OPTIMAL LOCATIONS OF LANDFILLS AND TRANSFER STATIONS IN SOLID WASTE MANAGEMENT

A THESIS

SUBMITTED TO THE DEPARTMENT OF

INDUSTRIAL ENGINEERING

AND THE INSTITUTE OF ENGINEERING AND SCIENCE

OF BILKENT UNIVERSITY

IN PARTIAL FULFILLMENT OF REQUIREMENTS

FOR THE DEGREE OF

MASTER OF SCIENCE

By

Nilüfer Nur Beğen

September, 2002

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Prof. Barbaros Ç. Tansel (Supervisor)

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Assoc. Prof. Ihsan Sabuncuoğlu

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Assis. Prof. Bahar Yetiş Kara

Approved for the Institude of Engineering and Sciences :

Prof. Mehmet Baray
Director of Institute of Engineering and Sciences

ABSTRACT

OPTIMUM LOCATIONS OF LANDFILLS AND TRANSFER STATIONS IN SOLID WASTE MANAGEMENT

Nilüfer Nur Beğen
M.S in Industrial Engineering
Supervisor : Prof. Barbaros Ç. Tansel
September, 2002

In the recent years solid waste management has been given an increasing importance due to health factors and environmental concerns. Solid waste management refers to a complex task that covers the collection, transfer, treatment, recycling, resource recovery, and disposal of waste. In this thesis, we investigate the siting aspect of solid waste management for the siting of landfills and transfer stations. We first review the context of solid waste management and clarify the elements associated with it. We review the actual siting process applied by the authorities and compare it with the methods proposed by the researchers. We aim to examine how good the models used in optimization may be at approximating the actual siting process. For that purpose we formulate p-median models for several countries and compare the exisiting landfill locations with the cost-based optimal solutions. Another issue that we concentrate on is the siting of the transfer stations. We propose a new mixed integer programming model for the siting of the transfer stations and apply the proposed method for the city of Ankara.

Key words : Solid Waste Management, Landfill Siting Problem, Transfer Station Siting Problem, p-median model

ÖZET

KATI ATIK YÖNETİMİNDE ÇÖP DEPOLAMA ALANLARI VE TRANSFER İSTASYONLARININ OPTİMUM YERLERİ

Nilüfer Nur Beğen
Endüstri Mühendisliği Bölümü Yüksek Lisans
Tez Yöneticisi :Prof. Barbaros Ç. Tansel
Eylül, 2002

Son yıllarda katı atık yönetimine verilen önem sağlık faktörleri ve çevresel endişelerden dolayı artış göstermektedir. Katı atık yönetimi atıkların toplanmasını, taşınmasını, işlem görmesini, geri dönüşümünü, kaynakta iyileştirilmesini ve elden çıkartılmasını kapsayan çok kapsamlı bir iştir. Bu tezde katı atık yönetiminin sorumlulukları içinde bulunan yer seçimi kararlarının verilmesi yönü, katı atık depolama alanları ve transfer istasyonlarının yerlerinin seçilmesi açısından incelemektedir. Öncelikle katı atık yönetiminin içeriği özetlemeklenmekte ve ilgili elemanlarına açıklık getirilmektedir. Yetkilililer tarafından uygulanmakta olan gerçek yer seçimi süreci özetlenmekte ve araştırmacılar tarafından teklif edilen yöntemlerle karşılaştırılmaktadır. Bu sayede, optimizasyonda kullanılan modellerin gerçek yer seçimi sürecine ne kadar yaklaştığı incelenmektir. Bu amaca ulaşmak için, çeşitli ülkeler için *p*-medyan modelleri formüle edilmekte ve mevcut çöp depo alanlarının yerleri optimal çözümlerle karşılaştırılmaktadır. Ele alınan diğer bir nokta da, transfer istasyonları için yer seçimi problemidir. Bu tezde transfer istasyonlarının yerlerinin belirlenmesi için yeni bir karışık tam sayılı programlama modeli önerilmekte ve önerilen model Ankara için uygulanmaktadır.

Anahtar sözcükler. Katı atık yönetimi, çöp depolama alanı yer seçimi problemi, Transfer istasyonu yer seçimi problemi, *p*-medyan modeli.

ACKNOWLEDGEMENT

I would like to express my sincere gratitute to the numerous people who have supported me in various ways during this thesis. I am mostly grateful to my supervisor Barbaros Tansel for suggesting this topic which really filled me with enthusiasm during the process of research. I want to thank him for his everlasting interest and patience and help in any way during my studies.

I am also indebted to members of my thesis committee: İhsan Sabuncuoğlu and Bahar Yetiş Kara for showing interest to the subject and accepting to read and review this thesis. Their remarks and recommendations have been invaluable.

I would like to express my deepest thanks to my family, without whom this study would not have been possible.They were always there when I neededed them. Thanks to my father, my mother and grandmother for their prayers, and to my sister for her encouragement.

I want to thank to Ömer Selvi, and Güneş Erdoğan who has helped me get used to the university and answered all of my questions patiently.

I would also like to express my special thanks to my friend Savaş Çevik who has been more than a friend to me. With him even spending the whole night at the lab was fun. I will never forget the helps and favours he has done to me.

Last but not the last, I owe special thanks to Rabia Kayan who has really been a real friend to me and given me support and encouragement. I will never forget the small chats we had.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

In recent years, the term solid waste management (SWM) has become a common term in the society. It refers to complex task that covers the collection, transfer, treatment, recycling, resource recovery and disposal of waste. Within the overall framework of urban management, one of the major concerns of the SWM is the disposal facility siting. Although the improved technologies in today`s world bring about new options and new facilities to be considered such as composting facilities, materials recovery facilities and waste-from-energy facilities, the landfills still constitute the backbone of solid waste disposal.

The purpose of this thesis is twofold. First, the landfill location problem, the issues related to it, and specific techniques used for approaching the solution are analyzed. Landfill siting has become the most contentious and difficult part of the solid waste management process, since it is difficult to find sites that are both technically feasible and environmentally acceptable. Another problem is the resistance to social acceptance that results from the urge of communities to be away from the landfills as much as possible. In light of the difficulties in attaining such goals, Ham (1993) pointed out that in the last decade landfills have become fewer in number, and are located at a longer distance from the sources of wastes.

The locating of the landfills at a longer distance from the communities leads to the introduction of new facilities into the solid waste collection system - transfer stations- the second concern of this thesis. The transfer stations serve as the link between a community's solid waste collection program and a final remote waste disposal facility.

In this thesis, we first provide some background to the reader who is not familiar with the concept of waste management by explaining the scope of solid waste management. Chapter 2 is mostly about definitions and explanations about the elements of the solid waste management and issues in solid waste disposal. This chapter aims to express why landfills still remain the primary place where the waste goes to and are more compatible than other disposal options, and why landfill siting is a critical challenge.

Chapter 3 is about the municipal solid waste (MSW) landfill siting process. We categorize people working on landfill siting into two groups: d*ecision-makers* (DMs) who do the actual siting of the landfills and *researchers* who study the problem with an academic viewpoint. In the siting process, we observe that while DMs generally apply complex methods and give prior concern to the technical feasibility of candidate sites, researchers mostly use mathematical programming and concentrate on the cost minimization objective. The models presented by researchers generally seek to minimize a well-defined and quantifiable cost subject to explicit constraints. Marks and Leibman (1970) explains that waste disposal facility-siting decisions are a part of the functions of the public sector rather than the private sector and that there is a divergence between the objectives of public and private systems, since the public objective function is more vague and difficult to express formally. In addition, the actual siting process is highly political and emotional. Therefore, Marks and Liebman (1970) suggest that these models should be consired to aid the DMs in the siting process and used carefully, by appreciating the factors that the model cannot consider explicitly. On the other hand, the DMs may use some judgement and emotion in the evaluation of the sites while applying some complex techniques in the siting process, consequently, attaining consistency may be problem.

In Chapter 3, we first identify the stakeholders in the siting process and their objectives. We then present the literature on the landfill siting problem that consists of models with a single objective as well as models with multiple objectives. The rest of the chapter is about the actual siting process followed by the DMs. The criteria used to eliminate potential sites and the methods of site selection are presented in the end of the chapter.

DMs generally use *prior feasibility checking* of the candidate sites that requires gathering lots of spatial data, maps, field studies, and evaluations for all candidate sites. This is a rather complex, long, and costly task that needs a multidisciplinary analysis. In Chapter 4, we look for a new approach to simplify the tedious decision making process. We consider the landfill siting problem as a *p*-median problem which locates *p* landfills relative to a set of garbage generation points such that the sum of the weighted distances between garbage generation points and the nearest landfills are minimized. The objective is to check whether the well-known *p*-median model is an applicable approach to locate landfills and how well it approximates the actual siting process of the DMs. For that purpose, we located landfills in different regions of the world using the *p*-median model, and compared the cost based optimal solutions with the existing landfill sites and presented the results on the maps of the studied regions. At the end of the chapter, we propose a method for the siting of the landfills. The method is based on iteratively finding the p-median solutions, and then checking the feasibility of the sites. The basic idea behind the method is to use *posterior checking* instead of *prior checking*, that is the common practice of DMs. In posterior checking, instead of collecting the necessary data for all candidate sites prior to evaluation, we solve the model first, and then check the criteria for *only* the resulting optimal sites. If the optimal *p*-median solutions do not satisfy the feasibility critea, the found sites are eliminated and the model is solved again until all the necessary conditions are satisfied. This simplifies and shortens the evaluation process.

As the trend to locate away from cities have become more pronounced, the need for transfer stations where the transshipment of solid waste from collection vehicles to a more economical means for long-haul transportation has been posed. The fundamental questions involve the desirability of transfer stations, their number, location, and capacity. These decisions may be viewed as a tradeoff between the building of facilites and the cost of transportation. Chapter 5 is on the siting of the transfer stations. The chapter firstly explains the reasons for the building of the transfer stations, and then a review of the literature on the siting problems is presented. The new model that we propose is presented and explained. The application of the new model for Ankara and the results are presented in the chapter.

The last chapter is a short summary and gives some final remark on the subject.

Chapter 2

Solid Waste :Overview

The management of waste is becoming an increasingly important issue for modern society. Excessive waste production leads to an inefficient use of resources and results in a large amount of unwanted material for which a safe means of disposal has to be found. In this chapter, some general but necessary information concerning solid waste and solid waste management is reviewed in order to provide some background for the reader not familiar with the issues in waste management.

Section 2.1 briefly reviews the development of the solid waste crisis from the ancient times to today's world. In Section 2.2, the definitions of different kinds of waste are provided in detail. Section 2.3 explain the definition, scope and goals of solid waste management, as well as the necessary elements in solid waste management. Section 2.4 disscusses the issues that makes the solid waste management a real challenge.

2.1 A Glance at the Solid Waste Crisis

The history of the solid waste is at least as old as the time before people had not yet lived in the cities. Before people started to move to the cities, the waste, which was made up mostly of organic materials derived from the plants, was used as fuel, crop fertilizer, or was fed to livestock. The communities who lived on hunting and gathering simply moved away when the garbage heap became a problem. This type of waste management is still practiced by people in some rural regions of the world [Solid Waste Overview, 2002].

The more concentrated the populations in the cities became, the bigger the garbage heaps grew. People could not just pack up and move to another city when their heap got too big. As cities became populated, they started to spread out and became increasingly farther away from their food sources. The organic waste was no longer useful to the people, so it became "*garbage*." The old habits of throwing wastes out the door to animals or into the garden caused public health problems in the densely populated cities.

In the Bronze Age, inhabitants of Troy (approximately 3000 to 1100 BC) kept some of their trash indoors and covered it with layers of dirt or clay. The remaining garbage was thrown into the streets. Although it was not a great problem at that time, as more and more people began to live in cities, the problem of waste disposal grew acute. By the Middle Ages, streets and alleys were often filled with garbage, and rain would turn them into open sewers where disease could flourish [The History of Municipal Solid Waste, 1999].

Some cities in parts of the Orient solved their garbage problem by hauling organic wastes out to farms and composting it to revitalize croplands [The History of Municipal Solid Waste, 1999]. Another solution was simply to take garbage out to the countryside and dump it in piles. Around 500 B.C in Athens, Greece, the Council of Athens issued an edict prohibiting the dumping of garbage within one mile of the city wall. This site is believed to have been the first open municipal waste site in western Civilization [Environmental Literacy Council-Landfills, 2002].

Although it was crude, the system of dumping or burying the garbage in an isolated place worked at that time. Because most of the solid waste consisted of biodegradable organic materials which could easily be broken down into simpler compounds by microorganisms and be decomposed [Solid Waste Management: Glossary, 2002]. Today, the problem is more complex than it used to be. Firstly, over the last 50 years new non-biodegradable synthetic materials, some of which produce toxic residue, have been introduced into the waste stream [Garbage, 2002] Secondly, the volume of the previously generated trash is much lower than today because there were fewer people and less packaging waste. An important point to mention related to the increased amount of waste is vast amounts of waste, which are formed during the manufacture of goods. These include the factory wastes from manufacturing processes, waste from burning fuel to transport things, waste such as coal ash from producing energy, and mining wastes from extracting raw materials [Rotten Truth about Garbage, 1998].

Remarkably, 2500 years after Athens' first garbage edict, open dumps still exist in our advanced industrial society [Solid Waste Overview, 2002]. The dumping practices have evolved over time; disposal practices vary from uncontrolled open dumping to long-term containment in well-managed sites. However, how to manage our wastes has been a problem for decades. The question of how to manage human trash whether to recycle, reduce, dump or incinerate has been the concern to every society. "There were no ways of dealing with it that haven't been known for thousands of years. These ways are essentially four: dumping it, burning it, converting it into something that can be used again, and in the first place, minimizing the volume of future garbage that is produced" wrote William Rathje (1991), a noted solid waste expert, about solid waste [The History of Municipal Solid Waste, 1999].

Over the past years the concern of the communities over the waste disposal grew so much that, a number of legislations regulating the disposal of municipal solid waste (MSW), industrial and, hazardous waste have been developed. The US Congress passed the Solid Waste Disposal Act in 1965 as part of the amendments to Clean Air Act, because in the early 1960s, cities and towns across the US were practicing open air burning of trash. This was the first federal law that required environmentally sound methods for disposal of household, municipal, commercial, and industrial waste [US-EPA, 2002].

In developed countries, as cities grew and spaces for dumping trash became scarce, dumps became centralized and evolved into burial pits that were covered with soil [Solid Waste Overview, 2002]. The introduction of non-biodegradable materials into the waste stream and increasing environmental awareness led to tighter environmental controls on dumpsites. These resulted in the building of new "sanitary landfills" which are sophisticated in design and regulated in every aspect from siting to filling to closing. On the other hand, uncontrolled dumping is common in developing countries. According to a working paper prepared by the World Bank and United Nations on Municipal Solid Waste Management in Low-Income countries, “in most cities of the developing countries waste management is inadequate: a significant portion of the population does not have access to a waste collection service and disposal of solid waste is unsatisfactory from the environmental, economic and financial points of view ” [Schübeler et al., 1999]. A significant amount of solid waste generated in urban centers is uncollected and either burned in the streets or end up in rivers, creeks, marshy areas, and empty lots. Waste that is collected is mainly disposed of in open dumpsites, many of which are not operated or maintained, thereby posing serious threat to public health [UMP Asia News, 1999]. Also, in Turkey, the majority of waste is being disposed of at landfills, which are practically, *dumps*, with no environmental protection standards operated by the municipalities. For those cities, plans for future use of sites suggesting a vision for long-term solid waste management should be made.

Today, modern landfills that are properly designed and operated are the most cost-effective and environmentally acceptable means of waste disposal when population density and land availability are not at issue [Evaluation of needs and alternatives for landfills, 1998]. For that reason, landfills continue to be the primary place where the waste goes. For example, the US disposed approximately 61 percent of its solid waste in landfills in 1999 [Solid Waste Overview, 2002]. The British landfilled 78% of their solid waste in 2000 [Municipal Solid Waste Statistics, 2000/01, DEFRA], whereas the same rate was 92% for Hong Kong in 1995 [Asia

Development Bank]. For Turkey, the rate is 82% , the methods that follow are sea and river disposal 14 %, and burial 1%, burning in open air %3 [DIE, 1991].

Controversies over landfills are more likely to focus on where they are built and how to prevent pollutants from escaping than on whether we will run out of room to put our trash [Environmental Literacy Council-Landfills, 2002].

2.2 Waste

There are several reasons to be concerned with waste. It is costly to dispose of and the generation of large amounts of waste affects the environment. Domestic and industrial dumping of waste contaminates air, land, and water with pollutants and toxics that may harm human health as well as animal and plant life. A WHO study (1982) defines waste as "every substance or object rising from human or animal activities that has to be discarded as useless or unwanted" [Economopoulos, 1993]. The study also emphasizes that the above definition covers an extremely heterogeneous mass of wastes, which may originate from people's homes, and from commercial or industrial activities. Our modern solid waste stream includes glass, complex metal alloys, plastics, construction materials, paper, and products such as hazardous wastes. Urban solid wastes consist of household wastes, construction and demolition debris, sanitation residues, industrial and hospital wastes [Planning Commission, 1995]. Broadly, it can be divided into three categories, as in Figure 2.1, depending on its source [Types of Solid Waste, 2001].

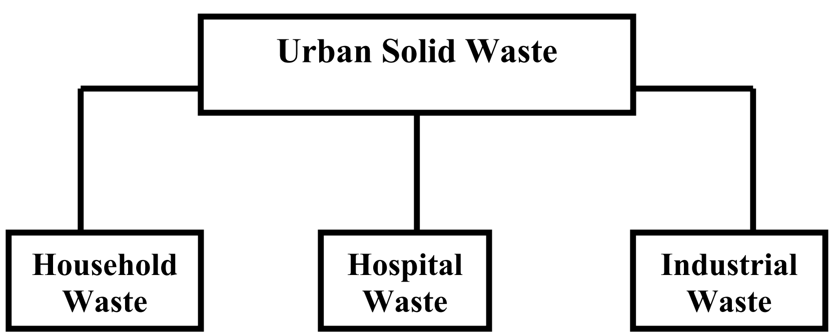


Figure 2.1 Categories of Urban Solid Waste (Planning Commission, 1995)

a) Household waste is generally classified as municipal waste,
b) Hospital waste or biomedical waste as infectious waste, and
c) Industrial waste as hazardous waste.

2.2.1 Industrial Waste

Industrial and hospital waste are considered hazardous as they may contain toxic substances. Hazardous wastes could be highly toxic to humans, animals, and plants; are corrosive, highly inflammable, or explosive; and react when exposed to certain things e.g. gases [Types of Solid Waste, 2001].

Certain types of household waste can also be categorized as hazardous waste, such as old batteries, shoe polish, paint tins, old medicines, and medicine bottles. Hospital waste contaminated by chemicals used in hospitals is considered hazardous. These chemicals include formaldehyde and phenols, which are used as disinfectants, and mercury, which is used in thermometers or equipment that measure blood pressure [Types of Solid Waste, 2001]. In the industrial sector, the major generators of hazardous waste are the metal, chemical, paper, pesticide, dye, refining, and rubber goods industries.

2.2.2 Hospital Waste

"Hospital waste is generated during the diagnosis, treatment, or immunization of human beings or animals or in research activities in these fields or in the production or testing of biologicals" [Types of Solid Waste, 2001]. It may include wastes like sharps, soiled waste, disposables, anatomical waste, cultures, discarded medicines, chemical wastes, etc. in the form of disposable syringes, swabs, bandages, body fluids, human excreta, etc. This waste is highly infectious and can be a serious threat to human health if not managed in a scientific and discriminate manner. It has been roughly estimated that of the 4 kg of waste generated in a hospital at least 1 kg would be infected [Types of Solid Waste, 2001].

2.2.3 Municipal Solid Waste (MSW)

In this thesis, the only kind of urban solid waste that will be considered is the Municipal Solid Waste (MSW), which is more commonly known as *trash* or *garbage*. White et al. (1995), define MSW as "waste collected and directed by the local municipality" [White et al., 1995]. MSW include refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals, government agencies, schools), market waste, yard waste and street sweepings [Schübeler et al., 1999]. For example, between 55 and 65 percent of the US municipal solid waste stream originates from residential waste and 35 to 45 percent is commercial waste [US-EPA, 1999].

Everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries are the examples of MSW. Semisolid wastes like sludge and night soil are generally considered MSW. However, although they may be disposed of in a landfill, they are the responsibility of liquid waste management systems [US-EPA, 1999]. Also, debris from construction and demolition constitute 'difficult' categories of waste, which also require separate management procedures [Schübeler et al., 1999].

While hazardous industrial and medical wastes are, by definition, not components of municipal solid waste, they are normally quite difficult to separate from municipal solid waste, particularly when their sources are small and scattered. "MSWM systems should therefore include special measures for preventing hazardous materials from entering the waste stream and - to the extent that this cannot be ensured - alleviating the serious consequences that arise when they do" [Schübeler et al., 1999]. Although waste from hospitals and nursing homes are required to be collected and treated separately, in cities like New Delhi, such wastes continue to form a part of MSW [TERI, 1998].

The progressively improved standards of living, rapid urbanization, and the wasteful consumer attitudes result in greatly increased quantities of municipal wastes to be handled. Figure 2.2 shows that in the US, families and non-industrial businesses created 88 million tons of municipal solid waste in 1960, 180 million tons in 1988, 209 million tons in 1994, and more than 230 million tons in 1999. In 1960, the average person produced 2.7 pounds of trash daily; in 1988, 4 pounds; in 1994, 4.4 pound, and in 1999, 4.6 pounds.

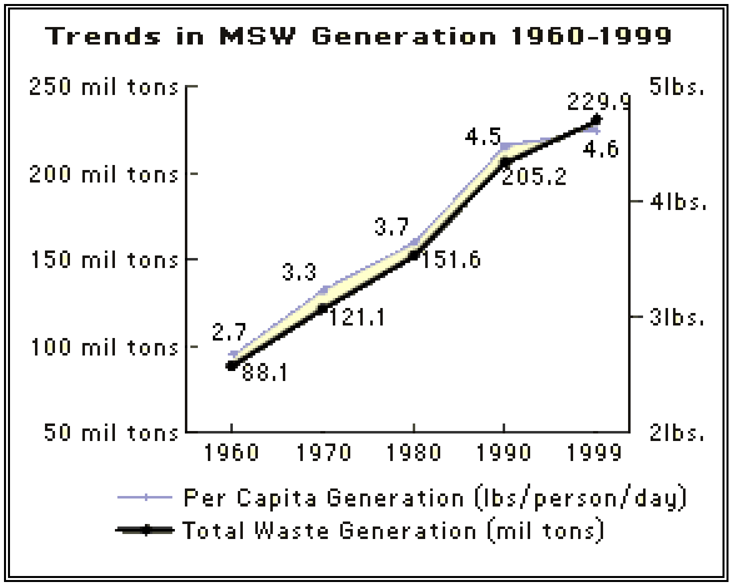


Figure 2.2 Trends in MSW Generation between 1960-1999 in the US[EPA, Municipal Solid Waste – Basic Facts- 2002]

Today, the urban areas of Asia produce about 760,000 tons of municipal solid waste (MSW) per day, or approximately 2.7 million m^3 per day. In 2025, this figure will increase to 1.8 million tons of waste per day, or 5.2 million m^3 per day. These estimates are conservative; the real values are probably more than double this amount [What a Waste- Solid Waste Management in Asia, 1999]. In Turkey, according to a study carried out by DIE (1993), the daily amount of solid waste produced is approximately 30 thousand tons .

Not only the sheer volume of what we generate has grown, but also the composition of municipal solid waste has undergone a metamorphosis presumably due to middle class consumerism. As our society changes, the contents of the garbage also change. Surveys from the early 1900s show that a city's waste typically included thousand of horse carcasses along with huge amounts of coal and wood ash, food and yard waste, street sweepings and other debris. Not surprisingly, the vast cultural and technological changes in the past century have transformed the contents of the municipal waste [Landfill Manual, 1999]. The primary components of municipal waste are now paper and paperboard products, yard trimmings, glass, metals, plastics, wood, and food wastes.

The study conducted by WHO in 1982 highlights two points [WHO, 1982]. Firstly, the quantity and proper management of municipal solid waste tends to vary from place to place and bears a rather consistent correlation with the average standard of living of the area. According to [Ladhar, 1996], a high economic status means generation of relatively high quality waste and high probability of its appropriate management and gainful re-utilization. Secondly, the composition of municipal wastes varies considerably from place to place. This variance is due to factors such as the extent of industrialization, climate patterns, cultural differences, local economic conditions, demographic patterns, and socioeconomic forces [Solid Waste Overview, 2002]. Wars, fads, inventions, economic booms, and recessions also affect what is thrown away [Rotten Truth about Garbage, 1998].

In developing countries, wastes are normally high in biodegradable matter and low in paper, metal, and glass [WHO, 1982]. In developed countries, the expected percent of paper and paperboard products, glass, metals, plastics, wood are higher. Table 2.1 provides some information to compare the solid waste compositions of developed and developing countries.

Composition (%) on dry weight basis

	DEVELOPED COUNTRIES				DEVELOPING COUNTRIES				
MATERIAL	UK 1993 (*)	UK 2000 (**)	USA 1995 (***)	North America 1999 (****)	Israel 1995 (*****)	India 1995 (******)	Nepal 1996 (*******)	Wuh Chi 1996 (********)	Turkey 1993 (*********)
Food Waste	20.2	20	6.7	6.7	45.3		38.0	16.0	
Paper & Cardboard	33.2	23	39.2	39.2	19.4	5.8	7.0	2.0	
Plastics	11.2	11	9.1	9.1	13.1	3.9	6.0		
Glass	9.3		6.2	6.2	3.0	2.2			
Metals	7.3	5	7.6	7.6	5.4	1.9	16.0		11.9
Yard Waste & Wood		22	21.4	24.4	3.0		33.0	2.0	
Disposable Diapers					5.0				
Rag/ Textiles	2.1	3				3.5		1.0	
Ash & Earth						40.3		79.0	23
Organic Materials						42.1			64.2
Others	16.7	8	9.8	6.3	5.8				

Table 2.1 Solid Waste Compositions in UK, USA, Canada, Israel, India, Nepal, Wuh Chi and Turkey

*	*Waste Watch 2001 (http://www.wasteguide.org.uk/waste/mn_overview_class.stm)*
**	*Waste Watch 2001 (http://www.wasteguide.org.uk/waste/mn_overview_class.stm*
***	*U.S environmental protection agency , 1992.Characterization of MSW in the U.S.:1992 update. EPA/530-R-92-019.*
*****	*Israel environment bulletin 1997 integrated solid waste management..Israel environment bulletin,vol. 20,no.2,p.2-6.*
******	*Survey of 23 cities on MSW EPTRI 1995 Draft Report*
*******	*http://www.ieagreen.org.uk/ch4-5.htm*
********	*http://www.ieagreen.org.uk/ch4-5.htm*
*********	*DIE, State Institude of Statistics,Turkey, Environmental Statistics, 1993*

2.3 Municipal Solid Waste Management

Before the emergence of waste management as a major environmental issue, most people's notion of solid waste management once was simply to "pick up the waste and dump it in a hole somewhere". However, recently the generation and disposal of waste has become a major concern of municipalities across the globe due to space constraints and health factors [Lant and Sherrill 1995].

