USE OF GEOGRAPHIC INFORMATION SYSTEM (GIS) TECHNOLOGY FOR OPTIMIZED LANDFILL SITE SELECTION IN REGINA, CANADA

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Abstract: The selection of a site for a new landfill is a complicated task because of social, geological, environmental, hydrological and economic issues. In this study we applied an optimized land use site selection based on overlay analysis using a Geographic Information System (GIS). Several important factors and criteria were considered, including terrain elevation, slope, location to ground water, distance to surface water, site accessibility via the existing road network, and current land use. Thematic maps of these criteria were developed and overlaid in a GIS to identify candidate locations for the landfill. The final site recommendation was selected from these candidates based on minimum site size and nearby population density. Our approach is unique because the environmental factors were considered as the primary governing factors, and the social parameter was only applied for the final selection of the candidate site.

1 INTRODUCTION

Landfill selection in an urban area is a difficult, complex, tedious, and protracted process involving the impact on the economy, social and environmental health of the region (Chang et al. 2008). An inappropriate waste facility may adversely affect the surrounding environment and other economic and socio-cultural aspects. The landfill site selection procedure usually takes place in to two main steps: the identification of potential sites through screening, and the evaluation of their suitability based on environmental impact assessment, economic feasibility, engineering design, and cost comparison (Charnpratheep et al. 1997). Therefore, the siting factors and criteria should be carefully organized and analyzed to produce a shortlist of potential areas.

In this study, the preliminary screening was performed using the combination of Geographical Information System (GIS) and Analytical Hierarchy Process (AHP) procedures to exclude unsuitable areas and retain potential areas for the site evaluation process. Several important factors and criteria were considered to decide the optimum location for new landfill site based on their potential effects on the regional economic, social and environmental sectors. Thematic maps of the siting factors were developed, weighted using the AHP method, and overlaid in a GIS to identify the potential sites for the landfill.

2 BACKGROUND AND STUDY AREA

The study area is the City of Regina (Figure 1). Regina is located at 50°27′17″N 104°36′24″ in the Canadian Prairies and is the capital of the Province of Saskatchewan. The city covers an area of 145 km^2 at an average elevation of 577 m above sea level. After many years of stagnant or declining growth, Regina's population increased by 7.7% between 2006 and 2011 to 193,100, largely as a result of positive trends in the province's resource economy (LEADER-POST, February 08, 2012). This growth has brought into question capacity issues at the city's existing landfill site. Regina’s citizens produce about 1,000 kilograms per capita of solid waste annually; most of which (84%) is disposed in the regional landfill with only about 16% diverted (Waste Plan Regina Report 2009). The city's existing landfill is expected to reach capacity within 15 to 30 years, depending on the waste-generation rate and local policies (Chi 1997).

