A Modified GIS-Based Procedure for HWTC Site Selection of Tehran Province

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ABSTRACT
Different methods have been reported in literature for site selection of a municipal or hazardous waste landfill, one of the most frequent of which is the "Simple Additive Weighting (SAW) Method". When the number of digital layers involved in the analysis and hence the associated number of weight factors increase, uncertainties shall appear in the results. The main objective of this paper is to propose a modified procedure for site selection purposes utilizing GIS-based models, to overcome some of the shortcomings of the conventional SAW method.

While it has been attempted to benefit from the positive aspects of the SAW, a new method is proposed in which the user-defined classes are differentiable in a one-step analysis and also a reclassification formulation is proposed. A nonlinear relationship has been derived to evaluate suitability of each pixel as a function of both the "distance from the feature" as well as the "weight of relative importance". This is a major improvement over the conventional methods in which two separate analyses are involved, while simply a single analysis is required in the modified procedure.

The new method is applied for the Hazardous Waste Treatment Center (HWTC) site selection of Tehran Province as a highly populated and industrial area using an extensive GIS based database.

Keywords: GIS, Hazardous Waste Treatment Center, Site Selection, SAW method, reclassification

RÉSUMÉ
Différentes méthodes ont été proposées dans la littérature pour la sélection de sites d'enfouissement municipaux ou de déchets dangereux, l'une des plus fréquemment utilisées étant la méthode SAW (Simple Additive Weighting). Quand le nombre de couches numériques impliquées augmente dans l'analyse, et donc le nombre associé de facteurs de pondération, augmente, des incertitudes apparaissent dans les résultats. L'objectif principal de cet article est de proposer une procédure modifiée de sélection de sites, en utilisant des modèles SIG, afin de compenser les lacunes de la méthode SAW conventionnelle.

Bien que l'on aie tenté de tirer profit des aspects positifs de la méthode SAW, une nouvelle méthode est proposée dans laquelle les classes définies par l'utilisateur sont différentiables dans une analyse à une étape et une formulation de reclassification est aussi proposée. Une relation non-linéaire a été dérivée afin d'évaluer la pertinence de chaque pixel en fonction à la fois de la "distance de la caractéristique" aussi bien que de "la pondération de l'importance relative". Ceci est une amélioration significative sur les méthodes conventionnelles dans lesquelles deux analyses séparées sont impliquées, alors qu'une seule analyse est requises dans la méthode modifiée.

La nouvelle méthode est appliquée pour la sélection du site du Centre de Traitement de Déchets Dangereux (CTDD) de la province de Téhéran en tant que zone densément peuplée et industrielle en utilisant une vaste base de données SIG.

Mots Clés: SIG, Centre de Traitement de Déchets Dangereux, sélection de site, méthode SAW, reclassification

1 INTRODUCTION

Department of the Environment (DOE) of Iran embarked on site selection projects for Hazardous Waste Treatment Center (HWTC) for each of the provinces across the country, within the past three years. The HWTCs are expected to professionally manage the HW incorporating recycling measures, incineration, landfill facilities etc.

Many factors are influencing the selection of a proper HWTC site, for which digital information layers are usually manipulated within the GIS-based software. Over 90 digital layers were involved in the province of Tehran for which a proper GIS-based modeling would be essential.

Simple Additive Weighting (SAW) Method based on weighted average has been widely used as a multi-attribute decision technique for environmental site selection projects (Malczewski 1997). An evaluation pixel value is calculated for each pixel in map by multiplying the pixel value (reclassified raster) with the weights of relative importance directly assigned by decision maker followed by summing of the products for all criteria.

Simple additive weighting method is the simplest and most often used technique in site selection projects (Malezewski 1997; Janssen 1992). Sener et al. (2006) compare SAW method with Analytical Hierarchy Process (AHP) method - developed by Saaty (1980) - and it is seen that AHP method creates more conservative results using 16 input data layers. Based on their field check results, Sener et al. (2006) recommend that additional parameters need to be included in the model.

