GIS APPLICATION IN SOLID WASTE MANAGEMENT

(Term Paper)

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ABSTRACT

Solid Waste Management (SWM) is an integral part of public health and environmental control. Improper SWM leads to both economical and environmental sufferings. SWM includes control of generation, storage, collection, transfer/transport, processing and disposal of waste. Almost all factors related to SWM has both spatial and non-spatial components, thus, traditional ways of storing and analyzing data keeps data in isolated form, which results in inefficient management system. This paper will introduce the use of Geographic Information System (GIS) in the field of SWM. Through different case studies and discussions, this paper will demonstrate the aid of GIS in areas related to SWM, to increase system efficiency, reduce workload, save time and cost, and its use as a decision support system. This paper will concentrate in three different operations of SWM, which are waste storage, waste collection, and waste disposal. Results from different case studies, with different solid waste problems, shows that with GIS agencies and organizations were able to save cost and time, reduce workload, improve serviceability and respond to customers in less time, solve any problem arise quickly, increase profit generation.

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1. LITERATURE REVIEW

Geographic Information Systems (GIS) is a relatively young field, with antecedents that go back hundreds of years in the fields of cartography and mapping. Today, GIS provides a digital way for storing, retrieving, manipulating, analyzing, and displaying geographically referenced data. Since GIS has the potential of including ecological, biological, demographic, or economic information, it becomes a valuable tool in the environmental and engineering sciences (Goodchild, 1992).

The Loudoun County Department of Natural Resources used GIS to find potential sites for new landfills. Layers such as slope, soils, bedrock depth to groundwater ratios, historical areas, streets, and jurisdictions were combined to design the model (Mitchell, 1998).

Whether restoring habitat, stopping contamination, measuring endangered species populations, or searching for environmentally sensitive land to acquire, spatially literate users have learned to utilize the power of GIS for increased efficiency with environmental issues faced by Government Agencies (Greene, 2000).

As the government system operates now, local governments are working independent of each other on environmental projects. Prior to this model, illegal construction waste was collected and hauled to the landfill with an estimated cost $300,000.00 per year. With the waste sites properly mapped, the municipality can assess what type of waste is present and recycle much of the materials saving hundreds of thousands of dollars, as well as saving precious landfill space. The model developed demonstrated how a GIS combined standard data collection with advanced computer capabilities, allowing the Environmental Services Department, for the city of San Antonio, to more easily maintain historical data, predict future environmental impacts more quickly, better optimize their resources, which provided added project control and better response time, and the result of our case study indicates that a GIS for the ESD is feasible both economically and environmentally (Susan, 2002).

2. INTRODUCTION

Solid Waste Management (SWM) is an integral part of the public health and environmental control. Solid waste generated right from the beginning of humanity, earlier societies mostly had natural and food waste. Problems were little earlier, however, with rapid urbanization, growth in urban population, and development of technologies -e.g. packaging-, the problems of solid waste become more complex as more and more solid waste is generated. With the passage of time and continuous urbanization as well as increase in population the situation get more and more critical.

Solid waste management issue is being of particular important in high populated areas. The increase in public concern about solid waste has resulted in sharp and large increase in the political priority given to waste management. Improper solid waste management leads to both economic and environmental sufferings, e.g. uncontrolled throwing of the waste and badly maintained waste results in growth of diseases as well as increase the presence of unwanted species such as rats and mosquitoes and bad odor created around the garbage area leading to unaesthetic conditions which in turn decrease the market value of the area.

3. THE NEED FOR GIS

"(E. Tinmaz and I. Demir, 2005) The issue of waste is not only because of increase quantities but also largely because of inadequate management system". One of the major management issues in solid waste management is improving methods for interpretation of data "(Dr. Vhora, 2006) Billions spent in improving scientific methods for interpretation of data, but the steps involved in the said area are much demanding". Almost all of factors related to solid waste management have a spatial component as well as non-spatial data. Manual methods used for analysis of many factors are lengthy and tedious work and in some problems it will be difficult to solve them without the aid of computer software, e.g. optimization software, and also there is possibility of merging spatial and non-spatial data. In most cases solid waste data and records are not managed properly and are often lie in isolated form. Because of the improper management of the data and records, it becomes difficult to

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assess system functionality and efficiency. For proper management it is important to manage the data in an integrated way so the complexity of various systems could be reduced to solve various interrelated issues. Hence the need for geographic information system (GIS) arise, since GIS helps in dealing with several factors simultaneously which need to be considered while planning waste management, and because of layers property of GIS there is least chance of confusion and error, and it is capable to coordinate between spatial and non-spatial data. Also in GIS information can be related spatially, exchanged, compared, evaluated, and processed with a very good flexibility. "(S. Upasna and M.S. Natwat, 2003) GIS is a system designed to allow user to collect, manage, analyze, and retrieve large volume of spatially referenced data and associated attribute data collected from a variety of sources"

4. OBJECTIVE

Solid waste management includes the control of generation, storage, collection, transfer, transport, processing and disposal of solid waste. The objective of this paper is to demonstrate the application of geographic information system (GIS) in different areas related to solid waste management in order to increase system efficiency, reduce the waste management workload, save time and cost and to maximize the profit generated and serviceability as well as its use as a decision support system.

5. METHODOLOGY

The functional elements of solid waste management are the following:

- Waste Generation
- Waste handling, Separation, processing, and waste storage at the source
- Waste Collection & Transfer/Transport
- Waste separation, processing, and transformation.
- Waste Disposal

Through different case studies, this paper will start discussing the application of GIS in solving problems related to waste storage, then demonstrating the usefulness of GIS in optimizing waste collection systems, and finally will demonstrate its aid in the selection of waste disposal site (landfills). Also problems due to improper SWM will be discussed.

6. WASTE STORAGE

Waste storage at the source is the second functional element of the solid waste management. Usually waste is stored in waste bins located in both sides of streets next to buildings and other sources of waste generation. More attention is given to residential waste storage because of its direct impact on the public health and attitude, as these storage points commonly are placed in close proximity to houses. Due to microbiological decomposition of the waste it is not recommended to store waste for long time. Uncollected garbage will cause a serious threat to public health as it is a breeding ground for insects, flies, and bacteria and this could spread desieses. Other drawback of garbage accumulation is the bad odor created around the garbage area which decreases the market value of the area due un-aesthetic conditions, and over all leaves a bad impression and poses a threat to the environment.

Common problems related to waste storage are:

- Garbage are not lifted in regular intervals
- Waste bins are not cleaned in regular bases.
- No route plans are prepared.
- Improper waste bin allocation: small bins are provided in places of high solid waste generation rate, bins are unnecessarily provided on some roads, people through their waste in open dumps because there is no waste bin close enough to them. Waste bins located near water bodies may contaminate it.

"(Orga. A.,2003) The municipal officers involved in solid waste management will be clear about the functions and their role in terms of managing the cities efficiently with the help of geographic information system. There will be complete inventory of the things associated

with solid waste management and proper logistic management and spatial planning can be done using GIS analysis based on various generated layers about the SWM issues for implementing and managing the system at the field"

6.1.   Case Study

(Using GIS in Solid waste Management Planning for the city of Aurangabad, India)

The aim of this case study is to analyze the present waste management situation in the study area of Aurangabad city in India and evaluate the problems that rise due to improper waste management and design a GIS model that could be able to improve waste management situation and reduce work load of waste management.

6.1.1. Methodology

The methodology of study includes:

1. Collection of information about the present waste management situation in Aurangabad city. City information is available in four different mediums which will be brought together in one plat form where they can be linked together and correlated. These four mediums are:
   - Maps containing spatial information.
   - Spatial data about location of waste bins and buildings.
   - Attribute information about spatial data.
   - Other information source through interview with municipal officials to provide information about working patterns, and a questionnaire was prepared for the public to know their behavior regarding waste management and get their opinion in this regard (Appendix A).
2. Preparing a database about the waste situation.
3. Analysis of present situation, to recognize problems as well as limitations and restrictions in city waste management.
4. Discussion and critical analysis of SWM models presented in literature studies.
5. Design and implementation of GIS model, and problem analysis using GIS

The conceptual model which demonstrates the methodology adopted for the use of GIS in the waste management planning in this case study is shown in figure 1.
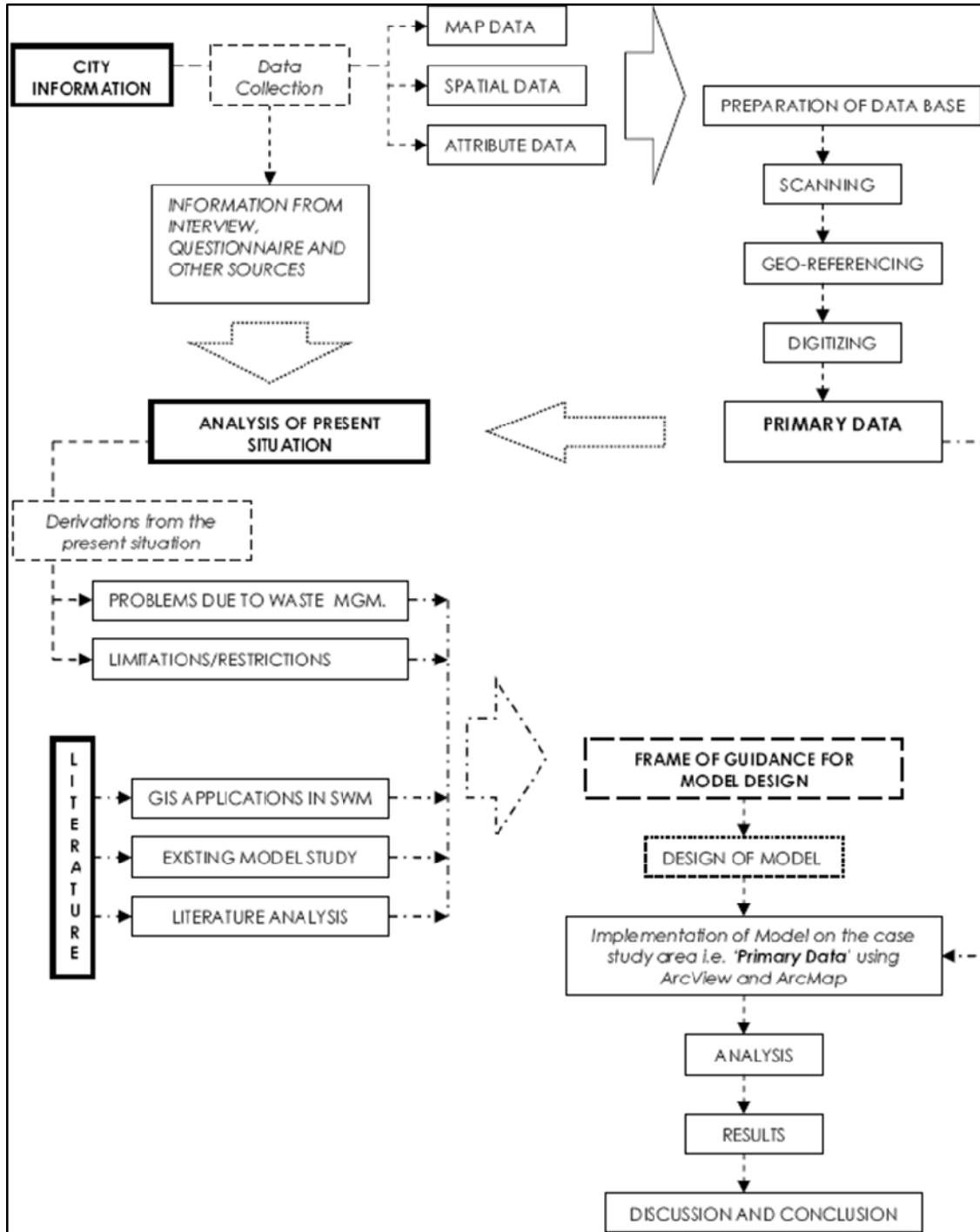

