriculture Engineering
IPCBEE vol.37 (2012) © (2012) IACSIT Press, Singapore

Combining AHP and TOPSIS Approaches to Support Site Selection for a Lead Pollution Study

Ali Al Maliki[1], Gary Owens[1] and David Bruce[2]

[1]Centre for Environmental Remediation and Risk Assessment (CERAR). University of South Australia
[2]School of Natural and Built Environments, Barbara Hardy Institute, University of South Australia

Abstract. This paper presents a case study involving evaluation of six mining and smelting regions across Australia for site suitability for an industrial Pb contamination study. Site selection was based on application of a Multi-Criteria Decision Making (MCDM) algorithm. This study showed that suitable sites could be identified and ranked using a combination of AHP and TOPSIS by restricting analysis to sites within 5 km of the Pb source, which included urban zones with potential health effects. In each Australian state, different areas were initially identified as being potentially suitable for a contaminated Pb study depending on the weights of seven predefined criteria and the priorities of the decision maker. However, after this process there were still some locations that were equally suitable in most states, so that final site selection was made only after each location was ranked in descending order of preference. This proposed technique allowed for an often qualitative assessment of site selection to be replaced by a more quantitative, informed and unbiased method.

Keywords: Lead Pollution, Industrial Pollution, Mcdm, Topsis, Ahp, Australian Pb Smelters

1. Introduction

There is now considerable evidence linking detrimental human health effects with lead (Pb) exposure, where mining, smelters and the associated industrial processes are the primary sources of Pb exposure especially amongst young children < 5 years of age due to accumulation of Pb in soils and household dusts. Numerous studies have shown widespread environmental Pb contamination in cities associated with the close proximity of smelters and/or mines, such as Port Pirie [1] and industrial areas in Port Kembla [2], Broken Hill [3] and Mount Isa [4]. This paper proposes a method for assessing site suitability for Pb a contamination study in the vicinity of industrial regions. Initially an extensive literature review was conducted to determine the most important selection criteria. Elevated blood Pb levels (BLL) were one criteria which had been widely identified in mining locations within Australia such as in Mount Isa [4,5]; Broken Hill [5], Lake Macquarie [6] and Port Pirie [1,4,5] as having a negative health impact. As children living in housing with elevated Pb levels were more likely to be exposed to Pb have BLL ≥ 10 µg/dL compared with other people [7], the number of children in a region was also considerable a significant selection criteria, as was the amount of Pb production and prevailing wind direction. In this paper, a Multi-Criteria Decision Making (MCDM) approach was used to find the optimum location for a lead pollution study. MCDM is based on analytical ranking of all alternatives which meet all the required criteria fully and is widely used in economic, social, political and environmental studies. TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) and AHP (Analytic Hierarchy Process) are two methods which can be used in MCDM to solve different decision making problems [8 9] and in this case study were combined to support site selection.

2. Site Selection Process

The overall Site Selection Process depicted in Fig.1 involved a three step procedure 1) Establishing selection criteria, 2) Evaluating weight of criteria by AHP and 3) Site selection using TOPSIS:

2.1. Establishing site selection criteria and data collection.

In the first stage a list of all potential sites representative of all industrial Pb contaminated centres from either mining and/or smelting activities within Australia were collated (Fig.1). Simultaneously, without reference to any particular site, a list of general site suitability criteria was developed. These criteria were selected following an extensive literature survey and included:

1) Distance from workplace and hence the expected associated travel cost when conducting field surveys.

2) Total human population in the vicinity of the mining or smelter activity.

3) Direction of surface winds.

