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Landfill Site Selection for Kerbala Municipal Solid Wastes by Using Geographical Information System Techniques

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ABSTRACT

One of the serious and growing potential problems in most large urban areas is the shortage of land for waste disposal. Although there are some efforts to reduce and recover the waste, disposal in landfills is still the most common method for solid wastes destination. Optimized siting decision reduces negative effects to residents living in its vicinity, thereby enhancing the overall sustainability associated with the life cycle of a landfill. In this study, candidate sites for an appropriate landfill area in Kerbala are determined by using the integration of Geographic Information Systems (GIS) and multi-criteria decision analysis (MCDA). Eight input digital map layers including urban centers, Hamlets, industrial areas, sub roads, wetlands, pipe line, soil characteristics, and surface water are produced using a geographical information system. Simple additive weighing method (SAW) within (MCDA) is used to analyze the prepared maps and produce final suitability map. According to the digital maps produced by this method, the analysis results in selection of one landfill site located in the north of Kerbala city. The area of landfill site selected is 6,800,000 m^2 and, its volume is 20,400,000 m^3.

Keywords: Landfill, Site Selection, GIS, SAW, MSW, Criteria, Kerbala.

اختيار موقع طمر صحي لنفايات البلدية الصلبة لمدينة كربلاء المقدسة باستخدام نظم المعلومات الجغرافية

الخلاصة

واحدة من المشاكل المحتملة والخطيرة التي تواجه معظم المدن الحضرية، هي نقص الاراضي المخصصة لطرح النفايات الصلبة البلدية. لذا يتم بذل الجهود لتقليل واستعادة هذه النفايات، ويعتبر طرحها الى الطمر الصحي من اكثر الطرق الشائعة لحد الان للتخلص من تأثيرها. فتوجب اتخاذ القرار الامثل

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للتقليل من اثار مواقع الطمر الصحي الضارة للقاطنين الذين يعيشون بالقرب منها وذلك للتعزيز من الاستدامة المطلوبة والمتعلقة بدورة حياتها.في هذه الدراسة، تم انتخاب مواقع من مدينة كربلاء المقدسة لتصلح ان تكون مساحات للطمر الصحي. وذلك بطريقة التكامل بين نظم المعلومات الجغرافية GIS وتحليل القرار للمعايير المتعددة MCDA. حيث تم انتاج ثمانية خرائط رقمية باستخدام نظم المعلومات الجغرافية لتمثل طبقات كل من المراكز الحضرية، القرى، المساحات الصناعية، الطرق الرئيسية والفرعية، الاراضي المبللة، خطوط الانابيب، خواص التربة والمياه السطحية. وباستخدام طريقة الاوزان المضافة المبسطة SAW كأحد طرق التحليل لاتخاذ القرار المتعدد المعايير، تم تحليل هذه الطبقات واعداد خرائط وانتاج الخارطة النهائية للمساحات الملائمة للطمر الصحي. ومن خلالهذا التحليل نتج اختيار الموقع الملائم للطمر الصحي والذي وقع شمال مدية كربلاء المقدسة والذي بلغ مساحته 6.800.000 م^2 وبحجم 20.400.000 م^3.

INTRODUCTION

In developing countries, the ever increasing human population and the associated anthropogenic activities have accelerated the phenomenon of urbanization in the past decade. Waste was an early problem of mankind, and a growing one that is of major concern to every nation of the world[1]. Source reduction, recycling and waste transformation are methods widely used to manage solid waste, however, in all these methods there is always a residual matter even after the recovery process to disposal. The necessity of getting rid of these waste yields in an economic approach which is called as land filling [2].

It is evident that many factors must be incorporated into landfill siting decisions, and geographic information systems (GIS) is ideal for this kind of preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources. It efficiently stores, retrieves, analyzes and displays information according to user-defined specifications [3].

Multi-criteria decision analysis (MCDA) is used to deal with the difficulties that decision-makers encounter in handling large amounts of complex information. The principle of the method is to divide the decision problems into more smaller understandable parts, analyze each part separately and then integrate the parts in a logical manner [4].Sener [5] used GIS for multi-criteria decision analysis (MCDA) to help the landfill site selection problem and developed a ranking of the potential landfill areas based on a variety of criteria. Al-Nakeeb [6] Implemented both GIS and MCDA to select the best solid waste landfill site in Baghdad, Iraq. Javaheri[7] used GIS and MCDA as a practical instrument to evaluate the suitability of the vicinity of Giroft city in Kerman province of Iran for landfill. Khanlari [8] integrated GIS and MCDA to identify a suitable landfill site for waste disposal in Malayer region, Iran. In this study, analysis of landfill site selection has been carried out by employing GIS system and MCDA. Kerbala city, which is one of the tourist centers in Iraq, is chosen as a case study area.

STUDY AREA

According to digital maps produced by GIS, the analysis indicates that Kerbala province area is about 5463 km^2 , and located at the 44°19′55.261" East longitude and 32°45′15.457" North latitude in middle of Iraq. Fig.1 shows the considered location of Kerbalaprovince in Iraq. Because of the special situation of Kerbala, the city contains the holy shrines, millions of visitors flock to the city each year. Large quantities of solid wastes are generated each year and must be dispose in proper way. Solid Wastes Management in Kerbala city, like any other urban center in Iraq, attained a crisis state. The unorganized system whereby wastes of all types are either burned on the side of the road or dumped in open lots, on roadsides, in gutters and in small suburbs dumps posing risks to public health.