Figure 1: Conceptual Design

6.1.2. Existing SWM Situation in Aurangabad City

Aurangabad is an average Indian city located in south central India (figure 2). Population of the city is around one million with a mixed type of income group people. The study area covers 2 square km of the city.
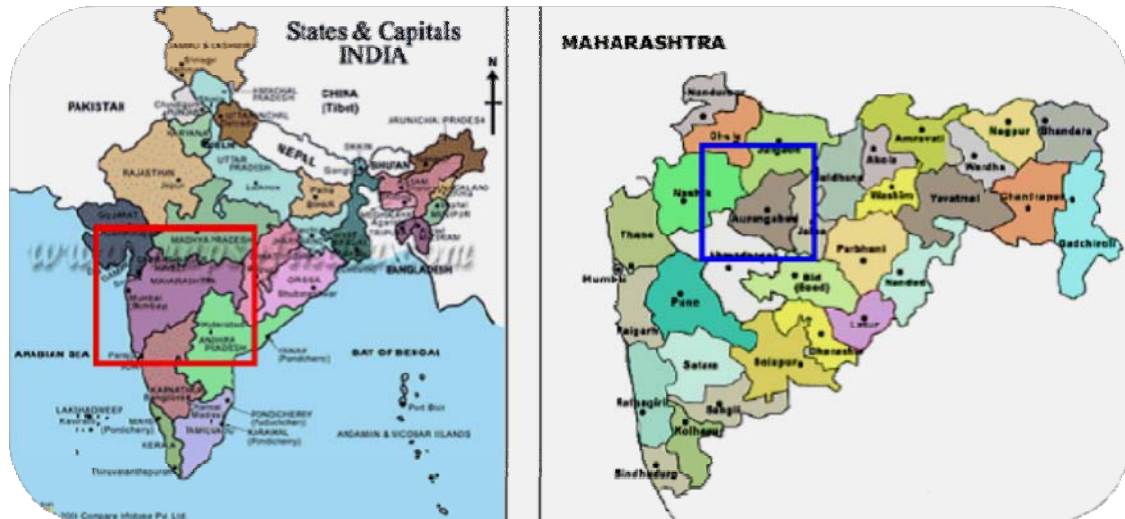
Figure 2: location of Aurangabad city

The information about working pattern is available from interview with municipal officials. The solid waste management system in the city works in team of area officers. Each officer is responsible of an area and run the system with the help of four cells of employees each cell holds the responsibility for part of that area. In each cell there is a sanitary inspector, helper, and few labors. Because each cell is assigned for particular area, the employee gets familiar with that area's problems and requirements, but there is no documentation of working schedules and employees' experiences. Therefore, a new recruited employee will learn the system from his colleges with time. Also the route planning is never prepared and is currently done as and when need arise.

Waste bins used in the city are RCC cylinders opened from both ends, and it is 0.9m diameter and 1.2m in height, the volume of the bin is approximately 0.75 cubic meters. According to Indian guidelines (CPHEEO, 2000), density of mixed waste is about 500 kg/m3. So the capacity of RCC cylinder waste bin is around 375 kg. According to (National Solid

Waste Association (NSWA) India, 2002) the city of Aurangabad is generating 300MT of municipal solid waste per day, and there are 1635 bins in the city. There for it is around 185 kg/bin, which is less than the carrying capacity of RCC bins. But it is observed that there is uneven waste produced in the city, there might be some bins that gets filled daily or even in less time. Unfortunately, the data about the most waste generation areas and along roads is not available. And also there is no segregation of waste, therefore; there is no idea about quantity and generation of recyclable waste. It is also observed that in most cases the waste spreads around bins because of animals spreading waste in search for food or waste fells partially outside the bin when people through their waste, which results in the accumulation of waste around bins. This situation of non-segregated waste, open bins, and the accumulation of waste around the waste cause a death of thousands of cows since cows swallow polythene bags along with food waste, and this also effect humans because it was discovered that milk from cows having polythene bags clogging their stomachs can cause disease like tuberculosis and cancer.

Because bins are open from both ends, in rainy seasons waste drains and pollutes streets, create a foul smell, and a breeding ground for mosquitoes. Such bins can not be placed close to environmentally sensitive areas such as streams where it has been noticed that the main reason of water contamination in streams is due to close proximity of waste bins. Also, there are several open dumps observed in the city, therefore, there is a need to know the convenient distance for citizens from their places to the waste bin and to find out areas which do not have a waste bin within that distant.

In the case of recyclable waste, it is observed that there is no separate bins for recyclable waste, but the questionnaire survey shows that there is a positive contribution of the recyclable waste buying businessmen, where they collect most of the recyclable waste from houses and pay for the resident then they sell it to the recycling industry, and this helps in reducing workload. According to statistics of National Solid Waste Association (NSWA) of India, the composition of MSW of Aurangabad city is 25% moisture content, 35% organic waste, and 40% inert material. The availability of recyclable waste is considered among the 40% inert material.

6.1.3. Data Collection and Limitation

As stated previously, data was collected through four different mediums, maps, spatial data about locations, attribute information about spatial data and other information through survey, interview, and questionnaire. Then all information from different types and forms transferred to the GIS database. The case study area covers 2 square km and its detailed map had the information about road network, major building, religious buildings, cinema halls, land mark, and water streams. Information about schools, hospitals, offices, marriage halls, land use, and exact waste bins location as well as open dumps was collected by general survey and entered in the GIS database. Information about shops and their locations was collected and they were categorized according to the waste generated in the shops, for this purpose the waste generated by shops was divided into three categories which are composite (organic), recyclable (inorganic), and mixed waste (table 1).

The results from the questionnaire done for the public shows that 90% of residents use personal house waste bins to collect and store waste then they through their waste directly to waste bins by emptying their own waste bins, while 10% use polythene bags to store and collect waste, and most of residents tend to keep their waste for two to three days at their places. People separate waste at their places in order to sell recyclable waste, even waste with least resale value, to waste buyers. Half of residents store recyclable waste for a week at their places, whereas 25% of them store it for two to three weeks and 25% of them store it for more than three weeks. The selling of recyclable waste found to be a common practice among different income groups, low and middle income sell it to get return out of it and for high income group usually they have servants working for them and these servants take the advantage of selling waste to make some additional income. Questionnaire also shows that the convenient distance between household and waste bins for most of citizens found to be 100 meters.

Table 1: Categorization of shops according to their waste generation type

Organic waste	Recyclable waste	Mixed waste
Green grocery	Stationary	Bakery
Dairy	Hardware	Restaurant
Meat/beef	Garment	Cigarette
Fish/chicken	Electronics	Grocery
Lunch home	Cutlery	
Tailoring	Photo studio	
	Medical	
	Cassette	

There were some limitations in the data related to both its type and availability, these limitations include:

- Maps were not up to date.
- Hospitals location represented in point features, it demonstrates the location but neither gives the area of hospital nor its boundaries. It will be more convenient to have the boundary to be more precise about waste bins proximity.
- Population density and land occupancy are not available; such information could increase the precision of the waste generation analysis.

6.1.4. GIS Workflow Model

Frame of guidelines was developed, using data collected, to get a defined direction to the objective. These guidelines stated the followings:

- The model should be flexible to meet future changes.
- Come across with some ways to generate revenue for the system without any compromise with environmental or health issues.
- Help to decide the areas which are in need of recyclable waste bins.

- Waste bins should be kept away from land uses related to sensitive issues, like health, and sentimental values of the citizens. A distance of 20 meters found to be suitable for this purpose.

- Waste bins should be at least 15 meters away from environmentally sensitive areas, such as streams.

- Waste bins should be within a convenient distant for the residents.

- Recyclable waste bins will be placed next to an existing waste bin.

Figure 3, shows the work flow pattern of the proposed GIS model, which is designed to help in reducing the waste management workload, and solve some the present situation problems. This model is divided into four components which are primary data, analysis, functions, and results. The results of the analysis will help as a decision support for the allocation of new waste bin or recyclable waste bin and relocation of existing bins whose present location causing threat to the citizens, or risk to the environment. The analysis processes include:

- *Inconvenience due to waste proximity*: this will eliminate waste bins within a buffer of 20 meters from sensitive land use. For the case of building represented with point feature a buffer of 10 meters will be applied in three layers, the first 10m will be considered as building boundary, and the other two will form a buffer of 20m around it.

- *Convenience distance to bins foe all user*: a buffer of 100m will be created around all waste bins, to see if there is areas do not fall within these buffer areas.

- *Proximity from environmentally sensitive areas*: a buffer of 15m will be applied on both sides of streams; all waste bins fall in this buffer area will be relocated.

- *Recyclable bins for buildings*: such as cinema theaters, educational institutions, offices, and other building that generates recyclable waste. A multi-buffer will be applied around them to select nearest location and that could serve more than one building.