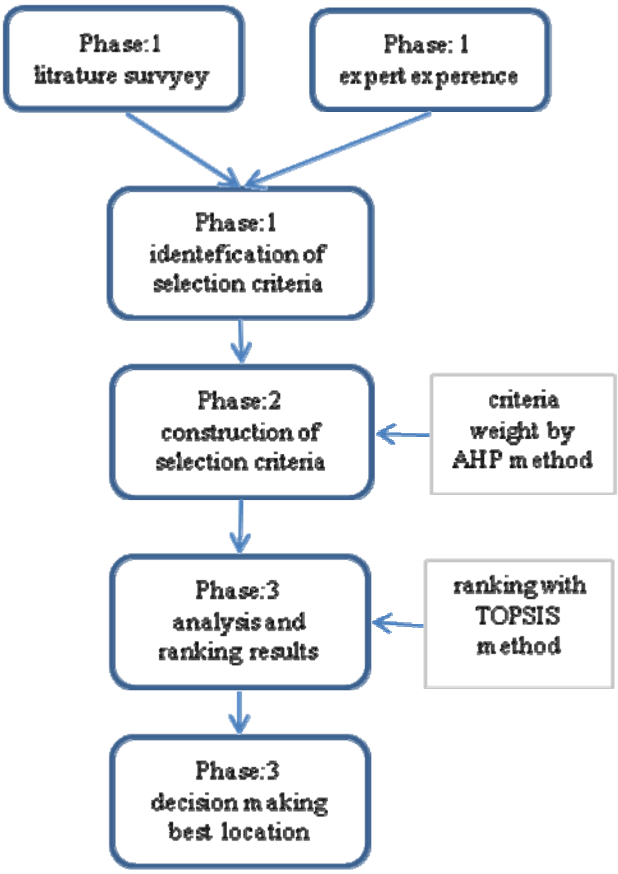
4) Quantity of Pb production at each site.

5) Percentage of children under 5 years of age with blood lead level (BLL) ≥ 10 µg /dL.

6) Number of children between 0-4 years of age.

7) Number of children between 5-14 years of age.

The final site was selected based on suitability as determined by matching of these selection criteria. The alternative sites and data pertaining to the relevant selection criteria is summarized in Table 1.



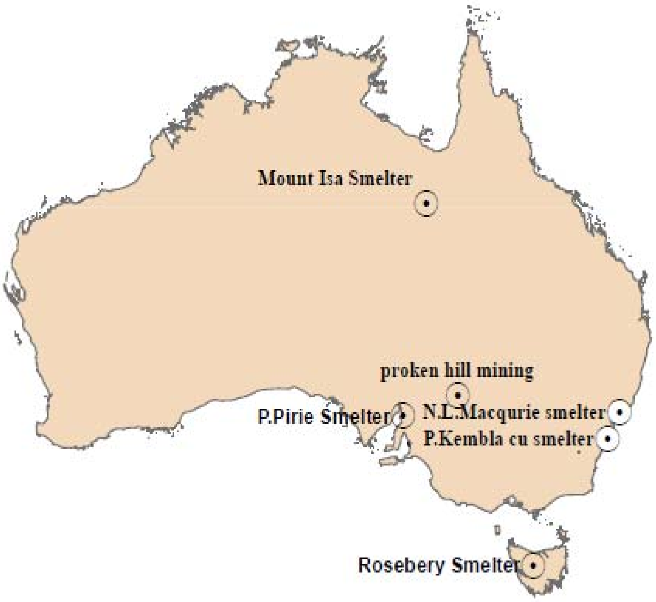


Fig. 1: Methodological flow diagram and location of major Australian industrial smelters.

2.2. Evaluating weight of criteria by AHP approach

The selection criteria at each level of the hierarchy structure have differing degrees of importance to the decision-making process, so that each alternative has a different level depending on the weight value apportioned to each criterion [9]. In this study the AHP method used paired comparison to weight the importance criteria based on a hierarchical structure. Notably, the AHP method has the advantages of yielding more precise results and verifying consistency of judgments [8-10]. The computation of the weights using the AHP approach involves two main steps 1) Development of the pair-wise comparison matrix and 2) synthesis of judgements.