METHODOLOGY

Satellite images of Kerbala and its environs are gathered from WorldView-2 satellite. The satellite multispectral image of Kerbala city, taken in year 2010 of 0.5 meter resolution is used. Raster images and maps input and processing by many GIS software such as ARCGIS version 9.3 prepared and analyzed digital environmental maps according to landfill site selection criteria.

The methodology used in this study consists of several steps. First step is the development of a digital GIS database in which spatial information is formed. Because of different scales upon which criteria are measured, it is necessary to standardize the effective factors before combination. Eight input map layers including urban centers, Hamlets, industrial areas, sub roads, wetlands, pipe line, Soil Characteristics, and surface water were evaluated and prepared to be used in the analysis in GIS environment.

Information collected from literatures about the acceptable distances to select a landfill sites are used to create the buffer zones for each layer. After determination of the classes for each layer by using buffer zones, each layer vector maps is converted into raster maps. The methods named ‘‘simple additive weighting’’ was selected from the decision rules to analyze the data for landfill site selection by using GIS.

Siting a sanitary landfill requires an extensive evaluation process in order to identify the optimum available disposal location. This location must comply with the requirements of the existing governmental regulations and at the same time must minimize economic, environmental, health, and social costs [3]. In assessing a site as a possible location for solid waste land filling, many factors could be considered. In this study, by taking into account the conditions of Kerbala city, eight criteria were selected. Some of which are described below: Settlement Areas Landfills should not be placed too close to high-density urban areas in order to mitigate conflicts relating to the Not in My Back Yard syndrome (NIMBY). This guards against health problems, noise complaints, odor complaints, decreased property values and mischief due to scavenging animals. Furthermore, future residential and industrial growth must also be considered in allocating the place of landfill. In this study, the settlement areas are subdivided into three layers. First layer consists of urban centers, second layer is consists of Hamlets, third layer consists of industrial. The reason for this division is the necessity of applying different buffer zone distances to the urban centers or hamlets and industrial areas.

After the digitization process, safe distances from the settlement areas are determined by literature review [5]. By considering all the suggested safe distances in the literatures, minimum distances for the study areaare determined as 5km for urban centers, 500m for

Hamlets, and 250m for industrial areas Figures (2),(3) and (4). These distances are used to create buffer zones around settlement areas and excluded from the study area.

Sub Roads

There are many buffer zone distances suggested in the literature. Minimum distance from the network is imported in order to avoid visual impact and other nuisances. Roads plus 100 m around them should be applied as a buffer zone [9]. On the other hand, the landfill site should not be placed too far away from existing road networks to avoid the expensive cost of constructing connecting roads [10]. The distance greater than 1 km from main roads and highways should be avoided [5]. By considering these suggested values, the buffer zone of 100 m was determined around sub roads as shown in Fig. (5).

Wetlands

The wetlands are digitized from the multispectral and panchromatic satellite images. The necessary buffer zone for swamp areas is determined as 250m [5]. The buffer zones are created and the study area is divided into two classes in the GIS environment. Then, the prepared vector map is converted to a raster map shown in Fig. (6).

Pipelines

There is strategic crude oil pipeline passing through the study area in the west east direction. The necessary buffer zone for pipeline is determined as 250m on both sides[5]. The buffer zones are created and the study area is divided into two classes in the GIS environment. After the creation of buffer zones, the prepared vector map is converted to a raster map shown in Fig. (7).

Soil Characteristics

Soil characteristics of geological structure, soil type will affect the waste leach ate containment characteristics of a site. Karbala University, Engineering Consulting Bureau studies shows that Kerbala city soils and its environs are categorized into two distinct classifications; soils having high rate of permeability (mixed soil) are considered moderate suitability for being used as a landfill while soils with medium and relatively low rate of permeability (silt to very fine silty clay soil) are considered fairly suitable and optimal to site a landfill respectively. After that, the prepared vector map is converted to a raster map shown in Fig. (8).

Surface Water

The waste disposal areas should not be in the vicinity of rivers, or lakes where the underground water level is high. Researchers have suggested a distance up to 500 m away from a freshwater body of the water[11]. The buffer zone is created and, the vector map is prepared and converted to raster map as shown in Fig.(9) to be used as an input map in the analysis.

SPATIAL ANALYSIS

Simple Additive Weighting (SAW):

Simple additive weighting, also known as weighted linear combination or scoring method is a simple and the most often used multi-attribute decision technique. This method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by summing the products for all criteria. The simple additive weighting method evaluates each alternative, Ai by the following formula:

$$Ai = \sum W_j * X_{ij} \quad \ldots (1)$$

Where

X_{ij} is the score of the i^{th} alternative with respect to the j^{th} attribute, W_j is the normalized weight.