- *Recyclable bins for shops*: apply a query to identify shops that generate recyclable and mixed waste, then apply multi-buffer around it to find nearest place
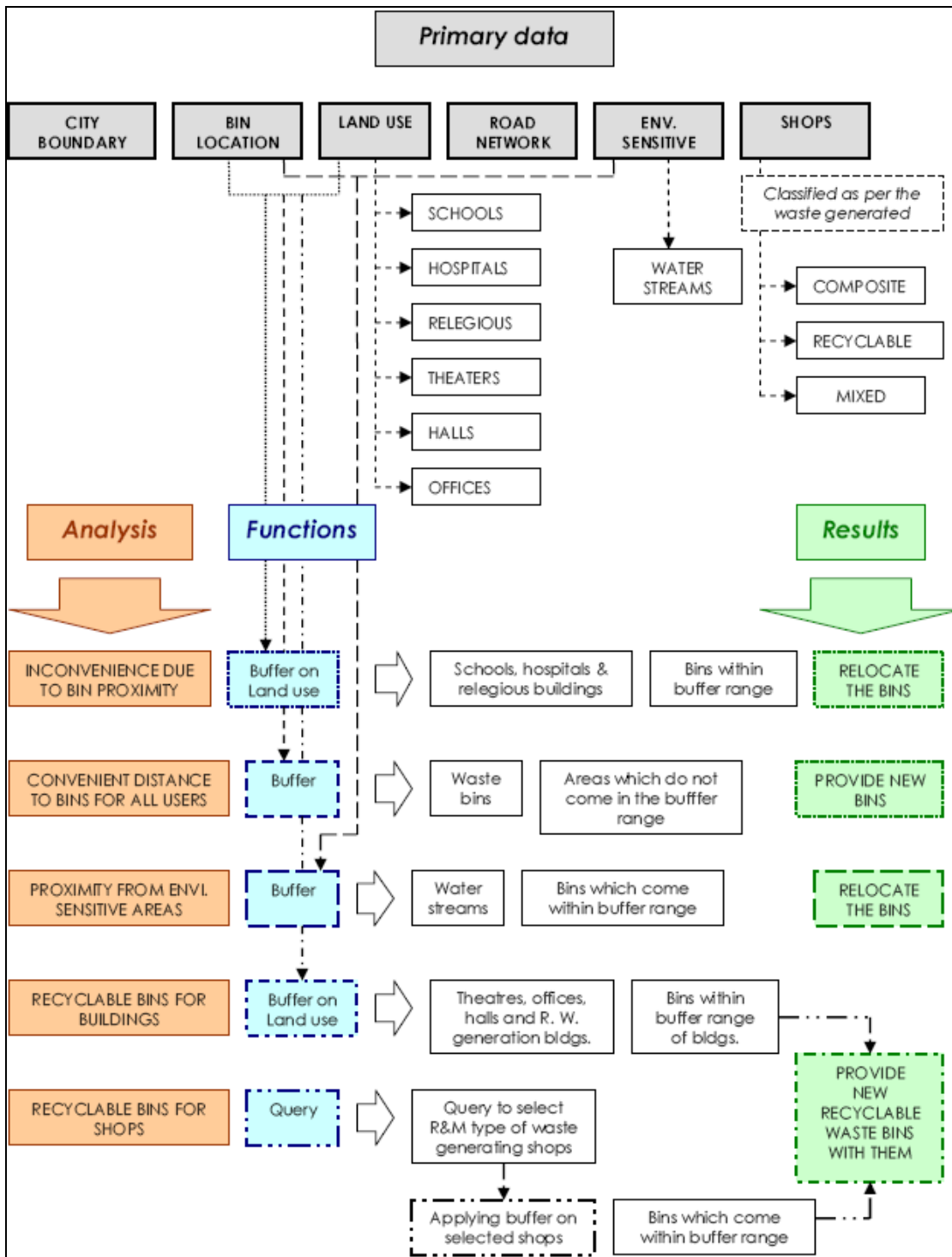
Figure 3: GIS workflow model

6.1.5. Implementation in Case Study and Results

The model has been applied to the case study area and the results were as the following:

- Six waste bins lies in close proximity to sensitive buildings and need to be relocated, (figure 4)
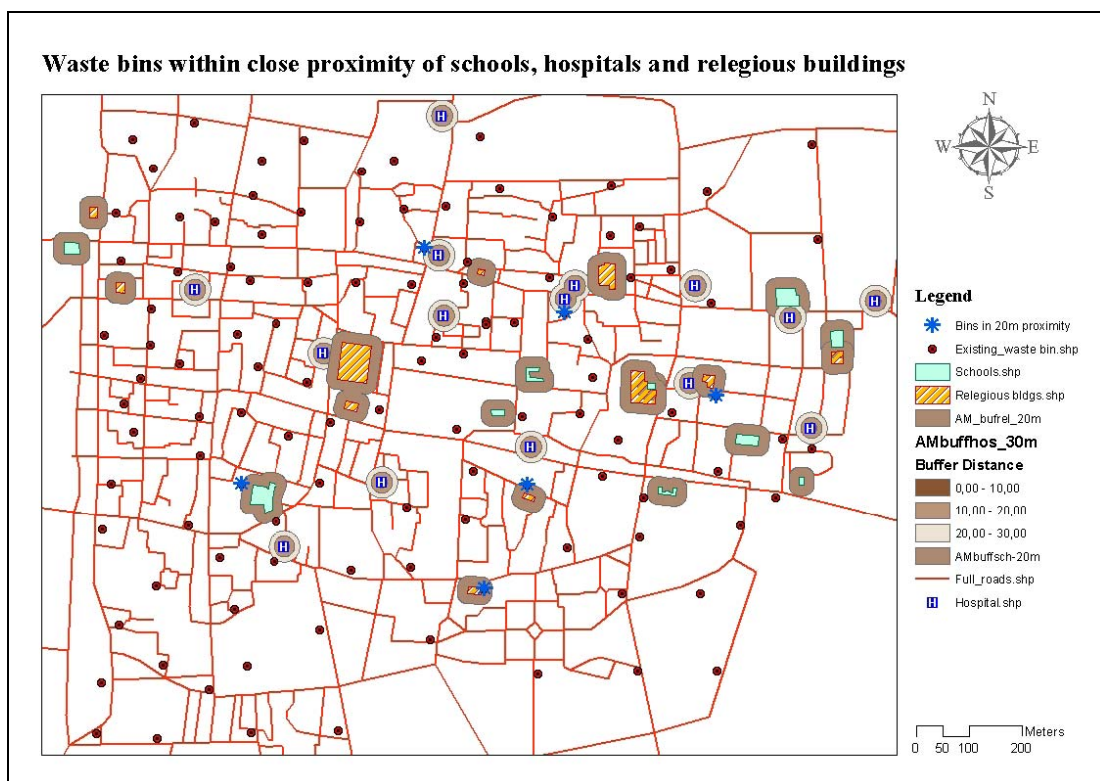
Figure 4 : Waste bins with close proximity to sensitive buildings

- Most of the case study area is covered with a buffer of the convenient distance to waste bins except few areas. New waste bins need to be provided for these areas, (figure 5)
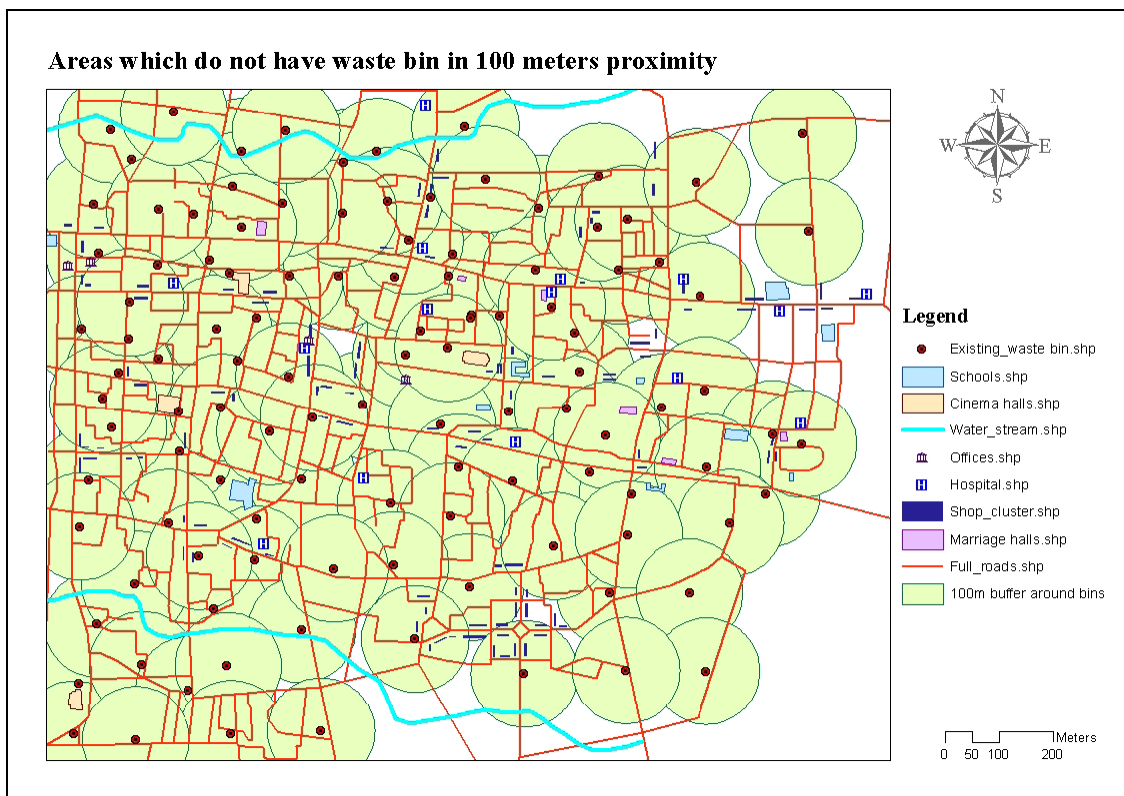
Figure 5 : a 100m buffering around waste bins.