2.2.1. Development of a pair-wise comparison matrix

The matrix of pair-wise comparisons was constructed from i × j elements, Where i and j were the number of criteria (n) so that in matrix A (Equation 1), a_{ij} represents comparative values of criterion i with respect to criterion j, such that $a_{ij} = 1/a_{ji}$ and $a_{ij} = 1$ when i = j.

Table 1: Locations of principle Australian Pb smelting industries and criteria associated with elevated Pb (Decision matrix)

Criteria(C) / Location (L)	C1: Distance to study location (km)	C2: Total population [11]	C3: No. of dominant wind directions	C4: Lead production (ton/year)	C5: Children < 5 years with BLL ≥ 10 µg /dL (%)	C6: No. of children (0-4 years old) [11]	C7: No. of children (5-14 years old) [11]
L1: Port Pirie (SA)	213	13206	3	245,000 [12]	61 [1, 5]	835	1955
L2: Port Kembla (NSW)	1354	41689	3	14 [13]	11 [14]	2486	5321
L3: Lake Macquarie (NSW)	1531	7401	3	90 [15]	17 [5, 6]	484	935
L4: Mount Isa (QLD)	1863	18,857	5	248,400 [16]	11.3 [4]	1781	3234
L5: Rosebery (TAS)	1330	1032	5	37,121 [17]	50.2 [18]	84	155
L6: Broken Hill (NSW)	497	18854	4	44,000 [19]	26 [5]	1156	2546

The comparisons between each criterion were made using the measurement scale of Satty [20] which gave numerical values between 1 and 9 depending on the relative importance of the criterion (Table 2).

Table 2: Pair-wise comparison in AHP preference [20]

Definition	Intensity of importance
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate values	2,4,6,8

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1j} \\ a_{21} & 1 & \cdots & a_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} \end{bmatrix} \quad (1)$$

2.2.2. Synthesis judgments

After all pair-wise comparison matrices were formed, the vector of weights, $w = [w1, w2. . . wn]$, of each criterion was computed on the basis of Satty's eigenvector procedure [28]. This procedure is known a synthesis judgment and involves three phases:

1) Sum the values of the elements in each column of the pair-wise comparison matrix A.
2) Divide each element of the pair-wise comparison matrix by its column total to obtain the normalized pair-wise comparison matrix (Equation 2).

$$a^*_{ij} = a_{ij} / \sum_{i=1}^{n} a_{ij} \quad \text{for all j =1,2,....n} \quad (2)$$

3) Calculate the average of elements in each row in the normalized matrix A, which represents the weight of each criterion (Equation 3). There is a relationship between the vector weights, w, and the pair-wise comparison matrix, A such that, $Aw = \lambda_{max} w$.

$$Wi = \frac{\sum_{j=1}^{n} a^*_{ij}}{n} \quad \text{for all i =1, 2 ...n} \quad (3)$$

Where the maximum eigenvalue (λ_{max}) can be calculated from the consistency value (CV) of each raw datum using Equation 4, by divided the summation of CV by n as shown in Equation 5.

$$CV_i = \frac{\left(\sum_{j=1}^{n} a_{ij} \times w_j\right)}{w_j} \quad \forall\, i; i = 1,2, \ldots .n \quad (4)$$

$$\lambda_{max} = \frac{\sum_{i=1}^{n} CV_i}{n} \quad (5)$$

In the AHP method the maximum eigenvalue (λ_{max}) is a significant parameter of the validation consistency and is used as a reference index to screen information by calculating the consistency ratio (CR) of the estimated vector. CR is calculated by applying Equations 6 and 7, which represents the consistency index for each matrix of order n

$$CI = (\lambda_{max} - n)/(n-1) \quad (6)$$

$$CR = CI/RI \quad (7)$$

The value of the random index RI depends on n. RI values corresponding with n between 1-10 are listed in Table 3. The consistency ratio (*CR*) represented the key check of inconsistency of the subjective values of the A matrix so that if *CR* is $\leqslant$ 0.1, the values of subjective judgment are considered acceptable [10].

