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Research Article

# A Case Study from Karbala, Iraq, of Geospatial Strategies for Optimal Asphalt Concrete Plant Placement

Muhannad Muhsin [1*], Salam A.Zeedan [1]

[1] *Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.*

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**ABSTRACT**

Having a new capital improvement facility means a significant and lasting commitment and the selection of an actual site is the key factor in success. This decision affects a wide range of undertakings including land use planning and location of industrial structures. The arrangement for asphaltic concrete plants is thus surrounded by several factors that include economic, social, technological and environmental factors. Site selection in a nutshell is the process of choosing sites that have suitable characteristics and within certain parameters to produce a good site from an operational point of view. In this study, we adopt the combination of GIS techniques and cost breakdown methods to overcome the hurdles facing choices of the most appropriate sites to establish asphaltic concrete plants. This research, undertaken in the Karbala Governorate of Iraq, systematically employs tools to map areas optimising economic, environmental and social costs. The study shows that there could be around 120 possible locations for asphaltic concrete plants, on a minimum area of 40,000 square meters. This paper takes GIS modelling and cost breakdown approaches to offer an efficient approach in determining suitable plant locations and thus serves as a useful guideline in decisions of infrastructural investments.

## 1. INTRODUCTION

The process of choosing the location of the development of industrial facilities including the asphaltic concrete plants is strategically sensitive and has lasting impacts. It means that such decisions, while influencing the efficiency and costs for infrastructural construction, also have tangible societal, economic and environmental concerns. The main decisions in the location of construction facilities objectives include transport cost, access to resources, proximity to markets and other environmental aspects. Traditionally industrial location theory developed from Thünen's least cost method and Weber's theory of industrial location which focuses on minimising the cost, transportation and handling cost in particular [1-5]. Many modern theories of location still use the given theories as their basis although modern very detailed and convoluted mathematical as well as spatial models are used for the models. There is however one major difficulty that consists in finding an optimal equilibrium between costs and impacts on the environment, as site choice concerns at the same time economic and social issues [6].

The steps involved in selecting the site for the establishment of an asphaltic concrete include an assessment of technical, economic social and environmental factors. It follows that site selection cannot provide all the conditions desired; what it aims at is to optimize the plus factors that surround a site while at the same time putting up with as many of the minus factors that surround the site as possible. For instance, a location could be chosen close to the raw material source i.e. a site that is not well positioned about transport systems might be chosen because the cost of transporting the raw materials might be cheaper than the cost of transport [7-9]. The literature has revealed that the location of the plant affects the cost of raw material acquisition, transport and energy costs and hence the profitability and competitiveness of construction projects [10]. Also, it is postulated that road construction projects are price sensitive, especially on the asphalt material where the location of the projects significantly affects transport cost and labour expenses [11].

One of the important construction materials, the asphalt concrete, has certain conditions regarding the temperature, both in the process of manufacturing and transportation. The correct working temperature of the asphalt concrete mixture should also be achieved to facilitate compaction of the material during placing and to enable the mix to reach the correct working

*Corresponding author. Email: it@gmail.com

temperature for it to be transported [12]. Other variables for consideration include the type of bitumen as well as the aggregates adopted for the construction of the asphalt surface; the climate of the region also applies in choosing the most appropriate one. Inadequate control of temperature during transport poses great risks to the quality of the asphalt mixture, consequently affecting the durability of the pavement. Hence the factors to be considered when selecting sites for the plant include the temperature characteristics since the temperature influences the efficiency of the plant as well as the quality of the asphalt produced [13]. Not only the place issue but also climatic conditions for specific functions of the plant and the temperature characteristics of the asphalt mixture.

As the demand for manufactured construction products and aggregates, including asphalt concrete has been rising, particularly in developing countries, site selection for production facilities has become the important than before. The use of GIS technology has proved to be useful in the selection of the best locations for establishing plants. Thermal mapping with a combination of transportation routes, population density, and impact on the environment as the layers of data, GIS provides data for the identification of the best areas for constructing plants. Literature review reveals that GIS increases objectivity and flexibility of analysis and enables a high-speed analysis and integration of large volumes of spatial form of data which would otherwise take a long time and could be error prone [14, 15]. Further, GIS can help in the selection of potential sites that least affect the environment and advises the plant establishment not to affect the ecosystem or the people living nearby. Another strength of GIS when selecting a site for an asphalt concrete plant is that once results are generated, it is easy to map them and make sense of what seems to be otherwise, a very baffling spatial correlation.