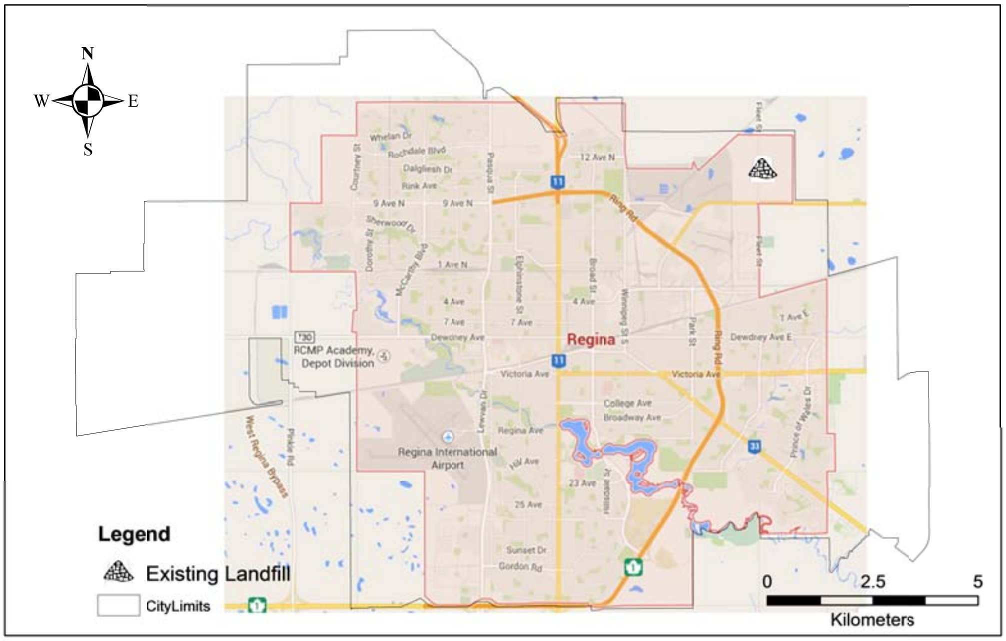


Figure 1: City of Regina

3 METHODOLOGY

3.1 GIS Application

A Geographic Information System (GIS) is capable of processing large volumes of spatially located data for advanced site-selection studies. GIS can minimize site selection costs, particularly at the preliminary stages. The combination of spatial data (maps, aerial photographs, and satellite images) with quantitative, qualitative, and descriptive information has made GIS an essential tool for landfill siting.

In this study, thematic maps for roads, land use, distance from residential and industrial areas, distance from surface water, aquifer class, elevation, slope, drainage quality of the soil, distance from the airport, and population distribution were prepared and reclassified based on their location criteria. These maps were then overlaid in a GIS[1] to identify potential sites.

3.2 Multi-Criteria Decision Making

In this study, AHP was selected as a tool for evaluating and weighting the primary criteria prior to GIS overlay analysis because of its efficiency to compare the relative suitability of a small number of alternatives concerning the overall goal (Guiqin et al. 2009). Among the ten original criteria, five were chosen as primary because of their significant effect on their surroundings. This selection was grounded on previous research and local conditions of the study area (Guiqin et al. 2009, Akbari et al. 2008, Sharifi et al. 2009, Moeinaddini et al. 2010, Sener et al. 2010, 2011).

The priority determination of multiple factors is difficult and therefore AHP, developed by Saaty in 1977, can be useful to analyze complicated problems with some interrelated objectives (Chuang 2001). The basic advantage of this method is the decomposition of a complex problem into a hierarchy based on a pair-wise comparison of the importance of different criteria and sub-criteria (Saaty 1977, 1996, 2001, 2005, Forman and Selly 2001). Saaty (1980) describes a suitable measurement scale for the pairwise comparisons, where verbal judgments are expressed by a degree of preference: equally preferred = 1, moderately preferred = 3, strongly preferred = 5, very strongly preferred = 7 and extremely preferred = 9.

[1] ArcGIS v10.1 was used in this analysis.

The numbers 2, 4, 6 and 8 are used to distinguish similar alternatives, as summarized in Table 1. Reciprocals of these numbers are used to express the inverse relationship. In addition, it is possible to calculate the consistency ratio (CR) of decisions in pairwise comparison in order to reveal the random probability of values being obtained in a pairwise comparison matrix (Uyan 2014).

Table 1: The comparison scale in AHP (Saaty 1980)

Numerical value	Definition	Remarks
1	Equal importance	Two activities contribute equally to the objects
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

As a first step of the determination of consistency ratio, the consistency index (CI) is calculated (Saaty 1980) as:

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

Where CI is the consistency index, λ_{max} is the largest or principal eigenvalue of the matrix, and n is the order of the matrix.

To ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of n by CR (Zou and Li 2008), that is,

$$CR = \frac{CI}{RI} \quad (2)$$

Where RI is the random consistency index. The RI values for different numbers of n are shown in Table 2.

Table 1: RI table values (Saaty 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

If CR ≤ 0.10 the degree of consistency is satisfactory.
If CR > 0.10 there are serious inconsistencies and in this case, the AHP may not yield meaningful results (Chakraborty and Banik 2006).

4 RESULTS: CRITERIA APPLICATION

The landfill site selection criteria differ from one region to another depending on the local conditions and circumstances (Ghobadi et al. 2013). In this study 10 input layers were investigated: roads, land use, distance from residential and industrial areas, distance from surface water, aquifer class, elevation, slope, drainage quality of the soil, distance from the airport, and population distribution. In accordance with the city's own waste disposal facility guidelines (Table 3), the first five criteria were selected as primary and subjected to AHP analysis.