Table 3: Random inconsistency indices (RI) for N=10[20]

N	1	2	3	4	5	6	7	8	9	10
RI	**0.00**	**0.00**	**0.58**	**0.9**	**1.12**	**1.24**	**1.32**	**1.41**	**1.46**	**1.149**

2.3. Site selection using TOPSIS

The TOPSIS procedure is based on an intuitive and simple idea, which is that the optimal ideal solution, having the maximum benefit, is obtained by selecting the best alternative which is far from the most unsuitable alternative, having minimal benefits[10,21]. The ideal solution should have a rank of one, while the worst alternative should have a rank approaching 0. As ideal sites are not probable and each alternative site would have some intermediate ranking between the ideal solution extremes [21]. Regardless of absolute accuracy of rankings, comparison of a number of different sites under the same set of selection criteria allows accurate weighting of relative site suitability and hence optimal site selection. Mathematically the application of the TOPSIS method involves the following steps:

Step 1: Establish the decision matrix

The first step of the TOPSIS method involves the construction of a $m \times n$ decision matrix (DM).

$$DM = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ L_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ L_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ L_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{matrix}$$

where i is the criterion index (i = 1 . . . m); m is the number of potential sites and j is the alternative index (j = 1 . . . n). The elements $C_1, C_2, \ldots, C_n$ refer to the criteria: while $L_1, L_2, \ldots, L_m$ refer to the alternative locations. The elements of the matrix are related to the values of criteria i with respect to alternative j.

Step 2: Calculate a normalized decision matrix

The normalized values r_{ij} denote the normalized decision matrix (NDM) which represents the relative performance of the generated design alternatives (Equation 8).

$$NDM= r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (8)$$

Step 3: Determine the weighted decision matrix

Not all of the selection criteria may be of equal importance and hence weighting were introduced previously to quantify the relative importance of the different selection criteria (see Section 2). The weighting decision matrix is simply constructed by multiply each element of each column of the normalized decision matrix by the predefined weights (Equation 9).

$$V= v_{ij} = w_j \, r_{ij} \quad (9)$$

Step 4: Identify the positive and negative ideal solution

The positive ideal (A^+) and the negative ideal (A^-) solutions are defined according to the weighted decision matrix via the equations below.

$$PIS = A^+ = \{ v_1^+, v_2^+ \ldots, v_n^+\}, \text{ where: } V_j^+ = \{ (\max_i (v_{ij}) \text{ if } j \in J), (\min_i v_{ij} \text{ if } j \in J') \} \quad (10)$$

$$NIS = A^- = \{ v_1^-, v_2^-, \ldots, v_n^- \}, \text{ where: } V_j^- = \{(\min v_{ij} \text{ if } j \in J); (\max v_{ij} \text{ if } j \in J') \} \quad (11)$$

where J is associated with the beneficial attributes and J' is associated with the non-beneficial attributes.

Step 5: Calculate the separation distance of each competitive alternative from the ideal and non- ideal solution

$$S^+ = \sqrt{\sum_{j=1}^{n} (V_j^+ - V_{ij})2} \qquad i = 1, \ldots, m \quad (12)$$

$$S^- = \sqrt{\sum_{j=1}^{n} (V_j^- - V_{ij})2} \quad i = 1, \ldots, m \qquad (13)$$

Step 6: Measure the relative closeness of each location to the ideal solution. For each competitive alternative the relative closeness of the potential location with respect to the ideal solution is computed (Equation 14).

$$C_i = S_i^- / (S_i^+ + S_i^-) \ , 0 \le C_i \le 1 \qquad (14)$$

Step 7: Rank the preference order

According to the value of C_i the higher the value of the relative closeness, the higher the ranking order and hence the better the performance of the alternative. Ranking of the preference in descending order thus allows relatively better performances to be compared.

3. Results

The weighted values of the criteria were assigned using the scale developed by Satty [20] and consequently a pair-wise comparison matrix was established to determine decision criteria in a hierarchical tree structure at different levels using AHP (Table 4) resulting in the final weight of each criterion (Fig. 2). Relative comparisons were made based on the research previously reported and expert experience.

