Application of GIS and AHP method to support of selecting a sutable site for a lead pollution: case study

Dr.Ali Al Maliki
Environment research centre
Ministry of Since and Technology, Iraq

Abstract

This paper presents a case study to evaluate site suitability for an industrial Pb contamination study of the mining and smelting regions of Australia. Suitable study sites were identified and ranked using a modeling of site selection based on ArcGIS processing supporting by the AHP method. The site for the industrial lead contamination study was restricted to within 5 km of the lead source. Different areas were initially assigned as being suitable for an industrial lead study depending on the weights of specific criteria and priorities of the decision maker. Five selection criteria were established for these areas and the best location amongst feasible alternatives was recommended. This paper focuses on the ability of ArcGIS to support the implementation of site selection decision-making, to select the optimal area for an industrial Pb contamination. Spatial analysis tools, such as feature extraction, reclassify, feature -to- raster conversion, overlay analysis, space calculator and query were integrated into a site selection model. Criteria weights derived with the analytical hierarchy process (AHP) which successfully allowed site selection by a weighted summation of the GIS raster data. In conclusion, Port Pirie in South Australia state was found to be a superior location for the study.

تطبيق نظم المعلومات الجغرافية مع طريقة التحليل الهرمي في دعم اختيار موقع مناسب لدراسة تلوث الرصاص

م.د.علي عبد الرضا عجيل المالكي
مركز البحوث البيئية/ وزارة العلوم والتكنلوجيا - العراق
aligeo69@yahoo.com

المستخلص

هذه الورقة تعرض دراسة لتقيم اختيار موقع ملائم لدراسة تلوث الرصاص في المناطق الصناعية التي تشمل عدد من مناطق المصاهر والمناجم في استراليا . ان عملية اختيار الموقع المثالي استندت على اساس التطبيقات الجغرافية في دعم القرار. حيث ان اختيار الموقع المثالي قد تم وفق موديل تم بناءه وفق برنامج ArcGIS المدعوم باسلوب التحليل الهرمي للمعطيات. ان حدود المناطق الصناعية الملوثة بالرصاص هي

مناطق تم حصرها بخمسة كيلو مترات عن مصدر التلوث ، وهي بذلك تقع ضمن مواقع حضرية ولها تاثير على الصحة العامة. ان جميع المناطق المقترحة للدراسة في ولايات استراليا تعتبر مناطق مهمة للدراسة وفق اسبقيات ودرجات متفاوتة على ضوء الادلة والمعطيات المتوفرة للاختيار . خمسة ضوابط او محددات تم اختيارها لتحديد الموقع الاكثر اهمية من بين عدة مواقع مختلفة من حيث انتاجها للرصاص وتاثيرها على الصحة العامة. هذا البحث ركز على تطبيق نظم المعلومات الجغرافية للمساعدة والدعم في اتخاذ القرارلاختيار الموقع المثالي لدراسة تلوث الرصاص في المناطق الصناعية. عدة تحليلات مكانية (spatial analysis) تم تطبيقها في موديل الاختيار بينما تم استخدام التحليل الهرمي لايجاد اوزان المحددات التي تم تطبيقها بنجاح في نتائج البحث اشارات الى ان موقع ميناء بيري الواقع في جنوب استراليا . مرحلة جمع الاوزان للبيانات الشبكية يمثل افضل المواقع لدراسة تلوث الرصاص.