The eight map layers each of which defines a criterion necessary to be considered in landfill site selection are prepared earlier. The set of feasible alternatives which are the pixels of the map suitable for landfill siting are obtained by exclusion of the areas restricted by rules and physical constraints. If the scores for the criteria are measured on different measurement scales, they must be standardized to a common dimensionless unit before the SAW method. The simplest procedure for standardizing the raw data is to divide each raw score by the maximum value for a given criterion.

$$X'_{ij} = {X_{ij}}/{X_i^{max}} \quad \ldots (2)$$

Where

X'_{ij} is the standardized score for the i^{th} alternative and j^{th} attribute, X_{ij} is the raw score, and X_i^{max} is the maximum score for the j^{th} attribute. The layers, used buffer zones and rankings are summarized in Table (1).After the standardization of scores in each map layer, the criterion weights were defined as shown in the Table (2). The output maps produced by this method include the multiplication of data layers, weights and constraints as presented in Fig. (9).

As mentioned earlier, the output maps produced by this method include the multiplication of data layers, weights and constraints as presented in Fig.(10). The criterion weights are normalized to generate the overall score for each alternative. These weights are then converted into map forms.

The score value of this resultant map is evaluated and the output values are divided into six classes. One represents the masked areas with value of 0 and defined as restricted areas for landfill siting. The other classes refer to the suitability of the land as a landfill site starting with most suitable, moderately suitable, suitable, least suitable, suitable but avoid areas. The output map produced by the method of Simple Additive Weighting is given in Fig.(11). Which shows that the areas belonging to the most suitable class covers approximately 63.179 Km^2, moderately suitable class 138.1 Km^2, suitable class approximately 149.119 Km^2, least suitable class covers an area of 116.14 Km^2,and suitable area but avoided 2943.544 Km^2 from Kerbala city. The analysis results in selection of one landfill site located in the north of Kerbala city. As shown in Fig. (12),The area of landfill site selected is 6,800,000 m^2.

Conclusions & Recommendations

In this research, eight important criteria which have principal effect on determination of landfill locations are identified including, urban centers, hamlets, industrial areas, sub roads, wetlands, pipe line, soil characteristics, and surface water . After determination of relative importance weight of each criterion and score value of sub-criteria in the GIS environment, final suitability map was prepared. Based on the final suitability map, the analysis indicated that from 2336.345 km^2 which is taken as study area to represent Kerbala city, there is about 201 km^2 available to landfill site selection. Only about 63.179km^2 and 138.1 km^2 considered as most and moderate suitable area respectively. Digital environmental maps prepared for Kerala could be useful or many purposes in solid waste management, such as determination of vehicle collection route, locating of waste containers, and transfer stations locations. Financial and economic criteria should be studied, to valuate costs of landfill land, accesses, waste transportation, operation and maintenance, and after care. Government and researchers should integrate the efforts toward an integrated solid waste management taking into consideration the results obtained in this study. Ownerships specification study for private and public land use parameters to analyses as new criteria in landfill selection decision making.

Table (1), the Summary of the Input Layers Used in Analyzing.

Parameter	Buffer zone	Score (X_{ij})
Urban area	0 m - 5000 m	0
	5000 m - 10000 m	10
	10000 m - 15000m	5
	> 15000 m	1
Industrial Areas	0 m - 250 m	0
	> 250 m	1
Hamlets	0 m - 500 m	0
	> 500	1
Sub Roads	0 - 100 m	0
	100 - 500 m	1
	500 - 1000 m	2
	>1000 m	3
Soil Characteristics	poorly suitable	1
	fairly suitable	2
Wetlands	0 m – 250 m	0
	> 250 m	1
Pipe lines	0 m – 250 m	0
	> 250 m	1
Surface Water	0 m – 500 m	0
	> 500 m	1

Table (2). The Criterion Weights Defined for Simple Additive Weighting Method.

The Criteria	Weight
Urban area	10
Industrial Areas	4
Hamlets	8
Sub Roads	6
Soil characteristics	1
Wetlands	5
Pipe Lines	2
Surface Water	7