Although weights of relative importance in the AHP method are determined by pairwise comparisons and a decision tree is developed for the landfill site selection, but the main strategy of SAW method and AHP method in summing weighted pixel values of re-classed rasters is closely similar.

The main problem using SAW-based methods is uncertainty in results wherever high-number of data layers are involved in the analysis. If the number of Layers is high and only a few layers are having poor conditions in a pixel, the poor scores (pixel values) are dominated by the good scores at that pixel. Suppose that 100 data layers are involved in an analysis and a particular zone is close to (not inside) three rejected buffers of a village, a river, and a fault. Such a zone from HWTC site-selection point of view is not suitable, but it is likely that the other 97 data layers would impose a very good or even excellent score for it.

The main objective of this research was to utilize a procedure to overcome the shortcomings of the SAW-based methods. The proposed procedure is developed in two steps. The first step involves the "Reclassification" method for calculating the pixel values in reclassified rasters and the second step includes formulation of determining the buffer zones during Reclassification using a defined function called "Suitability Function".

90 digital layer maps of Tehran Province have been analyzed with the proposed model as a case study. Following definitions are used within the text:

- Pixel: Pixel is the smallest unit of information in an image or raster map, usually square or rectangular.
- Raster: A raster consists of an array of pixels, and each pixel has a value named pixel value.
- Reclassification: The reclassification functions reclassify or change the pixel values to alternative values.

2 STUDY AREA

The province of Tehran is located in a semi-arid area shown in Fig 1. This province is hosting around 12 million people, mostly residing in two highly populated cities, Tehran and Karaj, in spite of numerous population centers including recently developed towns. The high population of the metropolitan Tehran as well as the concentration of different industries has resulted in high volume of HW. Tehran province is bounded in north by Alborz Mountain range with relatively cold winters and steep land, making it unsuitable for locating the HWTC. The southern zones, on the other hand, are having a much better situation with respect to satisfying some important criteria such as seasonal temperatures, precipitation, major and minor river distributions, distance from faults, and more specifically the availability of flat non-used land, as compared to north. The industries are mostly distributed in south, south-west and western parts of the province. It was expected to face a challenging task to come up with zones that could satisfy the standard criteria regarding the limited area and at the same time concentration of population, reserved areas, numerous faults, agricultural lands, and many other point, line and polygon features across the province. Yet the selected zone(s) are expected to have a reasonably close distance to the major industrial complexes.

Figure 1. Location of study area

3 ANALYSIS METHODOLOGY

3.1 Analysis steps

In SAW-based models, a preliminary analysis is carried out first to identify "acceptable" and "rejected" zones. The result of this analysis used as a mask and then the "acceptable" zones are classified summing weighted pixel values of reclassified rasters.

Similar procedure is followed in the proposed method, except that as the classes of the analysis are differentiable, no preliminary analysis is required to identify acceptable and rejected zones. In other words, the pixels that get rejected scores can be identified at the end of the analysis. The main differences between the new method and SAW method are specifying the particular pixel values in reclassification procedure and then formulation of the buffer zone definitions in reclassification.

The user can trust in the new method that overlaying results for which all the criteria are, for example, very good or excellent, having even no single weak or medium class pixel value within the zone. Attention has to be paid on reclassification as every pixel which has received a weak pixel value from a particular feature would be classified as weak zone at the end of the analysis (if would not be rejected), irrespective of the pixel values from other layers. To ensure logical output of this procedure for different layers with various importance weights, a formulation function is proposed in the process of buffer assignment in reclassification, as described in 3.3. The analysis steps are summarized below:

1- To identify the influencing layers in the analysis
2- Sorting out the layers on their importance basis and specifying weights of relative importance
3- To determine the Minimum Acceptable Limits (rejected buffer)
4- Preparing the distance rasters for each pixel from the specific feature.
5- Decision on number of classes (i.e. 6 classes of reject, weak, medium, good, very good and excellent).