An example of the application of GIS is the identification of the governorate of Karbala in Iraq to employ spatial analysis-based methods to evaluate possible sites for new asphaltic concrete plants. Using GIS in conjunction with other spatial analytical tools, Baran and colleagues have determined that there are over 120 possible sites within the region and that all within the qualifying area have ample space and accessibility to most facilities. Such sites have been chosen considering the technical characteristics that are needed for the design, as well as economic and ecological considerations. In pursuing the above objectives, the following research questions have been developed: The research questions are as follows: - What approach can be applied to determine the most suitable site for the development of infrastructure facilities with equal consideration given to both the economic and environmentally sound options available? In Figure 1, the reader is presented with a geographic information system-based research analysis about the potential plant locations overlaying a map of the region.

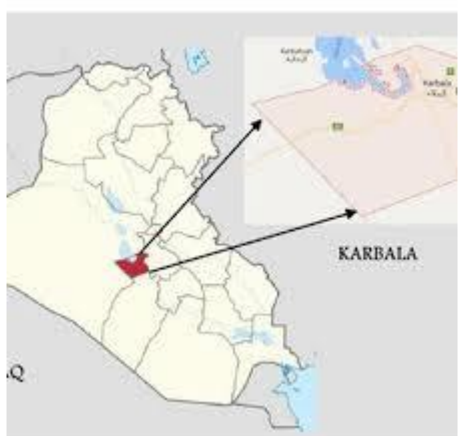


Fig. 1. GIS-Based Spatial Analysis for Asphaltic Concrete Plant Site Selection in Karbala Governorate.

## 2. MATERIALS AND METHODS

The present study investigates the availability of land and appropriate locations for asphaltic concrete plants and the spatial allocation of these promising areas. The data collected is subject to both geo-statistical and geo-graphic analyses, as Illustrated in Figure 2 below. One of the crucial activities in this research entails developing a universal geographical data information base, as well as collecting statistical information which forms the basis for further comparative analysis. For purposes of the spatial analysis, the ArcGIS software (version 10.7, ESRI, 2011) was used in its geodatabase environment in this study. In spatial analysis, there was a large number of datasets including raster and vector data. The data were gathered from the DST department of Karbala Governorate and Other Institutional data was obtained from ministries namely the Ministry of Environment, the Ministry of Agriculture, Ministry of Water Resources. At some times the spatial data layers were aggregated into overlying layers for simple analysis purposes for instance overlying the metropolitan and rural residential layers with different feature classes (points, lines, polygons). After this data gathering, all spatial information was projected into a conformal coordinate system to make it uniform and accurate for raster processing.

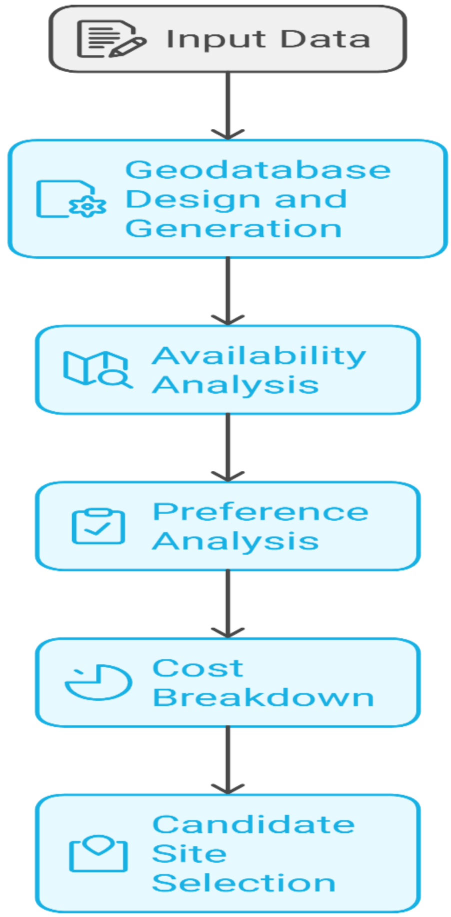


Fig. 2. Conceptual Model and Analytical Phases for Asphaltic Concrete Plant Site Selection.