Table 3: Different constraints areas based on City of Regina guidelines

Constraints
Buffer of surface water = 1000 m
Buffer of residential and industrial areas distance = 500 m
Aquifer class = High and medium
Buffer of accessible road distance = less than 500 m

AHP was used to assign weight (Table 4) to each primary criterion in order to perform weighted overlay analysis of the map of these primary criteria in the format of GRID. For this analysis, the estimated consistency ratio was 0.05 (<0.10) and hence indicates the degree of consistency is satisfactory.

Table 4: The pairwise comparison matrix and relative weight of the site selection criteria

	A	B	C	D	E	Weight
A	1.00	3.00	5.00	6.00	7.00	0.488
B	0.33	1.00	3.00	5.00	6.00	0.266
C	0.20	0.33	1.00	3.00	4.00	0.135
D	0.17	0.20	0.33	1.00	2.00	0.066
E	0.14	0.17	0.25	0.50	1.00	0.044

Here, A = distance from settlement, B = distance from surface water, C = aquifer class, D = land use pattern and E = distance from road

Each criterion is described in detail below and the evaluation scale for sub-criteria of each primary criterion is summarized in Table 4.

Table 5: Evaluation scale for the sub-criteria of the primary criteria

Evaluation Scale	Restricted	1	3	5
A	0-500	500-1000	1000-2500	>2500
B	0-1000	1000-1500	1500-2500	>2500
C	high	medium	low	No Data
D	Residential/Institutional	Parks	Lease	Urban Holdings
E	0-100	100-250, >500	250-350	350-500

Here, A = distance from settlement, B = distance from surface water, C = aquifer class, D = land use pattern and E = distance from road

4.1 Primary Criteria

4.1.1 Distance from Settlement

Due to excessive noise, traffic, odor, and litter, those living within close proximity to the landfill are significantly affected. Therefore, the impact will be moderate to low if the landfill is placed at a safe distance (Sharifi et al. 2009). In this study, the minimum distance from the settlement was chosen according to the city's guideline as 500 m. Buffer zones of 1000 m, 2500 m and greater than 2500 m were assigned as higher priority for the potential landfill sites. The buffer zones around the settlement were illustrated in Figure 2.

Figure 2: Distance from settlement

4.1.2 Distance from Surface Water

Wascana Lake runs through the centre of the city and divides Regina in to two parts. This lake, Wascana Creek, and other wetlands and ponds were identified as surface water. In order to prevent contamination, the landfill site must be at a safe distance from these water bodies. As per regulation, the new landfill site must be 1000 m away from any licensed well, lake or other permanent natural body of water used as a community water supply. Therefore, outside of the 1000 m restricted area, buffer zones of 1500 m, 2500 m and greater than 2500 m were prioritized accordingly. Figure 3 showed the buffer zones for surface water sources for the City of Regina.

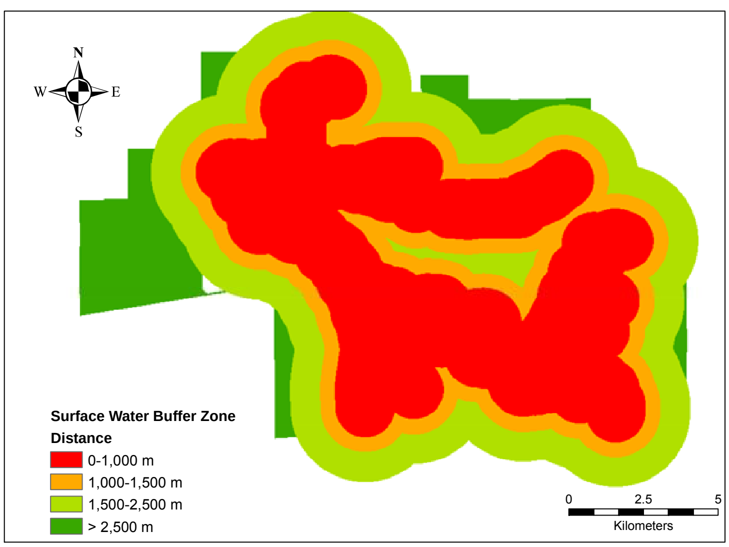


Figure 3: Distance from surface water

4.1.3 Distance from Aquifer

The location of aquifer or groundwater table plays an important role in determining the contamination risk of groundwater. High and medium class aquifers are found in the northern areas of the city with low class aquifer is found adjacent to these aquifers (Figure 4). According to city regulations, no new landfill can be sited over the aquifer zone. Thus, it is always safe to choose a new landfill facility away from known aquifers in order to prevent the risk of pollution through ground water flow from the landfill.