Keywords: lead pollution, industrial pollution, ArcGIS, analytical hierarchy process, Site Selection

1-Introduction

Many Australian smelter and mining towns have experienced lead (Pb) contamination which raises serious human health concerns, especially for children, and affects soil function. Numerous geochemical and environmental studies have shown widespread environmental Pb contamination in large inner cities associated with the close proximity of smelter and mines, such as Port Pirie [1,2]. Industrial areas surround Port Kembla [3-5], Broken Hill [6-8], Mount Isa [9, 10]. This article proposes a technique for the evaluation of site suitability for a Pb contamination study in the vicinity of industrial regions of Australia. An extensive literature review was initially undertaken to identify the major criteria that were considered important for locating a suitable Pb contaminated site. Elevated blood Pb levels BLL is one criteria which has been identified widely in mining locations within Australia such as in Mount Isa [10]]; Broken Hill ([11,12], Lake Macquarie [13, 14] and Port Pirie [1, 10]. All of these studies have been shown negative health impacts on urban populations living adjacent to industrial areas. As children are more likely to be exposed to Pb and have BLL ≥ 10 μg/dL compared with other people [15], Pb concentration at a site, as well Pb production and wind direction were all considered to be a significant selection criteria. A Geographic Information System (GIS) can analyse and process data according to spatial characteristics [16] and can be used to assist decision making and modelling of site selection [17]. Use of GIS software as a decision making tool allows for ranking of alternatives which meet the required multiple criteria fully. Analytic Hierarchy Process (AHP) is a one of Multi Criteria Decision Making (MCDM) has been applied (for the criteria evaluations) to construct an evaluation model and has criterion weights. In this paper, we combine the AHP with GIS approaches to support site selection for a Pb pollution study to assist in the formation of policies to more effectively protect public health. Ideal sites are not probably and each alternative site has some intermediate ranking between the ideal solution extremes [18]. 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.

2- Methodological overview

The methodology of a suitable site selection process consists of many steps including:

2.1 Data collection and data preparation

Initially description of the problem and definition of the objectives is required. Subsequently, identification of the actions required to extract the required data occurs. A rough summary of the site selection scheme and assessment procedure is depicted in Figure 1.

In terms of the aforementioned structure for site selection, a list of all potential sites representative of all industrial Pb contaminated centres from either mining and/or smelting activities within Australia was collated Figure 2. 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. Estimated number of children between 0-4 years of age. (Children < 4 years of age are more susceptible to elevated concentrations of Pb in dust and soil in the vicinity of the mining or smelter activity).
2. Estimated numbers of child between 5-14 years of age.
3. Annual Pb production at each site.
4. Percentages of children under 5 years of age with blood lead level (BLL) $\geq$ 10 mg/dL.
5. Distance from the workplace and hence the expected associated travel cost when conducting field surveys of the area.