6- Determination of pixel values and classes in reclassification specified on the basis of the method proposed in 3.2
7- Reclassification of the other information layers not recognized as a distance type (such as bedrock) on the basis of pixel values selected in step 6.
8- Reclassification of distance type rasters on the basis of pixel values in step 6, using the introduced function in 3.3
9- Adding up all reclassified weighted rasters
10- Representing the final result raster on the basis of the pixel values and classes in step 6.
11- Selection of several suitable zones and ranking them

To determine the Minimum Acceptable Limits, pointed out in step 3, international standards and protocols may be consulted. Depending on the specific condition of the study area, stricter criteria may be considered by the analyst. For non-defined features in standards, one may consider the values or criteria of comparable features using engineering judgment. Sample buffer limits are shown in Table 1. Steps 6 to 8 are thought to eliminate the limitations of SAW-based methods which is uncertainty in the final result, wherever the number of data layers is high.

3.2 Reclassification Methodology

The significant assumption in the proposed method is that if a pixel is given low score for a feature, but several other better scores from other features, it finally ends up in the lowest class. In other words, a pixel has been at class "i", if at least one reclassified raster of a feature has assigned class "i" while all other features have had better conditions.

Assume "m" is equivalent to the total number of data layers involved in the analysis. Then Table 2 shows the procedure for determining the pixel values. W_j is the weight of relative importance of data layer j and r_{min} shows the minimum acceptable limit for which sample examples are presented in Table 1. The weight of relative importance can only be selected from natural numbers.

R_i is the lowest pixel value a pixel can adopt if it falls in class "i". For class "n" (highest class i.e. "excellent") assume R_n=1. Therefore, if a pixel acquires class "n" with respect to all data layers, the pixel value would have the highest possible value in the class as shown by $\sum_{j=1}^{m} w_j R_n$ in Table 2.

Class "n-1" is one class lower than n (say "very good" versus "excellent") for which the minimum pixel value is one unit higher than $\sum_{j=1}^{m} w_j R_n$, that is $\sum_{j=1}^{m} w_j R_n + 1$.

Similar trend is followed for the subsequent lower classes as followed in Table 2. The final score for each pixel is calculated as the total sum of pixel values of the participating reclassified rasters in the analysis. If the pixel value for a pixel is greater than $\sum_{j=1}^{m} w_j R_n$, it indicates at least there is a layer with an effect in a class of lower than "i". This postulate shall help in the final results, provided that the reclassification is on the basis of the procedure described in 3.3. Otherwise, inappropriate buffers, even for one layer might end up in unsatisfactory results.

As the classes are differentiable in the modified procedure, the rejected zone can also be considered as one of the analysis classes with the "minimum pixel values" defined in Table 2 and no separate preliminary analysis is required. $\sum_{j=1}^{m} w_j R_{reject}$ is the maximum value a pixel may get mathematically, meaning that the pixel is rejected for all criteria, but this is very improbable. The maximum pixel value must be checked out at the end of the analysis not having caused numerical instability.

It should be noted that the user would have more choices as the number of classes increases. For example, if six classes of "reject", "weak", "average", "good", "very good" and "excellent" are specified in the analysis, the user would have the choice of eliminating all the pixels with "good" and lower values, and simply maintain the "very good" and "excellent" pixels. Therefore, the selected zones would be influenced by "very good" and "excellent" pixel values of all the data layers participated in the analysis. If it is realized that insufficient zones are emerged from the analysis, the "good" class pixels could also be included to widen the selected zones.

It is also possible to use the extremum functions to reach differentiable classes by selecting the minimum pixel values of the reclassified rasters at each pixel. The advantage of the proposed method in this paper on using the extremum functions is that the weights of relative importance of data layers (similar to SAW method) influence the results at the highest classes that have been chosen to select the final zones.