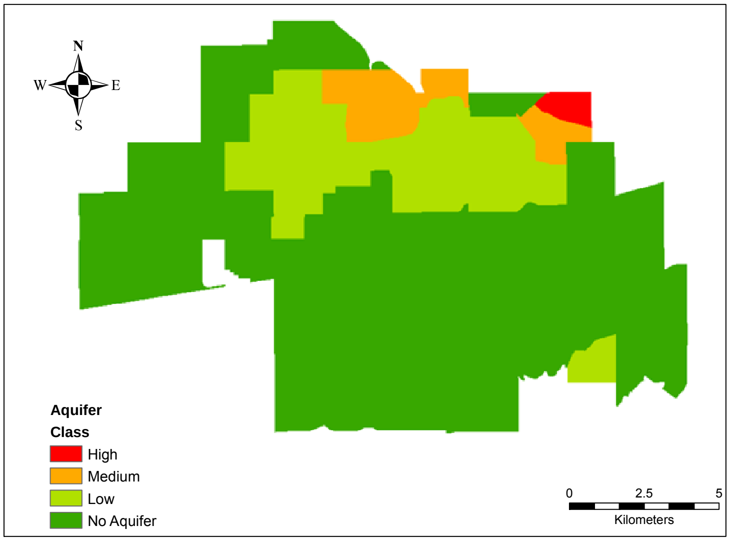


Figure 4: Aquifer class

4.1.4 Distance from Road

The road network plays an important role in selection of a new landfill site since close proximity plays a significant role in increasing accessibility to the new site as well as reducing construction costs. However, close proximity also has a negative visibility contribution. In this study, close distance - less than 250 m - and long distance - over 500 m – were scored lowest, and higher priority was assigned to distances of 250 m, 350 m, and 500 m. Figure 5 indicates the suitability of potential areas in terms of distance from the road network.

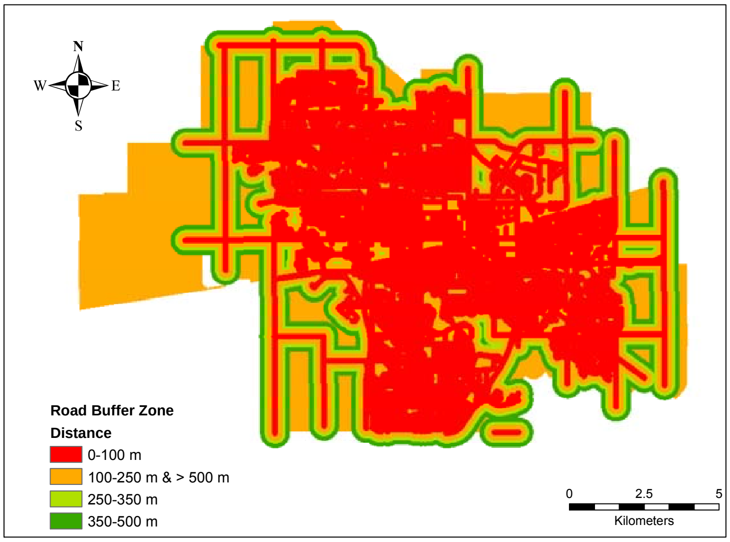


Figure 5: Distance from road

4.1.5 Land Use Pattern

Residential, institutional and commercial land uses were designated as restricted areas for a new landfill site. Parks, open spaces, lease areas, and "urban holding" zoning areas were evaluated as low to high suitability, respectively (Figure 6). From a visual analysis of the open space map, it can be seen that the West, South and South-West part of Regina have available areas for a new landfill site.