Two critical analytical steps were utilized to identify the optimal locations for asphaltic concrete plants: availability of land analysis and suitability of the land analysis. The first step involved the application of a restriction model which simply deletes elements based on compiled simple criteria such as legal and physical characteristics of the environment. In the second phase, the suitability model helped in outlining areas most suitable for the plants based on factors such as; infrastructure, impact and land use.

### 2.1 Land Availability Analysis

Land availability analysis is intended to evaluate the land and eliminate unsuitable areas according to restrictions defined by national legislation and Karbala Governorate ordinances. The first restriction employed includes geophysical limitations, and environmental and; cultural heritage restrictions to establish areas that ought not to be covered by the construction of asphaltic concrete plants. National regulation and local laws specify some of the sectors where the construction of the plant is prohibited, especially near residential, agricultural or protected zones. These regulatory limitations were overlaying on geo-referenced layers of restricted areas even though the areas may have no physical features of restrictions.

According to these regulations the minimum safety distance from the restricted zones, including living districts and agricultural lands, was created as a buffer zone along the edges of restricted zones. The obtained plant locations termed as “available” for construction cannot exist within these restricted zones and buffer areas. It also protects the community of the selected location for the asphaltic concrete plant from any social inconveniences, historical sites, or even a possible seedbed for developing the technique of agricultural production. Table 1 indicates Constraints and Buffer Zones for

Asphaltic Concrete Plant Site Selection. This table gives a brief on the identified regulatory constraints and buffer measures that were used during the assessment of available land.

TABLE I. SUMMARY OF REGULATORY LIMITATIONS AND BUFFER ZONES FOR SELECTING AN ASPHALTIC CONCRETE PLANT SITE.

| NO | Constraint | Buffer (Meters) |
|---|---|---|
| 1 | Oil Refinery | - |
| 2 | Tourism Zone | - |
| 3 | Virgin Land | - |
| 4 | Green Areas | - |
| 5 | Economic Free Zone | - |
| 6 | Lake Razzaza | 300 |
| 7 | Airport | 5000 |
| 8 | Settlement | 5000 |
| 9 | Archaeological sites | 1000 |
| 10 | Rail Roads | 1000 |
| 11 | Roads | 1000 |
| 12 | Oil Pipelines | 400 |
| 13 | Electricity Lines | 100 |

### a Land Suitability Analysis

The objective of carrying out the land suitability analysis was to identify the potential areas where the asphaltic concrete plants should be established in the region of Karbala. This involved a detailed multi-step process which was divided into two primary parts: specifying certain important criteria in site selection and incorporating these criteria in the GIS Model Builder for spatial analysis. The decision-making process regarding such sites was established based on a range of economic and non-economic criteria. These areas were those such as distance to raw materials, manpower, transport, energy, and markets. However, non-economic factors included social, political and Health. By incorporating these factors into the GIS system, the goal of the analysis was to identify sites that met the set conditions.

### b Main Criteria Identification

The identification of key criteria for asphaltic concrete plant location was essential for the GIS model's success. Criteria considered for site suitability included the proximity to labour force, transportation networks, raw materials, energy sources, and markets. Other important factors were the availability of land, which is essential for plant construction, and the distance from residential areas to reduce potential health and social impacts. The GIS Model Builder used various thematic layers, such as residential areas, roads, quarries, oil refineries, and demand centres, which provided critical data for determining suitability. These layers were converted into a raster format for compatibility with the model, and their influence was quantified through Euclidean distance measurements to capture the proximity of each factor to the potential sites.