3.3 Introducing the Function for Reclassification

The new proposed formulation is based on the assumption of "nonlinear reduction of the risk probability with respect to distance from the feature". For the HW site selection, increase in distance from the feature (like a fault) provides a better condition and therefore reduces the risk probability. The objective in the new formulation is to establish a formulated reclassification procedure of the distance rasters related to the data layers involved in the analysis. The parameters involved in the algorithm are as follows:

- r is the pixel distance from the feature
- r_{min} is the minimum distance below which the location is rejected and may be selected from Table 1. For $r<r_{min}$, "Suitability" and "Unsuitability" functions are defined as 0% and 100%, respectively. For a vast study area (say over 50 km^2), it is recommended to increase the r_{min} to the values specified in Table 3. Values less than r_{min} in Table 3 may result in smaller pixels in size. This issue is numerically investigated through the example presented in Section 4.

Table 1. Examples of the minimum acceptable limits

Reference / Feature	Guidelines for engineering landfill site selection, DOE, Iran, 2000	Design, Construction, maintenance and operation of municipal landfills, MPO, Iran	Landfill Criteria for Municipal Solid Waste, 1993, Ministry of Environmental Lands and Parks, British Columbia
Surface Waters	At least 200 meter	At least 100 meter	At least 100 meter
Freeways & Highways	At least 3000 meter	At least 300 meter	–
Cities	At least 4000 meter	-	At least 300 meter

Table 2. Pixel values for reclassification

Class	Reject ($r < r_{min}$)	1	...	i	...	n-1	n
Minimum Pixel Values	$R_{reject}=(\sum_{j=1}^{m} w_j R_1 + 1)$	$R_1=(\sum_{j=1}^{m} w_j R_2 + 1)$	...	$R_i=(\sum_{j=1}^{m} w_j R_{i+1} + 1)$	...	$R_{n-1}=(\sum_{j=1}^{m} w_j R_n + 1)$	$R_n=1$
Maximum Possible Pixel Values	$\sum_{j=1}^{m} w_j R_{reject}$	$\sum_{j=1}^{m} w_j R_1$	...	$\sum_{j=1}^{m} w_j R_i$	...	$\sum_{j=1}^{m} w_j R_{n-1}$	$\sum_{j=1}^{m} w_j R_n$

Table 3. Recommended minimum distances, r_{min}

Importance of data layer's buffer	**Low**	**Intermediate**	**Important**	**Very Important**
Examples	FREEWAYS RAILWAYS PIPE-LINES	FLOOD-WAYS PROTECTED AREAS MILITARY-AREAS DISUSED MINES	VILLAGES HISTORICAL-SITES RIVERS MINES (in operation)	CITIES SEA LAKES
Proposed weights of relative importance	1	1	3	5
r_{min} for data layers with crowded features (meter)	100 - 200	200 - 600	600 - 1500	1500 - 3000
r_{min} for data layers with non-crowded features (meter)	200 - 400	400 - 1200	1200 - 3000	3000 - 6000

- r_{max} is the maximum distance for each feature within the study zone. if r is equivalent to r_{max}, the "suitability" and "unsuitability" functions are specified as 100% and 0%, respectively. If $r_{max}<r_{min}$ for a distance raster, it would not be possible to select a site within the study zone.
- r_{80} is equivalent to a distance from the feature for which the "suitability" function is 80%, as expressed below:

$$r_{80} = r_{\min} + \frac{r_{\max} - r_{\min}}{I} \leq (5 - I) r_{\min} \tag{1}$$

"*1/I*" is a factor representing the buffer importance of the feature. The selection of the buffer importance of the feature is on the basis of "risk analysis quantification beyond the reject buffer". For example, the more the distance from the populated areas, places of pilgrimage, and the faults, the better. But on the other hand, for some other data layers, a certain distance is sufficient and farther distance is not essential. Examples of such features are roads & transportation lines, avalanche potential zones and caves. Based on several site selection projects, following values are suggested for "*I*":