- Six waste bins placed close to streams and need to be relocated, (figure 6).
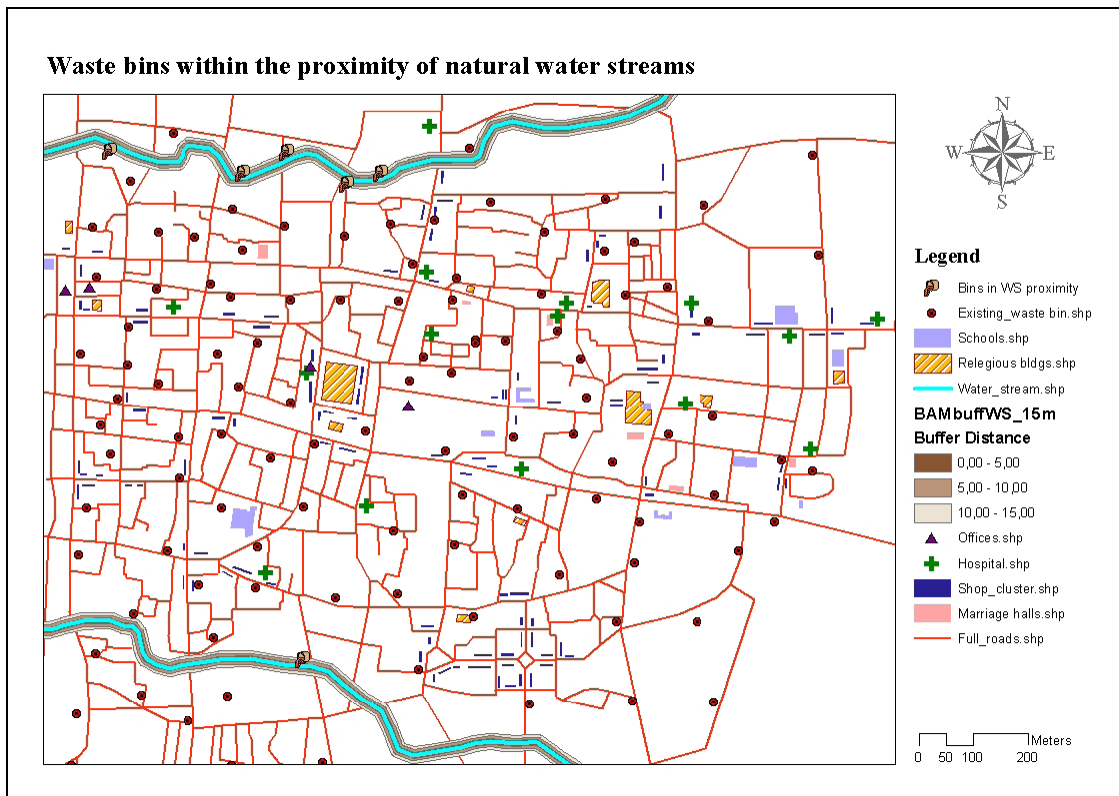
Figure 6: Waste bins close to environmentally sensitive areas

For placement of recyclable waste bins, a three band buffering applies with 25m for each band around buildings and 35m for each band around shops, (figures 7 and 8). For buildings 17 waste bins are selected in order to place a recyclable waste bin next to them, and only two building have no waste bin within the range of 75m. for shops 28 location chosen for the placement of a recyclable waste bin, eight of these location were also chosen for buildings recyclable waste, therefore a total of 37 recyclable waste bins will be placed in case study area.
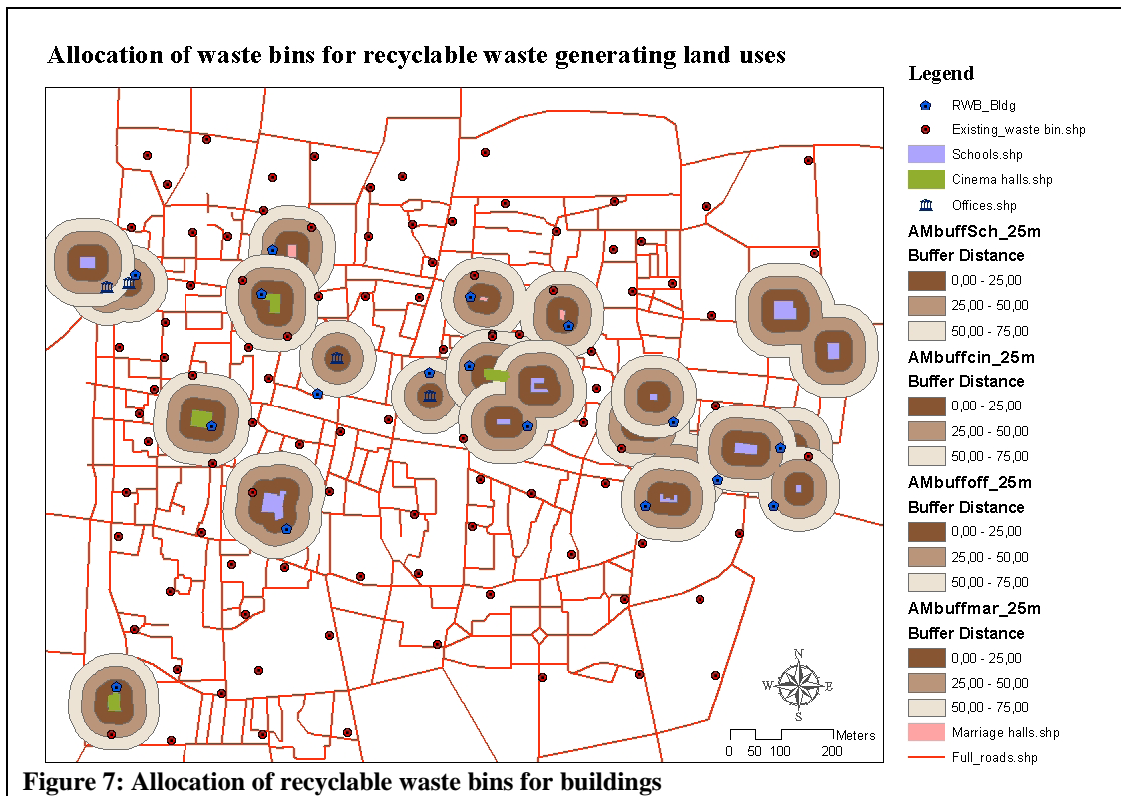
Figure 7: Allocation of recyclable waste bins for buildings
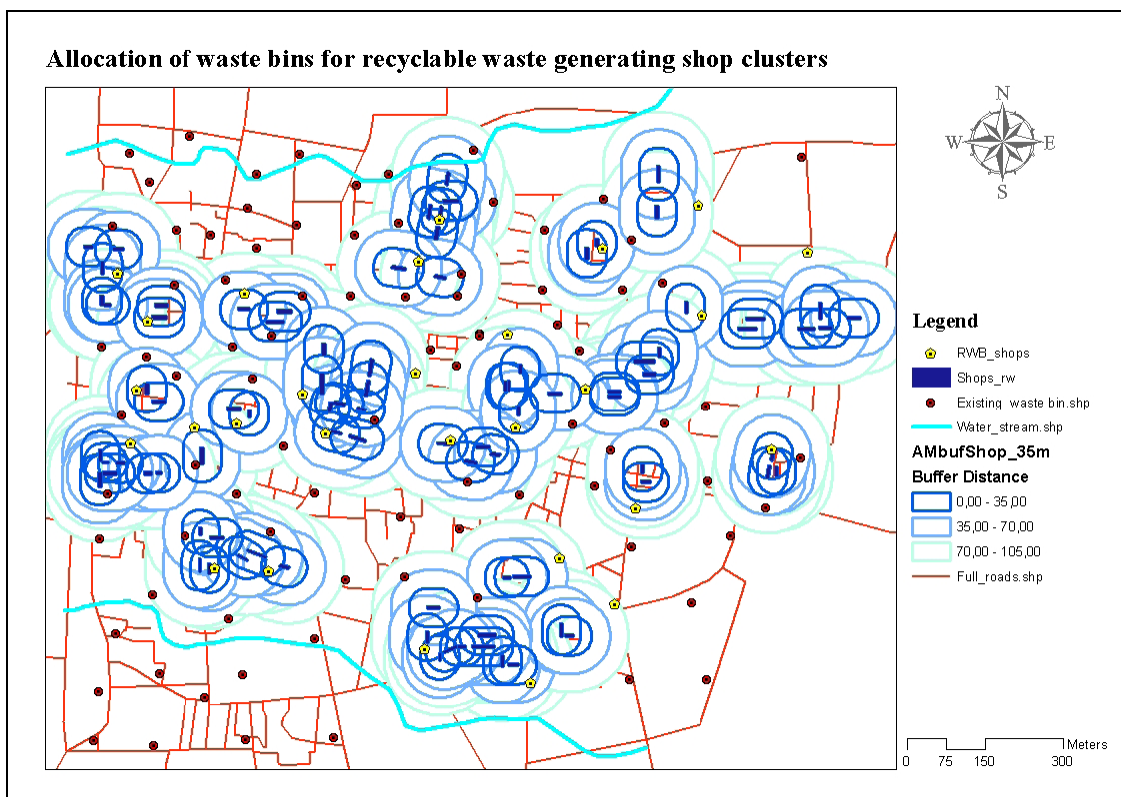
Figure 8 : Allocation of recyclable waste bins for shops

6.1.6. Discussion

During the implementation of GIS model in the case study are, all waste bins were considered in the five steps of analysis. This will cause some conflict because some of waste bins were required to be relocated due to their close proximity to sensitive areas, and the same waste bins were considered as a solution for placement of recyclable waste bins. And as stated in the model guide lines, recyclable waste bins should be placed next to existing waste bins. Thus, GIS analyst has to remove waste bins that are required to be relocated first then run the next step of analysis. In my opinion it will be better if the analysis process goes as following:

1) Remove waste bins that are *inconvenience due to bin proximity* to sensitive buildings.
2) Remove waste bins that are with close *proximity from environmentally sensitive areas*.
3) Check for *convenience distance to bins for all user*, and relocate bins, especially thus removed from previous analysis, to meet this requirement.
4) Allocate *recyclable waste bins for both buildings and shops*.

Also from GIS analysis, a lot of places satisfy all the requirements, thus, choosing one of these locations will be sub-solution to the problem it is better if the analyst consider other factors in the process of allocation of waste bin, such as routing for collection system, since there is more than one option. The selection of new bin location or relocating other bins should not only consider public convenience, it should also fulfill other technical factors and planning aspects

Also there was no consideration for road types, different size of containers, and the accessibility of different type of waste collection vehicles. And no solution mentioned regarding waste bins that would be filled in less than one day, and those found almost empty because they are placed in unnecessary places, to reduce the effect of uneven waste generation through the city.

As mentioned in the paper, people get paid for their recyclable waste by waste buyers, and that there is a good contribution from waste buyer where they goes to houses to pay for the residents for their waste. In the design of the GIS model, placement of recyclable waste bin

was considered as a way of generation revenue by selling the recyclable waste to waste industry. The problem is, what would make people through their recyclable waste in recyclable bins? How would pay for them? And how would they get paid? The model should consider a way to encourage people to use recyclable waste bins and ensure their participation.

6.2.   Other Successful Stories

Many organization and agencies throughout different nations uses GIS to solve their problems which are related to waste storage. The key solution for their problems was by identifying the exact locations of waste storage points and link its attributes to it. Dyess Air Force in United State and Garland's City Solid Waste Department in United State are examples.

6.2.1. Dyess Air Force, Texas, U.S.

Dyess air force base in Abilene, Texas, is like a small city with an area of 6000 acres and 7600 assigned personnel living there. Air Force Civil Engineering requires that trash dumpsters be tracked and logged for contract maintenance purpose. Surveys are performed annually to maintain records of dumpsters locations and problems, this completed by driving around the base and recording in papers. Written records rise some issues: exact location were hard to describe, unintentionally redundant data collection, survey takes 20 days to be completed, and during these days several dumpsters may be relocated or removed which makes the survey out of date before it was completed. To solve these problems engineers suggest using a mobile GIS (ArcPad) installed in handheld device with built-in GPS. Then a customized dumpster tracking application was developed. And a list of domain choices in a pull-down menu were created to simplify the process, reduce the time for entering attributes, and to ensure that all location will be attributed in the same way. The dumpster attribute collected are the dumpster number, type, time and date –they are captured automatically-, problems with dumpster, and serial number. Using the GPS the location of dumpsters was easily specified, and plotted in the GIS base map.