Municipal solid waste management [MSWM] refers to the collection, transfer, treatment, recycling, resource recovery and disposal of solid waste in urban areas. Briefly, it can be structured into four phases: collection, transportation, processing, and disposal [Caruso et al., 1993]. It is a complex task which depends upon the selection and application of appropriate technical solutions for waste collection, transfer, recycling and disposal, as well as upon organization and cooperation between households, communities, neighborhoods, municipal authorities, local officials and decision-makers, private enterprises, regulatory authorities, environmental organizations and if there are any, recycling service providers, secondary materials processors, and end-users.

MSWM is a major responsibility of local governments, typically consuming between 20% and 50% of municipal budgets in developing countries. Local governments in Asia currently spend about US $25 billion per year on urban solid waste management. This amount is used to collect more than 90 percent of the waste in high-income countries, between 50 to 80 percent in middle-income countries, and only 30 to 60 percent in low-income countries. In 2025, Asian governments anticipate spending at least double this amount (in 1998 US dollars) on solid waste management activities [What a Waste- Solid Waste Management in Asia, 1999].

The goals of MSWM can be summarized as:

1. To protect environmental health of the urban population; particularly that of low-income groups who suffer most from poor waste management.
2. To promote the quality of the urban environment by controlling pollution [including water, air, soil and cross media pollution] and ensuring the sustainability of ecosystems in the urban region.
3. To support the efficiency and productivity of the economy by providing demanded waste management services and ensuring the efficient use and conservation of valuable materials and resources.
4. To generate employment and income in the sector itself (Schübeler et al. 1999).

To achieve the above goals and meet the needs of the entire urban population, it is necessary to establish sustainable systems of solid waste management adapted to and carried by the municipality and its local communities. For this purpose, US Environmental Protection Agency (EPA), formed a *Solid Waste Hierarchy,* by ranking the most environmentally sound strategies for MSW in 1989. EPA's integrated waste management hierarchy includes the following three components, listed in order of preference:

1. Source reduction
2. Recycling
3. Disposal, including waste combustion and landfilling.

To avoid any conflicts, it is better to explain each strategy briefly.

1.Source reduction [or waste prevention], including reuse of products and on-site, or backyard composting of yard trimmings.

Source reduction includes the design, manufacture, purchase, or use of materials, such as products and packaging, to reduce their amount or toxicity before they enter the MSW management system. It is managed at the source of generation. *Composting* decomposes organic waste, such as food scraps and yard trimmings, with microorganisms [mainly bacteria and fungi], producing a humus-like substance.

According to Antunes (1999), the most efficient actions to reduce waste quantity and separate waste components for subsequent recovery and recycling operations are taken in the generation stage because afterwards there will always be a considerable amount of waste to collect and dispose of. The manufacturers, for example, are making products lighter, using fewer materials, and packaging them more efficiently in order to reduce the amount of waste. Compare, for example, the household goods and appliances made of pounds of steel and metals three decades ago with the smaller and lighter goods made of plastics. The amount of packaging used has also decreased. Bulky cardboard boxes used only a few years ago for compact disc, designed to discourage theft have now been replaced by magnetized strip that serves that same purpose. Technology, and particularly, "green design", is reducing the amount of materials that have to be disposed [Environmental Literacy Council, Municipal Solid Waste –2002]. On the other hand, Delong (1994) explains that source reduction can be harmful because it diverts attention from the positive benefits of packaging. Reduced packaging can increase spoilage waste, for example, and mandatory source reduction prevents consumers from making choices about preferred characteristics.

In 1999, U.S. prevented more than *50 million tons* of municipal solid waste from entering the waste stream [USEPA, 1999]. Additionally, some states have enacted laws mandating reductions in volume of waste entering landfills, and prohibiting certain kinds of materials. In North Carolina, for example, the state has established a goal of %40 waste reductions to be met by the counties by the year 2001, and the state law now bans materials such as yard trimmings, aluminum cans, and motor oil from landfills [Renkow, 1994]. Several European countries including France, Italy and West Germany have a standard of living comparable to the United States but generate only half as much waste. The lower waste generation rates in these other countries can be attributed to the use of fewer disposable products and fewer packages, more reliance on refillable containers and higher recycling rates [Solid Waste Overview, 2002].

2. Recycling, including off-site or community composting.

Recycling diverts items, such as paper, glass, plastic, and metals, from the waste stream. These materials are sorted, collected, and processed and then manufactured, sold, and bought as new products. In many countries recycling is necessary due to limited natural resources and the lack of space necessary to landfill waste and high cost of making landfills environmentally safe and limiting their impact on groundwater and other resources [Solid Waste Overview, 2002].

The first nationwide recycling initiative is started by The US Congress in 1970 by passing the Resource Recovery Act. Federal Agencies then started to recycle high-grade white paper and newsprint with the slogan, “Use it again Sam” [EPA, Guide to Environmental Issues, 1998]. EPA considers solid waste a true “resource ” when properly managed by both the household and the local authority responsible for it. According to EPA nearly one-half of a household’s waste is potentially recyclable [EPA, Municipal Solid Waste – Basic Facts- 2002]. In 1996, Germany recycled or composted 48% of municipal waste [Waste Incineration, 2002]. The same year US recycled 22%, and composted 5.7% of municipal waste [EPA, 1999].

On the other hand, some researchers also mention about the negative aspects of recycling. For example, Delong (1994) points out that EPA tends to equate possibility with practicality. He argues that much recycling makes no economic sense because the effort uses up resources-capital, energy, and labor that are worth more than the value of the recycled product. According to Delong, recycling is itself a manufacturing process and it uses resources of energy, capital and labor and produces waste. Secondly, some of the recycled materials may lose their desirable characteristics while being used over and over again and eventually must be discarded. Thirdly, right now it's often easier or cheaper for manufacturers to use virgin materials rather than recycled materials to manufacture things [Rotten Truth about Garbage, 1998]. So we’d better accept that recycling wouldn’t solve all our garbage problems; the best option is to reduce our consumption instead.

4. *Disposal*, including waste combustion (preferably with energy recovery) and *landfilling*. “The management process will not be adequate unless the final destination of waste is a sanitary landfill, built and operated according to the applicable rules” [Antunes, 1999]. “*Landfill* is a carefully designed structure built into or on top of the ground in which garbage is isolated from the surrounding environment (groundwater, air, rain) by a bottom liner and daily covering of soil” [How Landfills Work, What is a landfill, 2002]. Most people’s idea of a landfill is an

open hole in the ground where garbage is buried with various animals like rats, mice and birds swarming around, but in fact that is called a *dump*. Mathewson (1987) calls a landfill a controlled dump.

The purpose of a landfill is to bury the garbage in such a way that it will be isolated from the groundwater, will be kept dry and will not be in contact with air. In the modern landfills of today landfill wastes are systematically divided into smaller units called "cells". By isolating small working sections of the facility, cell structures minimize waste exposure to weather elements. Only one cell is open at a time and it is covered nightly to help reduce odor and vermin problems as well [Environmental Literacy Council-Landfills, 2002].

Under the condition that the waste is isolated from the surrounding environment, garbage does not decompose much. A landfill is not like a compost pile, where the purpose is to bury the garbage in such a way that it will decompose quickly. When old landfills have been excavated or sampled, 40-year-old newspapers have been found with easily readable print [How Landfills Work, What happens to trash at the landfill, 2002].

Combustion or Incineration is another MSW practice that helps reduce the amount of landfill space needed. "Combustion facilities burn MSW at a high temperature, reducing waste volume and generating electricity" [EPA, Guide to Environmental Issues- 1998]. According to Antunes (1999), to reduce storage space, incineration is the most effective operation since it reduces the waste to 25% of its initial volume. From the viewpoint of large reduction in volume of the waste stream, incineration of waste may appear to be an appealing option. However, incineration carries a high price tag, primarily because of the need for air pollution devices and the disposal of ash, which is typically about 30% of the original mass of the waste, and is usually a hazardous waste requiring special landfill requirements [Evaluation of needs and alternatives for landfills, *1998*]. "The high set up costs of incinerators compared to landfills is not compensated by smaller operating costs even after deducting the possible benefits arising from steam and energy production" [Antunes, 1999]. The high price tag can be justified in wealthier regions of the world where there are very high population densities; there is little available land, and significant government subsidies. Such has been the situation in Europe, Japan, and in certain regions of the US [Evaluation of needs and alternatives for landfills, *1998*]. Japan spends about ten times more for waste disposal than collection costs (mostly incineration costs) [What a Waste- Solid Waste Management in Asia, 1999]. Also incineration, if not properly managed, has the potential to cause environmental damage. It produces gases that can contain dioxins, heavy metals, sulfur oxides, and nitrogen oxides, some of which aren't covered by current air quality standards. Therefore, incineration should be considered as an option for disposal of special wastes, such as medical wastes, but not for the general waste stream. Citizens are often reluctant to accept an incinerator in their own community because of concerns about safety, cost, odors, and the conflict between recycling programs and incineration.

Figure 2.3. An Incinerator

Photo courtesy of the U.S. Environmental Protection Agency

Landfilling is the most widely used waste management option, even though waste reduction, recycling and incineration are now widely initiated to divert waste streams from landfills [Kao et al. 1997]. In the US the majority of municipal waste ends up in landfills: 57 percent, or 127 million tons, was landfilled in 1999 alone [Solid Waste Overview, 2002]. Since 1980s recycling and composing rates have risen consistently: 28 percent, or 49 million tons of municipal solid waste in now recovered annually. Recovery rates have grown significantly in the past five or six years: since 1990, the recovery rate has increased by 7 percent. The remaining 15 percent of municipal waste is incinerated [Landfill Manual, Chapter One- 1999]. Again in the UK the landfilling is the mostly used waste management option. The percentages of total waste landfilled, recycled and incinerated in the UK and US is given in Table 2.2.

	ENGLAND (2000) *		USA (1999) **	
Method	**Thousand Tons**	**Percentage of total**	**Million Tons**	**Percentage of total**
Landfill	22.055	78.30%	139.59	61.00%
Recycled/ Composted	3.454	12.30%	50.8	24%
Incineration with EfW	2.479	8.80%	30.2	14%
Incineration without EfW	20	0.10%	2.2	1%
RDF Manufacture	67	0.20%		
Other	75	0.30%		
Total	28.150		229.9	

Table 2.2 Amounts and percentages of waste landfilled, recycled and incinerated in the UK and US

EfW – Energy from waste, RDF- refused derived fuel

* *Municipal waste management statistics 2000/01, DEFRA*
** *Franklin Associates*

Figure 2.4 shows the pattern of waste management practices in a number of European countries.

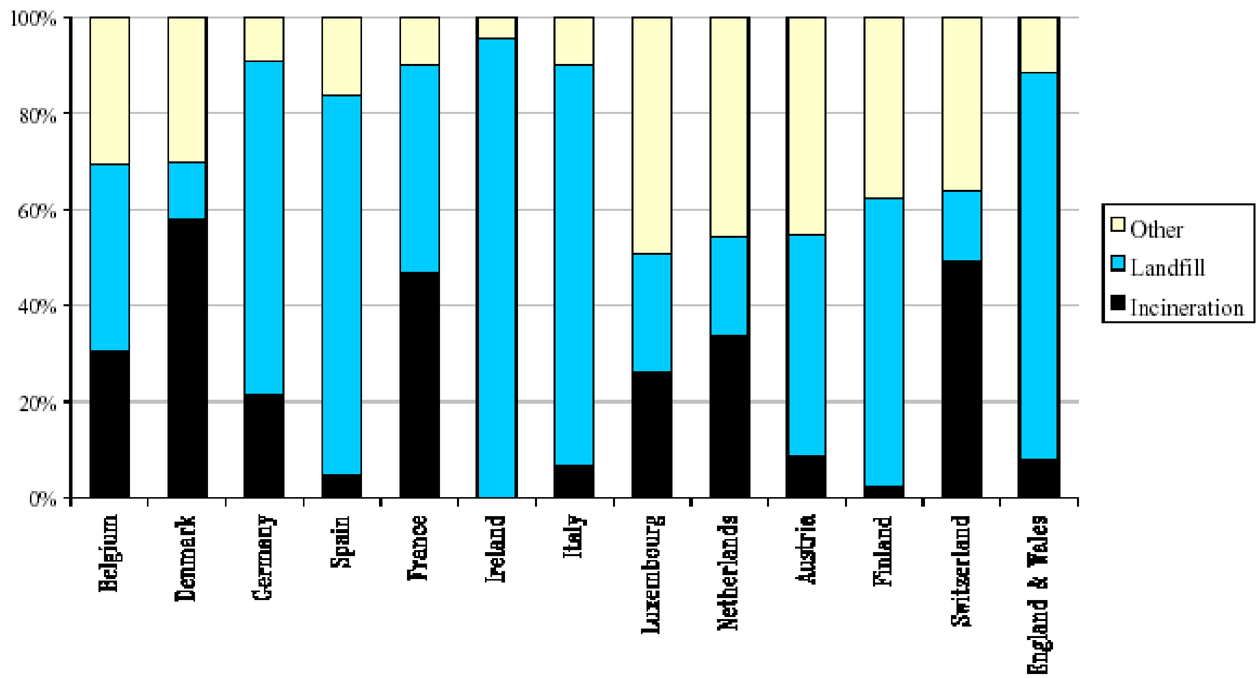


Figure 2 .4 Treatment and disposal of municipal waste, by method in Western Europe
Note: 1996 data except Germany (1993), Finland and Switzerland (1994) France and Ireland (1995) and England & Wales (1999/00)
Source: Waste Generated in Europe 1985-1997, Eurostat (2000)

The European Commission publishes an annual report on waste generated in Europe. The 2000 edition states the following on the issue of waste treatment and disposal: "The best accepted method to achieve management of waste is waste prevention followed by - and in the following hierarchical order - treatment methods such as recycling, composting or incineration (preferably combined with energy recovery), and landfill. Despite the recommendations mentioned, municipal waste treatment in most countries continues to be dominated by landfill, which is in many cases the cheapest option. Nevertheless, incineration is a method which is increasingly used" [Euro stat, 2000].

The main findings are that Denmark, Switzerland and the region of Brussels incinerate significant quantities of municipal waste (40-60%) and that incineration plants with energy recovery are gradually increasing in Western Europe. Countries that dispose of a significant proportion of their waste by recycling also tend to have higher incineration rates. This is probably a combination of two factors: the reduced availability of suitable landfill sites and the implementation of the waste hierarchy which defines reduction, reuse and recycling of waste as the preferred option and landfill as the least desirable form of waste disposal. Incineration with energy recovery is seen as preferable to landfill within this framework.

	DISPOSAL METHOD (%)			
Country / Territory	**Land Disposal**	**Incineration**	**Composting**	**Others**
Bangladesh	95	-	-	5
Brunei Darussalam	90	-	-	10
Hong Kong	92	8	-	-
India	70	-	20	10
Indonesia	80	5	10	5
Japan	22	74	0.1	3.9
Rep. of Korea	90	-	-	10
Malaysia	70	5	10	15
Philippines	85	-	10	5
Singapore	35	65	-	-
Sri Lanka	90	-	-	10
Thailand	80	5	10	5

Table 2.3 Disposal Methods for Municipal Solid Waste in Selected Countries/Territories of Asia
Source: Asia Development Bank, 1995

United States Environmental Protection Agency (EPA) predictions indicate an upward trend in waste generation. Agency estimates that increased diversion of yard trimmings from landfills to composting facilities decreased the amount of material deposited in landfills by the year 2000. However, projections for the year 2010 show that increases in discarded paper and paper products will exceed the amount of removed composting and result in a net increase in the amount of waste that ends up in landfills each year [Landfill Manual, Chapter One- 1999].

The truth is that garbage will not disappear, when we throw out garbage, put it on the street, take it to the dump, we can never really make garbage disappear. When we throw garbage "away," it just goes somewhere else. We bury most of our garbage in landfills where it may stay forever. We burn some trash, but burning can pollute the air if not properly controlled, and it still leaves ash to bury. We can recycle many things, but even these processes require energy, and create waste and pollution. There is no way to get rid of *all* our garbage. The best solution is to make less, then, find the most appropriate way to manage what's left, by reusing, recycling, burning, or landfilling.

“Due to potential for environmental damage form landfill sites, the scarcity of land near urban centers and growing public opposition, there is a trend towards creating integrated MSW management systems, which rely on a combination of waste management approaches to minimize the dependence on landfills” [Barlishen, 1996]. The truth is no one approach will take care of all the waste generated. For example, almost every community in the US has some type of recycling program and encourages citizens to practice the “3 Rs” (reduce, reuse, and then recycle) to minimize the amount of waste generated. Many communities have started collecting and composting yard clippings rather than putting them in landfills. Incinerators are used in many communities both to reduce the amount of waste in landfills and to generate energy [Environmental Literacy Council, Municipal Solid Waste, 2002].

There is no one method or a combination of methods that happen to be the optimal for all the regions in the world. In reality, before composting, recycling, or waste-to-energy systems can be considered, scientists must analyze the waste stream of the region in detail. First, investigators must calculate how much of the waste from many different samples falls into basic categories, such as glass, plastics, metals, paper, and food waste. They can then predict the volume of recyclable material, the amount of the biodegradable waste and the *BTU* (British thermal unit) value of the garbage which is the energy unit that represents the amount of heat needed to increase the temperature of a pound of water 1*Fahrenheit [Garbage, 2002]. The appropriate disposal method can then be chosen accordingly. Sudhir et al, (1996) mention that among the various technologies available for waste processing, only composting is found suitable in Indian context due to high organic and moisture content in the waste. Incineration is not suitable because of low calorific value of the waste.

The study prepared by United Nations and The World Bank mentions another important aspect of MSWM. The point is that the functioning of MSWM systems and the impact of related development activities depend on their adaptation to particular characteristics of the political, social, economic and environmental context of the respective city and country [Schübeler et al. 1999]. According to a study by Patrick (1984) on waste management planning in developing countries, the technology transfer in these countries should be made within the economic and technical abilities of the country concerned, even if they do not measure up to hygienic and environmental standards expected in developed countries. The study by the World Bank further elaborates that to achieve sustainable and effective waste management, development strategies must go beyond purely technical considerations to formulate specific objectives and implement appropriate measures with regard to political, institutional, social, financial, economic and technical aspects of MSWM.

Political aspects concern the formulation of goals and priorities, determination of roles and jurisdiction, and the legal and regulatory framework. Institutional aspects concern the distribution of functions and responsibilities and correspond to organizational structures, procedures, methods, institutional capacities and private sector involvement. Social aspects of MSWM include the patterns of waste generation and handling of households and other users, community-based waste management and the social conditions of waste workers. Financial aspects of MSWM concern budgeting and cost accounting, capital investment, cost recovery and cost reduction. According to a recognized solid waste expert White (1995), “a balance has to be achieved between economic considerations and environmental responsibilities to reduce the environmental impacts of waste management system as far as possible within acceptable level of cost. A trade-off is normally required between the objectives of low-cost collection service and environmental protection"[White et al.1995].

Within the overall framework of urban management, the scope of MSWM encompasses the following functions and concerns:

1. Planning and Management
   - Strategic planning
   - Legal and regulatory framework
   - Public participation
   - Financial management [cost recovery, budgeting, accounting, etc.]
   - Institutional arrangements [including private sector participation]
   - **Disposal facility siting**
2. Waste Generation
   - Waste characterization [source, rates, composition, etc.]
   - Waste minimization and source separation
3. Waste Handling
   - Waste collection
   - Waste transfer, treatment and disposal
   - Special wastes [medical, small industries, etc.]

One primary concern of this thesis is MSW landfill siting. The next section review the issues related to the issues in solid waste disposal to give the reader insights about the challenging waste management problem.

2.4 Issues in Solid Waste Disposal:

Finding and implementing appropriate waste disposal programs is an issue faced by communities all over the world. Communities seek environmentally sound, socially acceptable, and politically feasible means of disposing of solid waste. "Solid waste management today is made difficult and costly by increasing volumes of waste produced; by the need to control potential serious environmental and health effects of disposal, by the lack of land in urban areas partly due to public opposition to proposed sites" [Gottinger, 1988]. In addition, new disposal options bring about additional facilities to be considered: energy-from-waste facilities, centralized composting facilities, materials recovery facilities and mixed MSW processing facilities [which separate out and process a mixed MSW stream]. "The increasing number of options makes it more challenging for a waste management engineer or planner to decide on the combination of collection, processing systems that will best serve the present and future needs of a particular community" [Barlishen, 1996]. ReVelle (2000) also points out the fact that solid waste management problems are among the class of challenging environmental problems.

A difficult solid waste management practice is the siting of the waste disposal facilities since various facilities in the system- e.g. Landfills and incinerators- have special requirements such that not all undeveloped areas are suitable for use by these facilities. For example, incinerators are noisy and have unpleasant neighborhoods so that open land in industrial areas as opposed to residential areas is most suitable. Landfills require large tracts of areas that are relatively distant from residences because of the noise and the traffic these facilities generate [ReVelle, 2000].

In addition, the waste disposal plants are considered as *obnoxious* facilities. The introduction of the concept of noxious/obnoxious facilities dates back to 1975 (Goldman and Dearing, 1975). A noxious facility is one that poses threat to health and welfare whereas an obnoxious facility is one that poses a threat to lifestyles and enjoyment to amenities [Erkut and Neuman, 1989]. Despite their obvious differences, both are today referred to as *undesirable facilities*. These facilities are necessary for the society but they somehow provide a disservice to the individuals who live near them by lowering the quality of life through pollution, noise, odor, lowering the property values, and increasing the traffic.

Together with these, some trends created new challenges to find environmentally, politically, and socially acceptable places to build waste disposal facilities [Landfill Manual, Chapter One- 1999]. Factors that affect the level of difficulty of the siting problem are as follows.

Firstly, the growing population, increasing rate of waste generation caused by a well established “consume and throwaway” attitude, and limited land resources decrease the lifetime of the landfills, reduce the land suitable for dumping garbage, and make fewer potential sites available. The spread of suburban development leaves a few large parcels of land available that are far from residential development, yet close to urban waste generating centers [Solid Waste Overview, 2002]. As the number of the undesirable facilities increase in number, the issues surrounding the facilities become more important with the public [Erkut and Neuman, 1989].

Secondly, the increasing environmental awareness of communities results in negative public attitudes. Potential neighbors who don't want a landfill in their backyard are rejecting proposed landfill sites. This is referred to as the "Not in My Back Yard" syndrome or "NIMBY". A local siting decision even becomes a controversial issue receiving national attention because of strong local opposition. Such a disputed situation typically derives from either an inappropriate or incomplete siting analysis or the public’s misunderstanding of the siting procedure [Kao et al. 1997]. Moreover, the perceived nuisance caused by a nearby dumpsite is, in many cases, significantly higher than the actual nuisance [Erkut & Neuman, 1989]. The Portland Metro area experienced this very reaction in the 1980s when no acceptable local site could be identified for a regional landfill. As a result, the Portland Metro area is served by the Columbia Ridge Landfill located approximately 140 miles east of Portland in Arlington, Oregon [Solid Waste Overview, 2002].

Another social issue is to achieve environmental justice within all the communities. Environmental justice is achieved when everyone, regardless of race, culture, or income, enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work [EPA, Environmental Justice, 2002]. An example case is the environmental justice suit in Pennsylvania. Residents opposed siting of waste facilities in a minority neighborhood. Charging environmental injustice, the residents sued Pennsylvania’s Department of Environmental Protection, claiming that the state regulators had violated civil rights by permitting a facility in a predominantly African-American community. The court threw the case when the Pennsylvania officials opted not to extend the waste permit after all [Scarlett, 2000].

Communities have reasons to be concerned over the siting of landfills near residential areas. Erkut and Neuman (1989) explain that the economic prosperity of a society can be considered a necessary condition for being concerned about environmental issues and unpleasant effects of the landfills. The vast majority of the existing landfills have no liners, no leachate collection systems, and no groundwater monitoring systems. Leachate forms when liquid originating from rain, melted snow, or waste itself percolates through landfill cells and moves to the bottom or sides of a landfill [Landfill Manual, Chapter Three, 1999]. It can contain a variety of substances depending upon the contents of the waste, including metals, organic compounds, suspended particles, and bacteria. If toxic wastes are deposited in the landfill, the leachate can contain toxic chemicals that are hazardous even at low levels. Flowing through the waste, leachate transports a wide variety of chemicals to the extremities of a landfill [Landfill Manual, Chapter Three, 1999]. In 1977, an EPA (U.S. Environmental Protection Agency) contractor estimated that 90 billion gallons per year of leachate was entering U.S. groundwater from municipal landfills [Miller, 1980].

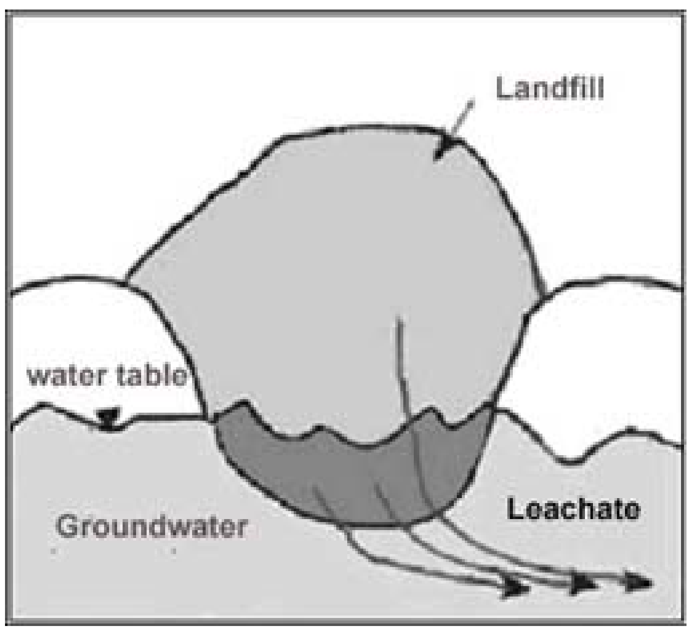


Figure 2.5. Groundwater that rises into the bottom of a landfill contributes to leachate production [Landfill Manual, Chapter Three, 1999].