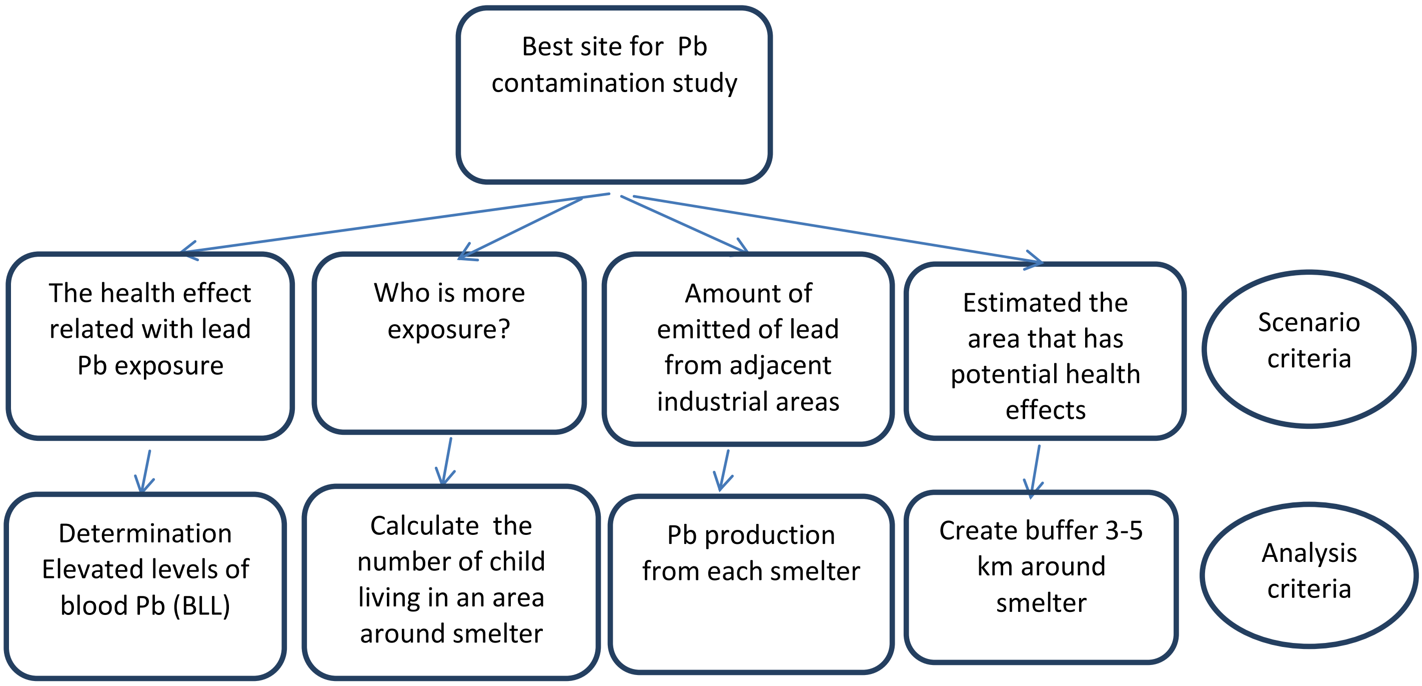

Fig 1. Structure of the problem and definition of the site selection criteria.

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

2.2. Modelling and implementation of site selection using GIS

A pretreatment model for analysis was built using ArcGIS geoprocessing following these basic steps:

1- Obtain the Australian standard geographical classification (ASGC) as raster image to represent a basic map.

2- Obtain population data (statistical data) by joining tables for ASGC with local government area (LGA) to extract criteria features C1 and C2.

3- Add fields for C3 and C4 to give four features representing the four selection criteria.

4- Parallel with three step above, create layers of the principle industrial smelters and mining areas within Australia and select the urban area around the smelters.

5- Create raster data sets representing the regionalized criteria (Conversion of feature data to layer data).

6- Reclassify raster data sets (criteria layers).

7- Calculate the distance C5 from site to work and then extract raster for five alternative locations using the Euclidean Distance tool and then reclassify distance.

8- Determine criteria weights using the AHP approach.

9- Calculating the result raster (suitability map) as weighted a summation of all criteria raster data sets.

The overall methodology and site selection process is illustrated in Figure 3.

2.3. Evaluating criteria weight using the 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 [28]. The AHP is one of the approaches commonly used in the human judgment process. 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 [28-30]. 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.

Tab 1. Locations (L) of principle Australian industrial lead smelting (and other metals) and variety criteria (C) which have been associated with elevated environmental lead concentrations

Location (L)	C1: No. of children (5-14 years old) [19]	C2: No. of children (0-4 years old) [19]	C3: Lead production (ton/year)	C4: Children < 5 years with BLL ≥ 10 mg /dL (%)	C5: Distance to study location (km)
L1: Port Pirie (SA)	1955	835	245,000 [2]	61 [1,11]	213
L2: Port Kembla (NSW)	5321	2486	14 [22]	11 [23]	1354
L3: Lake Macquarie (NSW)	935	484	90 [24]	17 [11,14]	1531
L4: Mount Isa (QLD)	3234	1781	248,400 [25]	11.3 [10]	1863
L5: Broken Hill (NSW)	2546	1156	44,000 [26]	26 [11,27]	497