After implementation it was revealed that 20% fewer dumpsters were being employed than required by contract. The dumpster's data was collected in two days by one person and produced a high accurate inventory. This represents a 90% reduction in number of man-hour required for this task. Now using GIS, places with greater demand for dumpster capacity, dumpsters in need for maintenance, and the physical condition of the dumpster can be monitored.

6.2.2. Garland's City Solid Waste Department, Texas, U.S.

The customers served by Garland's solid waste department were charged a one-time fee for the cost of the container, and $4 monthly for the service of garbage collection. The city provides additional container for residents. Garland's SWD planned to charge customers for each additional waste container. The last known quantity of additional containers was just over 10,000, and since customers were not billed monthly for the extra containers, no reliable records were maintained to track these additional containers. If $4 fee for each additional container is recovered from the customer, this could provide an additional $40,000 per month in revenue for Garland's SWD. But in order to bill accurately for the additional containers, it was necessary to identify the existing containers and their locations.

The workflow was simple enough, the user needed to be able to attach a number corresponding to containers to each address. However keeping track of your location and which locations had been surveyed presented the biggest problems. Thus, GIS mobile system -ArcPad- installed in a handheld device with GPS was recommended as a solution. Garland's SWD prepared a user interface and dialogs with ArcPad application builder that permitted the user to tap on a parcel on the displayed map, attach a container number attribute to each address, and after performing this operation the parcel would change to red indicating that it had been surveyed. After that, this information was integrated into the GIS. To enable analysts to assess the numbers and locations of additional trash containers. It was estimated to take four months to collect all the necessary data, however, the project completed a month ahead.

Results of the survey showed that there were over 13,000 additional containers in the city. These additional containers are now mapped and inventoried. The next step is to prepare a proposal Garland City Council outlining possible fee structures to charge residents for each additional container.

7. WASTE COLLECTION

Solid waste collection comes at the beginning of solid waste management process. Waste is usually collected using waste collection vehicle from its source of generation and transported to the special facility, such as recyclable waste facility, or to a disposal site. Mainly there are two collection systems, which are:

- Hauled Container System: where the waste collection vehicle hauls the container to the disposal site then emptying it and returns it pack. And this could be done in either of the following two ways:
  1) Conventional Mode: The vehicle visit the first site, hauls the container then emptying it and return it back to its location.
  2) Exchange Container Mode: The vehicle comes to the first site with an empty container to be exchange with the full container, and after emptying the container it will be exchanged with the full container in the second site.
- Stationary Container System: where the waste is loaded into the collection vehicle and the vehicle will continue emptying waste containers from different sites till it reaches its carrying capacity then it goes to disposal site.

The process of waste collection is very complex and too costly. Waste collection has about 50-70% of the total cost for solid waste management system. Thus, a big saving could be achieved by small changes in collection system, such as route layout and optimization. The steps to layout a collection route are:

- Establishing area maps with info related to solid waste generation points, such as location, frequency, waste size.
- Preparing of pertinent data, tables.
- Establishing pre-route, analyze it, and redevelop routes.

Many issues arise in the process of routes layout. There are too many attributes about generation points needs to be shown in the map or presented in a separate data sheets, this makes data tracking and accessibility for query very difficult. The solution for waste collection routes is achieved through trial and error processes which require a lot of calculation, and take a lot of time. Moreover, any change in the system, e.g. adding new customers or roads being closed, will require rerouting of collection system again. Routes analysis requires calculation of street length, distance from last emptied container to the disposal site, e.g. landfill, distance between respective containers, and also the system constraint such as speed limit should be considered. The need to recalculate all these parameters in each rerouting trial makes routing process a tedious work. System efficiency is hardly determined using static maps and data sheets. Thus, the need for a solution that would helps to adjust the routes in more timely and efficiently manner. Geographic information system (GIS) is capable of producing automated routing which can be edited in easy and fast ways. In addition, GIS can solve other problems by linking descriptive attributes of a generation point to its exact location, and all distances that are required for the analysis will be measured automatically. With customers presented in a map waste collection vehicle can reach customer in faster, easier, and more accurate way, providing better customer services. The assessment of system functionality and efficiency will be improved through GIS.

7.1.   Case Study

(Vehicle Routing Solution for Waste Management, Inc)

Waste Management, Inc. (WM) is the leading provider of waste management services in North America. The company network's of operation includes 293 active landfill disposal sites, 16 waste-to-energy plants, 72 landfill gas-to-energy facilities, 146 recycling plants, 346 transfer stations and 435 collection operations (depots). Combined, these resources enable WM to offer a full range of environmental services to nearly 20 million residential and two million commercial customers throughout the U.S. and Canada. WM provides solid waste collection services for residential, industrial, municipal and commercial customers in 48 states, the District of Columbia, Canada and Puerto Rico. With nearly 26,000 collection and

transfer vehicles, and about 19600 daily routes for six days a week, and collect about 80 million tons of solid waste each year.

7.1.1. Problems of Routes

WM fund that the annual operational cost of each collection vehicle is about $120,000. Thus WM had a good reason make daily routes as profitable and efficient as possible. The intention was to reduce the operating cost, but managing the daily activity of 19600 routes for six days a week was not a trivial task. This requires understanding of business line first.

WM is operating three different business lines, which are: residential waste collection, commercial waste collection, and industrial waste collection. Residential and commercial wastes are collected by stationary container system. Industrial waste collected by hauled container systems, using two different modes exchange container mode and conventional mode. A driver can use a point to point solution for commercial routes, while an arc-routing model is required for residential routes as it is only permitted to service customer on the right side of the street (figure 9). Industrial routes are like commercial but the containers are larger, thus a hauled container system is used which allowed servicing one container at a time. The difficulty arises when a driver is scheduled to perform different types of services throughout the day to customers with different container sizes.

WM seeks a solution that will meet three fundamental objectives, which are:

1) Rout reduction : cost saving
2) Workload balancing: number of routes across days of the week
3) Adherence to business constraints.

Figure 9: residential collection system
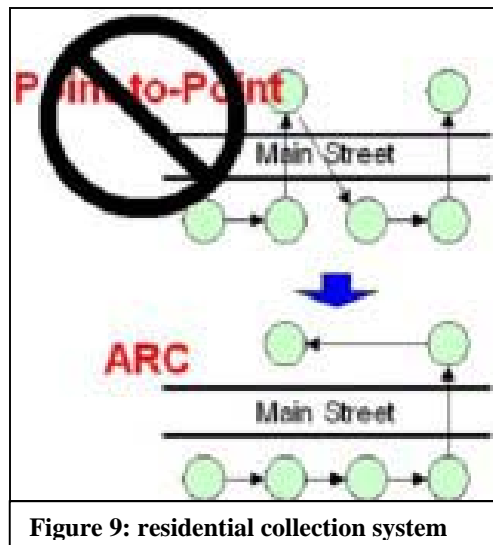
7.1.2. GIS and Optimization

A typical set of attributes for a customer would include name, billing information and address information. The address information is typically referred to mailings. Using typical information system, it is difficult to determine the proximity to other customers or routes, resulting in less-than-effective decision support. In GIS customers are represented spatially using a coordinate system. The location information and all other information are brought together with other spatial information such as streets. This will allow GIS to represent the exact distances and time on a street network between any two given points, taking into account various constraints that all contribute to generating a realistic result, including speed limits, directional attributes of the streets –e.g. one-way direction- , and accurate segment distances. GIS consists of both tabular data (in forms and reports) and a map displaying customer locations, landfills, and other facilities against a background of streets, landmarks, and other geographical boundaries. The unique coordination of the navigation tree, customer data and interactive map make the application simple to use.

7.1.3. GIS Deployment

GIS would fundamentally change the way WM services their customers. Getting people to change for any reason is very difficult. Employees tend to be defensive and resist changing the way they do their job. To maintain morale and build trust between employees and
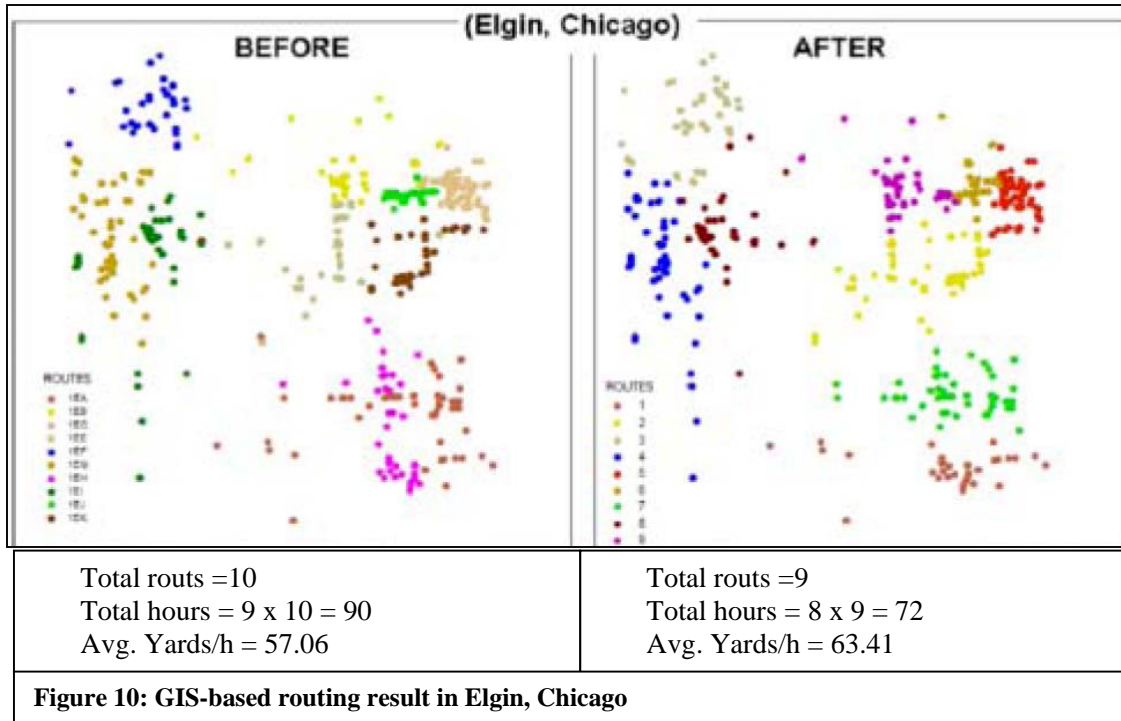
management, WM built a proactive communication plan and included employees at every step during the rollout and conducted classroom-training class. The objective was to train multiple people simultaneously while gaining on-the-job experience. The instructor-led training class was broken into two major components: standard operating procedures and application training. WM also deployed a series of self web-based training courses that covered each of the topics individually. Optimization Manager in Baltimore Renee Huff says, "Driver involvement has been a crucial success factor in implementing GIS at our site." The deployment for an individual site was broken into four major components:

- Service Boundary Analysis (SBA): gave the site the opportunity to remove any overlapping territories between neighboring WM sites.