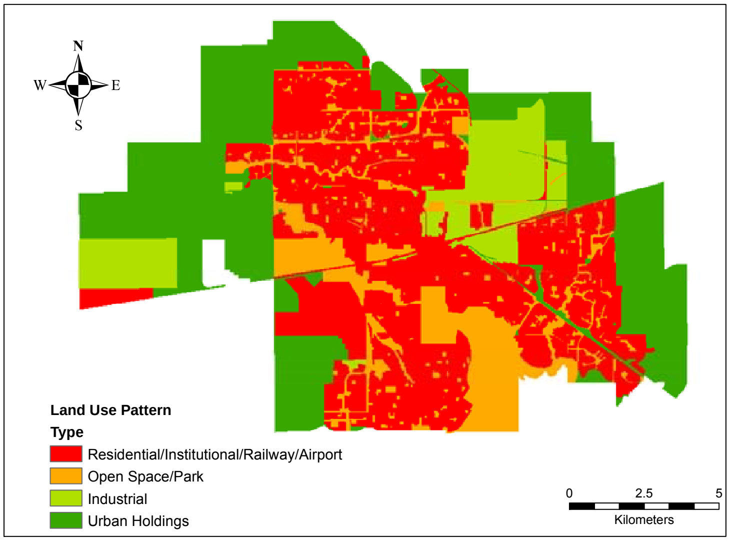


Figure 6: Land use pattern

4.2 Supporting Criteria

4.2.1 Elevation

Elevation is an important environmental and social consideration for situating a new landfill area. Higher elevations will protect the site from flooding, and it increases the distance to groundwater and surface water, thereby minimizing the possibility of runoff pollution. However, the local relief is almost negligible since the city is almost flat. This minimizes the impact of elevation on the site selection procedure so it was identified as a supporting criterion. The elevations in Regina were divided into 3 classes at 25 m intervals. The minimum elevation was recorded as 565m above mean sea level and the maximum height was 625m. The highest elevations are in the north-east part of the city and they decrease to west and south-west.

4.2.2 Slope

Slope was derived from the elevation data and categorized into 3 ranges: 0 to 5 degrees as mild, 5 to 15 degrees as moderate, and higher than 15 degrees as steep slopes. Overall, the city exhibits a mild slope running diagonally from the north-east to the south-west. Thus, similar to elevation, slope was designated as a supporting criterion. Elevation and slope were applied post-overlay to recommend placement of the landfill in higher locations to minimize flooding.

4.2.3 Population Distribution

Regina has higher population densities in its eastern neighbourhoods, medium densities in the central zone, and low densities towards the corners. These factors were applied as supporting criteria after the preliminary screening for potential sites.

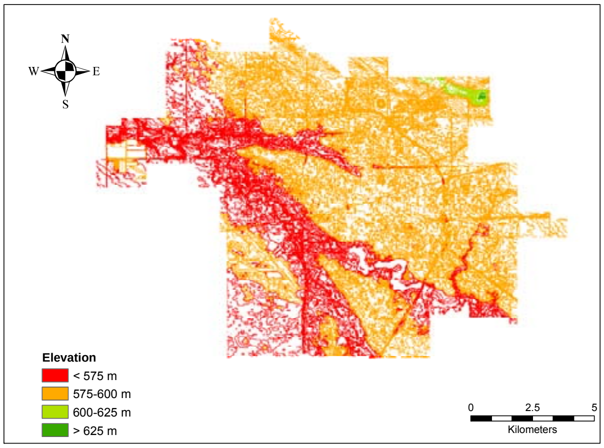
4.2.4 Distance from Airport

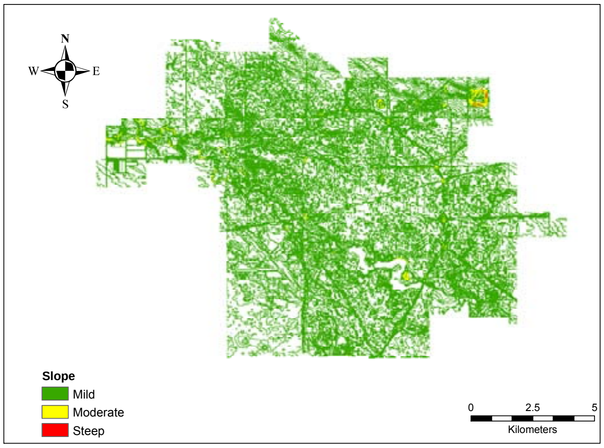
Following city guidelines, an exclusion zone of 3000 m was applied around Regina's only airport.