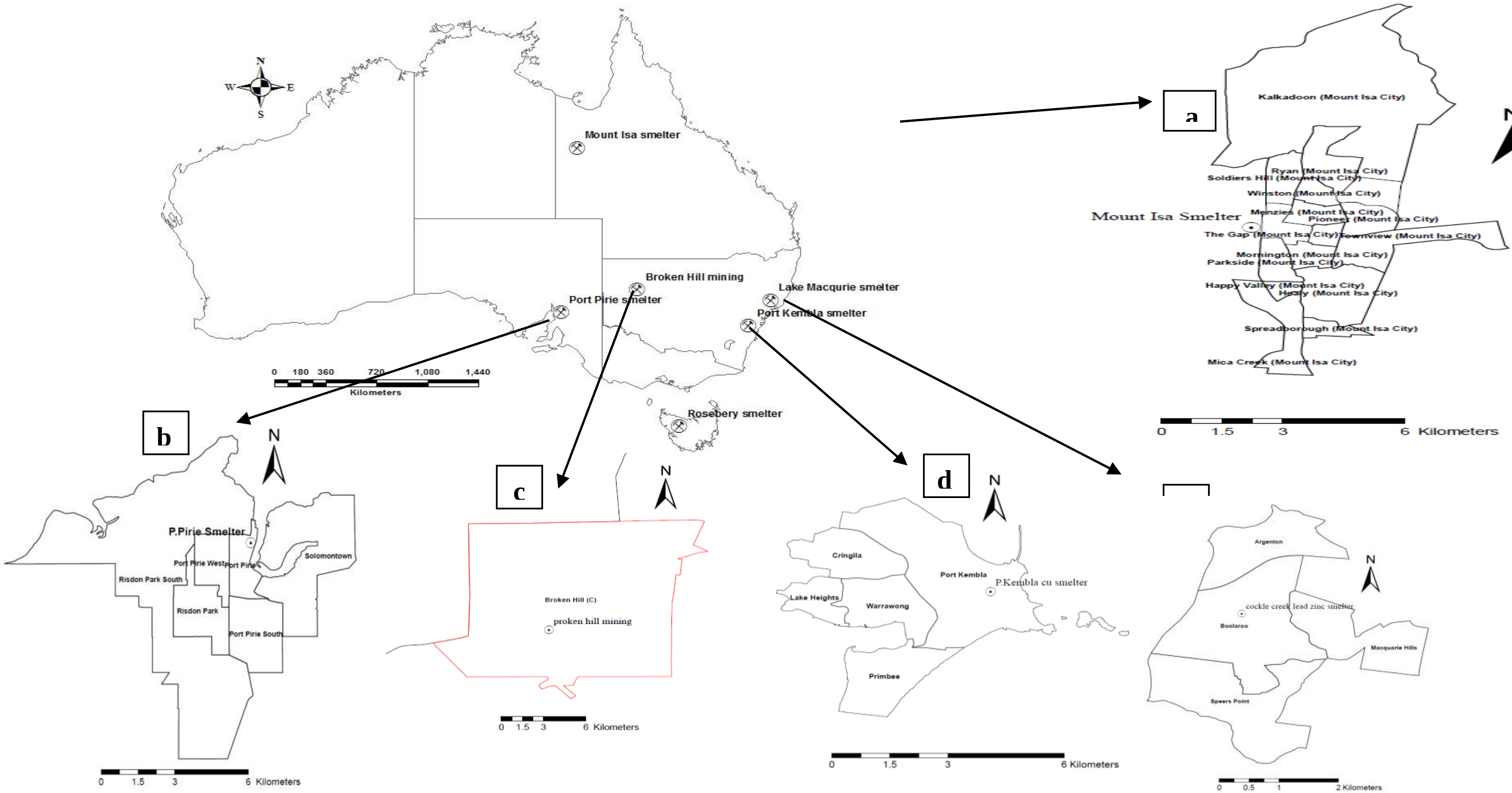

Fig 2. Map of Australia with the layers for location of principle industrial smelter a) Mount Isa b) port Pirie c) Broken Hill d) Port Kembla and e) Lake Macquarie