After assigning weight to each criterion using the AHP approach the places that were considered potentially suitable for a study of industrial lead pollution were ranked using the TOPSIS method:

- Construction of a decision matrix (DM) using Step3 of the proposed site selection process (Table 1).
- Calculation of the normalized decision matrix (Equation 8).
- Construction of a weighted normalized decision matrix (Equation 9).
- Identification of the ideal (A^+) and negative ideal (A^-) solutions (Equations 10 and 11).
- Calculation of the separation of each alternative from the ideal and negative ideal solutions using Equations 12 and 13 and then calculating the relative closeness to the ideal solution using Equation 14 (Table 5). Finally, the preference order was ranked from the final performance score using the TOPSIS method to select preferred locations for the lead pollution study. The preferred locations have the maximum performance score. The final ranking of site selection in descending order of preference was Port Pirie (L1) > Port Kembla (L2) > Mount Isa (L4) > Broken Hill (L6). Port Pirie (L1) was found to be a superior location for the study while Lake Macquarie (L3) was the worst location (Figure 3).

Table 4: Pair -wise comparison matrix

Criteria	C1	C2	C3	C4	C4	C6	C7
C1	1	3	1	0.5	0.3	0.3	1
C2	0.3	1	0.5	0.3	0.25	0.25	0.5
C3	1	2	1	0.5	0.5	0.5	1
C4	2	3	2	1	0.5	0.5	2
C5	3	4	2	2	1	1	2
C6	3	4	2	2	1	1	2
C7	1	2	1	0.5	0.5	0	1

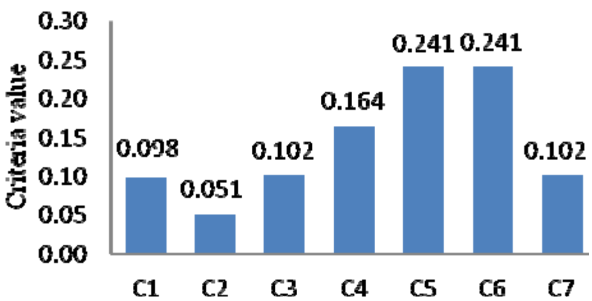


Fig. 2: Final criterion weight obtained via AHP.

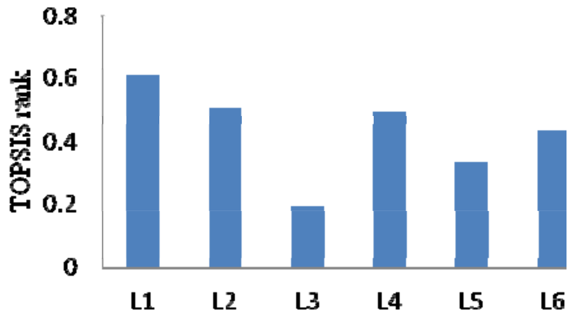


Fig. 3: Final result for site selection according to TOPSIS

Table 5: Separation measure and relative closeness coefficient

Location	S	S-	C
L1	0.129	0.199	0.606
L2	0.188	0.191	0.503
L3	0.223	0.053	0.190
L4	0.171	0.167	0.493
L5	0.227	0.114	0.333
L6	0.129	0.100	0.436

4. Conclusion

The paper proposed a new procedure for site selection, to find the most suitable location among six alternatives in which to conduct a Pb pollution study based on predefined selection criteria, which combined two decision making methods. AHP was used to determine the weights of seven criteria, chosen based on the human health effects, by pair-wise comparisons. Subsequently, TOPSIS was applied to achieve final ranking preferences in descending order thus allowing relative performances to be compared. Using this multiple criteria decision making approach, Port Pirie was identified as the best location to conduct a lead pollution study.