- Weekly balancing: attempts to move customers to different days of service to balance the workload.

- The clustering stops: gives the user a first look at the geographies of the routes without creating individual route sequences.

- Optimize each daily route: the creation of the routes, driver and management reviews concluded the pre-deployment steps.

Deployment also includes review each customer's container size and frequency. If a customer has a small container and is serviced three or more times per week, it is better to exchange the container for a larger one and reduce the frequency of service, thus reducing the cost of service for that customer.

7.1.4. Results

This GIS-based route management application delivered reduced operational costs by organizing routes to minimize overlap and thereby reduce the number of vehicles required to service customers; and sequencing the stops along a route to make the best use of fuel, driver schedules, and disposal trips. As an example, GIS-based routing system was deployed in Elgin, Chicago. The result shows a reduction of one route which represent 10% of the routes, reducing the hours per route by one hour, and increase in the productivity of the routes from 57 yards per hour to 63 yards per hour (figure 10)

Total routs =10	Total routs =9
Total hours = 9 x 10 = 90	Total hours = 8 x 9 = 72
Avg. Yards/h = 57.06	Avg. Yards/h = 63.41

Figure 10: GIS-based routing result in Elgin, Chicago

WM deployed GIS-based routing system cross the nation in 2003 with a net effect of 984 fewer routes at the end of the year resulting in a saving of $18 million. The estimated saving in 2004 is about $44 million. Cost saving was not the only impact of GIS deployment. Increase revenue was a direct impact as routes had more capacity. With routs shown in GIS maps marketing department can easily target new customers in the same routs. Stabilization of routes has resulted in more consistent and reliable service for customers. The process of routes reduction also delivers a positive impact on the environment and employees. Fewer trucks on the road has resulted in a noticeable reduction of emissions and noise. Reduced travel during busy times of the day. Optimize fuel efficiency. Using GIS helps setouts – handicap or elderly persons being unable to put their waste curbside- by identifying their location along the routes.

7.2. Other Successful Stories

Many organization and agencies throughout different nations uses GIS to solve their problems which are related to waste collection. In general, they were aiming to save cost and time, improve response time to customer, balance workload, optimize their system, and provide a system that will help them in the assessment of efficiency and functionality of collection system. Trabzon municipality in Turkey and Dallah Company in Saudi Arabia are examples.

7.2.1. Trabzon Municipality in Turkey.

Trabzon City located in the northeast side of Turkey has about 185000 inhabitants. The city consists of 39 districts. To collect waste Trabzon municipality has located about 2800 waste container in the residential area. Waste is collected by collection vehicles using both stationary container system and hauled container system. Total length of waste collecting road network is 416 km and collection vehicle travels about 60% of that distance every day. Solid waste collection has about 85% portion of the total cost for disposal expenditure. A study was conducted by Yildiz Technical University in Istanbul, Turkey. The objectives of the study are:

- To use data gathered by observing the collection of MSWC in 39 districts in the city and to form a GIS database on the route map of Trabzon
- Optimize collection routes and minimize empty miles.
- To compare present route with optimized route for cost and time

The results of the study shows that if the optimized routes are used in solid waste collection system, both distance and time will be decreased by 4-59 % and 14-65 %, respectively (table 2). Monthly costs for optimized and present route are US$55320 and US$73334, respectively. This difference expresses a decrease by 24.7 % in cost.

Table 2: time and distance comparison for present and optimize routes

MSW	Present route		Optimized routes		Advantage, %	
Collection	Route	Route	route	Route	distance	time
Route name	Distance, m	Time, s	Distance, m	Time, s		
Route1	4833	2150	1966	702	59	67
Route2	2590	1498	1481	529	43	65
Route3	2997	998	2574	859	14	14
Route4	6930	4016	6149	2202	11	45
Route5	2621	1477	2523	900	4	39
Route6	2751	1580	2015	668	27	58
Route7	3337	1491	3090	1104	7	26
Route8	3034	1760	1801	644	41	63
Route9	5577	2148	4696	1682	16	22
Mean	3852,2	1902	2921,7	1032,2	24,7	44,3

7.2.2. Dallah Company, Saudi Arabia

Dallah company serve three major municipalities in Saudi Arabia, Handling the waste collection operation for a population of over a 4.5 million through more than one thousand waste collection vehicles. Managing collection system and assessing its functionality and efficiency was not an easy task for managers, therefore, they seek a solution that would help in this issue. GIS system was advised and then implemented. GIS and GPS system works together to provide the following solution for Dallah company managers:

- Offline as well as online tracking of waste collection vehicles
- surveying and mapping of bins locations
- automatic reporting tools
- automatic audit systems: analysis of theoretical routes and stops v/s actual routes and stops
- routes statistics (speed, bins service time, driver performance, bins visit frequency…etc)
- optimizing different types of operations: bin collection sweeping, water suction through gathering of statistical data.

8. WASTE DISPOSAL

Safe solid waste residual is significant to SWM plan. The residual waste is the material remains after all possible processing. Open dumps cause threat to the public as well as to the environment. Thus, waste should be disposed in managed landfill. Landfills are the places in the surface soils of the earth where the residual solid waste is disposed and sanitary landfills are those designed to minimize environmental damage. Landfilling is the process of waste disposing the most important step in development of new sanitary landfill is the selection of site to be used. Choosing a landfill place is a big challenge since it requires handling of large amount of spatial data and is controlled by many constraints. Some constraints requires landfills to be away from the city, e.g. at least 3000 m from hospitals, and others requires landfills to be placed close to the center of urbanized areas, e.g. hauling distance, also significant future changes should be considered. In general landfill site considerations are:

- Haul distance.
- Location restrictions.
- Available areas.
- Site access.
- Soil condition and topography.
- Climatic conditions.
- Surface water and hydrology.
- Geological and hydrogeological conditions .
- Local environmental rules.

The public usually demand assurance that all factors have been considered before location decisions are made. Thus, the need for tools that could help decisions makers in not only making optimum decision but also showing to the public that the decision is reached through an objective and transparent process. Using GIS analysis tools, such as overlapping and buffering, analyst can assure that all constraints were met in easy and fast way. Virginia GIS reference book listed minimum and optional data requirements for the any GIS model to be used in landfill management (Appendix B).

8.1. Case Study

(*Ottawa University Landfill Site Selection (LSS) GIS interface.*)

Landfill site selection is divided into two main steps: the identification of candidate sites by preliminary screening sites and the assessing of their suitability according to environmental impact assessment and criteria, engineering design and costs. This case study focuses on the first of these. The purpose of preliminary site screening is to eliminate quickly the parcels of land that are obviously unsuitable and classify those remaining according to their degree of suitability based on a composite suitability analysis using map overlays and integration. The criteria used for the preliminary screening include primarily the proximity of potential sites to geographic objects that may be affected by the landfill or that may affect landfill operations.

8.1.1. Rules for preliminary landfill sitting

Generally, criteria for preliminary landfill sitting are divided into three groups:

1) Environmental factors: include impacts that the landfill may have on the surrounding biophysical environment.

2) Engineering factors: e.g. the costs associated with acquisition, development, and operation of each site.

3) Social/Cultural factors: A site may be technically feasible and meet the environmental and engineering criteria, yet may have to be abandoned due to heavy public opposition. Hence public involvement in landfill site selection for any specific location is an essential factor.

8.1.2. GIS and Methodology of LSS

Landfill site selection large amount of data must be evaluated and made available as quickly as possible. GIS can efficiently stores, retrieves, analyses, and displays information according to user-defined specifications. Relatively easy presentations of GIS sitting results are also one of its other advantages. There is several available software, using GIS; however, one of the most popular that can be customized is ArcGIS Desktop. The ArcGIS applications are engineered for ease of use and powerful geographic display, query, and analysis. By using programming language, there would be an unlimited freedom to customize the user interface for users' business needs. The approach was to utilize models, which combine and integrate

maps to determine an optimal landfill sitting. Thus a Landfill Site Selection (LSS) program was developed and its toolbar was added to ArcMap interface (figure 11).
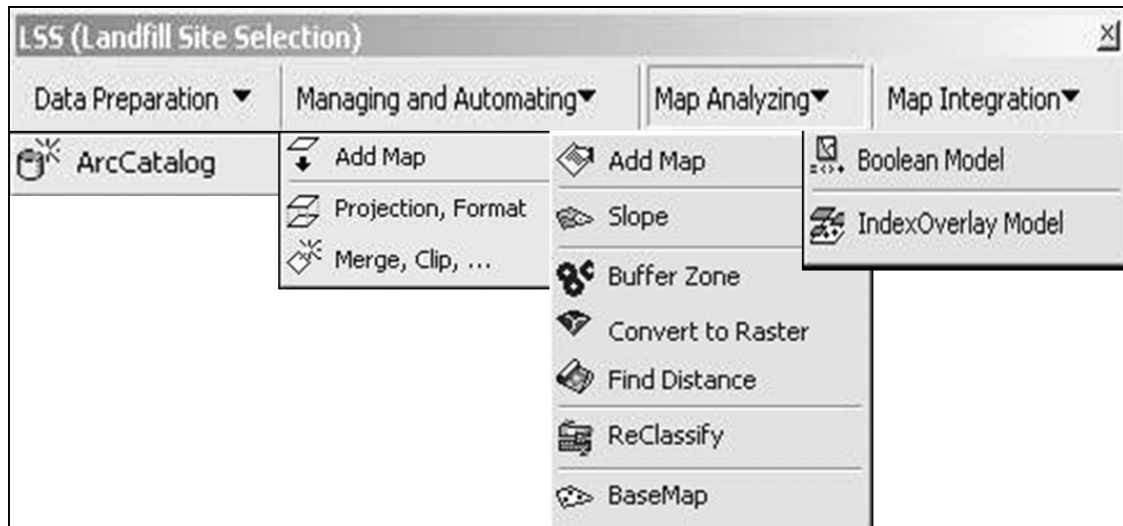