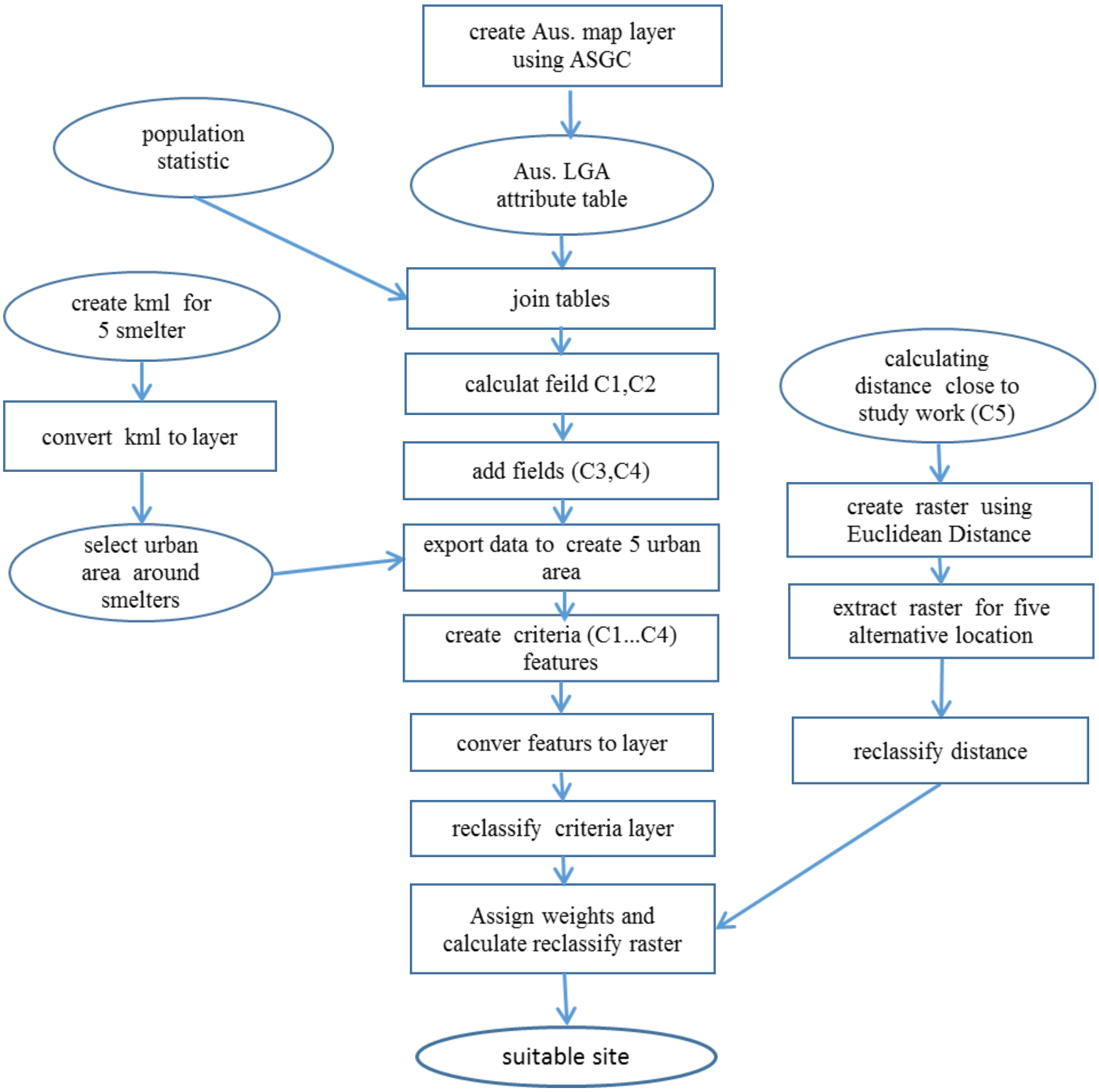

Fig 3. Complete workflow diagram. Ovals represent data inputs and outputs, while rectangles represent actions.