Buffer importance of the feature	*I*
Low	3.75
Intermediate	3.5
Important	3
Very Important	2.5

The upper limit for r_{80} value in Eq. 1 is conditions like vast zones or the zones with high aspect ratios. Various nonlinear functions were investigated through trial and error for suitability function, resulting as follows:

$$S(r) = \alpha [\ln(\frac{r}{r_{\min}})]^n \times 100\% \tag{2}$$

$$US(r) = 100\% - S(r) = (1 - \alpha [\ln(\frac{r}{r_{\min}})]^n) \times 100\% \tag{3}$$

S(r) - suitability function - is 0% for $r=r_{min}$. The exponent "n" controls the nonlinearity depending on the feature importance. Increase in n exponent from zero results in decrease in nonlinearity, approaching semi-linear condition when "n" approaches e. The r_{80} value is calculated from Eq. 1 and implemented in Eq. 2.

$$80\% = \alpha [\ln(\frac{r_{80}}{r_{\min}})]^n \times 100\% \tag{4}$$

The "α" value is determined such that at $r=r_{max}$, S(r) becomes 100%, hence:

$$\alpha = [\ln(\frac{r_{max}}{r_{min}})]^{-n} \tag{5}$$

Replacing "α" in Eq. 4 with "α" in Eq. 3:

$$[\ln(\frac{r_{80}}{r_{min}}) \; / \; \ln(\frac{r_{max}}{r_{min}})]^{n} = 0.8$$

$$\beta = \ln(\frac{r_{80}}{r_{min}}) \; / \; \ln(\frac{r_{max}}{r_{min}})$$

$$n = \frac{\ln 0.8}{\ln \beta} \tag{6}$$

Rearranging Eq. 2 for r:

$$r = r_{\min} e^{\sqrt[n]{\frac{S(r)\%}{100\alpha}}} \tag{7}$$

Eq. 7 calculates distance from feature, *"r"*, for various suitabilities, *"S(r)"*.

4 EXAMPLE

Five data layers are assumed within a relatively vast zone including very important cities, important village, medium important livestock, and pastureland. In addition, bedrock has been reclassed as A, B and C, on the basis of the geologist recommendations, as shown in Table 4.

The r_{min} and the weights of relative importance are assigned respectively, 4000m and 5 for the city, 1500m and 3 for the village, and 200m and 1 for the livestock. The r_{max} values are presented in Table 5, after providing the distance rasters with pixel size of 25*25 m^2. The r_{80} value can be obtained from Eq. 1. The function factor "α" and the exponent "n" can respectively be calculated using Eqs. 4 and 5. The suitability distributions for the three aforementioned features are presented in Figs. 2 through 4. For livestock, low values of r_{min} may result in too small pixels in size that is needed for the raster calculation. Buffer values determined with pixel dimension consideration are shown in Table 5.

Total of six classes including the reject class are specified, as shown in Table 5. The methodology described in section 3.2 is followed to determine the pixel values of the reclassified rasters.

For class 90-100% suitability (all the pixels in this class are over 90% suitable for all the criteria), the minimum pixel value is assumed one (R_n=1), thus the maximum possible pixel value in this class is $\sum_{j=1}^{m} w_j R_n$=10. Lower buffer limit of this class (r for 90% suitability) can be calculated from Eq. 7. Upper bound for r is equal to r_{max}. Similarly, for class 80-90% suitability, the minimum pixel value is 11, meaning one more than the maximum possible pixel value of the class 90-100% suitability. The maximum possible pixel value in this class is $\sum_{j=1}^{m} 11 w_j$ = 110. Lower buffer limit of this class (r for 80% suitability) can be calculated from Eq. 7. Similar methodology is followed for rest of the classes.