These municipal landfills constitute a hazardous nature [Rachel's Environmental & Health Weekly- 1991]. The U.S. Environmental Protection Agency (EPA) has identified many landfills as "Superfund" sites requiring special attention due to their toxic nature [Solid Waste Overview – 2002]. Landfills also produce methane gas as a result of organic materials decomposing in the absence of oxygen. Methane gas is explosive in high concentrations and may migrate into neighboring homes if not vented.

In most cities of Asia and Turkey, waste disposal sites are just open dumping grounds, nowhere close to a sanitary landfill. No measures are taken to prevent pollution of underground and surface waters; the waste is not covered. The organic refuse attracts scavengers, such as rats and gulls, and produces an unpleasant smell. Unsightly blowing paper, dust, noise, and concentrations of birds and insects all contribute to the obnoxious nature of the landfills.

Because of these and other problems, environmental regulating bodies like the U.S. EPA has adopted standards for the siting, operation and closing of landfills. Some of these standards require that new and existing landfills install impermeable liners below the burial areas to collect leachate for treatment, that methane gas be vented or utilized, and that systems be established to monitor potential surface and groundwater contamination.

Specifically, the underlying rock or soil unit and its permeability, structure, and attitude as well as the surrounding cover material decide the technical viability of a site [Siting a landfill in South Missouri, 1997]. Desirable characteristics of a sanitary landfill site include a topographic surface that tends to shed water [because ponded water filtrates to become groundwater], a natural water table at some depth below the base of waste disposal cells, presence of adequate quantities of a low-permeability substance (to provide daily cover material and to seal cells once they are filled), absence of permeable, water-bearing rock or sediment beneath the site, and absence of shallow water wells in the vicinity of the site. In the absence of these natural characteristics, it is possible to engineer an environmentally safe confinement of waste in landfill through the construction of liners [Erkut and Moran, 1991]. State-of-the-art technology makes it possible for all new sites to be environmentally safe and people friendly.

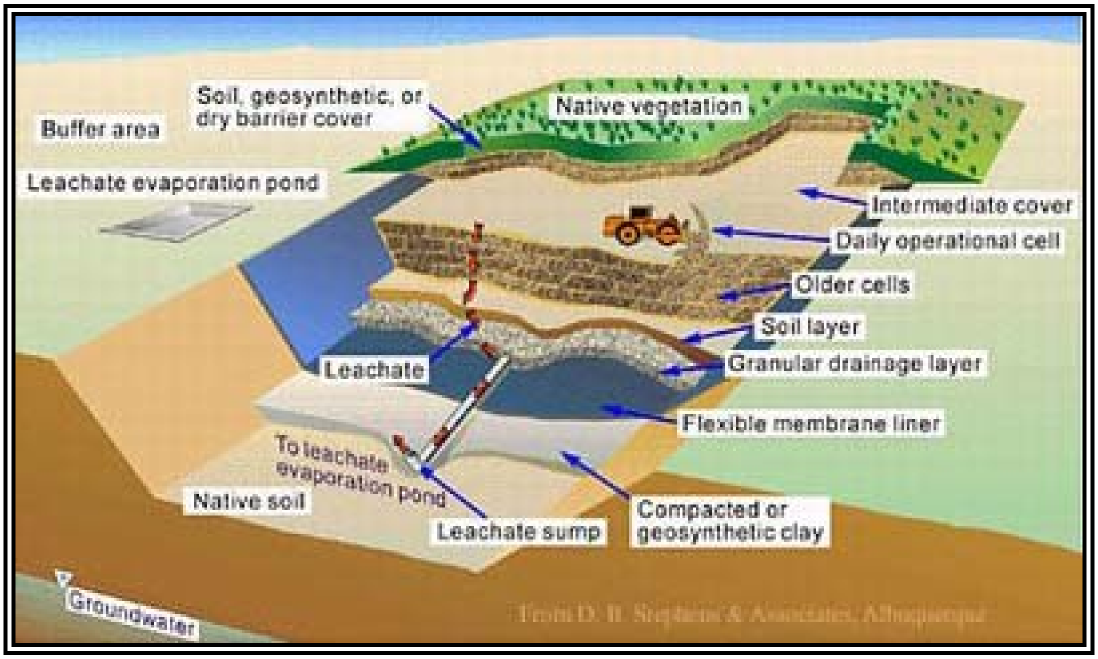


Figure 2.6 The cross-section of an ideal landfill (Solid Waste Management, 1999)

The EPA standards require new MSW landfills to be designed with a bottom liner of plastic [thus forming a plastic bathtub in the ground], a leachate collection system [a set of pipes in the bottom of the bathtub], and when the landfill is full of garbage, a plastic "cap" over the top to prevent the formation of leachate. Enclosing the garbage completely in a plastic baggie in the ground delays the introduction of the leachate into the environment but it will not prevent it because eventually the baggie will deteriorate due to natural processes or human errors [USEPA, 1988]. Therefore, contamination from the landfills cannot be prevented by regulations that deal with only the design and operation of the landfills while ignoring what goes into them.

While these increasingly strict guidelines on design and operation offer more safeguards, they also have resulted in landfill closings. The new landfills are very expensive to built and operate, the tipping fees (fee for unloading or dumping waste at a landfill) are very high. However, with the difficulty and cost of constructing new facilities, some landfills have continued to accept waste after their expected closure date. Due to the increased tipping fees, garbage has become a part of the interstate commerce in the US and a number of states routinely ship their garbage to out-of-state facilities where disposal costs are low [Landfill Manual, Chapter One- 1999].

Landfills are no longer an easy, inexpensive solution to our solid waste disposal needs. Also the cost of building other waste disposal facilities such as waste-to-energy plants, and MSW composting operations is now very large -- usually in the millions of dollars for facilities capable of handling moderate amounts of waste daily. For that reason, the OECD countries activated various legislative initiatives and procedures to involve regional, state, and federal authorities in waste management other than the local or the private sector [OECD]. “The two primary reasons to have solid waste management on a regional basis instead of on the level of local towns and cities which is the current practice, are not only economics but also technical feasibility” [Gottinger, 1987]. Kemper and Quigley have demonstrated the declining average costs in various case studies [Kemper and Quigley, 1976]. Also, the small local governments cannot operate the incineration, composting, recycling facilities, which require advanced technologies [Gottinger, 1987]. On the other hand, although regional management has distinct advantages, there are many political problems associated with it.

Typically, communities constructing a new disposal facility usually issue bonds to cover the high initial capital expenses. The major portion of the annual waste management budgets is the debt on capital. For example, the cost of building a composting facility capable of handling 150 tons of trash per day is about $10 million. $1 million per year is the amount of annual principle and interest payments that constitute about 10% of the project costs with ordinary rates of interest and payoff methods. If the facility operates at a full capacity six days per week, the fixed cost amounts to over $20 per tone. These fixed costs must be paid regardless of the amount of waste handled. This amount is close to the average tipping fee charged at landfills in the US [Renkow, 1994].

However, there is an important difference between landfills and other disposal technologies when the impact of these fixed costs are of concern. MSW composting plants and waste-to-energy plants are constructed to process a specific amount of waste per day. When a failure happens in fully utilizing available capacity, higher average costs are incurred because fixed costs are divided by a smaller number of tons of waste. The existence of one of these facilities may act as a deterrent for communities to recycle or reduce the amount of waste entering the local waste stream when waste reduction leads to under-utilization [Renkow, 1994].

For landfills, there is not the same kind of incentive to generate waste in order to cover fixed costs. Because the actions that reduce the amount of waste entering a landfill effectively postpones the costs of filling up the unit of space that is available today.

As a result, properly designed and operated landfilling appears to be more compatible than alternative disposal technologies economically and environmentally, and is a better option when implemented with community efforts to promote waste diversion through recycling or source reduction.

Chapter 3

MSW Landfill Siting

3.1 Introduction

A well-sited, carefully designed landfill is integral to most solid waste management programs, because the most cost effective and environmentally acceptable means of solid waste disposal is the modern landfills that are properly designed and operated when land availability is not an issue. Therefore, worldwide, the use of landfills is the primary means of waste disposal in solid waste management [Evaluation of needs and alternatives for landfills - 1998]. In the second chapter, Table 2.2, Table 2.3 and, Figure 2.4 supply relevant information about the high percentages of waste landfilled in European, Asian countries, as well as the UK and US.

Americans are producing 1637, Britains 737, Germans 823,and Turks 650 pounds of waste per year, indicating that the disposal of garbage is likely to remain a significant problem for planners [Solid Waste Overview, 2002; DIE, 1993]. The major concern about a landfill is its location because it is the primary determinant of the extent to which the landfill will pose an environmental threat [South Australia EPA, 1988].

Kao et al. (1997) explains that the growing population, urbanization and limited land resources have not only decreased the lifetime of the landfills, but also aggravated the difficulty of finding new landfills. Moreover, “decisions regarding the location of undesirable public facilities, which are obnoxious to their potential neighbor, have several unique characteristics relative to other location decisions” [Erkut and Moran, 1991]. Firstly, landfill site location decisions are extremely political and high level decisions that involve a lot of perception. Typically, during the siting process, the political and social aspects of the problem are at least as important as the economical aspects of the problem. Given the disutility associated with undesirable facilities, it is not surprising that the public, and hence the politicians, are taking a closer look at the issues surrounding these facilities [Erkut and Neuman, 1989]. Secondly, in these types of problems, there is generally a large number of somewhat powerful stakeholders, as well as a relatively large number of decision makers (DMs) with various objectives. The stakeholders include the public, the operators of the landfills, environmental organizations, residents affected by the landfills, whereas the DMs include the regulatory bodies like the municipalities or consulting agencies. By DMs, we refer to the people who do the actual siting of the landfills. DMs are generally municipalities in Turkey, whereas in the US, a governmental regulatory body, EPA (Environmental Protection Agency), is responsible for the decisions. The consultants may also act as DMs or aid in the decision process.

3.2 Objectives in Locating MSW Disposal Facilities

The search for sites to locate MSW disposal facilities are considered to fall in the realm of *obnoxious* facility location problems. Today, both noxious and obnoxious facilities are referred to as undesirable facilities. Erkut and Neuman (1989) give an extensive review of the approaches in locating undesirable facilities. The survey focuses on the maximization type location models in the operations research literature. In the case of an obnoxious facility location, the undesirability of the site might have a higher priority than the transportation cost to and from the facility. Therefore, the facilities should be built sufficiently distant from the population centers, near the outskirts of the city in order to pose minimum risk. The isolation of the facility from the residents brings out the social acceptability, which is one of the most important factors in siting of the disposal facility for the DMs. Erkut and Neuman (1989) explain that this is especially true when the facility is owned and operated by a public entity, such as a municipality, where political imperatives are of paramount importance for the majority of the DMs.

When we use a single maximization objective, such as maximizing the average or minimum distance between the waste generation points and the facilities, the transportation costs become more significant as the site moves away from the generation points. As a very large amount waste will be disposed of in the facilities, it will be very costly to convey the waste to a somewhat remote landfill. This is not a wise decision for the public, as they will have to pay for the high transport costs by tax or by some other means. Moreover, when the landfills are located too far away from the urban areas, there comes a need to build solid waste transfer stations (SWTS), where solid waste is transferred from smaller collection vehicles to larger, long haul trucks or trains [Rahman and Kuby, 1995]. The building of the transfer stations is also costly.

MSW disposal facility siting problem is in fact *not* purely obnoxious. The objectives of the stakeholders in the system show variation. The municipalities want to minimize their transportation costs, the operators of the landfills want to minimize their operating costs, those who are affected want to minimize the damage to the environment and their quality of life, and the regulatory bodies want to make sure that the rules and the regulations are obeyed.

Antunes (1999) mentions the multi objective nature of the landfill siting models. One would like to locate sanitary landfills as far from the urban centers as possible to reduce the disturbance from the effects of the landfills; using a maximum distance objective can satisfy that. However, as they will have to eventually pay for the high transportation costs, they cannot be too far from the disposal facilities. Simultaneously, the municipalities want to be as close to the generators of MSW as possible; using a minimum cost objective is necessary to satisfy these two cases.

Using a single maximum distance objective is politically difficult to sustain because it leads to a concentration of sanitary landfills in municipalities with small populations that produce very little waste. Nearby municipalities are often reluctant to struggle with the waste problem of an entire city. Besides, as Antunes (1999) further explains, proximity to MSW does not threaten people's health, as does proximity to hazardous solid waste. This is an important point, since it may decrease the importance of the maximization objective.

In fact, the role of the maximization objective in the siting problem is to overcome the NIMBY syndrome. However, it is possible to reduce the influences of the syndrome by following a correct process to arrive at and implement the sites. According to Sudhir et al. (1996), NIMBY arises due to lack of consensus between waste managers and residents, over the nature of the risk involved. Discussing NIMBY, Petts (1994) observes that in order to deal with such issues, it is essential to move away from a reactive approach to an interactive one by involving all interested parties in decision making. Behind –the-scenes decision making, called the "decide-announce-defend (DAD)" model, is likely to be unacceptable today. The public must be given an opportunity to participate in every phase of the siting process [EPA, 1995]. The readers can refer to Kleindorfer and Kunreuther (1994) for further reading on the process of siting. Also, Noble (1992) explains, one objective that has a significant impact on the process is "*a real need to site".* A real need to site means that a "zero opposition " is not realistic and an " objective dimension of reality" has an important role to play in conflict resolution. Therefore, DMs should consider the NIMBY syndrome as a part of the siting process, recognize and address the concerns of the communities. According to Noble (1992), another option to overcome the NIMBYism is to modify the design of the landfill to meet to the demands of the region. The design of the facilities can be extremely flexible. The ability to modify the design of the landfills shows that it is possible to built environmental friendly landfills, which give little harm to the environment and the residents. That NIMBY can be overcome may be the second point which decreases the importance of the maximization objective.

3.3 MSW Landfill Siting Procedures

A good landfill should have a minimum impact on environment, society and economy, comply with regulations, and be accepted by the public [Zyma, 1990].

According to Allanach (1992), finding such a site is a difficult, complex, tedious, and a protracted process.

In this section, the related procedures are reviewed. At this, it is better to identity two groups of people who approach the landfill-siting problem in somewhat different ways:

1. Researchers who do academic research on the siting of the landfills
2. Decision Makers (DMs) who do the actual siting of the facilities.

The next sub section, 3.3.1, is a summary of the methods and models that have been proposed by researchers. The actual decision making process of DMs and their methodologies will be explained in detail in the sub section 3.3.2.

3.3.1 Approaches Described by Researchers in the Literature

In this section, a review of quantitative models used in the literature to determine the locations of the MSW landfills and transfer stations (SWTS) is presented. In fact, the literature review also contains information about the siting of the other disposal facilities like the incinerators or the composting facilities to give the reader a detailed view of the research that has been made so far.

Since the 1970s, a number of mathematical models have been developed to address various issues relating to the siting of the solid waste disposal facilities. Some early attempts incorporate only the objective of cost minimization and ignore other objectives involved in the siting process. There are also more comprehensive multi-objective models that include some of the objectives of the stakeholders. The more objectives are introduced, the more difficult the problems become as the multi-objective models are integer programming models that are difficult to solve when model complexity and size increase.

Marks and Liebman (1970) first utilize the concept of locating cost-minimizing solid waste transfer stations and formulate a capacitated transshipment facility location problem for refuse collection. They suggest a mixed integer model in which the transfer stations have a fixed cost and a linear processing cost and wastes from the sources may be routed, through transfer stations or directly, to landfills. The objective function seeks a minimum cost trade-off between the sum of fixed and operating costs of transfer stations and the savings obtained in the transportation costs by having transfer stations. Rossman (1971) extends the work of Marks and Liebman (1970) by adding incinerators to the set of potential facilities. A comprehensive review of mathematical models used in solid waste management can be found in Liebman (1975).

Helms and Clark (1971) present a mathematical model with linear constraints and a nonlinear objective function with fixed costs and transportation costs. The model aids in selecting among various alternative systems for waste management. Incinerators and landfills are considered as potential facilities for the system and it is assumed that the facilities have a fixed cost and a linear processing cost.

Harvey and O'Flaherty (1972) develop a model which determines the optimal locations of the landfill sites as well as the locations of the transfer stations. They implement their model on a fourteen-district problem where there are five alternative sites for the transfer stations and three possible landfill sites.

Greenberg et al. (1976) apply linear programming techniques to an actual waste management systems planning study in New Jersey. Jenkins (1982) utilizes mixed integer linear programming techniques in a planning study for Toronto. A multi period approach is suggested to determine the best location of facilities for reclamation and disposal of municipal solid waste.

Chapman and Yakowitz (1984) describe a model that uses linear programming techniques to size and site facilities and a cost accounting system to incorporate economies of scale as well as estimate the effects of the decisions.

Perlack and Willis (1985) develop a nonlinear multi-objective programming model of the Boston sludge disposal problem. The model includes the objectives of maximum net economic benefit, minimum environmental impact and minimum variability of impacts. In order to solve for non-inferior solutions a generating technique is used. To reduce redundancy among the solutions and to aid the

DMs in the choice process, cluster analysis is applied to the generated noninferior solutions expressed in the decision space.

Kırca and Erkip (1988) utilize a cost-minimization approach with four stages to determine the number of transfer stations needed and their locations. They use a classical capacitated warehouse model, which identifies the trade-off between costs of carrying the waste by different transportation modes. The main motivation for having multiple stages is to allow the DMs participate in the decision process. The multi stage decision process also helps in building up a reliable and validated database that can be used in the model.

Gottinger (1987) expends the scope of the solid waste management problem to consider other issues such as resource recovery plants, capacity expansion strategies, and flow allocation in each year of a planning period. In another article, Gottinger (1988) describes a model for regional solid waste management as a network flow problem and develops a special purpose algorithm. The model minimizes a single objective function of total costs of transportation, processing, and construction. The model is applied to waste management and facility siting decisions in the Munich Metropolitan Area in Germany. Examples of other research that concern the regional planning of the municipal solid waste system are Kuhner and Heiler (1974) and Hasit and Werner (1981). Hasit and Werner (1981) describe WRAP (Waste Resource Allocation Program), which contains static and dynamic mixed integer linear programming models.

Shekdar et al. (1991) develop a transportation model to minimize solid waste handling costs over several development phases of an urban area. The model determines the resource requirements for the long term by determining optimal locations and loadings of the disposal sites and the allocation of various collection areas to different disposal sites and processing facilities. The model is applied to an actual case to demonstrate its usefulness for long range planning in cities.

Caruso et al. (1993) present a set of algorithms and a package which help to structure a location-allocation multi-criteria problem in a suitable way for modeling urban solid waste management systems. Their model is characterized by a multi-objective function which minimizes the total of investment and transportation cost, area used for disposal, and the environmental impact associated with the system. The results of the model are the number and the location of waste disposal plants, specifying the technology adopted, the amount of waste processed and the service region of each plant. The resulting procedure is applied to the Lombardy regional management of urban waste disposal.

Rahman and Kuby (1995) provide a multi-objective model locating solid waste transfer stations that examines the tradeoff between minimizing costs and public opposition. The cost objective combines the transshipment and the fixed –charge problems while expected public opposition is modeled as a decreasing function of distance from the facility. This is the first location model for any type of undesirable facility to locate an opposition function derived empirically from opinion survey data (Rahman et al., 1992). Their research modifies and extends the formulation of Marks and Liebman (1970) by considering public opposition as a second objective function. All of the prior studies treat transfer station location problem as a single objective cost minimization problem and this research adds another dimension to the concept by minimizing public opposition. In the location literature, some function of the distance from the residential zones to the objectionable facilities is commonly used as a measure for opposition rather than modeling opposition itself. Moon and Chaudhry (1984) and Erkut and Neuman (1989) have summarized the various model formulations for locating the facilities far from the residential population.

Sudhir et al. (1996), develop a nonlinear lexicographic goal-programming model consisting of six objectives that incorporate the interests of various actors involved in solid waste management. The study is not about the siting of the disposal facilities, however, it constitutes a general framework for sustainable development of integrated solid waste management in developing countries like India. The objectives of minimizing the uncollected quantity of waste on streets, minimizing the quantity of waste that is directly sent from collection points to the disposal sites, minimizing the cost and minimizing the under-utilization of existing vehicles and hiring of additional vehicles relates to the municipal body; minimizing unemployment in the informal recycling sector relates to waste pickers, and the last objective of obtaining maximum revenue from the processing plants objective relates to the private bodies engaged in waste processing. The utility of the model is demonstrated by applying it to a metropolitan city, Madras, in India.

Antunes (1999), develop a mixed integer optimization model combining elements of a p-median model and a capacitated facility location model with transshipments for locating landfills and transfer stations. The solutions of the minimum cost objective problem were used as benchmarks by the DMs during the actual locating process in the Portuguese Centro Region.

Apart from the models with single or multiple objective, there is one more approach taken by the researchers, using "*screening techniques*", developed by the help of *decision support systems*. A clear and unambiguous definition of "Decision Support System (DSS)" is still lacking, but two essential characteristics are generally recognized: DSS is an interactive tool including computer-based information and modeling systems; DSS has the purpose of aiding the decision-making activities, helping to understand the problem, exploring various alternative courses of actions, predicting their impacts, facilitating sensitivity analysis, etc [Rossi, 1997]. The Geographical Information System (*GIS*) -a computer software that supplies geographically referenced information- is used as a DSS in the screening process. Information about GIS will be given in more detail in the following sections while discussing the methods used by the DMs in the actual siting process. One example of the screening technique is by Mendes and Silva (1996), which reports a Portuguese application. This procedure uses a simple single cost minimization objective supported by a decision support system. Other examples of screening techniques are Siddiqui et al. (1996) and Siderelis (1991).

These models for the analysis of solid waste systems generally focus on subsystems of waste management systems. The trend in solid waste management recently is to take an integrated approach in solid waste management and use computer-modeling tools. In today's world, models are expected to handle more complex systems in order to face present changes in solid waste management.

Sundberg et al. (1994) propose a systems approach of two parts, first a comprehensive model, MIMES/WASTE (a model for description and optimization of Integrated Material flows and Energy Systems), for analyzing the technical properties of the waste management system, and second, procedures to make the model into an efficient tool in the planning process. The MIMES/WASTE model is a systems engineering tool for strategic planning for municipal waste management systems which is designed for the integrated analysis of: strategies for source separation, options for recycling, technical options for processing of solid waste, sales to the energy and material markets, and options for reducing pollutants and emissions resulting from waste management systems. The research also presents a pilot study for the Göteborg region in Sweden in order to illustrate the methodology and the use of the model.

Before MIMES/WASTE was proposed, Chapman and Berman (1983) had introduced another new tool for solid wastes management, RRPLAN (The Resource Recovery Planning Model). The model is developed to handle several planning problems of the regional waste management system but RRPLAN used a simple description of waste streams and processing equipment than MIMES/WASTE.

Rushbrook (1987) describes the HARBINGER waste management planning model, developed by the Harwell Laboratory. The model is made of eight sub-models, six of which are used to prepare inputs and the two for analyzing different strategies. HARBINGER does not support time-based optimization, and that strategies need to be compared and analyzed through several simulations. Also, the number of waste streams that can be considered is limited.

Light (1990) describes six commercially available software packages for planning integrated solid waste management systems.

Finally, before finishing the review, it will be better to mention some previous work that uses different tools in the siting of the facilities. One of these approaches is to use tools from decision analysis. There are two typical methods in this class: ELECTRE and PROMETHEE

Rey et al. (1995) present a multidisciplinary iterative approach that incorporates multi-criteria techniques like ELECTRE I to locate a stabilized waste storage facility. The proposed approach takes into account both the technical and socio-political aspects of the problem simultaneously so that the DM can identify the players that have to be consulted and define the technical and non-technical decisions that need to be taken over time as well as the process to be followed for each of them. The process is applied for the selection of stabilized waste storage facilities in Switzerland.

Another study that will be mentioned here is by Erkut and Moran (1991). They develop a decision modeling procedure, based on the Analytic Hierarchy Process (AHP) that can be used by public sector DMs to locate obnoxious facilities. They also demonstrate the applicability of the procedure in an analysis of recent decisions to locate a landfill for the City of Edmonton, Alberta, Canada.

3.3.2 The Actual Siting Process

In the actual siting process, the DMs, the people who do the actual siting of the landfill, use somewhat different and complex methods and have to take into account many other factors that seem to receive little attention from the researchers. DMs may be from the municipalities, local governments, ministry of environments, governmental organizations or from consulting agencies.

The concerns of the DMs are generally grouped into two domains. The first domain is purely technical, consisting of geographical, geological, and planning information used to locate potential sites. The second domain is about the political, social, and economic implications of each particular possible site such as natural resource conflicts, transportation, social and economic factors. Generally the DMs consider the first domain more important, but the public is more concerned about how the decision will affect them. As Bagchi (1994) states “ the general public is more concerned about the noise, dust, odor, traffic, and reduced property values ”.

From a geotechnical perspective, groundwater and surface water pollution, landfill gas formation, and site suitability have very high importance. Figure 3.1 shows a general listing of the environmental concerns compiled by Mathewson (1987). These kinds of lists are common in the literature (Rabe, 1994; Burt and Haycock, 1991).

WATER	SOIL
Depletion of dissolved oxygen though aerobic decay	Release of contaminants into soil
Bacterial/viral contamination	Uptake of contaminants by plants and roots
Surface runoff	
Chemical/thermal alteration of ground and surface water	
ATMOSPHERIC	**AESTHETIC**
Noxious odors/smells	Unsightliness
Releases of CH4, NH4, H2, H2S, H2SO4 gases	Traffic/truck's noise
Dust and smoke/particulates	

Figure 3.1 Pollution Potential of Landfills

The aim of the DM in the siting process is to avoid the need to take action to reduce environmental impacts by selecting a site where natural barriers protect environmental quality Therefore, the DMs firstly place emphasis on conducting appropriate geological, ecological, hydro geological, hydrological, topographic and meteorological evaluations to establish the appropriateness of the site [SouthAustralia EPA, 1998]. Another major concern of the DMs is to maintain a number of hard constraints which are specified in the regulations, forbidding the existence of a landfill within a certain distance to some critical areas.

Next subsection is a review of the criteria that has to be taken into account in the siting process.