2.3.1 Development of a pair-wise comparison matrix the matrix of pair-wise comparisons is constructed from i × j elements, where i and j are the number of criteria (n) as given in Equation 1:

In the matrix A, a_{ij} represents comparative value of criterion i with respect to criterion. j Such that $a_{ij} = 1/a_{ji}$ and $a_{ij} = 1$ when i = j.

The comparisons between each criterion were made using the measurement scale of Satty (1980) which gave numerical values between 1 and 9 depending on the relative importance of the criterion (Table 2.).

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1j} \\ a_{21} & 1 & \cdots & a_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} \end{bmatrix} \qquad \text{(Eq1)}$$

Tab 2. Pair-wise comparison in AHP preference [31]

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

2.3.2. 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[32]. This procedure is known as 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 using Equation 2.

$$a^{*}_{ij} = a_{ij}/\sum_{i=1}^{n} a_{ij} \qquad \text{for all } j = 1,2,....n \text{ (Eq2)}$$

3) Calculate the average of elements in each row in the normalized matrix A, which represent the weight of each criterion using Equation 3

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

(Eq3)

There is a relationship between the vector weights, w, and the pair-wise comparison matrix, A such that, $Aw = \lambda_{max} w$

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.

$$(Eq4)CV_i = \frac{\left(\sum_{j=1}^{n} a_{ij} \times w_j\right)}{w_j} \quad \forall\, i; i = 1,2, \ldots . n$$

$$(Eq5)\lambda_{max} = \frac{\sum_{i=1}^{n} CV_i}{n}$$

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 represent the consistency index for each matrix of order n.

$$(Eq6)CI = (\lambda_{max} - n)/(n-1)$$

$$CR = CI/RI \qquad (Eq7)$$

The value of the random index RI depends on n. RI values corresponding with n between 1 and 10 are listed in Table 3

Tab 3. Random inconsistency indices (RI) for N=10[32]

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**

The consistency ratio (*CR*) represent the key check of inconsistency of the subjective values of the A matrix. If *CR* is ≤0.10, the values of subjective judgment are considered acceptable [30].

3. Results and discussion

The weighted values of the criteria were assigned using the scale developed by Satty (1980) and consequently a pair-wise comparison matrix established to determine decision criteria in a hierarchical tree structure at different levels using AHP (Table 4). Final weight of each criterion is shown in Figure 4. 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 implemented using ArcGIS geographical analysis tools including: Euclidean distance, feature to layer conversion, reclassify, overlay analysis, raster calculation and query. In the last step of the suitability model, the preference order was ranked from the values of reclassified outputs for all criteria rasters using the raster calculate tool, where each map layer was ranked by how suitable it was for a lead pollution study. A suitability scale to each class in each layer was determined on a scale of 1–5, with 5 being the best. Assigning weights (percentage influence for each criterion) in raster calculation analysis was a subjective process depending on what criteria were most important. Consequently, the preferred locations have the higher result raster values (Figure 5).

Tab (4) Pair -wise comparison matrix

	C1	C2	C3	C4	C5
C1	1.0	0.5	0.3	0.3	1.0
C2	2.0	1.0	0.5	0.5	2.0
C3	3.0	2.0	1.0	1.0	3.0
C4	3.0	2.0	1.0	1.0	3.0
C5	1.0	0.5	0.3	0.3	1.0