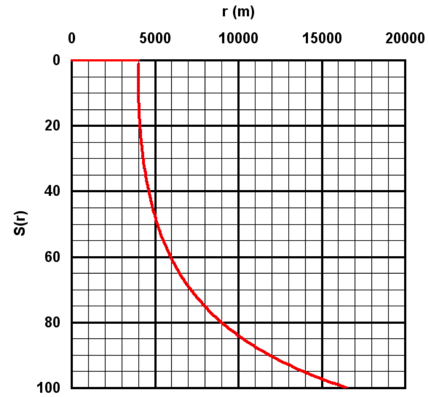

Figure 2. Distribution of suitability function for a city

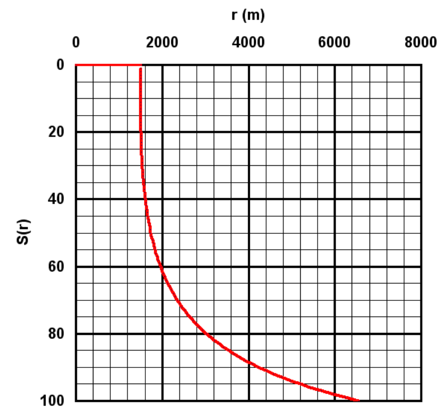

Figure 3. Distribution of suitability function for a village

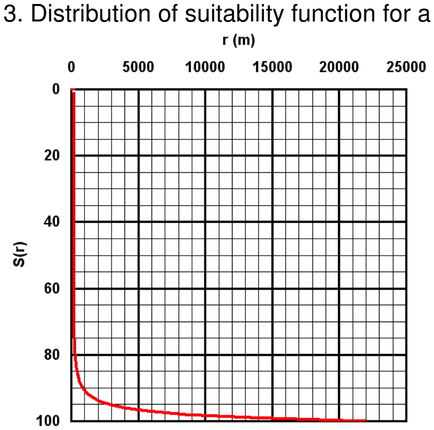

Figure 4. Distribution of suitability function for a livestock

Finally, for the reject class (the pixels in this class are rejected for at least one criteria), the minimum pixel value is 111,111 which is one above the maximum possible pixel value of the class above it (0-50% suitability in this example). The final result map (summing up the reclassified rasters) is represented based on pixel values shown in Table 5.

Table 4. Model parameters

Layer Name	W_j (weights of relative importance)	r_{min}	r_{max}	I	$r_{80}=(5-I)r_{min}$	n	α
City	5	4000	16700	2.5	9080	0.4	0.87
Village	3	1500	6350	3	3000	0.30	0.89
Live Stock	1	200	20000	3.5	300	0.09	0.87
Pasture	1	N/C	-	-	-	-	-
$\sum w_j$	10	-					

Table 5. Reclassification example

Suitability	Reject	0%-50%	50%-70%	70%-80%	80%-90%	90%-100%
City (m)	0 - 4000	4000 - 5138	5138 - 7149	7149 - 8999	8999 - 11879	11879 - 16700
Village (m)	0 - 1500	1500 - 1740	1740 - 2350	2350 - 3020	3020 - 4240	4240 - 6350
Live Stock (m)	0 - 200	200 – 200.4	200.4 – 219	219 - 297	300 - 860	860 - 20000
Live Stock with pixel dimension considerations (m)	0 - 200	200 - 225	225 - 250	250 - 300	300 - 860	860 - 20000
Bedrock	A		B			C
Pasture (m)	-	-	-	0 - 50	50 - 100	100 – 1E9
Pixel Values	111,111	11,111	1,111	111	11	1

To select the candidate zones for the HWTC, acceptable classes may be selected starting from the top best class. Assuming that 70% suitability and over has resulted in condidate zones with sufficient area, so the user is certain that no feature with less than 70% suitability is involved in the analysis results. The condidate zones can then be recommended for site visits for further fine-tuned evaluations. As the number of data layers involved in the model could be sufficiently high, the chances of rejection of the candidate zones during the site visits are small.