3.3.2.1 Suitability (Exclusionary) Criteria for Landfill Siting

The suitability criteria which represent the guidelines for site selection used by the DMs can be classified into two major groups: factors and constraints. They are identified here through a review of the relevant literature.

i. **Factors (Non-Exclusionary Criteria):** In the suitability analysis, factors are necessary to understand which site represents more suitable conditions. Here are some examples of these factors in the literature.

a) Soil permeability: The permeability of the underlying soil and bedrock will greatly influence how much leachate is escaping a landfill site. Sites that are rich in clay are preferred as its great impermeability prolongs the natural occurrence of leachate (Atkinson, *et al.* 1995).

b) Land use/land cover: The land use and land cover must be known because present and future land use patterns affect placement.

Other non-exclusionary factors include depth of suitable soils for cover, residential well density, scenic areas and depth to groundwater resources [Noble, 1992]. Issues regarding impact on nature and society, the landfill's lifetime [Oliet et al., 1993], the concession of land, and the protection of water resources [Rava, 1989] should also be evaluated.

ii. Constraints (Exclusionary Criteria): The constraints outline areas that are entirely suitable or entirely unsuitable for landfill development. They are so important that they preclude landfill no matter what mitigation is considered [Noble, 1992].

a) Slope of the land: Due to accumulation in smooth surfaces and difficulty in operations in erect surfaces, a low slope is required to minimize erosion, decrease water runoff and to allow for construction to be facilitated with less difficulty (Kao, et al. 1997). For these reasons, the best slope for the development of a landfill is between 5% and 25% [Sistem Planlama Rapor, 1992].

b) Proximity to surface water: A landfill must not be located within 100 meters of any surface streams, lakes, rivers or wetlands (Basagaglu *et al.* 1997). According to [USEPA, 1993], a landfill must not be located within 300m of a lake, 90m of a river and 365 m of a well. For waste storage, watery and swamp fields and areas with potential of flood are not preferred [Sistem Planlama Rapor, 1992].

c) Distance from transportation routes: Landfills should be near the roads to reduce the cost of construction and operation [Lindquist, 1991], but aesthetic considerations prohibit landfills to be constructed within 50 meters of any major highways, city streets or other transportation routes [Oliet, et al. 1993]. Traffic of trucks, approximate number of parks, schools and dwelling which are close to highways should be taken into account to determine its effects on the traffic [Sistem Planlama Rapor, 1992].

d) Distance from urban areas: Landfills should not be placed too close to high-density urban areas in order to overcome conflicts relating to the NIMBY. This guards against health problems, noise complaints, odor complaints, decreased property values and mischief due to scavenging animals. Development of a landfill has been prohibited within 1000 meters of high-density urban areas [Katı Atıkların Kontrolü Yönetmeliği, 1991].

e) Distance from gravel pits and open mines: Gravel pits and open mines are clearly incompatible land uses for construction of landfills so they should be eliminated from consideration [Minor and Jacobs, 1994].

Other criteria for landfill siting include wetlands, flood plains, fault zones, seismic impact zones, unstable areas, expansive soils [Noble, 1992], and areas with archeological and historical importance [Sistem Planlama Rapor, 1992].

3.3.2.2 Landfill Siting Process

There are many examples in the literature regarding the different approaches for suitability analysis for the siting of the landfills. Generally there are basically two components to the methodologies used:

1. Each potential site goes through a *prior* feasibility check with respect to the above *constraints* and the sites that are not feasible are excluded,

2. The remaining non- exclusionary areas are ranked in terms of the *factors*.

In the exclusion process, any areas that do not satisfy any of the constraints are mapped as exclusion zones. Generally, the exclusion process is carried out by the help of maps or, if available, digital data for each of the criteria. After the exclusion zones are identified and mapped, the maps of each criteria are arranged one upon the other. When the union of the infeasible regions is extracted, the suitable areas for landfills are identified. "Ian McHarg in his book *Planning With Nature* showed this might be achieved by mapping various aspects of large metropolitan areas on huge acetate sheets, and overlaying them to sieve out the salient features which point the way to future plans" [Noble, 1992]. According to Noble (1992), this work of transferring the maps of the acetate is labor intensive because there are so many factors to consider and the method does not provide us with enough flexibility. Noble

(1992) further explains that, after we have begun to receive geographic information from EARTHSAT, the computer has been increasingly used as a vehicle for storage of geographical data. Today, we can efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information by the help of organized collection of computer hardware, software and geographic data called Geographical Information Systems, or simply GIS [Esri Library, 2002].

The second component of the analysis considers the remaining areas that have not been excluded. These areas are rated according to suitability by the help of the weighting methods. In order to come up with a conclusion, the plans of the candidate sites must be studied, and the sites must be visited as well.

3.3.2.2.1 The Weighting Methods

The elimination of the infeasible sites results in a series of candidate sites. An option to organize the data to facilitate decision-making is to use weighting and ratings. By the help of the weighting methods, the level of the importance of the problematic factors that cannot be mapped as exclusion zones can be clarified and compared to one other.

DRASTIC has been developed by the U.S Environmental Protection Agency and the national National Water Well Association (EPA/ NWWA 1985) for evaluating groundwater pollution potential from a proposed landfill site. The system compares areas by assigning ratings and weights to seven parameters that affect groundwater contamination [Noble, 1992]. Basically, each criterion is weighted on a comparative basis, the most important criterion receiving the weight 5, and the least important criterion receiving the weight 1. Once the weigthing is accomplished, each candidate site can then be rated according to how it compares with the other candidates [Noble, 1992]. The total score for each site is then determined according to the following formula:

$$S_A = W_1 * R_1 + W_2 * R_2 + W_3 * R_3 + ... + W_k * R_k$$

where S_A = Total score for site A

W_i = Weight of the i^{th} criterion

R_i = Rating of the i^{th} criterion

k= number of criteria

Another method for evaluating groundwater pollution potential is the LeGrand Method [Canter et al. 1987]. DRASTIC and LeGrand Method are both examples of site evaluation procedures that focus on a single domain [Protecting Groundwater Resources Using GIS, 2002]. The disadvantages of these methods is that the procedure is limited to only a small number of criteria and there are so many more to be considered so that the results are just a small step in the process.

Two procedures, which are more general than the above two, are the interaction matrices method [Camp Dresser and McKee, Inc, 1984] and the weighted rankings method [Morrison 1974]. These two procedures are both general impact assessment techniques, which are used to evaluate the various impacts of proposed landfill sites. These procedures result in an impact rating which is interpreted as the relative suitability of each potential landfill site [Siddiqui et al., 1996].

The most widely used method used for landfill siting is the EPA Method, used by the US Environmental Protection Agency. The site selection process consists of the following stages [Sistem Planlama, 1992]:
1.Preliminary feasibility stage
2.Elimination stage
3.Final selection stage

Preliminary feasibility stage

Step 1- determining the legal and statutory restrictions (on a country-wide or local basis) in the following order:

a) Physical restrictions (slope of the land, geological structure, underground water level)

b) Demographic strictures (distance to the closest settlement hub, land utilisation factors)

c. Political strictures (possible public reaction, reactions from various social groups and associations)

Step 2- determining the alternative areas by taking into consideration factors listed below:

a. Calculation of largest radius of the operation area based on the carriage distance to the wastewater treatment plants and/ or potential service area centre

b. Drafting detailed and transparent charts and identifying areas with the following characteristics:

i. Inappropriate slope of land

ii. Dense population

iii. Undesirable geological structure (faulted/ fractured rock formations, fissures)

iv. Undesirable soil structure (shallow, highly-organic content, permafrost areas)

v. Improper surface and underground conditions (areas with a potential of flood, areas where water may pool or collect, backfill areas of underground waters)

c. Matching map of said location with the transparent charts on which areas with less proper characters are marked and determining potential (candidate) areas

Step 3-Determining the potential fields and carrying out the following procedures about these alternative fields:

a. Reporting to concerned local authorities

b. Reviewing the previous field inventories

c. Researches on land ownership on roads and ways in areas with a high probability of selection

Step 4-Rough cost estimations and calculations for alternative fields by taking into consideration the basic expenditure items such as carriage distance, field preparing costs and waste amounts, personnel and equipment expenses

Step 5-A preliminary feasibility on the fields by using the available data and evaluation of fields on a comparative basis in terms of the following factors:

a. Location

b. Land utilisation

c. Carriage distance and route

d. Topography

e. Characteristics of soil

f. Surface area

Step 6- Elimination of less proper fields after evaluating the factors in the foregoing step by taking into account the statutory and economic strictures

Step 7- Finding out the approach and thoughts of the local area for the determined alternative fields

Elimination Stage

Step 1- in this step, the items listed under the main headings of technical, economic and public opinions shall be assessed and proposed areas shall undergo an elimination process:

1. Technical issues

a. Carriage distance

b. Field life and capacity

c. Topography

d. Surface water

e. Soil structure and geology

f. Underground waters

g. Soil quantity & amount

h. Vegetation

i. Sensitive areas in terms of environmental issues

j. Accessibility

k. Land utilisation

2. Economic issues

Evaluation of the fields in terms of initial investment and operational cost; expropriation, road construction expenses, field preparation, equipment, operational expenditures etc

3. Evaluations in terms of public reactions

Step 2- Storage fields under evaluation, number of which generally varies from 4 to 6, shall be reviewed and problems specific to each field shall be determined. Data derived from the available sources may be used during the works. These data may be supported by land researches. Scope of the researches to be done may vary according to the land characteristics.

Step 3-At this step, the fields shall be evaluated and potential adverse effects of the alternative fields on the environment shall be figured out. In this system, criteria given in Table 3.1 shall be assessed based on the points set out in the same table, according to their significance. Points given for each criterion reflect the significance of the said criteria in comparison with each other.

BASIC OBJECTIVES FOR REGULAR STORAGE	RATING OF OBJECTIVES BASED ON PRIORITY	CRITERIA
The selected area shall not endanger social health	1000	- Pollution risk of underground water - Gas risk - Pollution potential of underground water - Pollution risk and potential of surface waters - Dusts, noise and odor pollution - Potential hazards in transportation stage
Selected field shall be acceptable to the public	800	- Outside the range of vision - Accessibility - Measures shall have been taken against noise, dust and odour - Pollution potential of surface water - Acceptable final utilization way and its benefits - Acceptable improved field utilization way
Avoiding any deterioration that may occur in field's ecology	500	- Density and variety of vegetation - Effects of current development on the land's environment in terms of species, kinds, variety and density
Utilization of the selected area should be in conformity with the accepted land utilization plan	500	- Finished storage field should be compliant with the future land utilization plan - Improvement of current utilization of the field must be desirable
Selected field should be open to prompt improvement and operation as a regular storage area	300	- Field life - Required coating material should be available in the field - Flow direction of surface waters shall be open to re-routing - General accessibility to the fields

Table 3.1 Grading of Sites by using the EPA Method

Step 4- Fields are rated according to points given in the preceding step. Technical details shall be taken as basis in rating step.

Step 5-In case site selection details are required for the top ranking field(s), an environmental effect evaluation report shall be submitted covering such details.

Step 6-On the last phase of the elimination stage, public participation is ensured during the evaluation of alternative fields.

Elimination stage is fulfilled and completed by a team consisting of parties specialized and experienced on the subject. The depth of details those specialist parties will delve into depends on statutory expectations. Method to be applied may be in such a manner to give points to alternative fields and to carry out subjective analyses concurrently. These evaluation steps are regarded more comprehensive than necessary for small-sized fields.

Final Selection Stage

Step 1- In the final selection stage, a regular storage method should be projected and preliminary design should be fulfilled for each field prior to giving a final decision for storage area. Design shall be in conformity with the characteristics of the waste and the area. In this step, preliminary drawings shall also be carried out.

Step 2-After regular storage method is determined, alternative ways are defined for using the land and final utilization way shall be determined for each field undergoing evaluation.

Step 3-First investment costs, operational costs, transportation costs and similar cost items are calculated in detail.

Step 4- Legal governmental policy in respect of the issue is taken into consideration and public participation is ensured. In this phase, meetings with a large audience and attendance may be organized.

Step 5- Storage field is selected.

Step 6-Title of the determined storage field may be obtained through purchasing, expropriation, long-term leasing.

After the widespread use of the digitalized data and GIS, several new methods became available. Implementing data processing according to a conventional approach using drawing and calculation tools is generally time consuming. With the help of GIS, manipulating the maps with computer use is more efficient. Some methods use the digitalized data only to screen out the exclusionary sites and still need the "rating and weighting" procedures to evaluate the remaining candidate sites. An example of the methods that use digital mapping is the Method of Intrinsic Suitability used by Minnesota Pollution Control Authority [Noble, 1992]. Another method is the Noble's own method that he introduces in his book *Siting Landfills and Other LULUs*.

3.4 Summary

According to Erkut and Moran (1991), deciding where to locate a municipal landfill is a difficult problem in which qualitative criteria compete with quantitative economic and engineering criteria, in a process that is highly political and emotional. The aim of the actual landfill siting process is to find a suitable site, that is, a location that meets the requirements of government regulations and minimizes economic, environmental, health and social costs. Such a process generally requires a multidisciplinary analysis and an extensive effort to evaluate numerous factors as well as environmental, economic, and social constraints and processes much spatial information before an appropriate decision can be made. The *prior* check requires gathering lots of spatial data, maps and, doing extensive field studies and measurement for all candidate sites in addition to the overall condition, for environmental, social, and economic factors to assess microscale impacts such as the exposure risk for adjacent areas [Kao et al. 1997]. The maps can be gathered from the studies of the government and academic institutions but generaly this data is not available, not of sufficient accuracy or not relevant for this prior feasibility analysis. Even if this data is available, there are too many sites to check and too much work to do. Implementing such a complicated procedure in a conventional information processing approach woud be tedious and expensive. Moreover, such a process may be repeated several times as new factors are introduced or as siting constraints are altered [Kao et al. 1997]. This is a very lengthy process and entails great cost. Moreover, besides the technical feasibility aspect, the site has to meet the requirements of government regulations and minimize economic, environmental, health and social costs. Many local governments generally do not have the sufficient funds and expertise to implement such a complex siting process; therefore, the chosen sites may be inappropriate and give damage to the surrounding environment.

Many of the applied methodologies in application use weighting and rating methods. This part is based on the judgments of the DMs, so attaining consistency may be difficult. Two people who use the same method may come up with two different decisions. Erkut and Moran (1991) explain that it is common for the DMs to have a strong vested interest, which causes them to oppose one or more of the decision alternative for personal reasons, quite independent of any intrinsic characteristics of the site. With the use of GIS, the bias in the siting problems becomes less because GIS has the ability to store, optimize and change relevant variables simultaneously about each site and gives convincing output and graphics. As more data becomes available, the usefulness and the accuracy of the tool increase.

As far as the models in the literature are concerned, we can see that there is a lack of applications in the actual siting process. This may be because of two reasons: the researchers either build very comprehensive models that lack flexibility or use very simple models with a minimization objective. Flexibility of a model is very important for being used in siting, in case a new constraint or a factor is introduced to the model later. Using a simple cost minimization objective leads to ignoring many factors that are taken into account by the DMs.

Chapter 4

A Comparison of Existing Landfill Sites with Model-Based Optimal Solutions

In this chapter, we use the p-median model, a well known mathematical model widely used in siting problems, to study the locational patterns of landfills in various regions of the world. We compare the locations of existing landfill sites with cost-based optimal solutions of the p-median model. The cost based theoretical optima are not expected to exactly match with existing landfill sites, due to omission of the environmental, social, geological, and geographical factors. A reasonably close agreement between model solution and existing locations would indicate that the p-median model may provide a good approximation for the complicated process involved in actual site determination for landfills. Some analysis is made about the reasonability of the results. Moreover, a procedure for locating the landfills is suggested based on the p-median model.

The rest of the chapter is organized as follows: In Section 4.1 the motivation of the study is given and the aims of the study are explained. In Section 4.2 the research approach is defined. In Section 4.3 the results obtained from various regions of the world are summarized. The chapter ends with concluding remarks and a procedure for the siting of the landfills.

4.1 Introduction

In this study, we consider the landfill siting problem as a p-median problem which locates *p* landfills relative to a set of garbage generation points such that the sum of the weighted distances between garbage generation points and their nearest landfills is minimized.

The motivating points behind this study are as follows:

In light of the review of the methodologies used by the DMs, it is apparent that the landfill siting process is a complex task which requires extensive evaluations of the sites about many factors and criteria, as well as social, environmental and health factors. Besides being a laborious evaluation work, the siting process is time consuming and very costly. The local bodies, which are responsible for the site selection, are generally not able to spend sufficient time and money; therefore, most of the existing landfills run the risk of posing an environmental risk due to improper siting. The main motivation in this study is to simplify the tedious decision making process and make an assessment of how well a simplified approach might be approximating the much more complex process that seem to be operative in the actual siting of landfills.

In the real world, there are not many examples of applications of the models in the literature. A single cost minimization objective does not include many of the features of the siting problem, whereas, a multi objective model overcomes this handicap. However, multi-objective models are highly complex integer programs that are hard to solve. They also lack the necessary flexibility needed in siting problems in case, for example, a new constraint or a factor is introduced later. There is a trade-off between these two approaches. There is a need for some simplistic but applicable approach proposed by the researchers. One example study of application in the real world is by Antunes (1999) that combines the elements of a *p*-median model and a capacitated-facility-location model with transshipments. The results of his study were not adopted fully in Portugal, but were used as benchmarks by the DMs in the siting of the landfills.

The purpose of this study is to use the p- median model to locate landfills, and test how well it approximates the actual siting process while disregarding physical, social, economic and political constraints. Since our main motivation is to simplify the actual siting process, we propose using a simple objective, e.g. the single cost minimization objective of the *p*-median model, and try to come up with a reasonably good approximation of the actual decision making process.

The first reason we use the p-median model is that, it is a well-known problem that can be solved in reasonable time by most commercially available solvers. Another reason is that the p-median model requires only two inputs: amount of waste generations and distances between the generation points and the candidate sites. Therefore, using the p-median model results in significant savings in time to collect the necessary data.

The objectives in this study can be summarized as follows:

1. To get to know how well the p-median model approximates the actual siting process when the physical, social, economic and political constraints are not taken into account.
2. To have some understanding of the objectives of the DMs in the siting process, by assessing if the predominant objective is cost minimization or other factors related to the NIMBY syndrome.
3. To evaluate the methodology and formulate recommendations.

4.2 The p-median Problem

The p-median model, formulated by Hakimi in the mid-sixties (Hakimi, 1964,1965), has established the foundations for a myriad of location problems in the public and private sector (Serra and Marianov, 1998). Canos et al. (1998) state the *p*-median problem as follows : Let G= *(V,E)* be a non-directed connected network, where V= $\{v_1, \ldots, v_n\}$are the vertices of G, and E is the set of edges. As G is connected, each pair of vertices v_i and v_j are joined by a path on the network. The length of a shortest path joining them is denoted by d_{ij}. Each vertex v_j has an associated weight h_j, usually called the demand at v_j. Given n demand points in some space (such as

Euclidean plane or road network), the goal of the model is to locate p service facilities, and allocate the n demand points to these service facilities so as to minimize the total distance to be traveled for service (Erkut and Bozkaya, 1999). It is possible to solve medium sized instances (n=200) of this problem optimally. Furthermore, efficient heuristics are available to solve larger instances of this problem (n=1000) to near optimality (Erkut and Bozkaya, 1999).

An integer programming formulation of the p-median problem is as follows:

$$Min \quad \sum_{i}\sum_{j} h_i d_{ij} y_{ij} \qquad (4.2.a.)$$

s.t.

$$\sum_{j} y_{ij} = 1 \qquad \forall i \qquad (4.2.b)$$

$$\sum_{j} x_j = p \qquad (4.2.c)$$

$$y_{ij} - x_j \leq 0 \qquad \forall i, j \qquad (4.2.d)$$

$$x_j = 0,1 \qquad \forall j \qquad (4.2.e)$$

$$y_{ij} = 0,1 \qquad \forall i, j \qquad (4.2.f)$$

where

$$x_j = \begin{cases} 1 & \text{if we locate at candidate site j} \\ 0 & \text{if not} \end{cases}$$

$$y_{ij} = \begin{cases} 1 & \text{if demands at node i are served by a facility at node j} \\ 0 & \text{if not} \end{cases}$$

h_i = demand at node i

d_{ij} = distance between demand node i and candidate site j

p = number of facilities to locate

The objective function (4.2.a) minimizes the total demand-weighted distance between each demand node and the nearest facility. Constraint (4.2.b) requires each demand node i to be assigned to exactly one facility j. Constraint (4.2.c) states that exactly p facilities to be located. Constraints (4.2.d) link the location variables (x_j) and the allocation variables (y_{ij}). They state that demands at node i can only be assigned to a facility at location j ($y_{ij} = 1$) if a facility is located at node j ($x_j = 1$). Constraints (4.2.e) and (4.2.f) are the standard integrality conditions.

The p-median formulation given above assumes that facilities are located on nodes of the network. Although this assumption can lead to sub optimal solutions for the set covering, maximum covering, and p-center problems, Hakimi (1965) has shown that for the p-median problem at least one optimal solution consists of locating nodes.

4.3 The Research Approach

In order to address the question of how good the p-median model is for locating landfills, p-median based optimal locations are found and compared with existing landfills in different regions of the world.
Namely:

- data is collected about locations of existing landfills in different regions of the world,
- a p-median problem for each region (with weights representing garbage generation amounts) is solved,
- p-median optimal locations are compared with existing landfills.

While solving the *p*-median model, all the geological, ecological, hydrological, ecological, topographical, and meteorological data about the regions are ignored in an a-priori sense, but they are not ignored in a posterior sense. This sort of data is very important in assessing the technical feasibility of the site and can not be ignored in the siting process. What is done in the real world is that the DMs apply *prior checking* which requires obtaining the geological, ecological hydrological, topographical, meteorological data for all sites and checking the feasibility of each candidate site relative to these criteria. Instead, what we suggest here is to use *posterior checking* rather than *prior checking*. *Prior checking* requires extensive field studies and measurement for *all* candidate sites, whereas, *posterior checking* requires solving the model first, and checking the criteria for *only* the resulting optimal sites. If some optimal locations are eliminated as a result of the check, the problem is re-solved with a new set of candidate sites that no longer include the eliminated ones. This process is repeated as many times as necessary until all of the optimal sites pass the feasibility check. *Posterior checking* checks the criteria for significantly fewer sites and results in much less work. This relates to the Mendes and Silva (1996) procedure in some sense. Their procedure can be summarized as follows:

Step 1: Determine the estimated quantity of garbage at all the pertinent points.

Step 2: Determine a p-median solution based on the garbage supplies determined in Step 1.

Step 3: Draw a circle of prespecified diameter (e.g., 50 miles) around the medians.

Step 4: Within the circle(s) reject areas based on

- Environmental protection criteria,
- Infrastructure protection criteria,
- Land use criteria.

GIS aids in the decision process in this step, during the screening of the areas.

Step 5: Within the remaining areas, use suitability criteria to identify potential locations.

This procedure is an example which uses posterior checking in the elimination process of the candidate sites, since it proposes finding the optimal *p*-median based results first and then eliminating, within a prespecified radius, the sites that do not satisfy the criteria.

For comparison of the existing landfills and the *p*-median solutions, each optimized location is matched with its nearest current existing landfill and the distance between them is calculated. This way, for each optimal solution, within how many kilometers an existing landfill is situated can be observed and some analysis can be made based on the results.

4.3.1 The Studied Regions

Data about the existing landfill locations is collected and a p-median problem is solved for the following countries and regions:

- Turkey: Ankara and Istanbul
- Germany: State of Mecklenburg-Vorpommern and State of Hessen
- India: State of Rajasthan

The data about the existing landfill locations are collected via an extensive search on the Internet. However, generally that was not enough, so the data was attained by personal correspondence, either by e-mails or by face-to-face interviews in case of Turkey. The most difficult part was to find out which governmental unit was responsible for the siting decisions.

4.3.2 Computations

We formulated a p-median model for each of the countries by using the generic IP formulation explained in Section 4.2. In the p-median model, the weights represent the garbage generation amounts and are estimated by population density in each node. In order to be more accurate, the nodes represent the smallest region whose population data could be found. For Turkey, the nodes represent the districts; for Germany, the nodes represent the municipalities, and for India the nodes represent the cities.

The node coordinates used in the formulations are the centroids of the nodes. For Turkey, these coordinates are calculated by using a GIS program which automatically calculates the centroids of the districts when the digital maps of the regions are supplied. For Germany, the nodes are calculated manually by using the digital environmental database supplied by the ministry of environment, which consists of several environmental maps of Germany. For India, the centroids are calculated manually by using a map of the region.

The node-to-node distances between the nodes are determined by using the Euclidean distances between the centroids of the nodes. We coded the p-median models by using GAMS 2.25 and solved them by using **CPLEX 5.0.** The following sections represent the results of the models.

4.3.1 Turkey

In Ankara and Istanbul, current landfills are essentially *open dumps* with no natural or human made environmental protection. Generally, the Greater City Municipalities carry out the siting process on their own. Given the essential nature of the landfill for final disposal, and the lack of local experience and financial resources for introducing sanitary landfills, central government support in terms of technical assistance and access to financing is needed in Turkey.

4.3.1.1 Ankara

Ankara, has a population of approximately 4 million [DIE, 2000] and covers an area of about 30 200 squared km. Ankara, being the second most populated city in Turkey, has one large landfill, situated in Mamak. The *p*-median model for Ankara consists of 354 demand nodes, which represent the districts administered by the Greater City Municipality. The model is solved for *p*=1.