Fig 4: Final criterion weight obtained via AHP

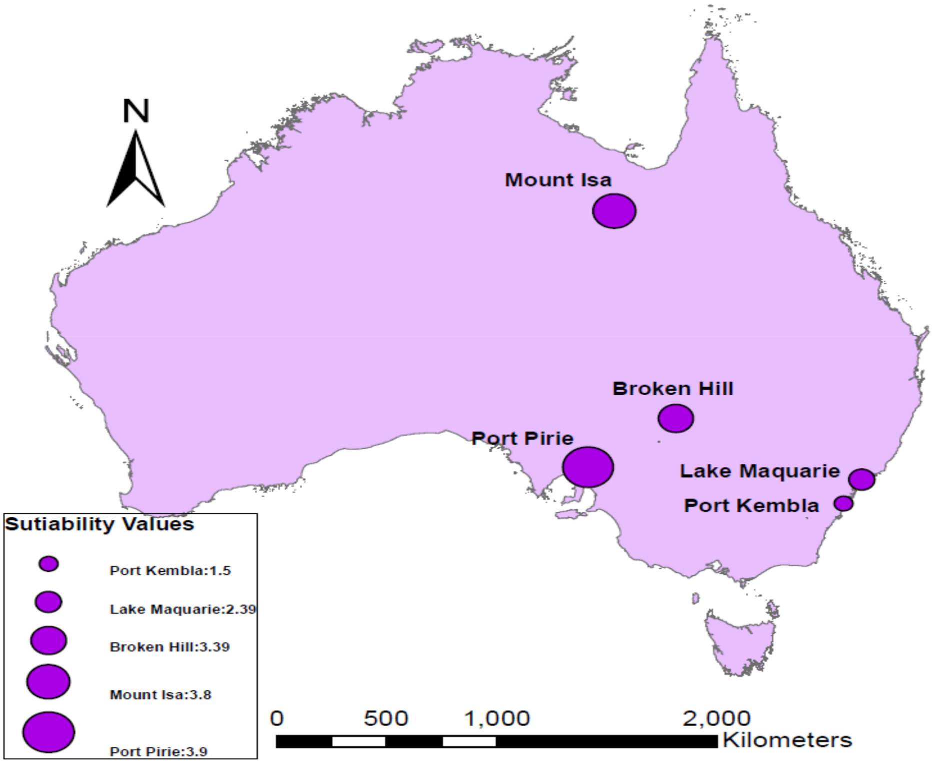

Fig 5. Final result for site selection according to ArcGIS geoprocessing. The most suitable areas for Pb contamination studies have the higher values (largest dots).

The above steps, yield various factors which affect the scope map because each layer will affect the result, to some extent, and with the support of network analysis of ArcGIS, overlay of all impacts on the scope map can occur according to their weights [16].

The final ranking of site selection in descending order of preference was Port Pirie (L1) > Mount Isa (L4) > Broken Hill (L5) > Northern Lake Macquarie (L3) > Port Kembla (L2). Port Pirie (L1) was found to be a superior location for the study while Port Kembla (L2) was the worst location (Figure5)

4. Conclusion

ArcGIS geoprocessing is a significant component of ArcGIS and includes many operations that can be used to derive information from existing data. As a flexible application for modelling of treatment schemes [17] it can support spatial decision making. Selection of a site location for a specific project represents a multi criteria evaluation and decision-making process biased by the geographical situation[17]. This paper proposed the use of ArcGIS geoprocessing to find suitable locations for a Pb pollution study amongst five potential locations considered as being important Australian smelter and mining towns. This procedure was based on integration of ArcGIS geographic analysis tools, which allowed users to derive criteria weights, with the AHP approach, which was used to determine the weights of five criteria by pair wise comparisons between criteria. The “Annual Pb production at each site (C3) and the percentage of children less than 5 years of age with high BLLs (C4)” both had 0.31 influences on the suitability model, and the “numbers of children between 5-14 years of age (C1)" had an influence of 0.10. The "Distance to study site C5" also, had an influence of (0.10) and the “numbers of children between 0-4 years of age C2” had an influence of 0.18. The weights of criteria were chosen based on the human health effects and were determined through an extensive literature review.Calculating raster operation was used to combine the characteristics of several datasets into one, which allowed successful site selection by a weighted summation of GIS raster data sets so that a specific locations (suitability map) could be produced. According to ArcGIS Geoprocessing model, Port Pirie was the best location for a Pb pollution study.