5 RESULTS AND INTERPRETATIONS

The new proposed method was used for the HWTC site selection of the Tehran province. The main criteria and buffers were applied for 90 digital maps in 1:25,000 scale, classified in 7 groups as follows:

- Population distribution including 7 data layers
- Educational, recreational and populated centers including 19 data layers
- Hydrology & Hydrogeology including 19 data layers
- Geology including 6 data layers
- Land-use including 19 data layers
- Road and transportation line including 14 data layers
- Industrial zones including 14 data layers

The sum of weights of relative importance was 140 and the number of classes was selected as 6. The distance from HW sources as a highly weighted data layer was applied in the model with inverse effect as an economical restriction.

An accurately developed slope layer was also incorporated in the analysis. A total of 7 candidate zones with over 70% of satisfaction were selected for the site visits out of which 3 zones were recommended and approved by the Department of the Environment to be developed as the HWTC of Tehran province, as shown in Fig. 5.

The main advantages of the proposed method with respect to SAW-based methods are: a) certainty in the final results, b) one-step analysis, and c) the diversity and flexibility of the model in adjusting the final results. The limitation of SAW-based methods is its uncertainty when the total number of layers involved in the analysis and the weight coefficient is high. for example, Fig. 6 shows results of SAW method near a city. Total of 60 layer maps are involved in the analysis. The city buffer zone and effect of other data layers on the basis of the new method are presented in Fig. 7. Any site selected in green zones is definitely in "Good" or "Excellent" class for all the layers involved. But it would not be possible for the conventional SAW-based methods to result in such a clarity, as observed in Fig. 6. It is further possible to subdivide the green zone of Fig. 7 in smaller zones to fine tune the best sites applying meaningful weights of relative importance.

The other issue is the two-step analysis involved to come up with the results of Fig. 6, that is removing the rejected zones during the first-step (often represented as mask for the analysis), and subsequent classification of the acceptable area. This is while the results of Fig. 7 are achieved in one-step of analysis only.

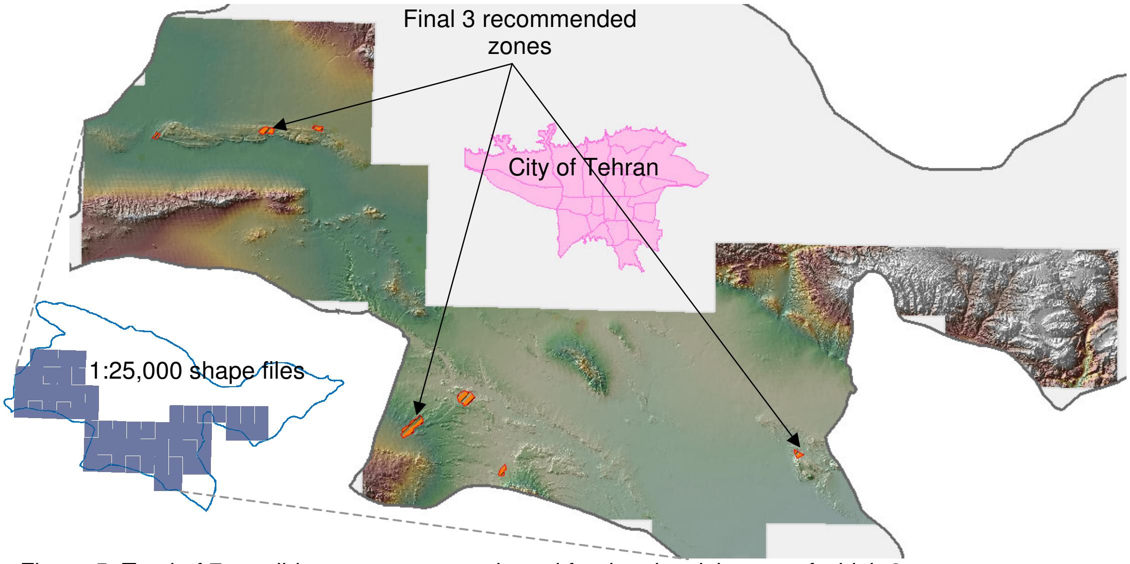

Figure 5. Total of 7 candidate zones were selected for the site visits, out of which 3 zones were approved