Figure 11: Landfill site selection interface added to ArcMAp

Two models of map integration were developed which are Boolean model and IndexOverlay model. Boolean model involves the logical combination of binary maps resulting from the application of conditional operators. Criteria and guidelines have been established as a set of constraints (figure 12). The output is a binary map, because each location is either satisfactory or not.
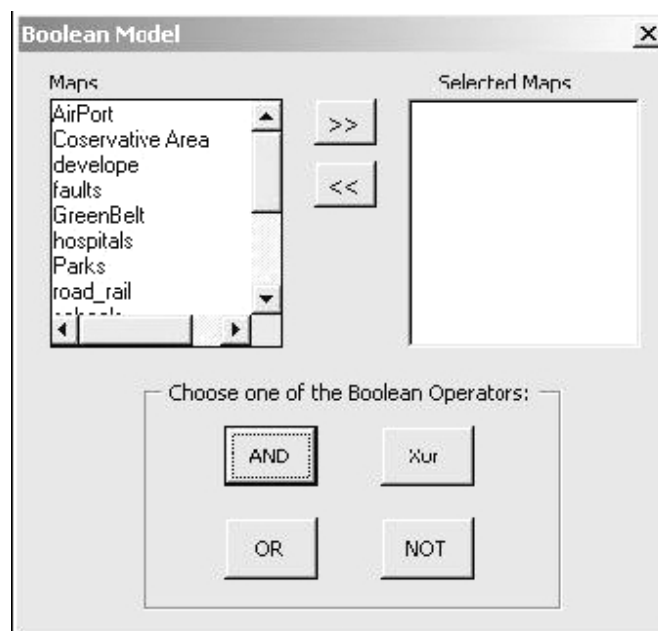

Figure 12: Boolean model in LSS

In practice, it is usually unsuitable to give equal importance to each of the criteria being combined. Evidence needs to be weighted depending on its relative significance. Thus, in IndexOverlay model each factor maps will be assigned a score to express the relative importance (figure 13). Final map will be generated that identifies regions that are most suitable for the location of a landfill site. An optimal site will be chosen based on the highest suitability values and the size of the site.
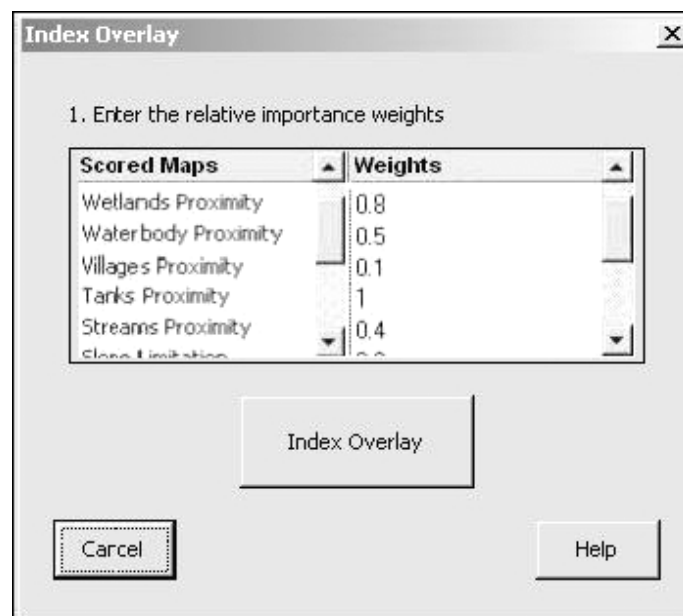

Figure 13: IndexOverlay model in LSS

8.1.3. Landfill Site Selection Project

The project was conducted for Ottawa, Canada. The main steps of project are:

1) Identify the criteria and constraints for the study region: to make sure that the necessary regulations and criteria are complied with. For the sake of demonstration the following criteria and constrains were considered:

The landfill :

- Can not be located in Greenbelt area (Source; City of Ottawa).

- kept more than 3000m away from runways used by turbojet (Source; USEPA)

- Should have a slope lower than 40% degree (Source; Taiwan University)

- Should be kept more than 300m away from streams (Source; Illinois, USA)

- Should not be located in Parks (Source; Ohio EPA)

- Must be more than 155m from developed area (Source; Illinois, USA)

- Must be kept more than 60m away from faults (Source; US EPA)

- Should not be located in Wetlands (Source; Regulation 232/98, Canada)

- kept more than 60m away from and water body (Source; Pennsylvania, USA)

- Should be kept more than 60m away from tanks (Source; Tennessee, USA)

- Must be kept more than 150m away from residence (Source; Guilford, USA)

- must be kept more than 3000m away from Hospitals and schools(Source; Illinois, USA)

2) Create and design the database for analysis.

3) Managing and automating maps: e.g. digitizing and scanning.

4) Analyzing maps: using LSS tools.

5) Integrating maps: the two models were considered Boolean and IndexOverlay.

8.1.4. Boolean Model Results

Figure 14 shoes the constraints maps for the study area, and the final constraint map which includes all of the constraint maps generated by map overlaying is shown in figure 15.
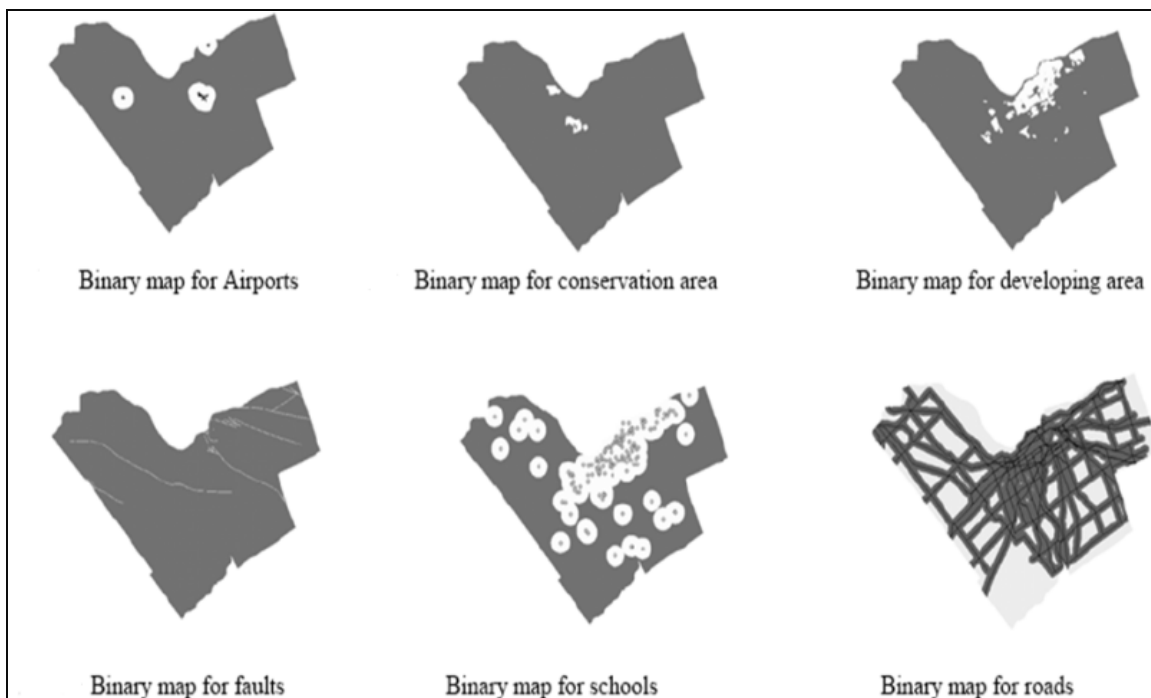
Figure 14: constraints maps for Ottawa, Canada. Using Boolean model
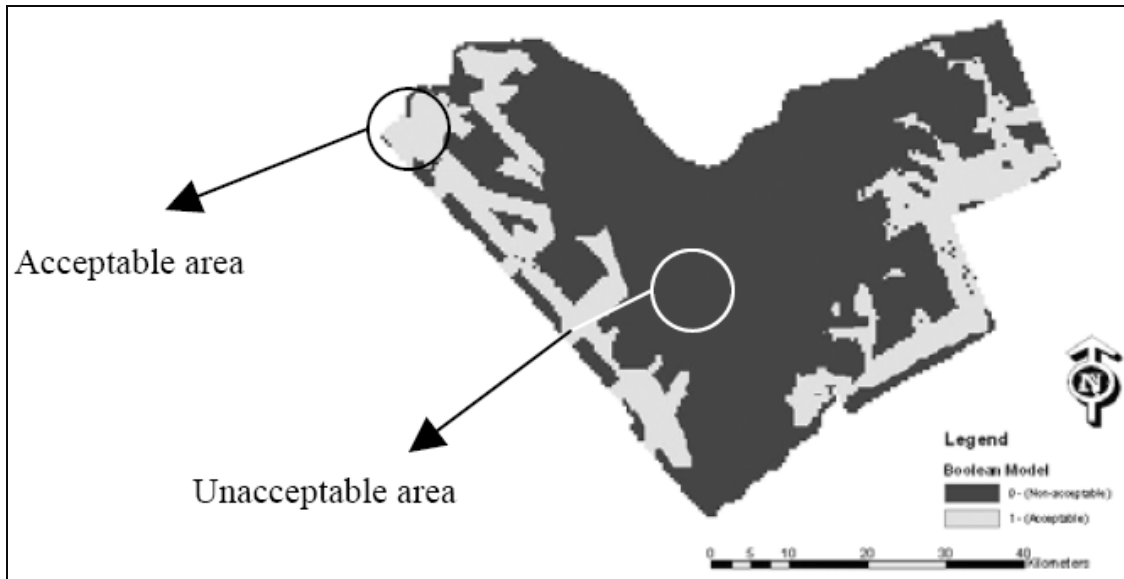
Figure 15: map formed by overlay of Boolean model constraints maps for Ottawa, Canada