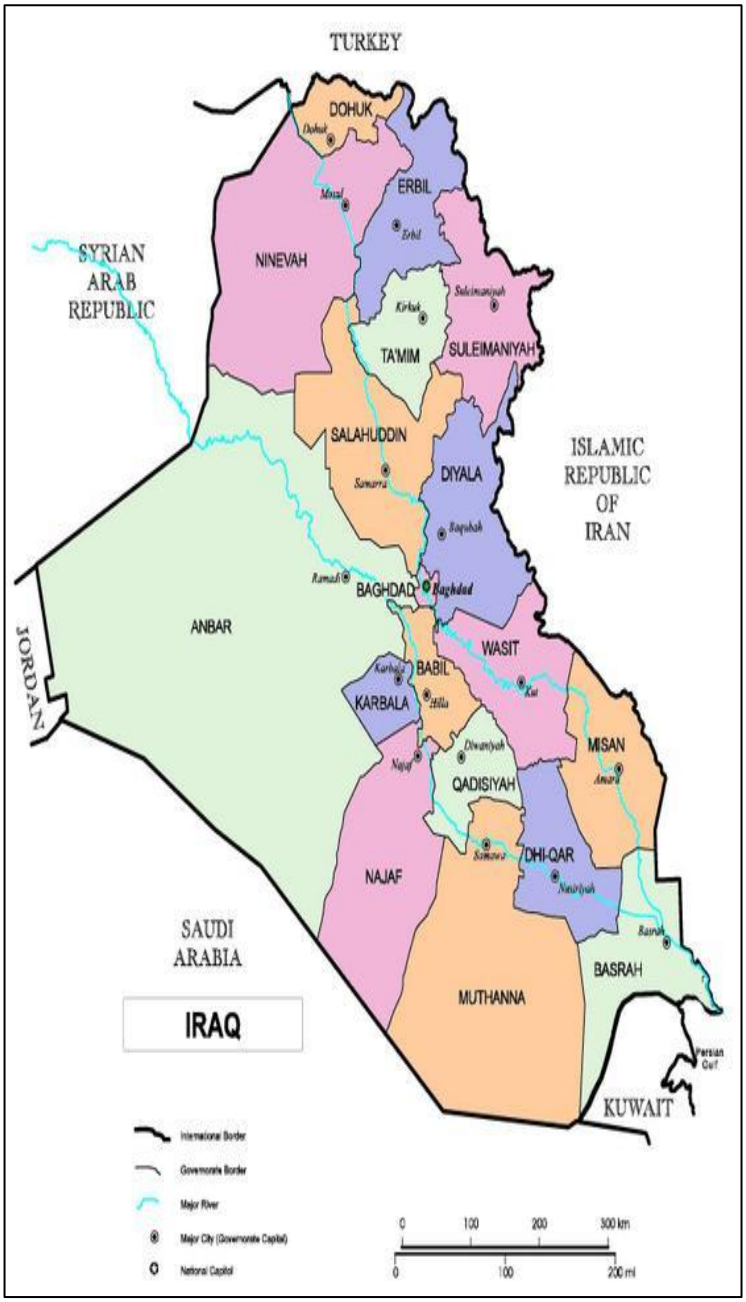

Figure. (1) Location of the study area.

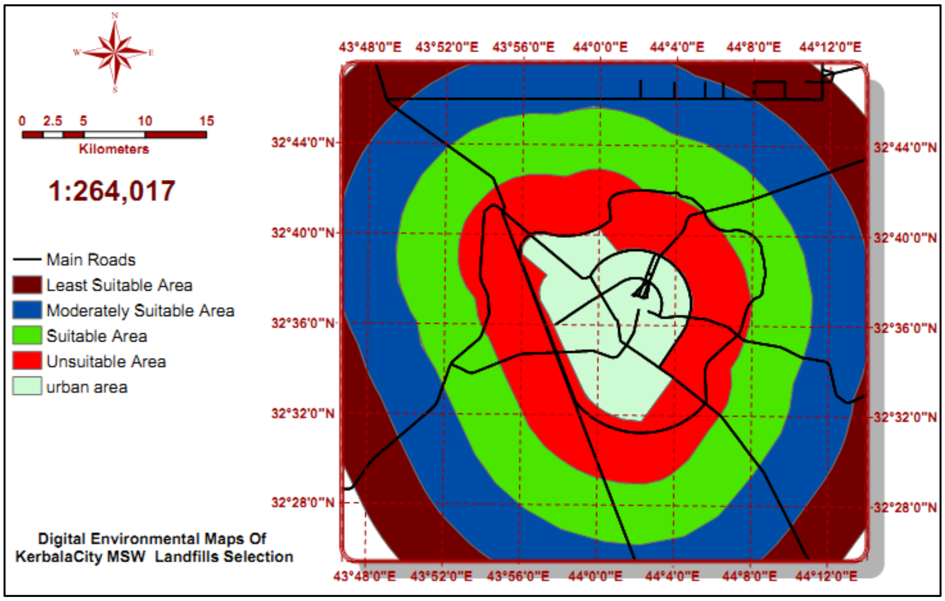

Figure. (2) Classes Produced for Urban Area.

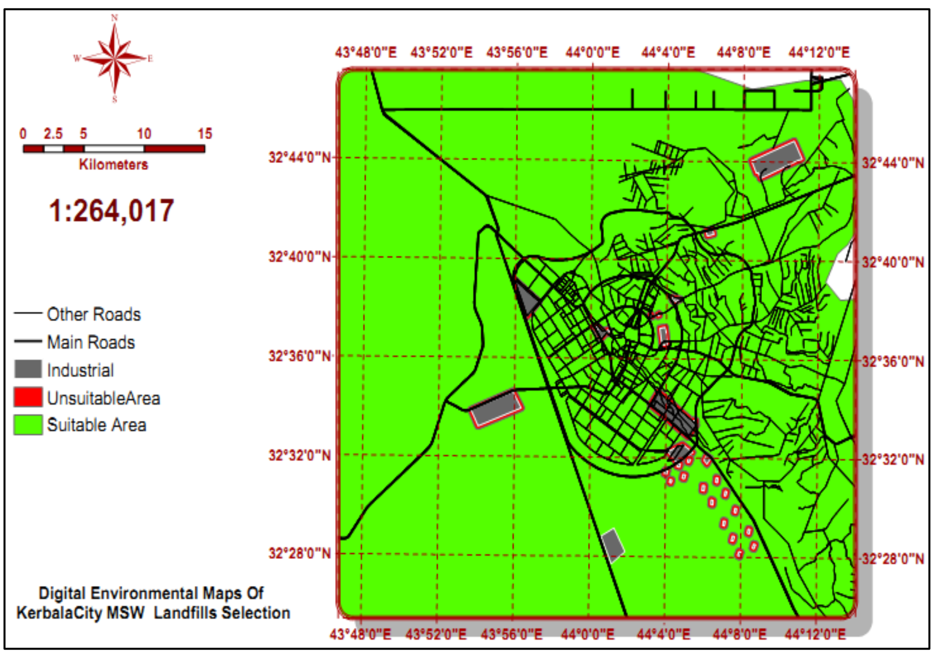

Figure.(3) Classes Produced for the Industrial Areas.