Figure 4.1 The map of the existing landfill, Ankara

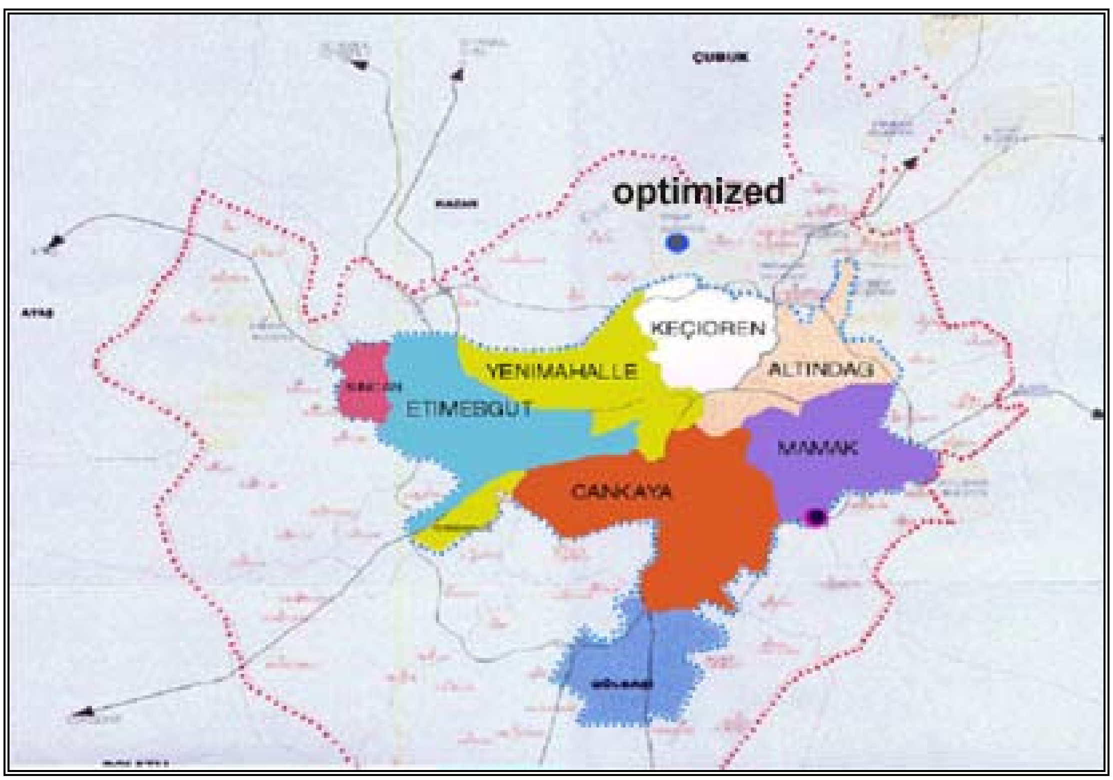


Figure 4.2 The optimized location for p=1, Ankara
Source: Greater Municipality of Ankara

p=1	***ANKARA***	
Optimized Location	Closest Existing Landfill	Distance from the nearest landfill (km)
Bağlum	Mamak	**32**

Table 4.1 The cost based optimized location and its closest existing landfill, Ankara

4.3.1.2 Istanbul

Istanbul, has a population of approximately 11 million [DIE, 2000] and covers an area of about 5220 squared km. Istanbul, being the most densely populated city in Turkey (1770 inhabitants per square km), has two large landfills, situated in Kemerburgaz and Kömürcüoda.

The *p*-median model for Istanbul consists of 618 nodes, representing the districts, and is solved for p=1 and p=2. The model is solved as a whole for the city, not separately for each side of the Bosphorous.

Figure 4. 3 The map of existing landfills, Istanbul

Figure 4.4 The optimized location for p=1, Istanbul

Figure 4.5 The optimized locations for p=2, Istanbul
Source: The Greater Municipality of Istanbul

p=2	***ISTANBUL***	
Optimized Location	Closest Existing Landfill	Distance from the nearest Landfill (km)
Cebeci	Kemerburgaz	**34**
Sarıgazi	Kömürcüoda	**78**

Table 4.2 The cost based optimized locations and their closest existing landfills, Istanbul

4.3.2 Germany

In Germany, each fedaral state has its own ministry of environment which determines the locations of the landfills collectively for all the cities within its jurisdiction. The German Ministry of Environments has a very detailed database about geological, geographical and environmental data. Very detailed maps and digital data about all of the states are available. Therefore, the landfill siting process can be somewhat simpler than other countries, e.g. Turkey, where it is tedious to find and obtain data. Data is collected and the *p*-median model is solved for two states: Mecklenburg-Vorpommern and Hessen. Figure 4.6 shows their situation in Germany. The numbers show the number of the landfills in each federal state [Umwelbundesamt, 2001].

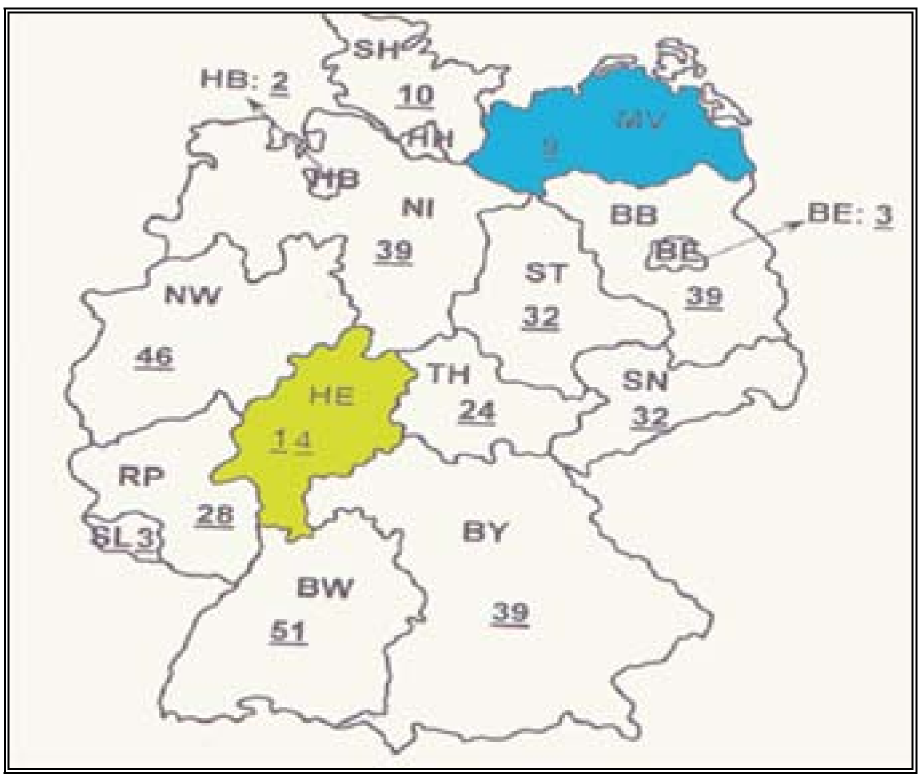


Figure 4.6 The map showing Mecklenburg and Hessen,
Source: Umwelbundesamt, 2001

4.3.2.1 State of Mecklenburg-Vorpommern

Mecklenburg-Vorpommern is located in northeast Germany. The state has a population of approximately 1.8 million and covers an area of about 23 170-squrare km. The state is the most thinly populated state in Germany (79 inhabitants per square km)[Statistisches Landesamt MVP, 20001]. The p-median model for Mecklenburg consists of 352 nodes, representing the municipalities. The state has 9 existing landfills, shown in figure 4.7.

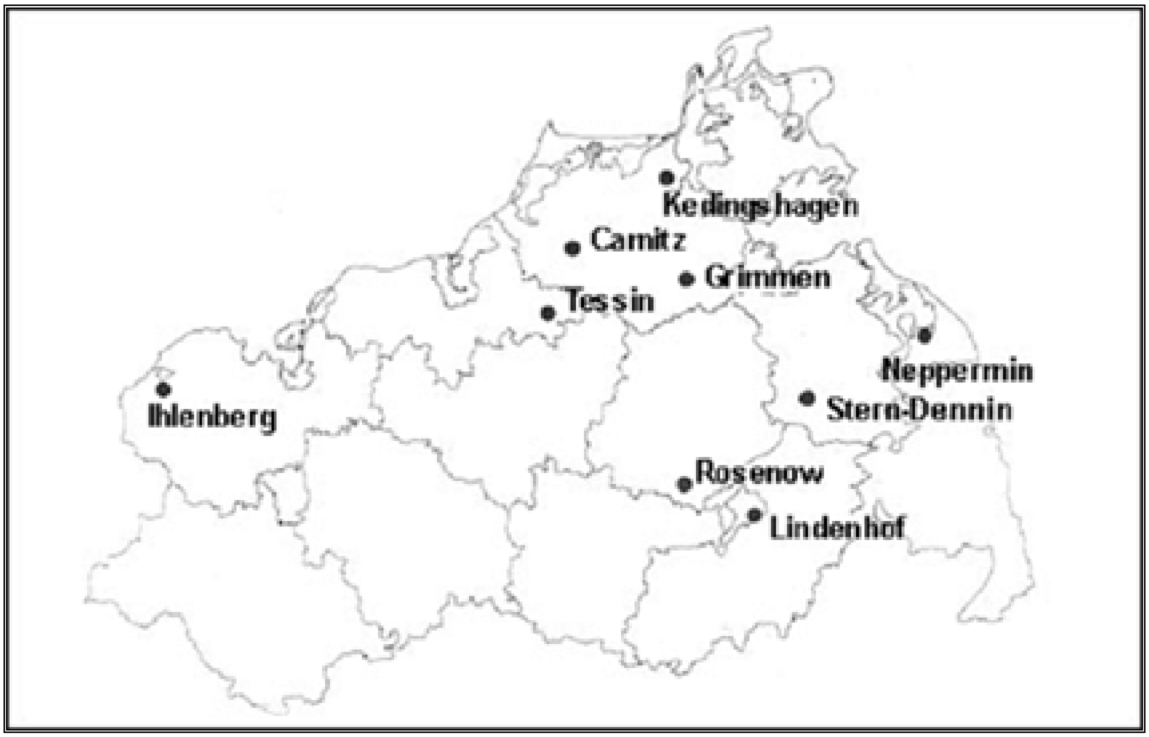


Figure 4.7 The map of existing landfills Mecklenburg-Vorpommern

Source: Ministry of Environment of Mecklenburg-West Pommerania

The p-median problem is solved for p=9 and Figure 4.8 shows the optimized locations and the match of each optimized landfill to its closest existing landfill.

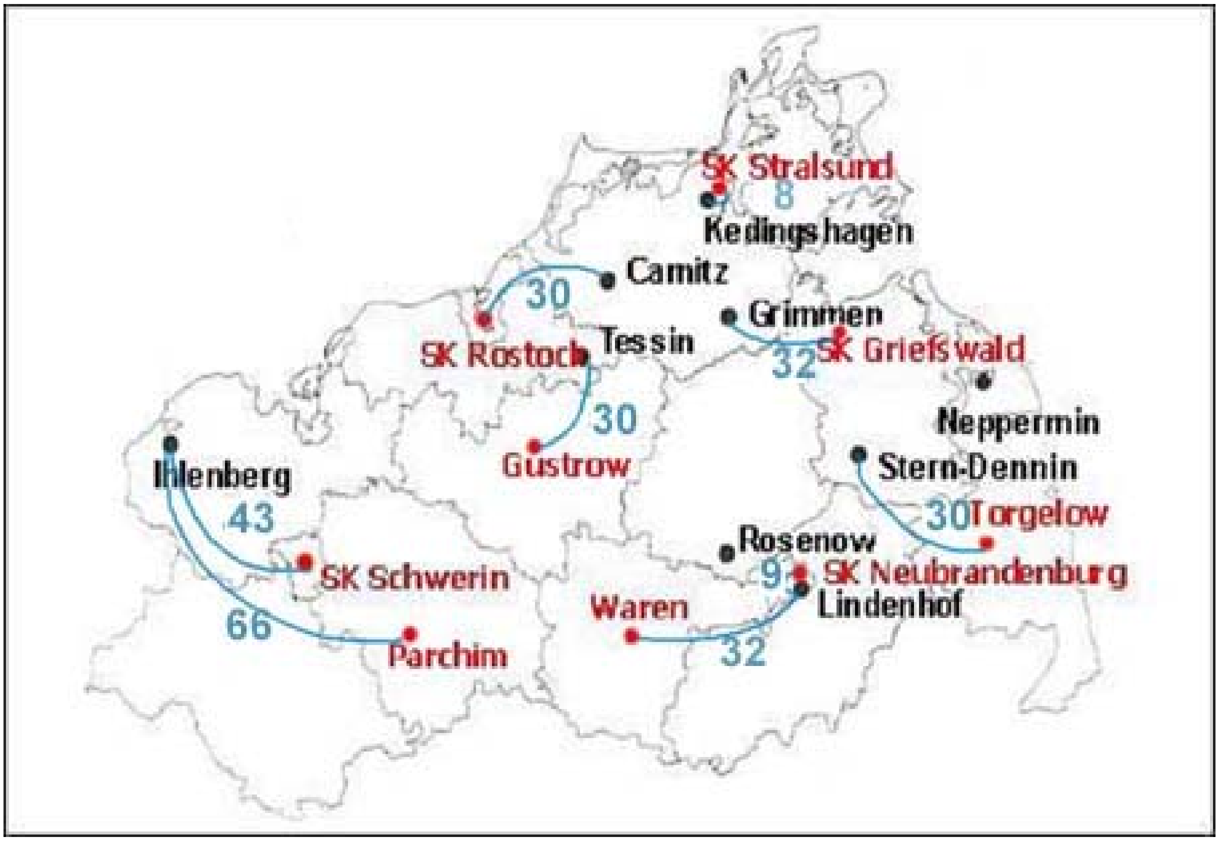


Figure 4.8 The optimized locations for *p*=9 and the match of each optimized landfill to its closest existing landfill, MVP

The blue lines indicate the match of each optimized location to its closest existing landfill, with the distance marked on it. As it can also be seen in table format in Table 4.3, the maximum distance between the optimized locations and the existing landfills is 66 kms, which is the distance between the optimized location Parchim and the Landfill Ihlenberg. When the planning horizon of the capacity and the life time of the landfills are considered, an explanation to that point may be that Ihlenberg has the highest capacity and the longest expected life time among the other 9 landfills. It is planned to be in service until 2017 and has a capacity of 9.700.000 tons left, whereas, the next landfill with highest capacity and lifetime has 3.700.000 tons left and is planned to serve until 2005. Therefore, such a huge landfill is built in a remote area on the west of the state.

P=9	***MECKLENBURG VORPOMMERN***		
Optimized Location	Population (Thousand)	Closest Existing Landfill	Distance to the closest existing landfill (km)
SK Rostock	220.506	Camitz	30
SK Schwerin	101.267	Ihlenberg	43
SK Neubrandenburg	73.318	Lindenhof	9
Stralsund	60.663	Kedinshagen	8
Griefswald	54	Grimmen or Kedinshagen	32
Waren	22.044	Lindenhof	32
Torgelow	11.449	Stern-Demmin	30
Gustrow	32.323	Tessin	30
Parchim	20.048	Ihlenberg	66

Table 4.3 The cost based optimized locations and their closest existing landfills, MVP

4.3.2.2 State of Hessen

Hessen is a part of Germany's geographic center. The state has a population of approximately 5.5 million and covers an area of about 21 114 -square km [Hessisches Statistisches Landesamt, 2001]. The *p*-median model for Hessen consists of 328 nodes, representing the municipalities. The state has 14 existing landfills, shown in figure 4.9.

Figure 4.9
The map of existing landfills Hessen

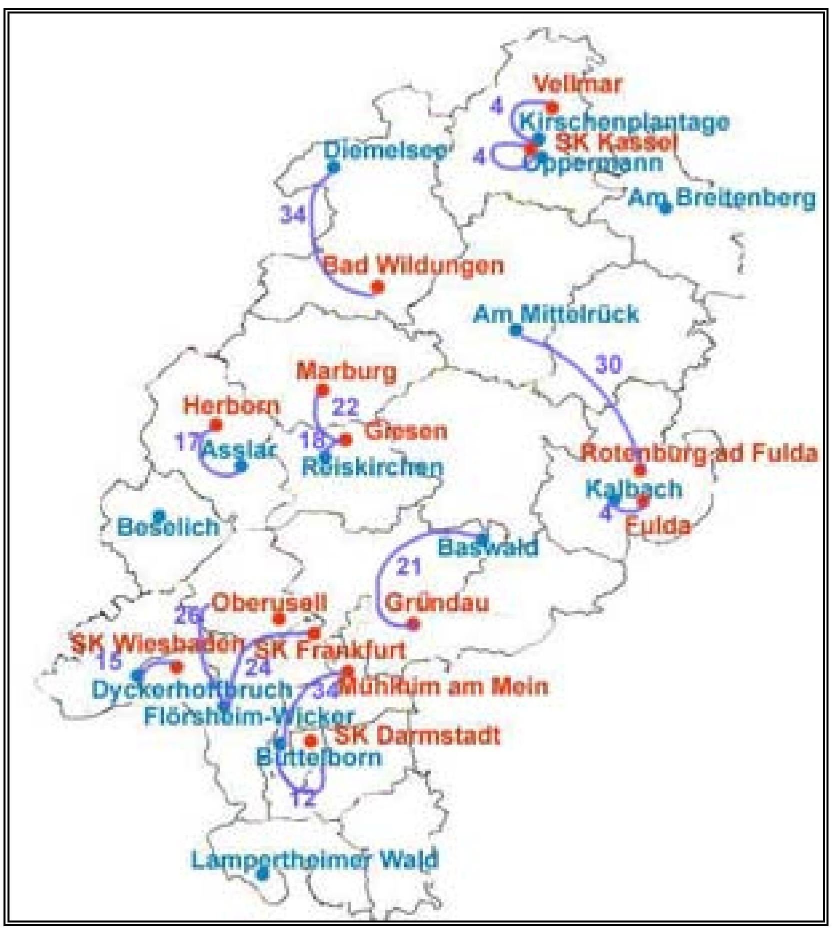


Figure 4.10 The optimized locations for p=14, and the match of each optimized landfill to its closest existing landfill, Hessen

Figure 4.10 shows the optimized locations when p=14. The purple lines indicate the match of each optimized location to its closest existing landfill, with the distance marked on it. As it can also be seen in table format in table 4.4, the maximum distance between the optimized locations and the existing landfills is 34 kms, which is the distance between the optimized location Mühlhimam Main and the Landfill Buttelborn and the optimized location Bad Wildungen and the Landfill Diemelsee. The distance is quite normal because, during the p-median formulation we assume the center of the nodes as their centroids. It is not possible to built the landfill right in the middle of a city; therefore, this deviation is, in fact, expected.

p=14	***HESSEN***		
Optimized Location	Population (Thousand)	Closest Existing Landfill	Distance to the closest existing landfill (km)
SK Frankfurt	600	Florsheim-Wicker	**24**
SK Kassel	208	Kirschenplantage	**4**
SK Wiesbaden	216.972	Dyckerhoffbruch	**15**
Fulda	54.995	Kalbach	**4**
SK Darmstadt	117.797	Buttelborn	**12**
Mühlhimam Main	22.931	Buttelborn	**34**
Grundau	13.611	Baswald	**21**
Vellmar	16.921	Kirschenplantage	**4**
Herborn	19.26	Asslar	**17**
Rotenburg ad Fulda	14.208	Am Mittelrück	**30**
Marburg	67.352	Reiskirchen	**22**
Bad Wildungen	16.327	Diemelsee	**34**
Giesen	62.711	Reiskirchen	**18**
Oberusell	33.523	Florsheim-Wicker	**26**

Table 4.4 The cost based optimized locations and their closest existing landfills, Hessen

4.3.3 India

According to Gupta et al. (1998), the collection, transportation and disposal of MSW are unscientific and chaotic in India. Uncontrolled dumping of wastes on outskirts of towns and cities has created overflowing landfills, which are not only impossible to reclaim because of the haphazard manner of dumping, but also have serious environmental implications in terms of ground water pollution and contribution to global warming.

4.3.3.1. State of Rajasthan

The State of Rajasthan is situated in northwest India, as shown on the Figure 4.34. It covers an area of about 342 114 square kilometers and has a population of approximately 44 milion [Rajdarpan, 2000]. About 10 million of this population lives in urban places, whereas, about 33 million lives in rural parts.

Figure 4.11 Rajasthan State Location Map

Source: *www.mapsofindia.com*

Currently, the state has 24 landfills. The data used here is obtained from the Directorate of Local Bodies, Government of Rajasthan.

Figure 4.12

The map of existing landfills, Rajasthan

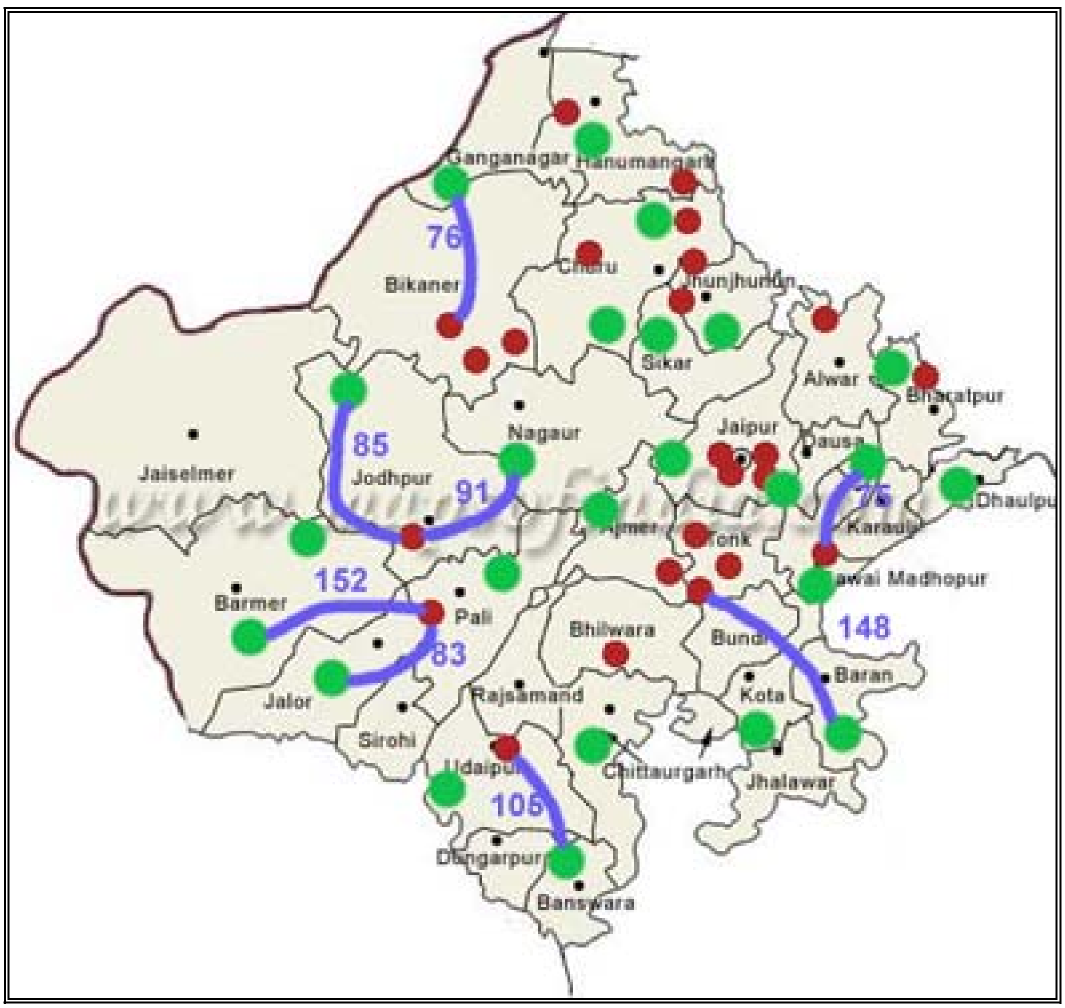


Figure 4.13 The optimized locations for p=24, Rajasthan

The figure 4.13 shows the optimized locations for p=24 with the green points and the red point indicating the existing landfill locations. The purple lines indicate the maximum distances between these two points. The distances between each optimized location and its nearest current landfill is summarized in Table 4.5.

P=24	***RAJASTHAN***			
Optimized Location	Population	State	Closest Existing Landfill	Distance from the Existing Landfill (km)
Rojhri	178.849	Ganganagar	Gajner Road, Bikaner	**76**
Pilibanga	116.722	Hanumangarh	Near Tibbi Road,Hanumangarh	**29**
Taranagar	147.916	Churu	Khasara.No 1254	**13**
Salasar	147.916	Churu	Khasara.No 1260,Jhunjhunun	**60**
Udaipur	191.309	Jhunjhunun	Nanagram, Sikar	**50**
Kanasar	288.077	Jodhpur	Keru Village	**85**
Tankia	231.157	Nagaur	Keru Village, Jodhpur	**91**
Sikri patti	149.88	Bharatpur	Village Noh	**45**
Kharra	151.058	Barmer	Keru Village, Jodhpur	**70**
Rohia	151.058	Barmer	Near Mandir Road, Pali	**152**
Sojat	181.92	Pali	Near Mandir Road	**66**
Pushkar	155.751	Ajmer	Makhupura	**72**
Devli	121.134	Tonk	Soraw	**2**
Sakrai	119.708	Dausa	Bagrana near Kanota	**75**
Gajipura	160.942	Jalor	Near Mandir Road, Pali	**83**
Jaitpur	111.603	Sawai Madhopur	Near Latia Nallah,Alanpur	**29**
Bansiwara	263.221	Udaipur	Savina Kheda	**44**
Ghatoli	156.858	Kota	Soraw, Tonk	**95**
Badora	78.659	Baran	Soraw, Tonk	**148**
Kapasan	112.666	Chittaurgarh	Savina Kheda, Udaipur	**41**
Lahoria	166.713	Banswara	Savina Kheda, Udaipur	**105**
Phulera	477.489	Jaipur	Bagrana near Kanota	**60**
Basi	477.489	Jaipur	Bagrana near Kanota	**2**
Baseri	109.201	Dhaulpur	Village Noh, Bharatpur	**60**

Table 4.5 The cost based optimized locations and their closest existing landfills, Rajasthan

Results are quite surprising and confirm Gupta ‘s opinion about the unscientific and chaotic waste management in India. The long distances between the optimized locations and the existing landfills may arise from two reasons. Firstly, as can be seen from the maps, the landfills tend to gather in the middle of the state, e.g eight cities near the border of the state have got no landfills. Secondly, in some cities, the landfills are established in the middle of the city. One example is the Jaipur City that has four landfills that are very close to the city center. This situation may arise when the importance of the transportation costs outweighs the NIMBY factor. Another factor may be the limited availability of trucks for transporting solid waste.

4.4 Conclusion

The aim of this study is to simplify the time consuming and costly siting process of the landfills. An approach to this difficult task may be the widely used and well-known p-median formulation. Data have been collected from the various countries of the world about the locations of the landfill sites and p-median problems have been solved for each of the regions. The p-median formulation uses a cost minimization objective and does not take into account the environmental data which is necessary to establish the technical suitability of candidate site, therefore, it was not expected to encounter with solutions which are not quite different from the existing landfill sites. Nevertheless, the goal was to explore the subject and also, explore how well the p-median model approximates the actual DMs' siting process. Another objective may be to be able understand the objectives of the DMs. Using the p-median objective is useful to understand if the DMs behave costwise or consider the NIMBY syndrome.

As far as the results are concerned, we can say that surprisingly the p-median results are more reasonable than expected, except for India. In India, there seems to be a tendency for the landfills to be built towards the middle of the region, which is propably a result of unplanned waste management as Gupta (1998) mentions. In all the countries but India that we have investigated, the optimized locations seem to provide a good match with the existing landfill locations, based on the fact that for each optimized location there is at least one existing landfill within a distance of 50 miles. This is quite consistent with the approximation procedure suggested by Mendes and Silva (1996).