### c Locating Suitable Locations

Identification of appropriate locations to set up asphaltic concrete plants requires assessment of spatial data in the GIS environment. For every site, the nearest distance criteria including settlements, main roads, quarries, oil refineries, oil depots, and demand centres were calculated using the Euclidean Distance tool. The results of these proximity analyses were then superimposed on the availability map to map out areas that are capable of meeting all the criteria to accommodate plant locations. Additional thematic layers were added to enhance the intermediate suitability evaluation, and each element was given a relative weight in proportion to the plant's performance. For instance, manpower and transportation access were rated higher since they influence operations and accessibility respectively (Wu and Du, 2017). The breakdown of costs is shown in Table 2, which was used in estimating the proportionate importance of the several economic criteria for one ton of asphaltic concrete.

### d Criteria Weighting and Final Suitability Map

That is, the contribution of each criterion and sub-criteria to the overall suitability analysis had a significant influence on the study. The first process in the weighting included an allocation of the relevance level to each of the criteria. For instance, land accessibility and its closeness to residential zones received 12% credit since it was significant as per the regulations. The economic factors that include; sources of raw materials including aggregates, energy, labour and transport facilities were rated as the total cost of producing asphaltic concrete. For instance, locations about raw material and transportation expenses were given higher ratings because of their effect on the cost of production. To source information on the current often volatile employment costs, transportation expenses and the cost of raw materials. These inputs, the cost breakdowns were used in the GIS model and the final suitability map was developed using the weighted factors accumulation. The end product is a site map that locates potential asphaltic concrete plants in Karbala about the technical and economic considerations. The conceptual model for site selection for asphaltic concrete plants can be depicted in Figure 3.

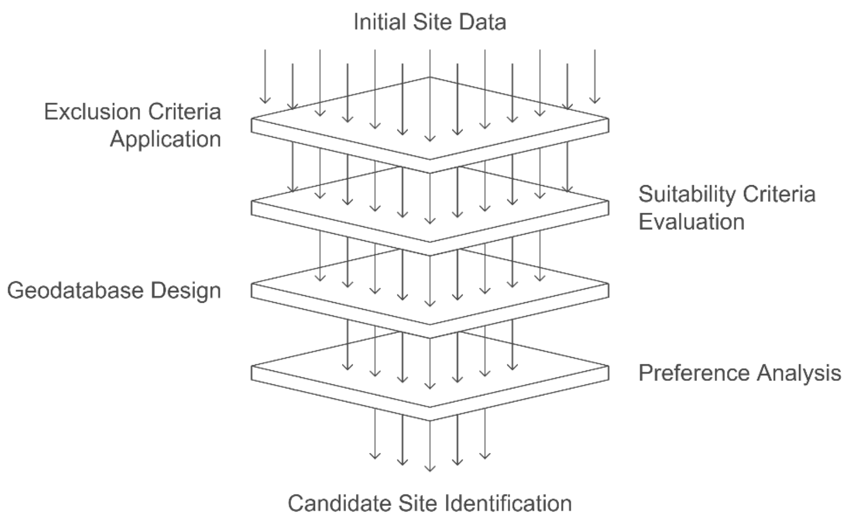


Fig. 3. Conceptual Model of Site Selection for Asphaltic Concrete Plants

TABLE II. COST BREAKDOWN FOR ONE TON OF ASPHALTIC CONCRETE

| No | Item | Unit | Quantity | Price | Cost |
|---|---|---|---|---|---|
| 1 | Gravel | $m^3$ | 0.4 | 17500 | 7000 |
| 2 | Sand | $m^3$ | 0.3 | 15000 | 4500 |
| 3 | Filler | ton | 0.05 | 35000 | 1750 |
| 4 | Asphalt | ton | 0.05 | 250000 | 12500 |
| 5 | Fuel | liter | 12 | 500 | 6000 |
| 6 | Labor | lump sum | lump sum | 2000 | 2000 |
| 7 | Asphaltic Concrete | ton | 1 | 41400 | 41400 |
| 8 | Trans Gravel | $m^3$ | 0.4 | 7500 | 3000 |
| 9 | Trans Sand | $m^3$ | 0.3 | 8000 | 2500 |
| 10 | Trans Filer | ton | 0.05 | 15000 | 750 |
| 11 | Trans Asphalt | ton | 0.05 | 35000 | 1750 |
| 12 | Trans Asphaltic Concrete | ton | 1 | 7000 | 7000 |