5. Acknowledgements

All authors would like to thank the support of the Centre for Environmental Risk Assessment and Remediation (CERAR), the University of South Australia while undertaking this research. The first author gratefully acknowledges the financial support of the Iraq government.

6. References

[1] E. Maynard, *et al.*, "An evaluation of recent blood lead levels in Port Pirie,South Australia," *The Science of the Total Environment,* vol. 303, pp. 25-33, 2003.

[2] E. Martley, *et al.*, "Metal concentrations in soils around the copper smelter and surrounding industrial complex of Port Kembla, NSW, Australia," *Science of the Total Environment,* vol. 325, pp. 113-127, 2004.

[3] F. Boreland and D. Lyle, "Using performance indicators to monitor attendance at the Broken Hill blood lead screening clinic," *EnvironmentalResearch,* vol. 109, pp. 267–272, 2009.

[4] M. Taylor, *et al.*, "Soil Cd, Cu, Pb and Zn contaminants around Mount Isa city, Queensland, Australia: Potential sources and risks to human health," *Applied Geochemistry,* vol. 25, pp. 841–855, 2010.

[5] M. Taylor, *et al.*, "Lessons learned on lead poisoning in children: One-hundred years on from Turner's declaration," *Journal of Paediatrics and Child Health,* 2010.

[6] A. Morrison and B. Gulson, "Preliminary findings of chemistry and bioaccessibility in base metal smelter slags," *Science of the Total Environment,* vol. 382, pp. 30-42 2007.

[7] M. Taylor, "Lead pollution health impacts on kids still being ignored at Mount Isa," *Medical Journal of Australia. ,* vol. 2010, 2010.

[8] M. Lin, *et al.*, "Using AHP and TOPSIS approaches in customer-driven product design process," *Computers in Industry,* vol. 59, pp. 17-31, 2008.

[9] C. Chen, "Applying the Analytical Hierarchy Process (AHP) Approach to Convention Site Selection " *Journal of Travel Research,* vol. 45, 2006.

[10] K. Abd, *et al.*, "An MCDM Approach to Selection Scheduling Rule in Robotic Flexible Assembly Cells " *World Academy of Science, Engineering and Technology,* vol. 76, 2011.

[11] Asutralian Bureau of Statistics. 2006, *Census data,* . viewed 10 January 2012 http://www.abs.gov.au/websitedbs/censushome.nsf/home/data

[12] M. Alphen, "Atmospheric heavy metal deposition plumes adjacent to a primary lead]zinc smelter," *The Science of the Total Environment,* vol. 236, pp. 119-134, 1999.

[13] Department of Sustainability Environment Water Population and Communities, "State of the Environment theme reports," 2001.

[14] R. Mosman. (1997, LEAD Action News. *The Port Kembla Community's Dilemma with Toxic Dust* [Lead Advisory Service]. *5(1)*. viewed 10 May 2011: http://www.lead.org.au/lanv5n1/lanv5n1-5.html

[15] A. Morrison, "An assessment of the effectiveness of lead pollution reduction strategies in North Lake Macquarie, NSW, Australia," *The Science of the Total Environment,* vol. 303, pp. 125-138, 2003.

[16] B. Noller, *et al.*, "Heavy Metals and Metalloids in the Leichhardt River: Lead Pathways Study," The University of Queensland Queensland 2009.

[17] "Zinifex Limited Rosebery Site ", Rosebery2006.

[18] R. Ashbolt, "lead levels of children living in west coast communities,Tasmania," Menzies centre for population health research, Tasmania1997.

[19] "Rasp Mine Zinc–Lead–Silver Project," Broken Hill Operations Pty Ltd - Rasp Mine, NSW2010.

[20] L. Satty, *The Analytical Hierarchy Process: Planning, Priority Setting*. New York: McGraw-Hill: Resource Allocation, 1980.

[21] K. Shyjith, *et al.*, "Multi-criteria decision-making approach to evaluate optimum maintenance strategy " *Journal of Quality in Maintenance Engineering,* vol. 14, pp. 375-386, 2008.