4.5 The Proposed Method

Since the results obtained so far seem to indicate that the p-median solution is a good approximation to the actual decision process, now we can go one step further and suggest an iterative procedure to locate landfills. The target of the proposed method is to locate landfills on sites which satisfy both the environmental criteria and are costwise optimal. To be able to reach this target, the proposed method uses the feasibility checks and the p-median solutions repeatedly, one after the other until all of the found optimal sites satisfy the environmental feasibility criteria. In fact, the proposed method follows from the research approach explained in Section 4.2 and uses GIS as a tool to perform *posterior checking*. After the p-median solutions are found, the optimal sites are evaluated by the help of GIS, and the sites that are not feasible are eliminated. The candidate set is updated after each iteration by removal of the infeasible candidate sites. This procedure lasts when all of the optimized locations satisfy the environmental criteria represented by the GIS. The logic may be more visible when shown on diagram in Figure 4.14.

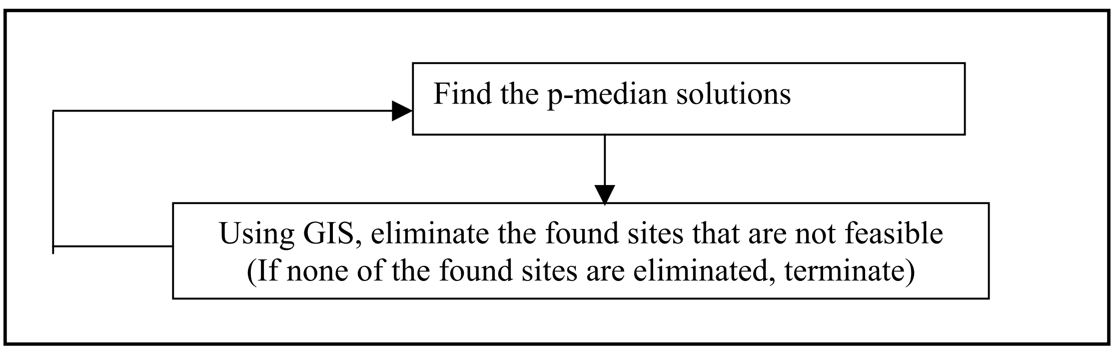


Figure 4.14 The Iterative Procedure

The proposed method needs GIS data in the elimination process, not all of the digital data needed to exclude the unsuitable areas for landfill development is available for all the studied regions. Throughout the study, we observed that for Germany, some of the technical data needed to evaluate potential sites and exclude the unsuitable sites are available. When we superimposed the maps in hand and

Figure 4.9 which shows the existing landfill sites in Hessen, none of the existing sites showed any inconsistency with any of the maps, since none of them are built on an infeasible site. Under the light of this observation, we may conclude that in the siting process of the landfills in Hessen the DMs have acted rationally. Therefore, we assume for the rest of the study that the existing landfill site locations in Hessen are costwise rational and optimal or near optimal. To have an idea on how well the method performs computationally, we used the existing landfills of Germany and determined in how many iterations the proposed method converges to the existing landfills assuming that they are minimum cost solutions among the technically feasible ones. In the German case, there is a good reason to believe that the locations of existing landfills are determined conscientously by taking into account cost objectives as well as technical admissibility criteria. The optimized solutions are matched with the existing sites that are assumed to be optimal and if all the *p* locations do not match with the existing locations, the solutions that do not match with the existing sites are eliminated. The *p*-median model is solved iteratively until all the optimized solutions match with the existing sites. The approach can be clearer when Figure 4.15 is examined.

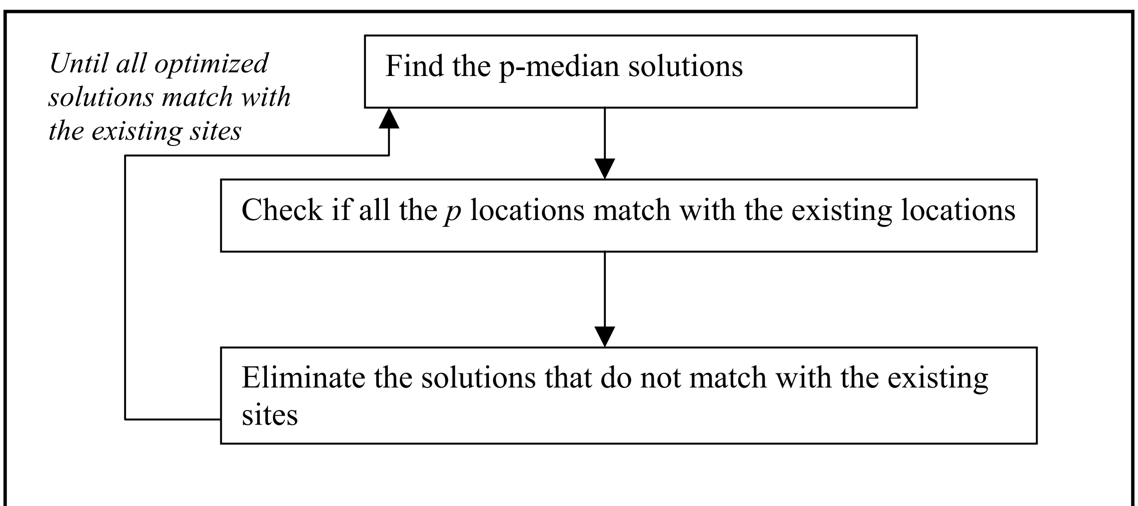


Figure 4.15 The Second Approach

This method is an exact procedure, not a heuristic, and its computational effectiveness is determined by the number of iterations. When this approach is implemented for Hessen, the following results in Table 4.6 are obtained.

HESSEN			
Iteration	**Size of Candidate Set**	**Number of matches**	**Number of sites to evaluate**
1	328	0	14
2	314	2	14
3	302	3	12
4	291	3	12
5	280	4	11
6	270	7	10
7	263	6	7
8	255	5	10
9	246	8	6
10	240	7	7
11	233	7	7
12	226	7	7
13	219	6	8
14	211	6	8
15	203	8	6
26	**176**	**14**	**174**

Table 4.6. The iterations and the size of candidate set while matching the existing locations,before preprocessing, Hessen

We observe that after 26 iterations all of the optimized locations match with the existing sites. Table 4.6 shows the size of the candidate set after each iteration, and the number of matches of optimal sites with the existing landfills. In the first iteration there is no match of optimal sites with the existing landfills and one has to make technical evaluations about 14 sites. In the second iteration, after making 14 more evaluations one sees that 2 sites satisfy the criteria, so in the next iteration, if the found optimal sites contain these two sites, the evaluations that have to be carried out falls down to 12. In the fourth iteration, one of the three found optimal sites is different than the two found in the previous iteration, so again 12 new sites have to be evaluated technically. This way, in the 26^{ith} iteration, we see that all of the found sites match with the existing landfill sites which are assumed to be costwise optimal and satisfy the environmental criteria. This indicates that if we had implemented the proposed method to site landfills in Hessen, instead of evaluating 328 candidate sites, we would have had to evaluate 174 sites, and this would have resulted in half as much work done for apriori checking.

While applying the method, we reach the optimized locations after some number of iterations. However, the effects of preprocessing on the quickness of convergence of optimal solutions to the existing sites should also be examined. By using preprocessing, we expect less number of iterations since the beginning candidate set is reduced. To check whether this statement is true, we implemented the same approach to the Hessen State with the GIS data in hand. These data include the faultline map and the groundwater level map of the State Hessen. The map in Appendix Figure A.1 is the faultline map that identifies the areas more likely for earthquakes to happen and, therefore should not be considered as potential landfill sites. Another map in the Appendix, Figure A.2, is the groundwater level map that shows proximity of the groundwater to the soil. The areas marked with red are not suitable for the building of a landfill since they pose a high risk for groundwater contamination. The final map shown in Figure A.3 shows the areas in Hessen that have a suitable soil type for the landfills. 64 candidate areas are excluded by the help of the data. The table 4.7 summarizes the results.

HESSEN		
Iteration	**Size of Candidate Set**	**Number of matches**
1	264	5
2	255	7
3	248	8
4	242	9
5	237	11
6	234	13
7	**233**	**14**

Table 4.7 The iterations and the size of candidate set while matching the existing locations, after preprocessing, Hessen

Table 4.7 shows a much quicker convergence of the optimized locations to the existing locations, which is expected since the use of the GIS data eliminates the candidate sites that do not meet the environmental criteria and decreases in the number of elements the starting candidate set.

Although using preprocessing helps us save computational time, it introduces an additional cost of evaluating potential sites. If the data is readily available, it can be used to exclude the unsuitable sites. Otherwise, it may be more costly, when compared to starting to solve the problem without preprocessing. A tradeoff between the cost of reducing the number of iterations by performing preprocessing and the cost of solving the problem without preprocessing which increases the number of iterations should be made. The DMs must be aware of this tradeoff in the siting process.

Chapter 5

Transfer Station Siting

5.1 INTRODUCTION

In recent years, a new trend that is intensified is to move from a large number of small landfills to a smaller number of larger, more remote,and regional landfills. This is a result of very large costs of building a new landfill that are beyond the means of many local governments as well as heavy regulatory and social forces. Worldwide, federal and state environmental regulations have closed thousands of small, substandard landfills and replaced them with larger, environmentally more sound landfills. For example, in the US, there are now less than 2900 municipal solid waste landfills, down from more than 20,000 in the late 1970s [Waste Age, 1999]. As older landfills near urban centers reach capacity and begin closing, cities must decide whether to construct new landfills or to seek other disposal options. Many communities find the cost of upgrading existing facilities or constructing new landfills to be rather high, and prefer to close existing facilities. Renkow (1994) mentions that significant economies of scale in landfill construction exist. To balance the high cost of constructing and maintaining a modern landfill, facility owners construct large facilities that attract high volumes of waste from a greater geographic area. The high operating costs of a landfill can be kept low by maintaining a high volume of incoming waste. Public opposition is another factor that makes siting new landfills near population centers difficult. Also, adequate land is often not available near densely populated or urban areas. These social, political, and geographical factors have further stimulated the rise in construction of large, remote, regional landfills. In these circumstances, a transfer station serves as the critical consolidation link in making cost-effective shipments to these distant facilities [EPA, 2001]. DeLong (1994) mentions that the combination of improved transportation combined with the construction of "megafills" can handle massive volumes of trash.

Solid waste transfer stations (SWTS) are facilities where solid waste is unloaded from smaller, specialized (and less efficient) collection vehicles and reloaded onto larger (and more efficient on a cost per weight basis), long haul trucks or trains that convey the wastes to a somewhat remote landfill or other treatment or disposal facilities [EPA, Waste Transfer Stations, 2002].

In the transfer stations, the waste is compressed by the help of special hydrolic compresses and the density of the waste is increased by two or three times. At many transfer stations, workers screen incoming wastes on conveyor systems, tipping floors, or in receiving pits in order to separate recyclables and any wastes that might be inappropriate for disposal from the waste stream (e.g., whole tires, auto batteries, or infectious waste). No long-term storage of waste occurs at a transfer station; waste is quickly consolidated and loaded into a larger vehicle and moved off site, usually in a matter of hours.

The primary reason for using a transfer station is to reduce the cost of transporting waste to disposal facilities. Consolidating smaller loads from collection vehicles onto larger transfer vehicles reduces hauling costs by enabling collection crews to spend less time in traveling to and from distant disposal sites, and more time in collecting waste. This also reduces fuel consumption and collection vehicle maintenance costs, plus produces less overall traffic, air emissions, and road wear [EPA, 2001].

Besides the savings obtained, Erkip and Kırca (1988) summarize the following benefits of SWTS:

- Labor force is more effectively utilized since more time is spent on collection.
- The rate of response to service calls is increased as collection vehicles are not away from the area in which they operate.
- Installations of sorting and separation facilities within the transfer stations may become economical as the loss in the quality and therefore in value of sorted material is kept at a low level by transporting them to smaller distances (compared to transporting them directly to waste processing plants).
- Screening for inappropriate wastes is more efficient at the transfer station than at the landfill.
- Main roads to landfill areas or processing plants are less congested as one transfer vehicle replaces a certain number of collection vehicles).

Moving of landfills away from populated areas to remote locations makes the construction of SWTS economically justified if the savings in haul costs is likely to exceed its operational and financial costs. Decision-makers need to weigh the planning, siting, designing, and operating costs against the savings the transfer station might generate from reduced hauling costs. According to the draft study by EPA on *Waste Transfer Stations*, although cost-effectiveness will vary, the transfer stations become economically viable when the hauling distance to the disposal facility is greater than 15 to 20 miles. Also, Erkip and Kirca (1988) mention that the transfer stations become especially important when disposal sites are at least 30 kilometers away from the metropolitan areas.

The EPA report also represents a "cost versus miles" relationship diagram between direct hauling waste to disposal facilities in collection vehicles versus consolidation, transfer, and hauling in larger vehicles. Figure 5.1 illustrates how the cost per ton-mile advantage for the hauling vehicle overcomes the initial cost of developing and operating the transfer station.

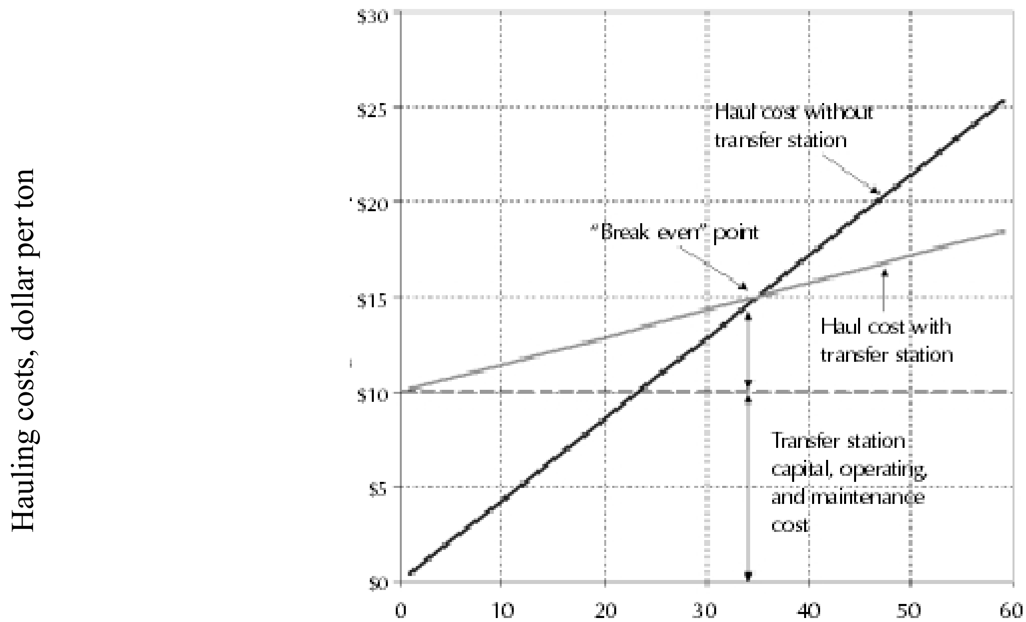


Figure 5.1 Sample Comparison of Hauling Costs With and Without a Transfer Station

In this example the following assumptions are made for the comparison:

- Cost to build, own, and operate transfer station—dollars per ton $10
- Average payload of collection truck hauling directly to landfill—tons 7
- Average payload of transfer truck hauling from transfer station to landfill—tons 21
- Average trucking cost (direct or transfer hauling)—dollars per mile $3

Under these assumptions, the cost per ton per mile for a collection vehicle is $0.43 ($3/mile truck operating cost divided by 7 tons per average load). In the EPA' s example, the transfer hauling vehicle's cost per ton-mile is much lower, at $0.14 ($3 divided by 21 tons per average load). In this example case, the break-even point is 35 miles, which means that cost savings begin when the round trip hauling distance exceeds 35 miles (17.5 miles one way). It is clear that the breakeven point shows variation since the costs of building, operating, and maintaining collection vehicles depend on the local parameters.

5.2 General Information about Transfer Stations

Figure 5.2 Tipping floor in the Transfer Station

The area where the trucks empty their loads of trash inside the transfer station building is called the "tipping floor". In Figure 5.2, the truck in the background is dumping its load directly onto the floor. In the foreground, the loader moves the refuse dumped by another truck into the top of the compactor. The compactors, located near the tipping floor, will compact the waste and push it into containers. The waste is then taken into trucks and transported to the landfills.

Figure 5.3 Compressors in the Transfer Station

Waste transfer stations include more than just the tipping area. The loads of waste received from the tipping floor are sent to the hydraulic pumps and cylinders that compact the waste. After the waste is compacted, the refuse is pushed to containers on the trucks. These containers are then shipped to the landfill or the other disposal sites.

Figure 5.4 Aerial view of a totally enclosed transfer station.

5.3 Transfer Station Siting

5.3.1 Literature on The Location of Transfer Facilities

The concept of selecting intermediate points for transfer of materials in order to minimize transportation costs is first utilized in a Ph.D dissertation by Marks (1970). The model is a mixed integer capacitated transshipment facility location problem and models potential transfer stations as having fixed costs. The problem is to find which transfer facilites should be built and which demand points and disposal sites each facility serves, so that the total cost of facilities and transshipment is minimized. This model is a basic model for the transfer station siting problems in the literature, since most of the subsequent models are the modifications of this model.

In the model, there is a set, I , of demand points with an amount of S_i at each source. In addition, there is a set of final disposal sites, K , each with an upper and lower bound on demand of D_k^u and D_k^l . A set of proposed transfer facility sites, J , has been suggested as transshipment points between the demand points and the disposal sites. Each proposed facility has a fixed charge, F_j , a variable unit cost, v_j , which is linear function of the amount shipped through the facility, and a capacity Q_j. y_j is a zero/one variable which takes the value one 1 one if j is assigned to a transfer station and 0 otherwise. The model is:

$$Min \quad \sum_{j=1}^{m} F_j y_j + \sum_{j=1}^{m}\sum_{k=1}^{n} c_{jk} x''_{jk} + \sum_{j=1}^{m}\sum_{i=1}^{p} c_{ij} x'_{ij} \qquad (1)$$

s.t

$$\sum_{j=1}^{m} x'_{ij} \geq S_i \qquad i = 1,2,....,p \qquad (2)$$

$$\sum_{k=1}^{n} x''_{jk} = \sum_{i=1}^{p} x'_{ij} \qquad j = 1,2,....,m \qquad (3)$$

$$\sum_{i=1}^{p} x'_{ij} \leq Q_k y_k \qquad j = 1,2,....,m \qquad (4)$$

$$D_k^u \geq \sum_{j=1}^{m} x''_{jk} \geq D_k^l \qquad k = 1,2,....,n \qquad (5)$$

$x'_{ij,} x''_{jk}$, non-negative integers

Constraint (2) expresses the requirement that flow from the demand point cannot exceed the supply of material there. Constraint (3) states the conservation of flow requirement that the flow entering the j^{th} facility must be equal to the flow leaving it. Constraint (4), appropriately relates the flow variables to location variables. If the j^{th} facility does not exist, y_j =0 and no flow may take place through it. Constraint (5) specifies that flow to sink k must be between the upper and lower bound on the capacity of the sink.

Marks and Liebman (1971) provide several modifications on the basic model. Transport costs are introduced to include the trips from the collection areas to the disposal facilities.

Harvey and O`Flaherty (1972) formulate a model that considers from among several alternatives which landfills and transfer stations should be selected for opening. A mixed integer linear programming formulation was used to determine least cost solutions for various population growth patterns. The model is similar to the one developed by Marks and Liebman (1971) since it also allows transfers between the demand points and the landfills and includes the operating cost of the landfills. All the costs used in the model are considered on a present worth basis over fifteen years. The model is applied to a study area with 14 demand points, 5 candidate transfer sites, and 3 candidate landfill sites.

Jenkins (1982) uses a fixed charge model to locate reclamation and disposal facilities for the Metropolitan Toronto. The model is a mixed integer problem that minimizes the cost of transportation, facility capital costs and facility operating costs after the revenue from sale of reclaimed materials are subtracted. The model is applied to Toronto region for 167 demand points, 19 candidate transfer stations, and eight possible landfills.

Yurteri and Siber (1985) present a linear transportation model to select the locations of the transfer stations. The potential cost reductions are investigated through transferred operations. The model limits itself to the optimum allocation of solid wastes from the collection districts to the proposed transfer station sites, depending on certain unit costs and subject to a set of constraints. The model is applied to the solid waste collection system in Ankara for different capacity alternatives for the purpose of investigating the advantage of transfer.

Kirca and Erkip (1988) utilize a cost minimization approach to locate transfer facilites by presenting a classical capacitated warehouse location model. The model specifies a tradeoff between relative costs of carrying waste by different transportation modes. It is assumed in the model that unit cost of transportation by collection vehicle is more expensive compared to transportation by transfer vehicles. One of the objectives of the study is to suggest alternative locations and an investment plan for transfer stations for the metropolitan city of Istanbul.

Rahman and Kuby (1995) modify and extend the formulation of Marks and Liebman (1970) by considering public opposition as a second objective function. The second objective function is to minimize the public opposition and is derived empirically from an opinion survey data (Rahman, et al. 1992). This research adds another dimentions to solid waste location problem, since none of the earlier location models take into account undesirability on the actual basis of a survey of how people feel about undesirability.

5.3.2 The Actual Transfer Station Siting Process

Richard Peluso, professional engineer and senior vice president of Emcon, a national environmental services firm, explained that when siting a transfer station, a municipality or company first looks for locations zoned for transfer stations, in the National Environmental Justice Advisory Council (NEJAC) held by EPA. Peluso says that, the site must be large enough to handle the design requirements for the daily waste volume and to allow for quick truck unloading times. Sites also must have easy access to local utilities. In most cases, sites must be industrial areas [Waste Age, 1999]. Next, he explains that local transportation infrastructure is analyzed, including accessibility to the interstate or limited access highways and local transportation patterns. The best sites are streets designated as commercial routes.

According to Peluso, the quality and cost of transportation routes determine whether the trash will be shipped by truck, or by train. Trucking generally is the least expensive way to transport solid waste, especially for shorter distances. Hauling by rail requires larger amounts of trash to be hauled longer distances to reach economies of scale. Peluso says that transfer stations have to satisfy many local requirements and zoning rules.

EPA's report on Siting and Operating Waste Transfer Stations summarize the site selection factors. The report mentions that the below issues will vary according to urban, rural, or suburban settings,

1.Physical Features

- Existence of buffer and natural screening (e.g., natural vegetation, elevation differential)
- Wind direction with respect to adjacent land uses
- Conditions that would impact site development (e.g., shallow groundwater or bedrock)

- Prior site uses that could impact site development (e.g., buried tanks)
- Site usability constraints (e.g., easements, pipelines, rights-of-way)
- Potential expansion as region grows and waste volume increases
- Existing site constraints such as wetlands, utility easements, etc.

2. Location

- Zoning or land use restrictions
- Compatibility with existing and projected land uses
- Setbacks and isolation from sensitive areas
- Cost of land and number of owners involved in consolidating the properties into one parcel
- Taxes, fees, surcharges, and host community benefits costs

After the technical feasibility of the candidate sites has been determined, the DMs generally use the weighting methods in the siting process, similar to the landfill siting process discussed in Section 3.3.2.2.1. The weighting methods may involve subjectivity and inconsistency. In order to overwhelm the situation, in the next section, we propose a new model for the siting of the landfills and transfer stations. The section also analyzes the collection of the solid waste by the collection trucks.

5.4 The Problem Statement

The obnoxious features of a SWTS (traffic, noise, odor, unsightliness, other people's trash) have stirred up public opposition, making them nearly impossible to site as landfills [Rahman and Kuby, 1995]. In this chapter, we propose a mixed integer model based on a cost minimization objective to determine the locations of the transfer stations as well as the landfills. Before describing the model, information about the waste collection operation and the network, in which it is implemented, is discussed.

Suppose we are given a network, $G=(N,E)$, with $N=\{1,..,n'\}$ being the node set and E being the arc set, illustrated in Figure 5.5. We assume that the nodes

1,..,n are the demand points which generate waste. Let $D = \{1,...,n\}$ and refer to the set D as the demand set. We can define another set of nodes $T = \{n+1,...,n+t\}$ as candidate locations for transfer points of the network that act as links between waste generation points and disposal sites. The candidate disposal sites are defined by another set of nodes $L = \{n+t+1,...,n+t+l\}$. The arc set E is composed of the road segments in the network. The sets T and L need not be disjoint; however, generally, the set D can not be considered as part of candidate sites for transfer stations or landfills due to proximity constraints to urban areas. Associated with each arc $(i,j) \in E$ and $(j,k) \in E$ $d_{ij} > 0$ and $d_{jk} > 0$, represent the length of the shortest path, connecting nodes. Similarly, associated with each arc, there is a cost of transportation, c_{ij} and c_{jk}.

The collection trucks of given tons of capacity collect the waste from each generation (demand) point and carry the waste to a transfer point where the waste is consolidated from multiple collection vehicles into larger, higher volume transfer vehicles for more economical shipment. The emptied collection truck goes back to the generation point if there remains any waste to be collected. If not, it goes back to the garage. In the transfer stations, waste is loaded into larger vehicles for long haul shipment to a final deposit site, typically a landfill.