By employing spatial analysis tools, and mathematical models this study identifies the best site for asphaltic concrete plants arising out of the various technical, economic and environmental factors. The filler material (limestone, Portland cement, hydrated lime, or any other non-plastic material) constituted 4% of the asphalt concrete, however, it does not limit the plant location but it has a portion of the aggregates estimate. The location of the plant is determined by other factors including; proximity to raw materials, labour, transport systems, energy, consumers and land. Here is how the analysis is made:

1. Reclassification and Weight Assignment: The various criteria determining locational suitability in terms of resource, labour and market accessibility are first of all ranked according to their relevance. These weights are reclassified to a scale of 1-10 using the Reclass tool in an Arc Geographic Information System GIS. This is used to establish a scale of preference for each criterion in assessing the potential sites.
2. Weighted Linear Combination (WLC): The reclassified raster layers are then converted using a weighted linear combination to combine them. This approach involves the integration of the various criterion layers that weight to generate an overall new raster format layer. That is why the following equation is used in this process:

$$\sum_{j=1}^{m} W_j \, C_{ij} \tag{1}$$

3. Suitability Categories: The obtained raster values are then split into 10 classes. Depending on the value obtained, the higher it is, then the more favourable the location for establishing an asphaltic concrete plant. Locations classified in class 10 and 9 are categorized as restricted because of environmental or legal reasons. From the above

analysis of the results obtained from the logistic regression analysis, it is seen that the areas with a score of class 8 are more appropriate to accommodate the plant, so as not to be within restricted areas and fit all the requirements for an ideal site.

4. Site Identification: The extent of the region is divided into a grid mesh, wherein the cell size is (1 x 1) km, and a potential site for the plant has been identified in every cell satisfying the criterion. This method assists in faster assessment of extensive geographical zones and identification of optimal sites for the asphaltic concrete plants.

The GIS model output used here determines the most appropriate places to set up an asphaltic concrete plant by taking into account the technical, economic and environmental attributes. This method helps to ensure that the selected sites have low cost, environmental effects and operational insecurity while having high production, resource accessibility and security for the plant.

## 3. RESULTS AND DISCUSSION

The selection of locational requirements of asphalt concrete plants in Karbala Governorate was considered based on availability and suitability considering economic and technical factors. As depicted in Figure 4 below; this is the available land for the construction of asphalt concrete plants. The results showed that the overall area optimal for such developments is 28.03% of the total area of Karbala, the rest of the area is occupied by agricultural lands, residential areas and their setback area as well as the area around Al-Razzaza Lake. The shaded areas in Figure 5 illustrate the constraint in setting up asphalt concrete plants because of environmental and legal considerations.

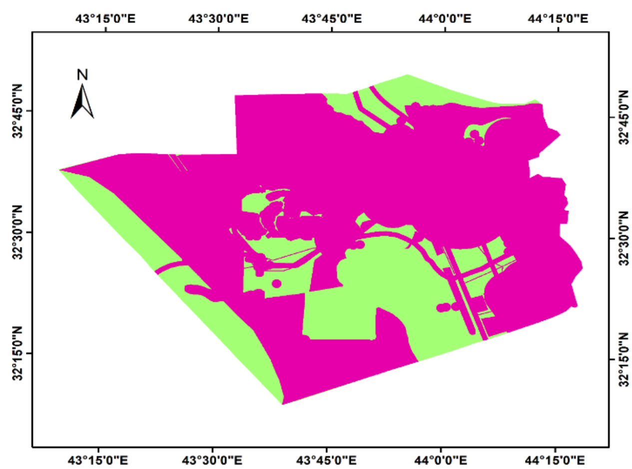


Fig. 4. Available land for asphalt concrete plants

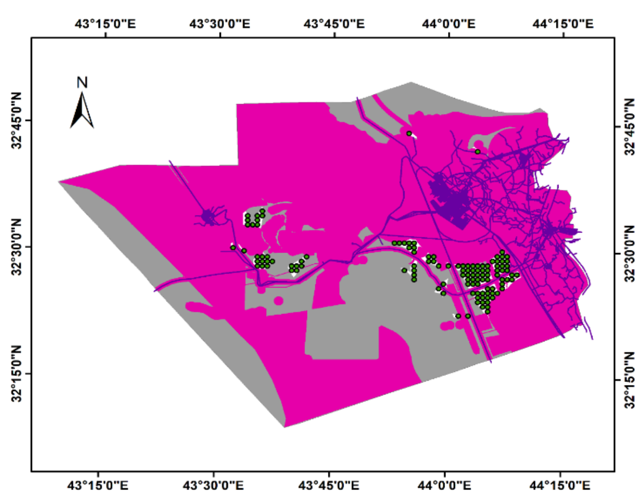


Fig. 5. Suitable land and the optimal potential locations for asphalt concrete plants