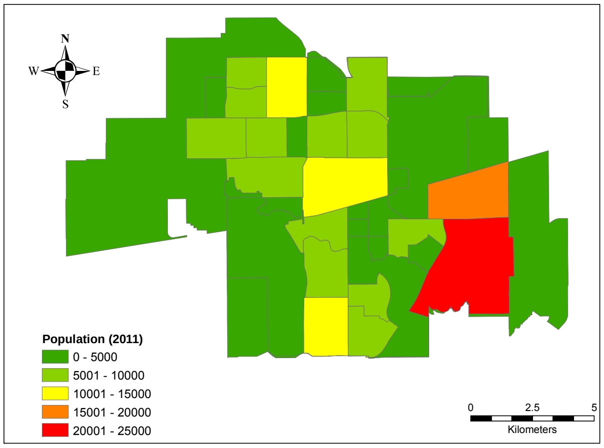
4.2.5 Drainage Quality of Soil

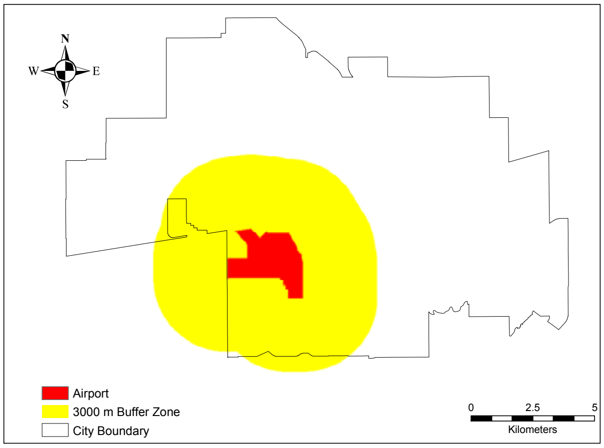
Drainage quality of soil is a crucial criterion for any landfill site selection process. However, since much of the city is built on well-drained glaciolacustrine sediments, this criterion was not a significant factor in the present analysis.

Thematic maps illustrating all of the supporting criteria are shown in Figure 7.









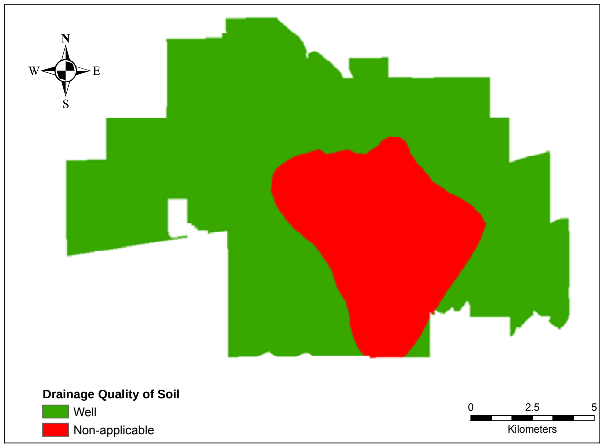


Figure 7: Supporting criteria

5 DISCUSSION

The primary criteria were assigned weights according to the AHP analysis and overlaid in the GIS to produce a suitability map for potential areas. The graduated colours in Figure 8 from red to green indicate the suitability of potential areas for a new landfill site. Red represents restricted areas governed by the City of Regina regulations, while green areas represent potential sites with strong support.

The analysis of the primary criteria indicate that the west and south-west parts of Regina are suitable for a new landfill because of available space, absence of surface water or subsurface aquifers, distance from residential or industrial settlements and proximity to major roads for waste transportation. However, the overlay of this potential areas map with the other supporting criteria maps ultimately excludes the south-west part of the city due to civil aviation regulations of 3000 m buffer zone around the airport.

Figure 8: Potential areas for landfill after preliminary screening

6 CONCLUSION

The optimization for municipal solid waste landfill site was performed based on the available data and maps for the city of Regina. The methodology and assessment procedure described in this study is shown to be an effective approach to using GIS and AHP to create a potential site location map. The logical categorization of criteria can reduce processing times by efficiently screening out less suitable areas during the preliminary analysis.

This analysis serves as a base study that can be used to evaluate the impact of introducing additional criteria into the analysis. For example, the assumption used here that the location of the new landfill site should be inside the city boundary may be overly restrictive. Further, the addition of comprehensive soil and air quality data would improve the analysis for the new disposal site.

Finally, it should be noted that the contribution of the presented methodology is its demonstration as a tool to aid decision-makers: it is not the decision itself generated from the analysis. The final decision to site a landfill is as much as a political decision as it is logistical and strongly depends on public opinion and regulation criteria.

7 ACKNOWLEDGEMENT

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