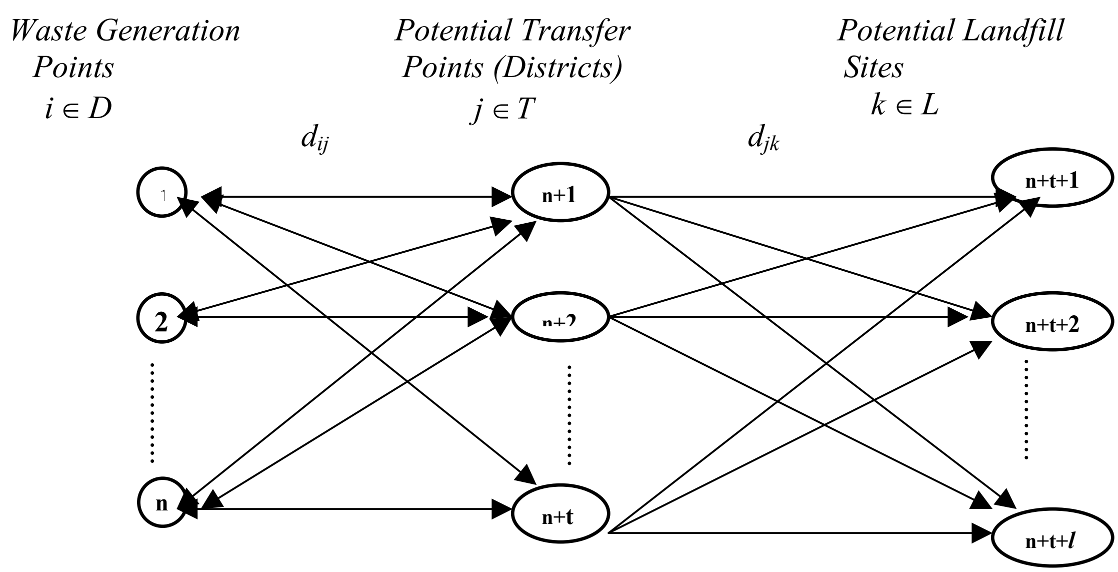


Figure 5.5 The Waste Collection Network

5.4.1 The Model

The assumptions of the model are as follows:

- The waste is collected from the centroid of the generation points (districts).
- The alternative sites for the building of the transfer points (stations) and landfills are known.
- The capacities of the collection trucks that carry the waste to the transfer stations are the same.
- The capacity of the long hauling trucks that carry the compacted waste from the transfer stations to the landfills are the same.
- Each district can be served by one transfer station; fractional service is not allowed for the districts.
- The model assumes a fixed number of trips of collection trucks between the districts and stations.
- When a collection truck is emptied in the transfer station, it goes back to the garage if there is no waste to be collected in the districts.
- The landfills and transfer stations are uncapacitated. Each district sends its waste to the closest transfer station, and the waste is transferred to the nearest landfill from the transfer stations.
- There is a sufficient number of long haul trucks available in the transfer stations to transfer the waste to the landfills at one time. Consequently, the non-availability of long haul trucks in transfer stations is not an issue in the model. The model, however, uses only as many long haul trucks as needed to satisfy this assumption by assigning an appopriate cost to each long-haul truck trip.
- There is one collection truck operating for each district.
- The cost of opening a transfer station is the same for all candidate sites. The assumption holds also for the landfills.

Parameters of the model are as follows:

$n =$ Total number of the waste generation points from where the waste is collected

$t =$ Total number of potential sites for the building of the transfer stations

$l =$ Total number of potential sites for the building of the landfills

$d_{ij} =$ The shortest path distance between the generation point i and the candidate transfer site j in kilometers

$d_{jk} =$ The shortest path distance between the transfer station j and the candidate landfill site k in kilometers

$g_i =$ The amount of waste generated by the generation point i

$c_1 =$ The total cost of loaded trips of a collection truck per km

$c_2 =$ The total cost of empty trips of a collection truck per km

$c_3 =$ The cost of a trip of a long haul truck per km

$F_j =$ The fixed cost of building a transfer station at point j

$F_k' =$ The fixed cost of building a landfill k

$C =$ The capacity of a long hauling truck

$M =$ A sufficiently large number

The decision variables are as follows:

$$x_j = \begin{cases} 1 & \textit{if a transfer station is built at site } j \\ 0 & \text{otherwise.} \end{cases}$$

$$y_k = \begin{cases} 1 & \textit{if a landfill is built at site } k \\ 0 & \textit{otherwise.} \end{cases}$$

$$v_{ij} = \begin{cases} 1 & \textit{if the waste generated by district } i \textit{ is transported to a transfer point } j \\ 0 & \textit{otherwise.} \end{cases}$$

$$u_{jk} = \begin{cases} 1 & \textit{if the transfer point at site } j \textit{ sends its waste to a landfill at site } k \\ 0 & \textit{otherwise.} \end{cases}$$

$n_{jk} =$ *the number of long haul trips taking place between the transfer site at site j and the landfill at site k*

Since, we assumed that there are enough number of long haul trucks to carry the waste to the landfills, n_{jk} can be considered as the number of long haul trucks that should be made available at the transfer station

The mathematical formulation of the model is as follows:

$$Min \sum_{i\in D}\sum_{j\in T}(c_1+c_2)v_{ij}d_{ij}+\sum_{j\in T}\sum_{k\in T}c_3 n_{jk}d_{jk}+\sum_{j\in T}F_j x_j+\sum_{k\in L}F_k' y_k \qquad (1)$$

s.t.

$$\sum_{j\in T} v_{ij} = 1 \qquad \forall\ i\in D \qquad (2)$$

$$v_{ij} \le x_j \qquad \forall\ i\in D\ and\ j\in T \qquad (3)$$

$$u_{jk} \le y_k \qquad \forall\ j\in T\ and\ k\in L \qquad (4)$$

$$\sum_{k\in L} u_{jk} = x_j \qquad \forall\ j\in T \qquad (5)$$

$$n_{jk} \le u_{jk}\mathrm{M} \qquad \forall\ j\in T\ and\ k\in L \qquad (6)$$

$$n_{jk} \ge \frac{\sum_{i\in N} g_i v_{ij}}{C}+(y_k-1)\mathrm{M} \qquad \forall\ j\in T\ and\ k\in L \qquad (7)$$

$$x_j = 0\ or\ 1 \text{ for } \forall\ j\in T \qquad (8)$$

$$y_k = 0\ or\ 1 \text{ for } \forall\ k\in L \qquad (9)$$

$$v_{ij} = 0\ or\ 1 \text{ for } \forall\ i\in D\ and\ j\in T \qquad (10)$$

$$u_{jk} = 0\ or\ 1 \text{ for } \forall\ j\in T\ and\ k\in L \qquad (11)$$

$$n_{jk} = \text{non-negative integer} \qquad \forall\ j\in T\ and\ k\in L \qquad (12)$$

There are other costs including the total cost of the trips of collection trucks from the garage to the districts, plus, the total cost of the return trips of collection trucks from the transfer stations to the garage, and the cost of collecting the waste within the districts. These costs add up to a constant which does not depend on or affect the decisions of the model.

The objective function represents the cost function to economically locate landfills and transfer stations. The first two sets of terms in (1) compute the total cost of short haul collections and long haul transfers. The third and the fourth terms add the capital cost of opening a transfer station and a landfill. The first constraint (2) represents that no district can be served by more than one transfer station. The second constraint (3) ensures that a district cannot send its waste to a transfer station, unless the transfer station is open. The constraints (4) and (5) together provide that a transfer from a transfer station to a landfill is possible only if both the transfer station and the landfill are open. Constraint (6) ensures that if a transfer does not exist between a transfer station and a landfill, then the number of the trips between them is zero. Constraint (7) represents the number of long haul trips that should be made in order to transfer all the collected garbage from a transfer station to a landfill.

5.4.2 Application of the Model for Ankara

5.4.2.1 General information about waste collection in Ankara

In Ankara, when a collection truck becomes full, it goes directly to the dumpsite, Mamak, to unload its waste, and then returns to the same district to collect the remaining garbage. This trip takes slightly more than one hour on the average. The officers in the cleaning departments of the municipality complain that the transportation costs of the collection trucks make up about 90% of their budget and add that building of transfer stations will definitely reduce the costs and, decrease the under-utilization of trucks and increase the efficiency for the waste collection. Therefore, we apply the above model for the city of Ankara in order to locate transfer stations. Besides, the existing landfill, Mamak, poses a threat for the environment and cannot satisfy the needs for Ankara anymore, so the model also seeks for a potential landfill site for the city.

The city of Ankara is divided into seven main municipalities that have their own cleaning departments that are responsible for the collection of waste from the districts within their boundaries. These seven main municipalities are Etimesgut, Yenimahalle, Altindag, Çankaya, Keçiören, Mamak, and Gölbaşı. There are 354 districts within the boundaries of these seven municipalities.

5.4.2.2. Collection of the Data

Firstly, the potential sites for the building of the transfer stations and landfills are determined. This phase is based on the examinations of the city plans for the future, the borders of the main municipalities, and conversations with the officers in the construction department who are responsible for the siting permits. The Metropolitan Area Planning Bureau of Ankara has been studying the closing of the Mamak dump and selecting of a new site since 1990. The siting process has ended with the conclusion that a new solid waste deposit site would be built in Yenikent, Sincan. The conclusion also covered the introduction of four new transfer stations into the solid waste collection system in Ankara. The Planning Bureau explained that these four sites were choosen because they were the only sites that approved the land and sanitation requirements and the monthly capacity requirements. These sites for the new landfill and the transfer stations are marked in Figure 5.6. The blue boxes show the candidate transfer sites. For the model, we chose a candidate set of 53 sites for both the landfill and the transfer stations. These sites are out of the boundaries of the main municipalities, but inside the boundaries of Ankara, and are marked with red points in Figure 5.6.

Secondly, information about the waste generation of the 354 districts is collected. Lastly, the road network is identified between each district and potential sites. This phase is the most difficult part because although the Metropolitan Municipality has all the data, they do not want to share it with the public, even for academic purposes. Using the GIS data, the actual shortest path distances between all candidate transfer stations and landfill sites are calculated. This data is taken from the Database Management Department of the Metropolitan Municipality and took about one month to collect.

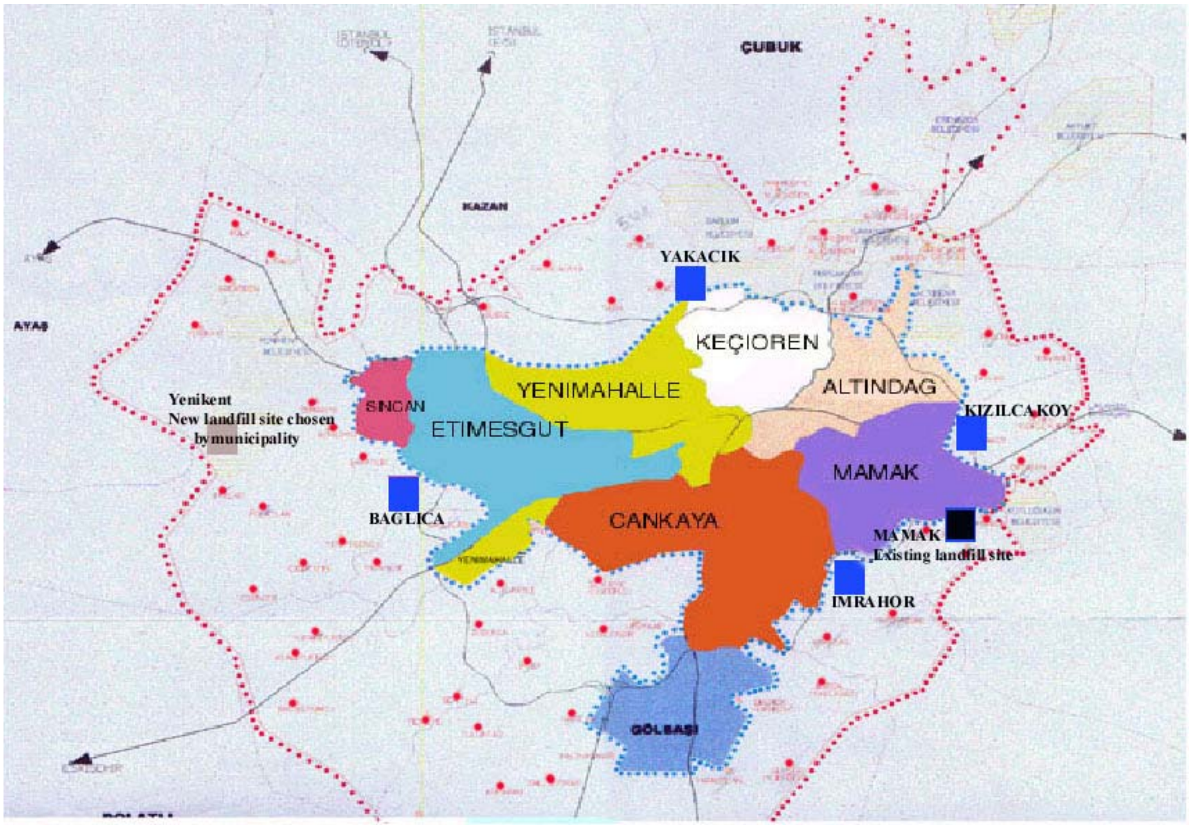


Figure 5.6 Locations of candidate transfer stations and landfills used in the model for Ankara

5.4.2.2. Computational Results

We solved the model for three scenarios.

(1) The model is solved for the four candidate transfer station sites chosen by the municipality: Bağlıca, Kızılcaköy, Imrahor, and Yakacık. There are 354 demand points, 4 candidate transfer stations, and 53 candidate landfill sites in the model.

(2) The model is solved for 354 demand points, 57 candidate transfer station sites, and 53 candidate landfill sites. The candidate set for transfer stations includes the 53 candidate sites for landfills as well as the four candidate sites proposed by the municipality.

(3) The model in the second scenario does not have any constraints to limit the number of open transfer stations, so in the third scenario we limit the open number of transfer stations to 4.

We solved the model with the collected data using **CPLEX 7.1**. For each scenario, the number of variables, constraints and the CPU times are reported in the following table.

SCENARIO	*NUMBER OF VARIABLES*	*NUMBER OF CONSTRAINTS*	*CPU (SECONDS)*
1	1896	2410	139.87
2	26330	29652	628166.78
3	26330	29653	457337.77

Table 5.1 Number of variables, constraints and the CPU times for each scenario

(1) The results of the first scenario show that the optimal location for the new landfill site is *Kusunlar* which is surprisingly very close to the existing landfill in Mamak. Also, the results show that all of the four candidate transfer stations should be opened. Figure 5.7 summarizes the found optimal locations. The objective function value and the number of trips between the transfer stations and the landfill is shown in Table 5.2.

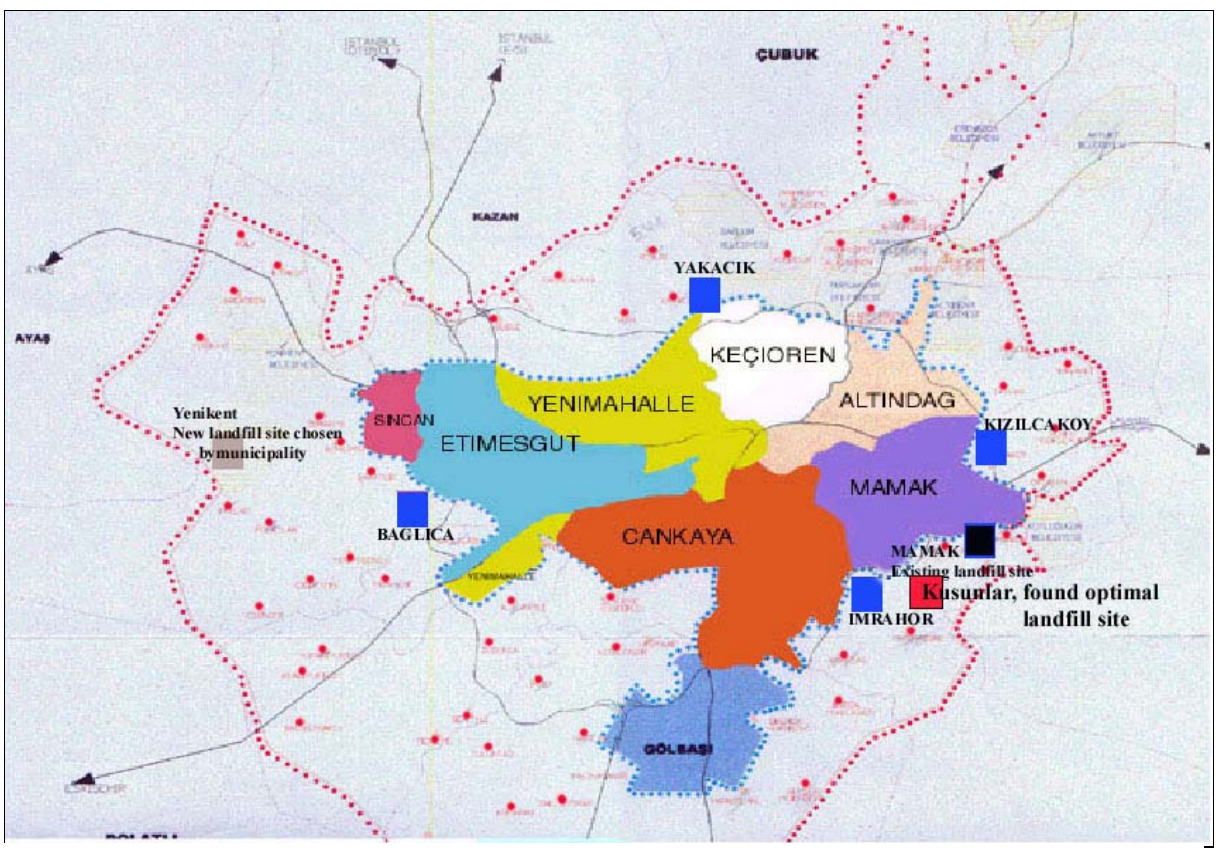


Figure 5.7 Locations of found optimal locations for transfer stations and landfills, when only four transfer stations are allowed to open.

OBJECTIVE FUNCTION VALUE	*19 904 798 382 000*
Number of trips need for long haul trucks to the optimal landfill sıte in Kusunlar	
Bağlica	5
Kızılcaköy	7
Yakacık	5
Imrahor	8

Table 5.2 Results of scenario 1.

(2) As far as the results of the second scenario are concerned, the optimal location for the new landfill is again in *Kusunlar*. We imposed no limits in the model on the number of open transfer stations the model found nine optimal locations for the building of the transfer stations.Figure 5.8 shows the optimal locations of the transfer stations and the landfill.

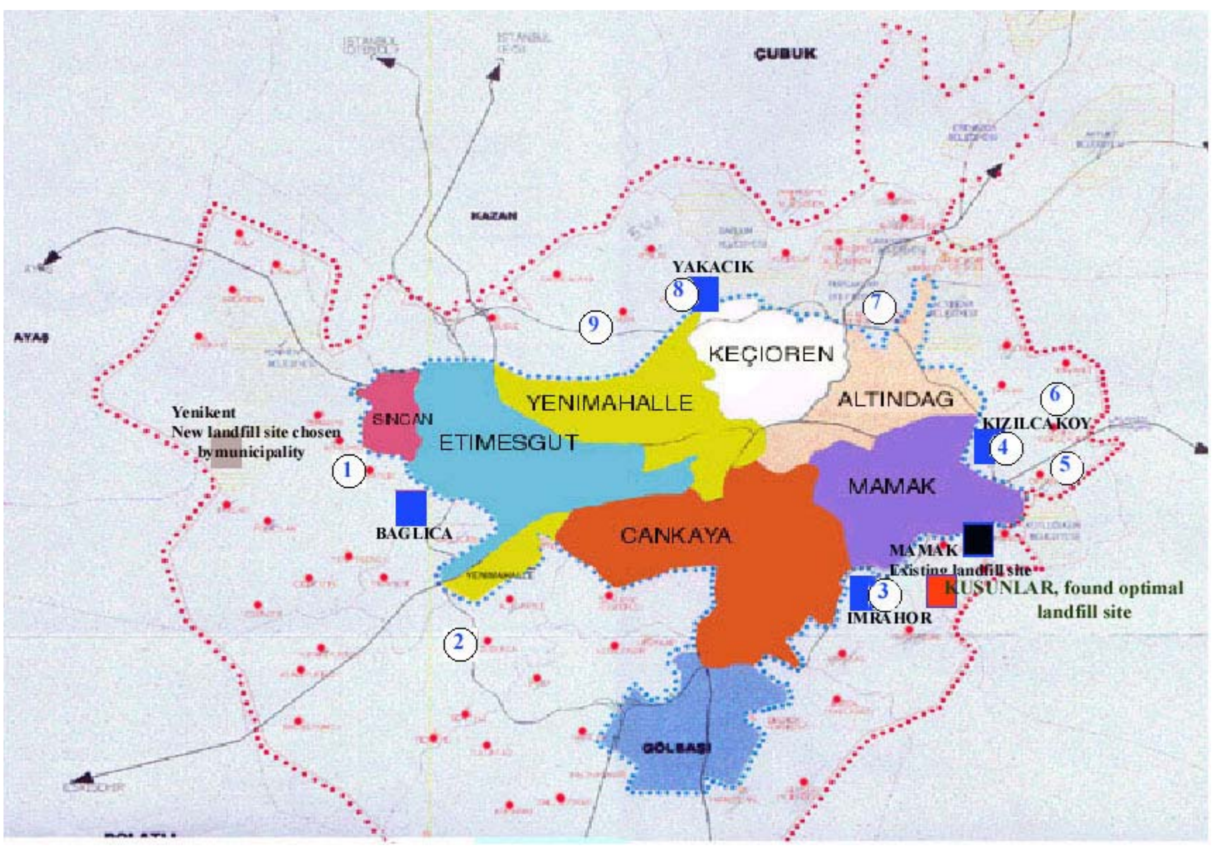


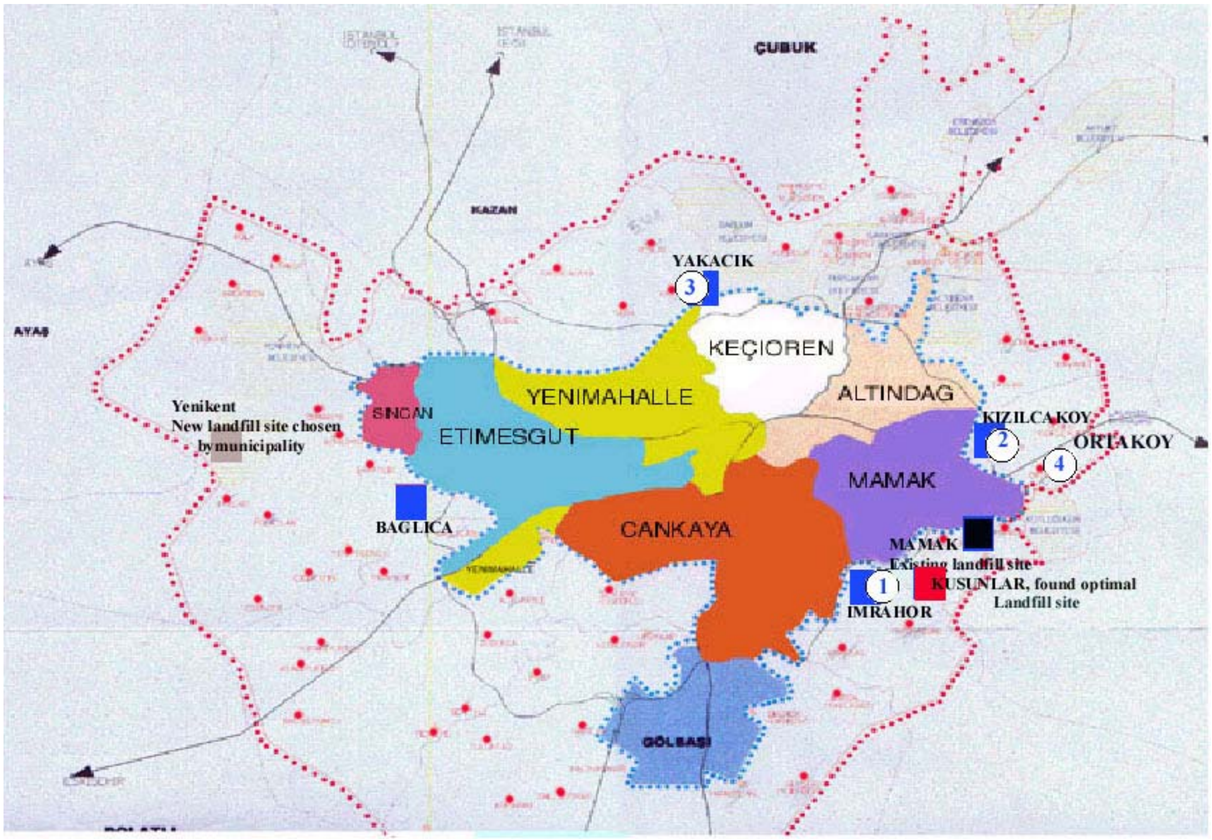
Figure 5.8 Locations of found optimal locations for transfer stations and landfills, when there is no limit on the number of open transfer stations.

Figure 5.8 shows that three of the optimal transfer station sites match with the sites chosen by the municipality and that the fourth optimal site is close to the prosed one in Baglica. The objective function value and the number of trips between the transfer stations and the landfill is shown in Table 5.3.

OBJECTIVE FUNCTION VALUE	*17 412 289 603 000*
Number of trips need for long haul trucks to the optimal landfill sıte in Kusunlar	
Saraycık	2
Dodurga	2
Ortaköy	3
Kızılcaköy	2
Gökçeyurt	2
Kocaören	2
Yuva	1
Yakacık	8
Imrahor	3

Table 5.3 Results of scenario 2

In the third scenario, we limit the allowable number of open transfer stations to four, since the municipality is also considering opening four stations. The results show that again the optimal location for siting a new landfill is *Kusunlar*. Figure 5.9 shows the optimal locations of the transfer stations and the landfill.



5.9 Locations of found optimal locations for transfer stations and landfills, when the allowable number of open transfer stations is four.

When Figure 5.9 is examined, it is visible that three of the optimal transfer station sites match with the four sites chosen by the municipality. The objective function value and the number of necessary trips between the transfer stations and the optimized landfill is summarized in Table 5.4.

OBJECTIVE FUNCTION VALUE	*18 437 014 760 000*
Number of trips need for long haul trucks to the optimal landfill sıte in Kusunlar	
Ortakoy	4
Kızılcaköy	13
Yakacık	4
Imrahor	5

Table 5.4 Results of scenario 3

Chapter 6

Summary and Conclusions

This thesis is on the siting of municipal solid waste landfills and transfer stations. Siting of these facilities is one of the critical challenges in solid waste management, since the siting process requires very detailed analysis of various aspects. We first provided a background to the reader about various issues in solid waste management in Chapter 2. This chapter is more like an introduction to the context of solid waste management and does not involve much information about the siting process; however, it gives the reader some insights about why the landfill siting process is a real challenge.

The siting of landfills and transfer stations is mostly in the hands of local authorities that generally apply very long, detailed and costy evaluations in the site selection process. Mostly, such a detailed process requires a multidisciplinary analysis which most of the authorities cannot afford to provide. Therefore, most of the chosen landfill sites cannot satisfy people`s needs anymore and constitude an environmental threat to human life. Another group of people working on landfill siting are the researchers who model the siting problem using mathematical modeling. According to Erkut and Neuman (1989), there is no one model that can determine the optimal location of a landfill, since the problem is very complex, and analytical methods treat only a small fraction of the issues. In fact, the models discussed in the literature review should be considered to aid in the decision process, not replace it. This is also akin to Marks and Liebman (1970) who mention that solid waste problems are mostly parts of the public sector and have a more vague and more difficult-to-express objective function than usual. They further mention that the models in the literature should be used carefully while appreciating the factors that the models cannot consider explicitly. While the cost minimization is given the predominant objective in the models, the DMs consider mostly the environmental feasibility of the candidate sites. On the other hand, the communities are getting more conscious about environment and NIMBYism is getting more common. We conduct a study on landfill siting to simplify the actual siting procedure and to understand the objectives of the DMs in Chapter 4.