After the land availability analysis, another cost evaluation was carried out to include, economic criteria based on the cost of producing the asphalt. Table 3 shows the weightage of each criterion and GIS layer used for the cost breakdown process. These criteria were crucial in the definition of the overall basis of the costs specifically to the plant areas to consider, with clustering particularly to the raw materials, energy sources, transport networks, and demand markets being particularly important.

TABLE III. WEIGHTS AND RELATED GIS LAYERS IN THE COST BREAKDOWN PROCEDURE.

| No | Criterion | GIS Layer | Percentage |
|---|---|---|---|
| 1 | Proximity to raw material | Quarries | 13% |
| 2 | Proximity to raw material | Oil refinery | 12% |
| 3 | Proximity to energy sources | Oil depot | 6% |
| 4 | Proximity to transportation network | Main roads | 15% |
| 5 | Proximity to the labor force | Residential areas | 3% |
| 6 | Proximity to the market | Demand centers | 39% |
| 7 | Land value | Residential areas | 12% |

However, after the analysis of the costs was done, the results of the breakdown of the cost were interpolated into the suitability model. Subsequently, based on the reclassification weights, the last map depicting the potential of the locations for establishing asphalt concrete plants was prepared. Further from the raster computations, the availability and suitability maps displayed 120 locations as viable having a value of 8 as the most suitable places for plant construction.

Every chosen site must be compliant with an extensive area of not less than 40 000 sqm for proper accommodations of plant functioning, for instance, for receiving raw materials and storing manufactured goods. In addition, the site's closeness to the road network especially the Karbala main roads were important in minimizing transport distances to enhance operational logistics.

## 4. CONCLUSIONS

As the case may be, DEC further noted that the selection of sites where industrial facilities such as asphaltic concrete plants will be established has been a more complicated affair in the recent past because of the increasing complications associated with increasing environmental regulations to growing public consciousness issues to do with zoning and the environment. Due to several abiotic and biotic factors, including ecological, social and logistics, decision-making becomes difficult regarding the sites which are best suitable for the installation of wind power plants. This research specifically aimed to identify, assess and select potential sites where asphalt concrete plants can be developed using restriction and suitability models in the Karbala governorate of Iraq and integrating a cost breakdown analysis and Geographic Information Systems (GIS). It has been demonstrated that both GIS and cost breakdown analysis are viable and effective instruments to tackle the problems associated with site selection. Although each of these tools has some unique benefits when applied on its own, each of them has its problems too, when used singly. However, by incorporating each of these methods, this study reduces the adverse impacts of employing any single approach while enhancing the effectiveness of each tool. This integration not only provides a more accurate solution but also comes with a new paradigm to the site selection decision-making problem. Many of the evaluation criteria are weighted and therefore the weighting has a great influence on the site selection process. Each element, from the closeness to the source of supply, energy, markets, and potential impact on the environment must be given due consideration as to the importance of any one factor as opposed to another. What may favor one candidate may disqualify another and this depends on which criteria are included or excluded. Thus, a need to develop a clear, rational and coherent weighting system that will adequately capture the priorities of project stakeholders. By doing this, this research shows how the application of A-GET with spatial data and constraints facilitates the improvement of the planning and development of industrial facilities such as asphalt concrete plants. Through GIS the decision makers of Karbala governorate can get the right information regarding the environmental, economic and social impacts that will enhance the performances of the industry and develop the societal wellbeing. The study also contributes to the development of a new methodology that can be employed by other successive infrastructure projects to achieve sustainable development.

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## Conflicts Of Interest

No potential conflicts of interest with funding sources, organizations, or individuals are disclosed in the paper.

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