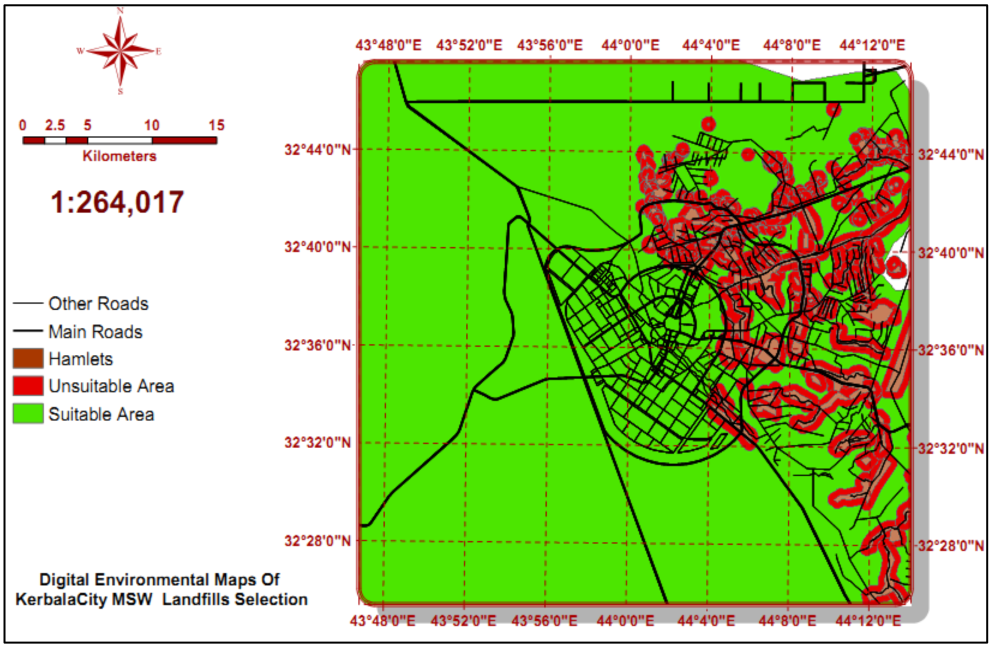

Figure. (4) Classes Produced for the Hamlets Areas.

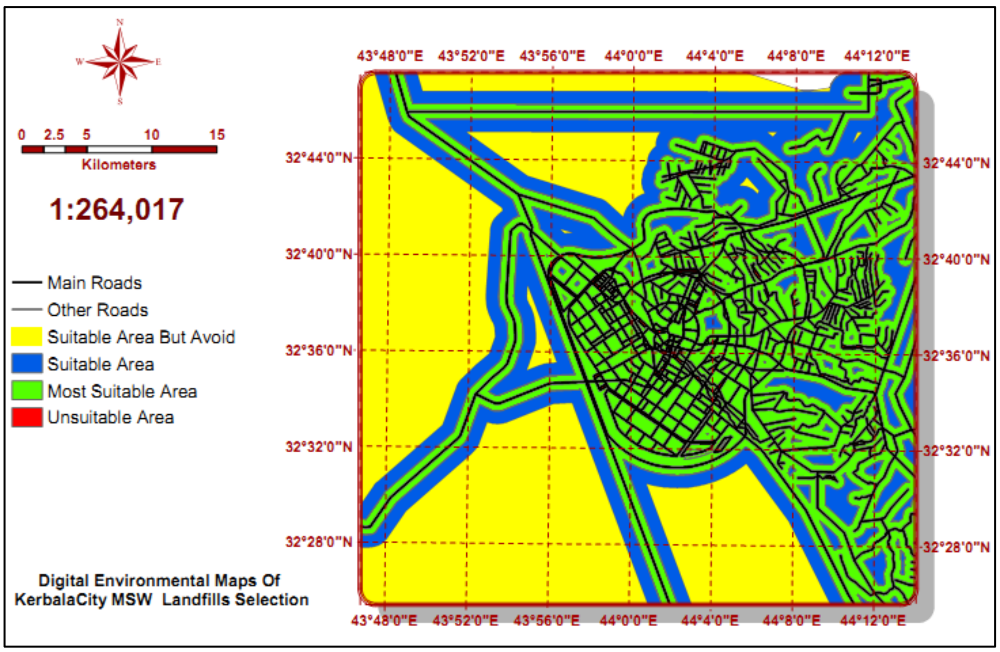

Figure.(5) Classes Produced for the Sub Roads.