In Chapter 4, we aim to understand how the p-median model approximates the actual process of the siting of the landfills without taking into account the physical, social, economic and political constraints. We model *p*-median problems for regions of Turkey, Germany, and India and compare the optimal solutions with the existing site locations. The results obtained show that *p*-median provides a quite good approximation for the actual siting process, since except for India, we found an an existing landfill within 50 miles of each optimal site as suggested by Mendes and Silva (1996). The distances between the optimized locations and the existing landfills are more in India, which can be a result of insufficient importance given to environmental problems. The results obtained also indicate that the DMs do not take into account the NIMBY syndrome so much, since the cost minimization objective of the p-median model provided a pretty good match with most of the existing landfill sites. We also proposed a new method on the siting of the new landfills that is based on a p-median model and GIS to assess the environmental feasibility of a candidate site. The method aims to find landfill site locations that are costwise optimal while also satisfying the environmental criteria.

As a final topic, we analyze the siting of the transfer stations which are a result of the trend about regional solid waste management in the world. Transfer station siting is as difficult as the siting of the landfills and requires a detailed analysis of many factors as in the siting of landfills. In Chaper 5, we proposed a new model for the site selection of transfer stations. The model is applied for Ankara for three cases.

Bibliography

Allanach, W.C., 1992, Regional Landfill Planning and Siting, Public Works, December 48-50.

Antunes, A.P., 1999, "Location Analysis Helps Manage Solid Waste in Central Portugal", *Interfaces* 29/4, 32-43.

Atkinson, S.F., Schoolmaster, A.F., Lyons, D.I, and Coffey, J. M., 1995, "A Geographic Information Systems Approach to Sanitary Landfill Siting Procedures: A Case Study", The *Environmental Professional* 17, 20-25.

Bagchi, A., 1994, Design, Construction and Monitoring of Landfills, 2nd edition

Barlishen, K.D, and Baetz B.W, 1996, "Development of a Decision Support System for MSW Management", *Waste Management & Research*, Vol. 14, pp. 71-86.

Basagaglu, H., Celenk, E., Marino, M., and Usul, N., 1997, "Selection of Waste Disposal Sites using GIS", *Journal of the American Water Resources Association*, 33(2): 455-462.

Camp Dresser and McKee, 1984, Cumberland County Landfill Siting Report, Camp Dresser & McKee Inc., Edison, N.J.

Canter, L., Knox, R., and Fairchild, D., 1987, Groundwater Quality Protection. Lewis Publishers, Chelsea, Mich.

Caruso, C., Colorni. A., Paruccini, M., 1993, "The Regional Urban Solid Waste Management System: A Modeling Approach", *European Journal of Operational Research* 70, 16-30.

Chapman, R., Berman, E., 1983, "The Resource Recovery Planning Model: A New Tool for Solid Waste Management", Special Publication 657, Washington, DC, USA: US Department of Commerce/National Bureau of Standards.

Chapman, R.E., and Yakowitz, H., 1984, “Evaluating Risks of Solid Waste Management Programs: A Suggested Approach”, *Resources and Conservation* 11, 77-94.

Church, R.L., Garfinkel, R.S., 1978, “Locating an Obnoxious Facility on A Network”, *Transportation Science* 12, 107-118.

Clark, R.M, 1974, Solid Waste Management and Models, Models for Environmental Pollution Control (R.A Deininger, ed.) Michigan: Ann Arbor, pp. 269-305.

DeLong, J.V., 1994, “Mismanaging Municipal Solid Waste”, *Competitive Enterprise Institute Monograph.*

DRASTIC,1987, A Standardized System for Evaluating Groundwater Pollution Potential Using Hyrogeologic Settings, United States Environmental Protection Agency.

Economopoulos, A.P, 1993, Management of Solid Wastes. 1–40 Assessment of Sources of Air, Water, and Land Pollution: Part Two Rapid Inventory Techniques in Environmental Pollution Geneva: WHO.

Erkut, E., and Neuman, S., 1989, “Analytical Models for Locating Undesirable Facilities”, *European Journal of Operational Research* 40, 275-291.

Erkut, E., Moran, S.R., 1991, “Locating Obnoxious Facilities in the Public Sector: An Application of the Analytical Hierarchy Process to Municipal Landfill Siting Process”, *Socio-Economic Planning Science* 25, 89-121.

Erkut, E., and Bozkaya, B., 1999, "Analysis of Aggregation Errors for the p-Median Problem," *Computers & Operations Research*, Vol. 26, No. 10-11, pp. 1075-1096

Goldman, A.J., and Dearing, P.M, 1975, “Concepts of Optimal Locations for Partially Noxious Facilities”, *Bulletin of Operational Research Society of America* 23/1, B 85.

Gottinger W., (1988) “ A Computational model for solid waste management with application”, *European Journal of Operational Research* 35, 350-364

Göttinger, H., 1987, “A Long-Range Planning Model for a Resource Recovery Plant” Hazardous Material Disposal: Siting and Management, Edited by Manas Chatterji, Gower Publishing Company, Brookfield, Vermont.

Greenberg, M., Caruana, J., and Krugman, B., 1976, “Solid waste management: A Test of Alternative Strategies Using Optimization Techniques”. *Environment and Planning* A8, 587-597.

Gupta, S., Krishna, M., Prasad R.K., Gupta, S., and Kansal, A.,1998, Resources, Conservation and Recycling 24 (2): pp. 137-154

Hakimi, S.L., 1964, “Optimal Location of Switching Centers and the Absolute Centers and Medians of a Graph,”,, *Operations Research*, 12, 450-459.

Hakimi, S.L., 1965, “Optimum Distribution of Switching Centers in a Communication Network and some Related Graph Theoric Problems”, *Operations Research* 13, 462-475.

Ham, R. K., 1993, "Leachate and Gas Generation," in Geotechnical Practice for Waste Disposal, D. E. Daniel, ed., Chapman and Hall, London, p. 113 - 36.

Harvey, D.J., and O’Flaherty, T.G., 1973, “An analysis of solid waste transportation and disposal alternatives”, *INFOR* 11, 187-200.

Hasit, Y., and Werner, D.B., 1981, “Regional Solid Waste Planning with WRAP” *Journal of Environmental Engineering ASCE*, 107, 511-524.

Helms, B.P., and Clark, R.M., 1971, “Locational Models for Solid Waste Management”, *Journal of Urban Planning and Development Division*, 97/SA2.

Jenkins, L., 1982, “Developing a solid waste management model for Toronto”, *INFOR* 20, 237-247.

Kao, J.-J., Lin, H.-Y and. Chen, W.-Y, 1997, “Network Geographic Information System for Landfill Siting”, *Waste Management & Research* 15: 239-253.

Katı Atıkların Kontrolü Yönetmeliği, 1991, T.C Çevre Bakanlığı.

Kemper, P., and Quigley, J.M., 1976, The Economics of Refuse Collection, Ballinger, Cambridge, MA

Kirca, Ö., and Erkip, N., 1988, “Selecting Transfer Station Locations for Large Solid Waste Systems”, *European Journal of Operational Research* 38, 339-349.

Kleindorfer, P.R. and Kunreuther, H.C, 1994, “Siting of Hazardous Facilities”, pp.403-440 in Pullock, S.M. et al. (eds.) Handbooks in OR&MS, Elsevier Science.

Kuhner, J., and Heiler, B., 1974, Regional Planning for Solid Waste Management. Models for Environmental Pollution Control (R.A Deininger, ed.) Michigan: Ann Arbor, pp. 327-362.

Ladhar, S., 1996, Solid Waste Management in Punjab, 22nd WEDC Conference: Discussion paper New New Delhi, India,

Lant, C. and Sherrill J., 1995, “The Role of NIMBY Groups in 22 Sanitary Landfill Sitings in Illinois”, *The Environmental Professional*, 17:243-250.

Liebman, J.C, 1975, Models of Solid Waste Management, A guide To Models in Government Planning and Operations (S. Gass & R. Seson, eds), Potomac, Md, USA.: Sauger Books, pp. 139-164.

Ligth, G.L, 1990, Microcomputer Software in Municipal Solid Waste Management : A review of Programs and issues for developing countries . Water and sanitation paper series (DP no. 6), UNDP-World Bank waster and sanitation program, Washington, D.C., USA.

Lindquist, R. C.,1991, "llinois Cleans Up: Using GIS for Landfill Siting",*Geo Info. Systems*, February 30-25.

Marks, D.H., and Liebman, J.C.,1970), "Mathematical analysis of solid waste collection", Bureau of Solid Waste Management, U.S Dept. of Health, Education and Welfare, Washington, DC.

Mendes, J.F.G and Silva, J.M.F., 1996, "Landfill facilities siting using GIS", *The Pennsylvania Geographer* XXXIV, no. 1, 24-40.

Minor, D., and Jacobs, T., 1994, "Optimal land allocation for solid and hazardous waste landfill siting", *Journal of Environmental Engineering*,120(5): 1095-1108.

Miller, D.W, 1980, "Waste Disposal Effects on Ground Water", Berkeley, Ca: Premier Press, pg. 509.

Moon, D., and Chaudhry, S.S, 1984, "An Analysis of Network Location Problems with Distance Constraints" *Management Science*, 30 (3), 290-307.

Morrison, T.H., 1974, Sanitary Landfill Site Selection by the Weighted Rankings Method, MSc thesis, Univ. of Oklahoma, Norman, Okla.

Noble, G.,1992, Siting Landfills and other LULUs. Technomic Publishing Company, Inc., Lancaster, PA, USA. 215pp.

OECD, 1981, Economic Instrument of Solid Waste Management, Paris.

Oliet, M., Negro, C., Blanco, M.A and Mirada, F.J, 1993, "Site Best Suitable for the Disposal of Urban Solid Waste", *Journal of Environmental Science and Health* 28, 1037-1054.

Patrick, P,K, 1984, "Metropolitan Waste Management Planning in Developping Countries" , Managing Solid Wastes in Developing Countries.

Perlack, R.D, Willis, C.E, (1983) "Multi Objective Decision Making in Waste Disposal Planning " *Journal of Environmental Engineering* 111, 373-385.

Petts, J., 1994, "Effective waste management: understanding and dealing with public concerns". *Waste Mgmt Res*. 12, 207-222.

Planning Commission, 1995, Report of High Power Committee: Urban Solid Waste Management New Delhi: Planning Commission, Govt. of India. 58pp.

Rabe, B.G., 1994, Beyond NIMBY: Hazardous Waste Siting in Canada and the United States. Washington, D.C.: Brookings Institution.

Rahman, M., Radwan, A.E., Upchurch, J., and Kuby, M., 1992, “Modeling Spatial Impacts of Siting a NIMBY Facility” *Transportation Research Record*, No. 1359, 133-140.

Rahman, M. and Kuby, M., 1995, “A Multi-Objective Model for Locating Solid Waste Transfer Facilities Using an Empirical Opposition Function ”, *INFOR* 33, 34-49.

Rathje, W., 1991, Once and future landfills, *National Geographic*, pp. 117-134.

Rava, C.F., 1989, Landfill Planning and Siting Current Municipal Problems 15, 23, 326-337.

Renkow, M., 1994, “ Trends in Solid Waste Management”, *NC State Economist* August, http://www.ces.ncsu.edu/resources/economics/waste/

Revelle, C., 2000, “ Research Challenges in Environmental Management”, *European Journal of Operational Research* 121, 218-231.

Rey, M., Soriano, Stampfli, E., 199, “La localization d’une installation de stockage de dechets stabilizes: le cas de la Suisse Romande , *INFOR* 33, 50-62.

Rossi, G., 1997, “Role of Decision Support Systems for mitigation of drought impacsts in the Mediterranean Regions”, http://unescoairo.org/Programmes/science/ihp/7th/Rossi.htm

Rossman, L.A., 1971, “A General Model for Solid Waste Management Facility Location”, Department of Civil Engineering, University of Illinois, Urbana,

Ruschbrook, P., 1987, Illustrated description of “HARBINGER the Harwell waste management model, *Wastes Management* 77(6), 348-361.

Schübeler, P., Wehrle, K., Christen, J., 1996, "Conceptual Framework for Municipal Solid Waste Management in Low-Income Countries." Urban Management Programme Working Paper No. 9, World Bank, August.

Shekdar, A.V, Krishnaswamy, K.N, Tiketar, V.G., and Bhide, A.D., 1991, “Long term Planning for Solid Waste Management in India ”, *Waste Management Research* 9, 511-523.

Siddiqui, M., Everett, J., and Vieux, B, 1996, “Landfill Siting Using Geographic Information Systems: A demonstration,” *Journal of Environmental Engineering*, Vol. 122, No. 6, pp.515-523.

Siderelis, K., 1991, “Land Resource Information Systems, ” Geographical Information Systems: Principles and Applications- Vol.2, eds. D. Maguire, M.Goodchild, and D. Rhind, Longman, London, UK, pp. 261- 273.

Sistem Planlama, Müşavirlik Mühendislik ve Proje LTD. ŞTİ, 1992, Ankara Büyük Şehir Belediyesi, Ankara Katı Atık Yönetimi Uygulama Projesi, Ankara Katı Atık Sahası Yer Seçimi Fizibilite Raporu. Rapor No: 1.

Sudhir, V., Muraleedharan, V.R., Srinivasan, G., 1996, "Integrated Solid Waste Management in Urban India: a Critical Research Framework", *Socio-Economic Planning Science* 30,163-181.

Sundberg, J., Gipperth, P., Wene, C.O., 1994, "A Systems Approach to Municipal Solid Waste Management: A Pilot Study of Göteborg", *Waste Management Research 12*, 73-91.

TERI, 1996, State of India's Environment (A Quantitative Analysis) New Delhi: TERI (Report no. 95EE52), 16pp.

TERI, 1998, Solid Wastes In Looking Back to think Ahead: GREEN India 2047 New Delhi: Tata Energy Research Institute.

UMP Asia News, 1999, "Solid Waste Disposal in the Asian Cities", Summer, Volume II. , No.2 .

US EPA, Characterization Report for Municipal Solid Waste in the United States: 1999, Executive Summary, EPA Office of Solid Waste and Emergency Response, November.

US EPA, 1995, Decision Maker's Guide to Solid Waste Management, Volume II, EPA 530-R-95-023.

White, P., Franke, M. and Hindle , P., 1995, Integrated Solid Waste Management, Blackie Academic & Professional ,London.

WHO, 1982, Rapid Assessment of Sources of Air, Water, and Land Pollution Geneva: WHO Offset Publication.

Yurteri,C., and Siber,S., 1985, Application of Location Models for Transfer Stations. Waste management of developing countries (K. Curi, ed.). New York, USA.: Plenum Press, pp. 633-642,

Zyma, R., 1990, Siting considerations for resource recovery facilities. Public Works. September , 84-86.

DEFRA Digest of environmental statistics:
http://www.defra.gov.uk/environment/statistics/des/index.htm

DIE Devlet Istatistik Enstitusu
www.die.gov.tr

Evaluation *of needs and alternatives for landfills* **-** 1998
http://www.cmc.gov.za/Press/wwreport/CHAPT_5.html

EPA, Municipal Solid Waste – Basic Facts- 2002
http://www.epa.gov/epaoswer/non- hw/muncpl/facts.htm

Environmental Literacy Council-Landfills –2002
http://www.enviroliteracy.org/article.php/63.html

Environmental Literacy Council, Municipal Solid Waste –2002
http://www.enviroliteracy.org/article.php/204.html

Esri Library, 2002,
http://www.esri.com/library/index.html

EPA, Environmental Justice- 2002
http://www.epa.gov/compliance/environmentaljustice/index.html

EPA, Guide to Environmental Issues- 1998
http://es.epa.gov/oeca/guide/solwast.htm#solwas%20chapter

EPA, Wastes: Waste transfer stations: http://www.epa.gov/epaoswer/non-hw/transfer.htm

EPA Guidelines for Major Solid Waste Landfill Depots, 1998
www.environment.sa.gov.au/epa/pdfs/swlandfill.pdf

EPA Waste Transfer Stations, 2002 www.epa.gov/epaoswer/non-hw/trans-1.htm

Garbage – 2002
http://www.howstuffworks.com/framed.htm?parent=landfill.htm&url=http://www.pbs.org/ktca/newtons/11/garbage.html

Hessisches Statistisches Landesamt 2001, www.hsl.de

How Landfills Work- what is a landfill? - 2002
http://www.howstuffworks.com/landfill3.htm

How Landfills Work, What happens to trash at the landfill, 2002
http://www.howstuffworks.com/landfill7

Landfill Manual, 1999
http://www.foe.org/ptp/manual.html

Protecting Groundwater Resources Using GIS, 2002,
http://www.globesa.org/Conrad.htm

Rachel's Environmental & Health Weekly- 1991
http://www.monitor.net/rachel/r231.html

Rajdarpan, 2000 www.rajgovt.org

Rotten *Truth about Garbage*- 1998
http://www.howstuffworks.com/framed.htm?parent=landfill.htm&url=http://www.astc.org/exhibitions/rotten/rthome.htm

The *History of Municipal Solid Waste* - 1999
http://eerc.ra.utk.edu/tnswep/activitiesPDFs/mc-W.pdf

Types *of Solid Waste- 2001* http://edugreen.teri.res.in/explore/solwaste/types.htm

Scarlett, L., 2000. Landfill Siting Challanges and Environmental Justice.
http://www.rppi.org/opeds/030600.html

Solid Waste Overview – 2002
http://home.attbi.com/~homeecology/Garbage/Garbage_Sub-ages/Soild_Waste_Overview/solid_waste_overview.htm

Solid Waste Management*:* Glossary- 2002 http://www.gdrc.org/uem/waste/swm-glossary.html

Siting a Regional Landfill in Southwest Missouri – 1997
http://home.earthlink.net/~stoutd/writings/landfillsum.html

Solid Waste Management, 1999 http://www.ela-iet.com/el00014.htm

South Australia EPA, 1988

Statistisches Landesamt MVP, 20001 www.statistik-mv.de

U.S *Environmental Protection Agency* –2002
http://es.epa.gov/oeca/guide/solwast.htm#solwas%20chapter

Waste Age, 1999
www.wasteage.com

What a Waste, Waste Management in Asia, 1999
www.worldbank.org/urban/publicat/whatawaste.pdf

Appendix A

Maps of State Hessen

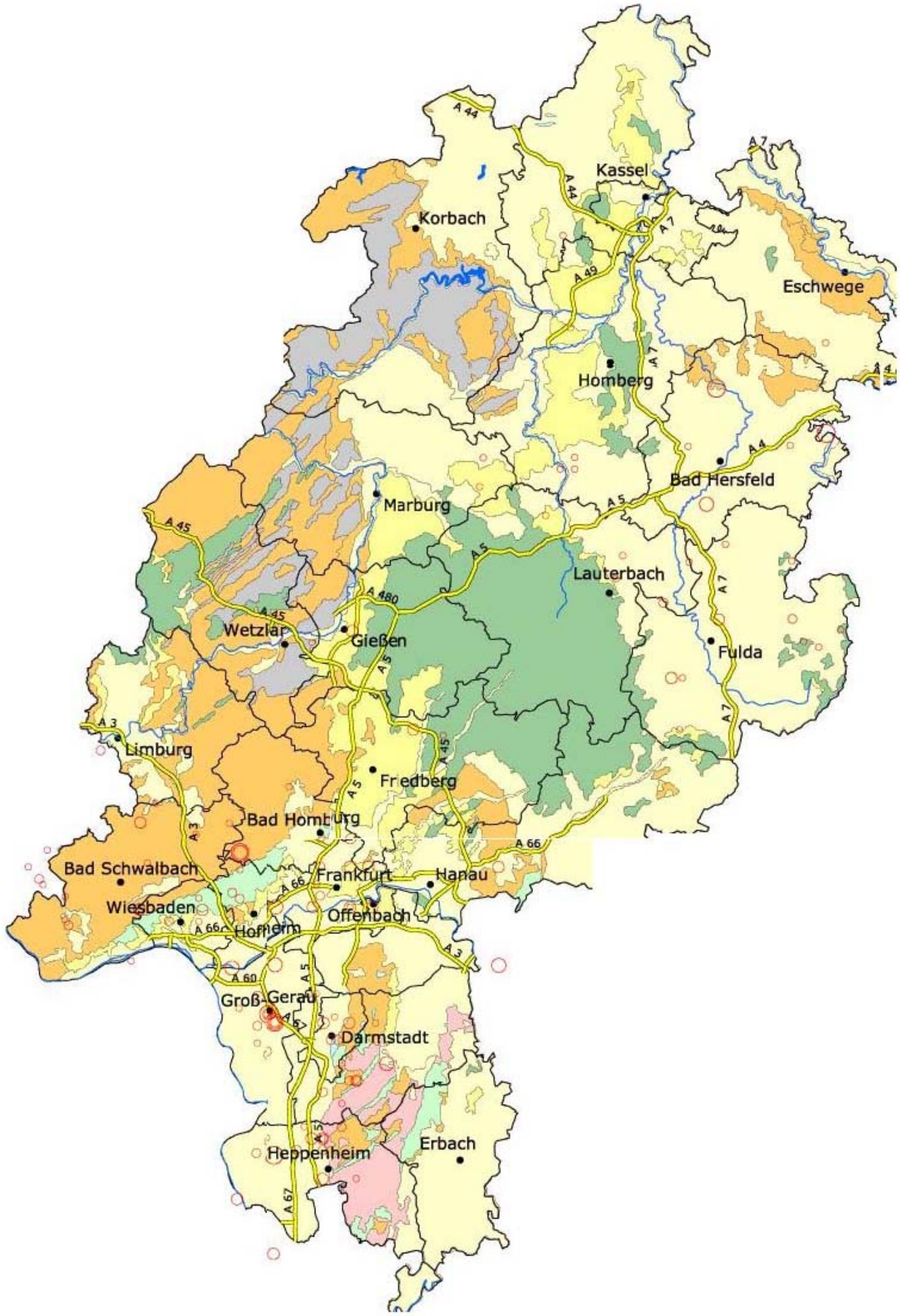
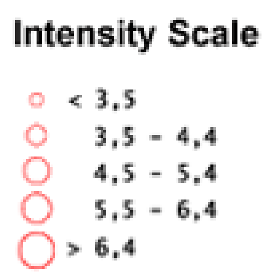


Figure A.1 Faultline Map of Hessen State



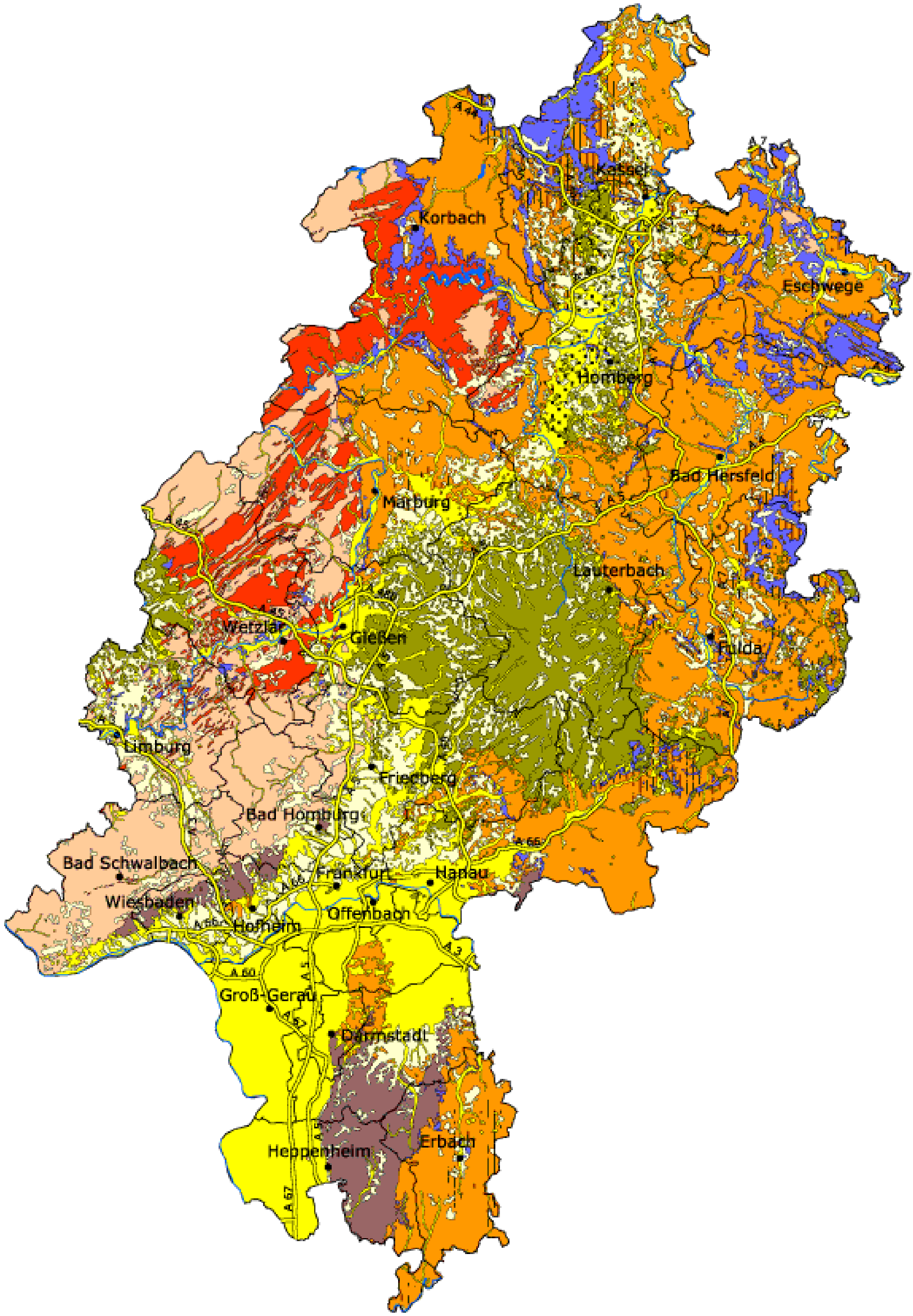


Figure A.2 Ground Water Map of Hessen State