5. 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] 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.

[3] A. Kachenko and B. Singh, "Heavy Metals Contamination of home grown vegetable near metal smelters in NSW," presented at the 3rd Australian New Zealand Soils Conference, University of Sydney,Australia, 2004.

[4] A. Kachenko and B. Singh, "Heavy Metals Contamination in Vegetables Grown in Urban and Metal Smelter Contaminated Sites in Australia," *Water,Air ,and Soil Pollution* vol. 169, pp. 101-123, 2006

[5] 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.

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

[7] 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.

[8] D. Lyle, "New South Wales Lead Management Program in Broken Hill," *N S W public health bulletin,* vol. 12, 2001.

[9] M. Taylor and C. Schniering, "The public minimization of the risks associated with environment lead exposure and elevated blood levels in children ,Mount ISa," *Archives of environmental & occupational health,* vol. 65, 2010.

[10] 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.

[11] 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.

[12] B. Gulson, *et al.*, "Source of lead in humans from Broken Hill mining community " *Environmental Geochemistry and Health* vol. 16, pp. 19-25, 1994.

[13] B. Gulson, *et al.*, "Identification of Sources of Lead in Children in a Primary Zinc–Lead Smelter Environment," *Environmental Health Perspectives,* vol. 112, pp. 52-60, 2004.

[14] 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.

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

[16] X. Qiuping, *et al.*, "House site selection decision support system based on ArcGIS," in *International Conference on Management and Service Science,* 2009.

[17] X. Liu, *et al.*, "Assistant Decision-making Modeling of Project Site Location and its Application based on ArcGIS Processing," presented at the Audio Language and Image Processing (ICALIP), 2010.

[18] 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.
[19] Asutralian Bureau of Statistics. (2006, *Census data*, . Available: http://www.abs.gov.au/websitedbs/censushome.nsf/home/data
[20] Asutralian Bureau of Statistics. (2007.
[21] K. Devi, *et al.*, "Extension of Fuzzy TOPSIS Method Based on Vague Sets," *International journal of computational cognition*, vol. 7, 2009.
[22] "Australia state of the environmental " 2001.
[23] R. Mosman. (1997, LEAD Action News. *The Port Kembla Community's Dilemma with Toxic Dust* [Lead Advisory Service]. *5(1)*. Available: http://www.lead.org.au/lanv5n1/lanv5n1-5.html
[24] 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.
[25] B. Noller, *et al.*, "Heavy Metals and Metalloids in the Leichhardt River: Lead Pathways Study," The University of Queensland Queensland 2009.
[26] "Rasp Mine Zinc–Lead–Silver Project," Broken Hill Operations Pty Ltd - Rasp Mine, NSW2010.
[27] M. Lesjak, "Blood lead trends in children aged less than 5 years in broken hill " GREATER WESTERN AREA HEALTH SERVICE, BROKEN HILL,NSW2009.
[28] C. Chen, "Applying the Analytical Hierarchy Process (AHP) Approach to Convention Site Selection " *Journal of Travel Research*, vol. 45, 2006.
[29] M. Lin, *et al.*, "Using AHP and TOPSIS approaches in customer-driven product design process," *Computers in Industry*, vol. 59, pp. 17-31, 2008.
[30] 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.
[31] L. Satty and K. Kearns, *Analytical Planning: The Organization of Systems*, 1st Edition ed.: Pergamon Press, Oxford, 1985.
[32] L. Satty, *The Analytical Hierarchy Process: Planning, Priority Setting*. New York: McGraw-Hill: Resource Allocation, 1980.