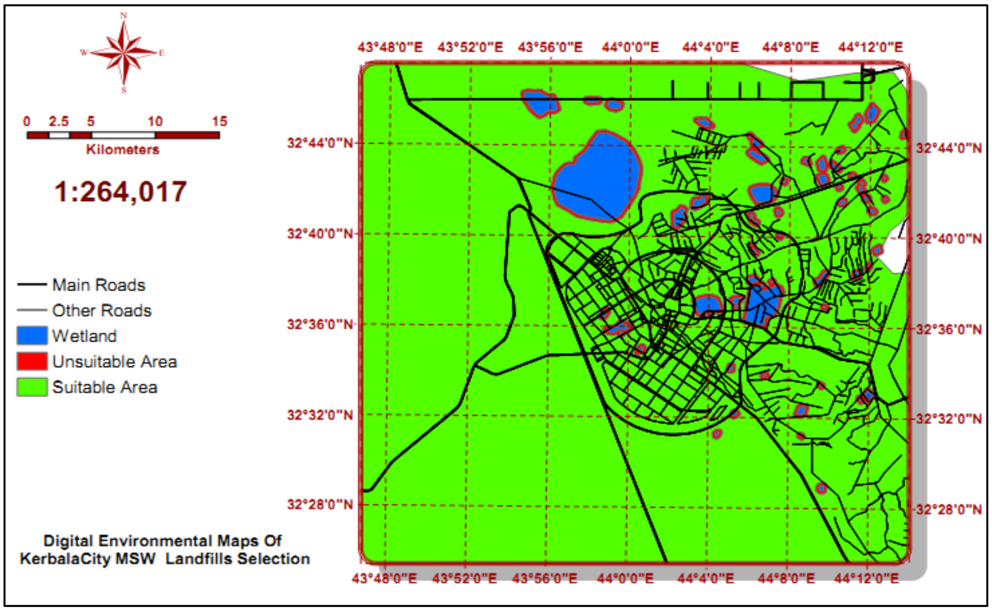

Figure.(6) Classes Produced for the wetlands.

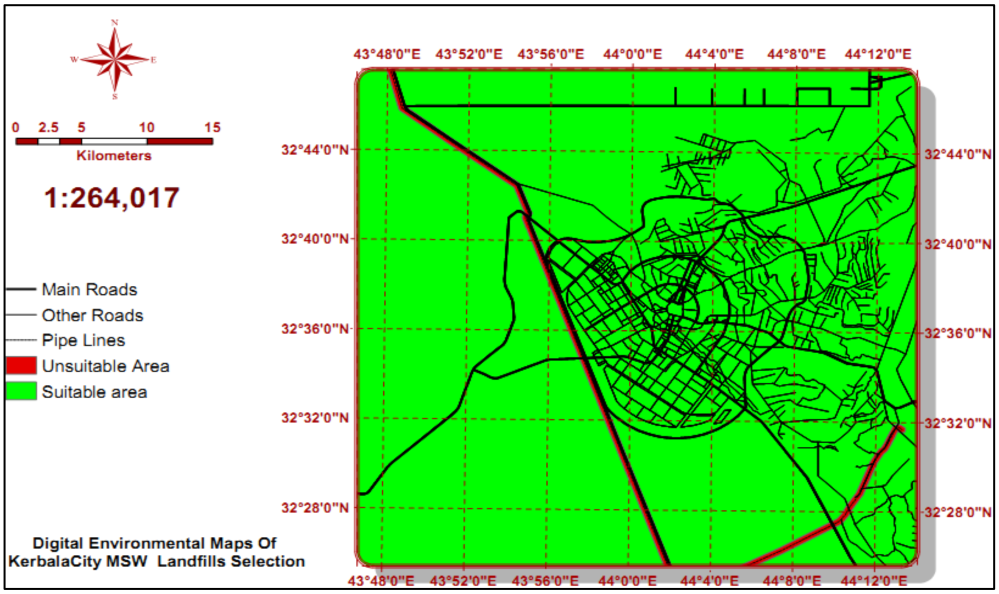

Figure.(7) Classes Produced for the Pipe Line.

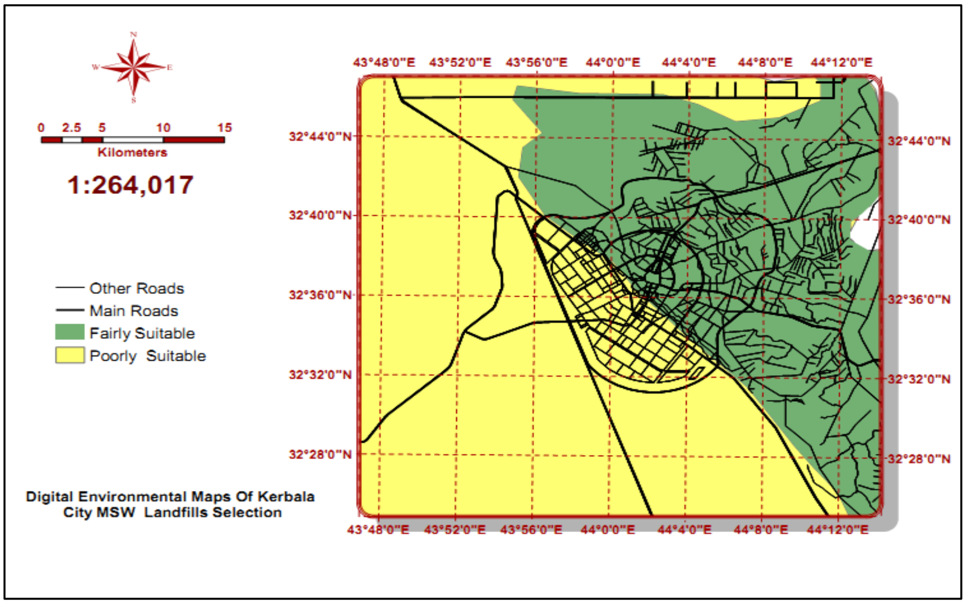

Figure.(8) Classes Produced for the Soil characteristics.