8.1.5. IndexOverlay Model Results

Figure 16 shows the scored maps for the constraints. Higher wheight is given for factors that are more important (table 3). And the final map resulting from overlaying all maps is shown in figure 17.
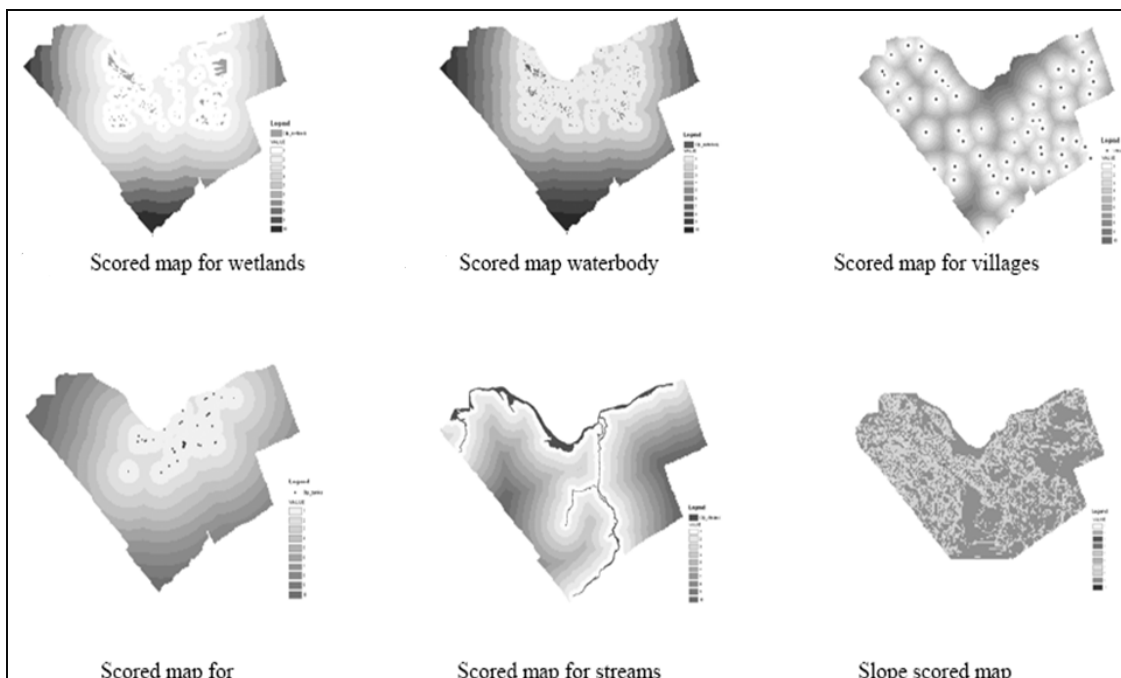

Figure 16: scored maps for Ottawa, Canada. IndexOverlay

Table 3: weights assigned to scored maps

Scored Maps	Weight
Scored map for wetlands	0.8
Scored map for waterbody	0.5
Scored map for villages	0.1
Scored map for tanks	1.0
Scored map for streams	0.4
Scored map for slope	0.2
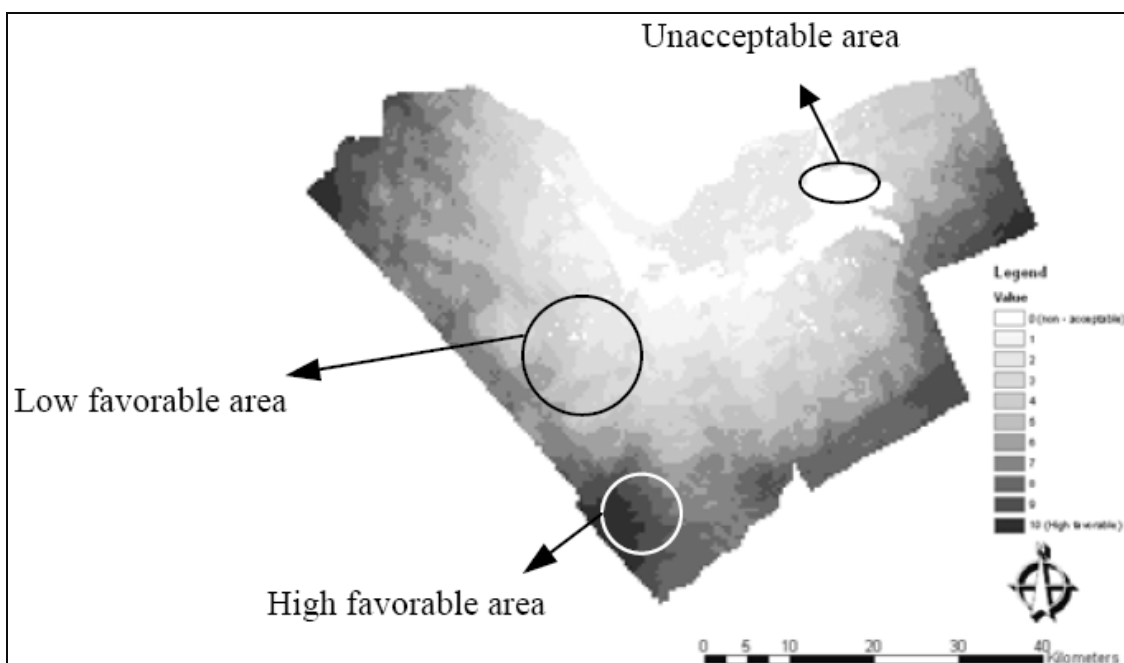
Figure 17: map results of IndexOverlay model, by overlaying scored maps

8.1.6. Conclusion

This method was tested successfully in Ottawa area based on the available data. ArcGIS toolbar, is a very flexible and straightforward tool for engineers and planers and could be applied to any region and site selection problems and should result in an optimal result given the same data. As more data becomes available more constraints could be considered in the selection process easily. IndexOverlay model allows for a more flexible combination of evidence maps and making decision.

8.2. **Other Useful Applications**

The purpose of proper landfill site management is to dispose of waste efficiently, safely and economically, with minimal environmental impact to the surrounding area, in both the long and short term. GIS can be used throughout landfill life cycle. Many researches being carried out involves the use of a GIS to record, store and display a wide range of information of the physical data related to landfilling. A GIS is an important tool in the planning and development of a landfill site and has many purposes from capacity calculation to monitoring of settlement and methane levels. Also GIS can be used during the landfilling process to protect the surrounding environment from potential contamination, either from leachate or gas migration. Best and worst case scenarios can be worked out for leachate contamination, gas migration, or surface settlement simply and easily on a GIS.

9. CONCLUSION

This paper starts by giving brief introduction about solid waste (SW) and solid waste management (SWM). Then mentions the benefits of geographic information system (GIS) that that can be utilized in the field of SWM. The objective of this paper is to demonstrate the aid of GIS in different areas related to SWM. Three functional elements of SWM were discussed, which are waste storage, waste collection, and waste disposal.

In areas related to waste storage, the main approach was to use GIS to identify the exact location of waste storage points and link its attributes to its location. This approach have been used in different ways: in the case of Aurangabad city, India, this approach was used to identify waste bins that are improperly placed in order to relocate them, to allocate new recyclable waste bins, and to balance workload. For the case of Dayees Air Force in Texas, U.S. the same approach used to record condition of waste dumpsters and schedule them for maintenance and the use of GIS save a lot of working hours that was required for this job. For the case of Garland's city in Texas, U.S. the same approach used to identify owners of the additional trash containers provided by the city municipality.

Waste collection is complex and costly process it has more than half of the budget allocated for waste management services. The goal was to make collection system as efficient as possible. The key solution to achieve this goal was by optimizing routes, and tracking collection vehicles. The implementation of GIS-based routing system results in big time and money saving. Also route optimization has other intangible advantages, such as reduce noise and car emission.

The use of a GIS in waste disposal management starting from the site investigation stage of a landfill site, through the site's development and filling, and then during its post closure care, will allow the many different parameters of the complex life of a landfill to be recorded, displayed, and analyzed. This will ensure that the maximum capacity of a landfill has been achieved with the minimal environmental impact on the surrounding environment.

APPENDIX A

Questionnaire for the public

Case of Aurangabad city, India

Questionnaire for Citizens

Q1. What kind of waste do you throw in the municipal waste?
    a) Vegetable waste (100%)
    b) Food waste (100%)
    c) News paper (100%)
    d) Plastic (10%)
    e) Swept garbage (100%)
    f) Yard/garden waste (100%)

Q2. What kind of waste do you produce which you dump in municipal bins?
    a) Dry
    b) Wet
    c) Mixed (100%)

Q3. How do you store/collect the waste at your place?
    a) In a polythene (10%)
    b) In a paper bag
    c) In your personal waste bin (90%)

Q4. How do you throw the waste in the municipal bin?
    a) In a polythene (10%)
    b) In a paper bag
    c) News paper
    d) Directly empty the waste from your personal waste bin into municipal waste bin (90%)

Q5.How long do you keep the Municipal waste at your house bin?
    a) 1-2 day (65%)
    b) 2-3 days (30%)
    c) 3-4 days (5%)
    d) A week

Q6. Out of these, which items do you sell to the waste buyers?
    a) Glass
    b) Old books
    c) News paper
    d) Plastic bottles
    e) Polythene bags
    f) Metals
    g) Clothes
    h) Foot ware
    i) Others
    j) All mentioned above (100%)

Q7. Do you find it feasible to sort the resalable waste and keep it separately?
 a) Yes (100%)
 b) No

Q8. What do you do to the recyclable waste you generate at your place?
 a) Dump in the municipal waste bin with municipal waste
 b) Sell it to the waste buyers (100%)
 c) Also try to use it some how (45%)

Q 9.How does the waste buyers contribute to your personal waste management?
 a) Positively (100%)
 b) Negatively
 c) No contribution

Q 10.How long do you keep/store the recyclable/resalable waste at your place?
 a) 1-2 days
 b) 2-3 days
 c) 3-4 days
 d) 1 week (45%)
 e) 2 weeks (15%)
 f) 3 weeks (15%)
 g) More (25%)

Q11. What would be the convenient distance for you to the municipal waste bin from your place?
 a) Up to 50 meter (20%)
 b) Up to 100 meter (70%)
 c) Up to 150 meter (10%)
 d) Up to 200 meter
 e) Up to 250 meter

APPENDIX B

Landfill Layers

Virginia GIS Reference Book

VIRGINIA GIS REFERENCE BOOK

2. Minimum Spatial Data Requirements

General Description	GIS Data Layer
Landfill	Boundary
	Monitoring Wells
Land Base / Planimetric Data	Jurisdictional Boundaries
Natural Features	Ecologically Critical Areas
	Flood Plains
	Geology
	Ground Water
	Open Water
	Soils
	Wetlands
Socio-Political	Demographic/Census Data
	Historical
	Hospitals
	Natural Parks
	Schools
	Land Use
	Zoning
Transportation	Street Centerlines
Utilities	Potable Water Wells
	Reservoirs

3. Optional Spatial Data Requirements

General Description	GIS Data Layer
Land Base / Planimetric Data	Orthophotography
Natural Features	Terrace Areas
	Vegetation
Socio-Political Data	Fire Stations
Transportation	Airports
	Railroads
Utilities	Electric
	Gas
	Storm Water
	Wastewater System
	Water System

4. Minimum Attribute Requirements

GIS Data Layer	Attributes
Landfill	Site ID
	Property Address
	Acreage
	Waste Type
	Status
Buildings	Feature ID
	Dimensions
Streets	Address Ranges
	Street Name

5. Optional Attribute Requirements

GIS Data Layer	Attributes
Landfill	Year Constructed
	Closing Data (if applicable)
	Base Elevation
	Top Elevation
	Environmental Test Results
	Permit Status
	Ground Water Monitoring (Y/N)
	Dump Type

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