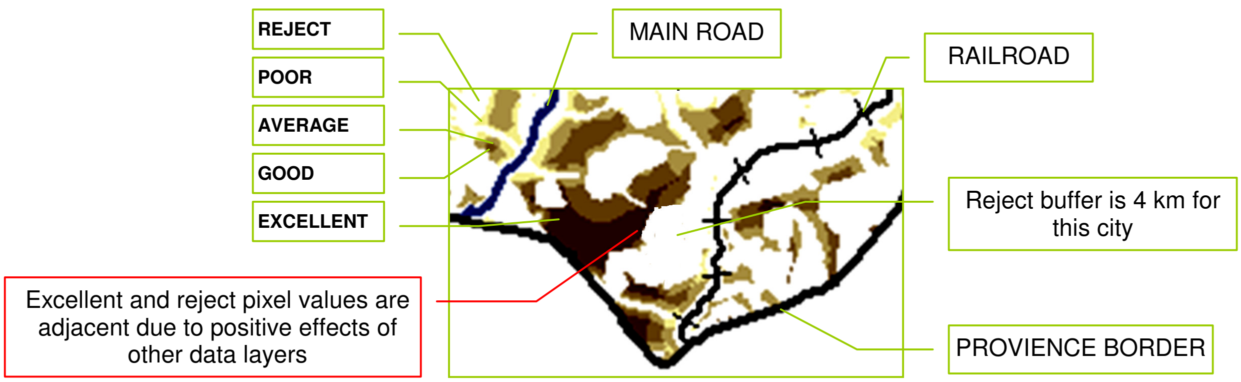

Figure 6. Sample analysis results using SAW method

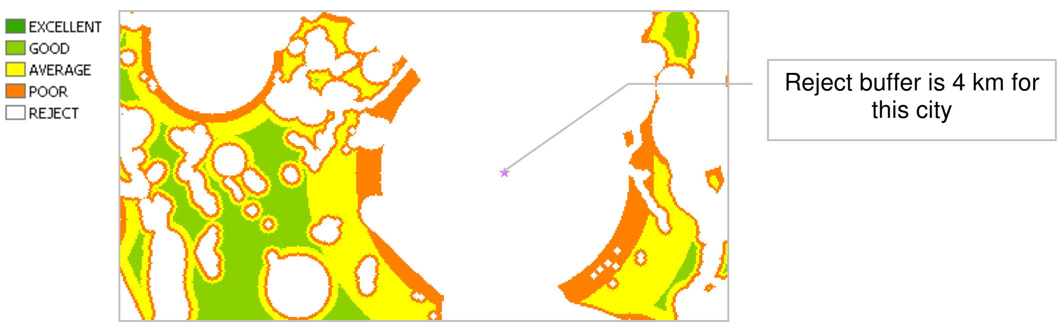

Figure 7. Sample analysis results using new method

6 CONCLUSIONS

A new GIS-based site selection model is proposed involving two steps of a "Reclassification Method" for calculating the pixel values in reclassified rasters as well as proposing a "Suitability Function" to determine the buffer zones. The most important findings of the presented study are summarized below:

- The user is certain that in top zones, no feature with less than a predefined suitability is involved in the analysis results.
- This method applies the weights of relative importance to fine-tune the final top zones. In addition, the buffer importance of the feature on the basis of "risk analysis quantification beyond the reject buffer" is applied to the determination of the buffers. (Eq. 1)

- It is not necessary to carry out a separate initial analysis to introduce the rejected zones.
- The final score can be differentiated into classes specified for the analysis.

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