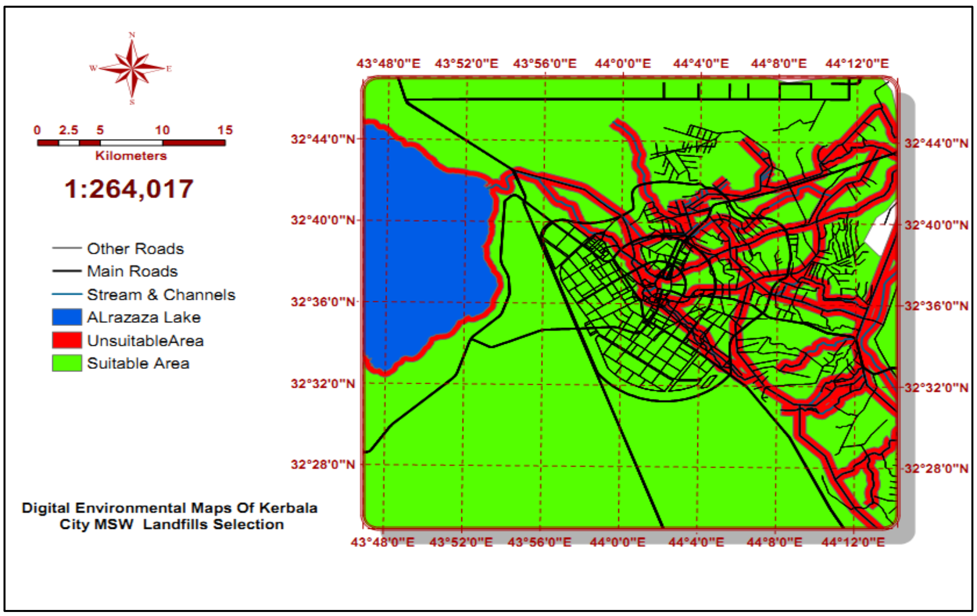

Figure.(9) Classes Produced for the Surface waters.

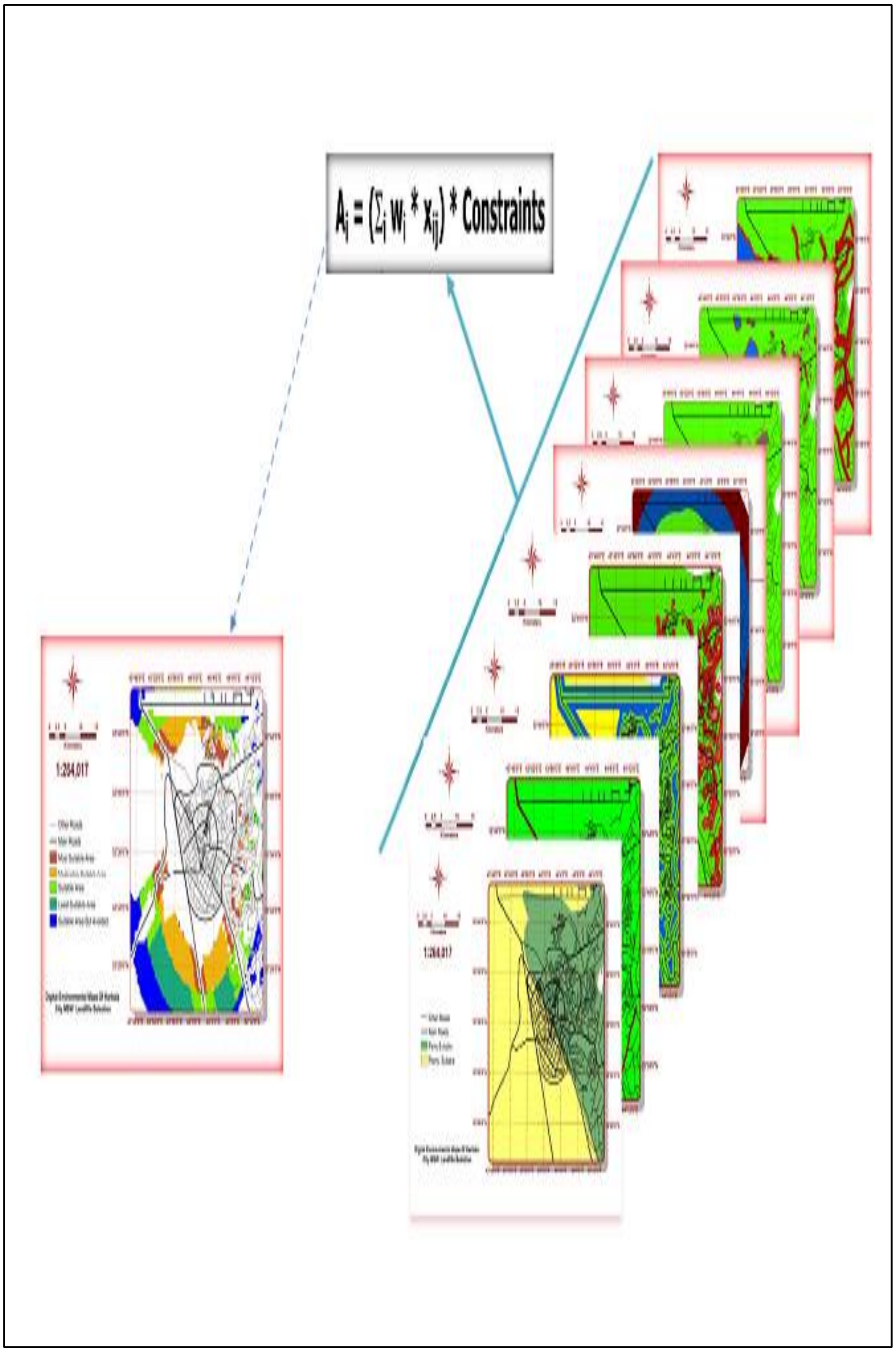

Figure.(10) The Procedure for Simple Additive Weighting Method.

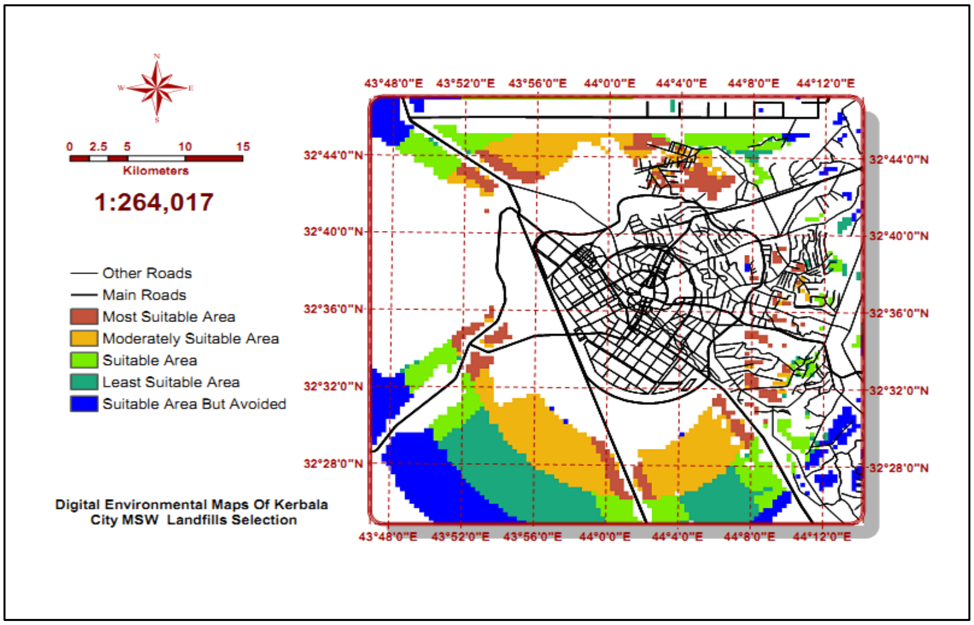

Figure.(11) The Result Map Prepared by Simple Additive Weighting Method.

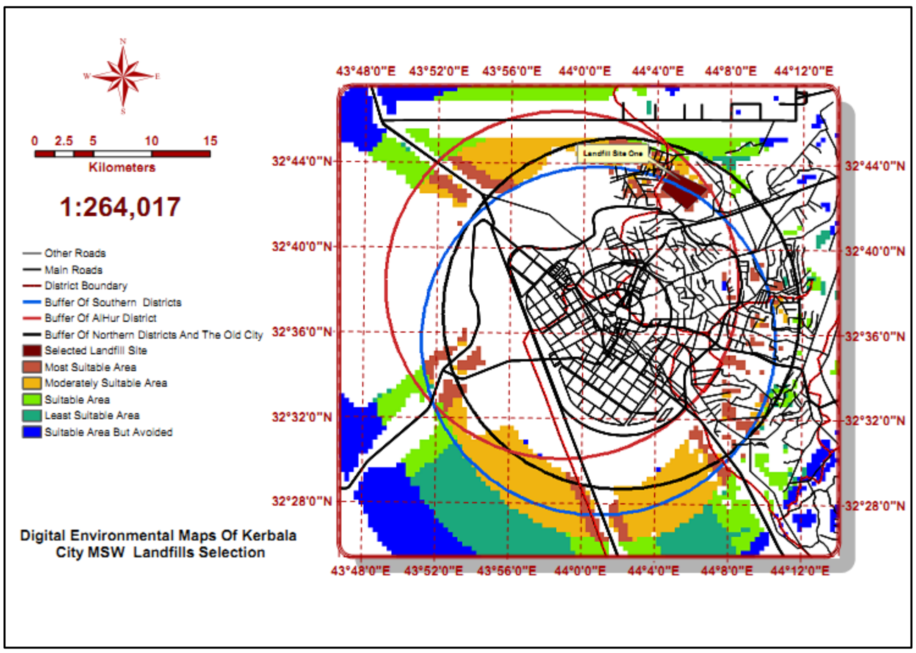

Figure.(12) Selected Landfill Site

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