सत्यमेव जयते

Ministry of Housing and Urban Affairs
Government of India

## Training Module on

# Application of Geospatial Tools in Municipal Waste Management

*Sustainable Cities Integrated Approach Pilot in India*


gef

UNIDO
UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

NIUA
National Institute of Urban Affairs

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## (Solid Waste & Waste Water)

*Sustainable Cities Integrated Approach Pilot in India*

May, 2022

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Component 3: Partnerships, Knowledge Management and Capacity Building

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CONTENT
The given module is prepared by compiling information sourced from various knowledge products and training modules prepared by Ministry of Housing and Urban Affairs (MoHUA), National Institute of Urban Affairs (NIUA) and Central Public Health and Environmental Engineering Organization (CPHEEO) for knowledge dissemination and capacity building of municipal officials.

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THE FULL MODULE SHOULD BE REFERENCED AS FOLLOWS
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## BASIC PROJECT INFORMATION

| | |
|---|---|
| **Project Title** | Sustainable Cities Integrated Approach Pilot in India |
| **Project Component** | Component 3 - Partnerships, Knowledge management and capacity building |
| **Project Deliverable** | Delivery of tailored training and capacity building activities in 5 pilot cities – Bhopal, Guntur, Jaipur, Mysuru and Vijayawada |
| **Project start date** | December 2019 |
| **Duration of Project** | 2 Years |
| **About this Module** | This module is a part of the second deliverable for the project to provide training modules for three sectors. |

## ABOUT THE PROJECT

"Sustainable Cities Integrated Approach Pilot in India" is one of the child projects under GEF's Sustainable Cities Programme in the GEF 6 cycle. The aim of the project is to integrate sustainability strategies into urban planning and management to create a favourable environment for investment in infrastructure and service delivery, thus building resilience of pilot cities. The three main project components comprise- Sustainable Urban Planning and Management, Investment Projects and Technology Demonstration and Partnerships and Knowledge Management Platform.

National Institute of Urban Affairs (NIUA) has been engaged to undertake the implementation of Component 3 – Partnerships, Knowledge Management and Capacity Building. As a part of this component of the Project, a Training and Assistance Needs Assessment (TANA) was conducted from February 2020 to August 2020 for the ULBs of five cities - Bhopal, Jaipur, Mysuru, Vijayawada and Guntur to assess and identify the needs of the ULB officials to prepare on-the-job training modules.

## ABOUT THE TRAINING MODULE

Based on the results of TANA, training modules on Solid Waste, Wastewater and Water Management have been developed by NIUA. The modules are an outcome of the activity 2 of the project which included the following tasks:

- On the basis of TANA results, training modules were prepared for relevant stakeholders
- For developing the Module & Pedagogy, NIUA has synergized the experience of practitioners and subject experts.
- The modules have been finalized in coordination with experts and officials from cities.

This module on Application of Geospatial Tools in Municipal Waste Management is a part of the series of modules that would supplement the training activities.

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Chapter
1

# Municipal Separate Storm Sewer System (MS4)

## Summary

Urban Flooding is a growing threat towards the direction of sustainable development in our cities, yet the tools needed to study these infrastructure systems in data-scarce environments are woefully inadequate. In majority of our Indian cities, chief engineers still use paper maps, tabular data and sketches to maintain the sewerage system. Once pipeline is buried underground, no one is able to trace it, due to which new constructions accidentally damage pipes. In support of developing informed planning policies, through a comprehensive infrastructure inventory, various measurements are used in conjunction with GIS software

## Training Objectives

- To understand the need of GIS Mapping for Sewerage System
- To study in depth the Infrastructure of Drainage Pipes & Basin.
- To familiarise the audience with mobile application tracking & GIS Dashboard for monitoring

## Training Outcomes

- Gain importance of GIS Mapping for Sewerage System.
- Understand working mechanism of underground Drainage pipe, Size of Crate, Sensors, Pipe Material Pipe Size etc.
- Understand GIS Applications, Geotagging & Preparation of dashboard for monitoring.

## Chapter Contents

## 1.1 Introduction

Urban Flooding is a growing threat towards the direction of sustainable development in our cities, yet the tools needed to study these infrastructure systems in data-scarce environments are woefully inadequate.In majority of our Indian cities, chief engineers still use paper maps, tabular data and sketches to maintain the sewerage system. Once pipeline is buried underground, no one is able to trace it, due to which new constructions accidentally damage pipes. Furthermore, lack of proper data municipalities unable to manage sewerage system.

### Need of GIS Mapping for Sewerage System

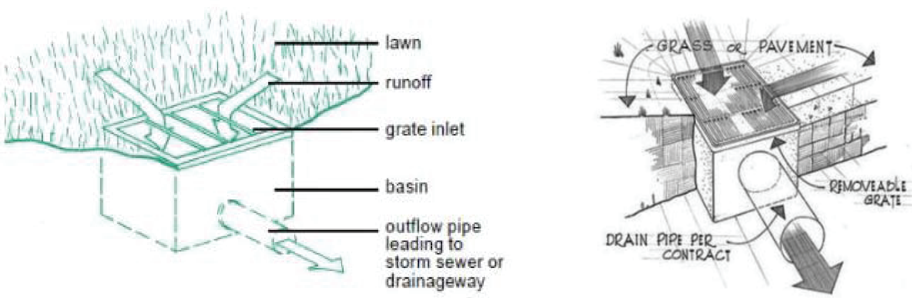
GIS based mapping helps to locate sewerage network and allow building database of it. To identify trends in water main breaks to prioritize pipe replacement and rehabilitation projects. Such projects are typically analyzed using a variety of weighted criteria such as - pipe material, diameter, age, surrounding soil conditions, proximity to critical locations (hospitals and schools), main-break history, water quality, and coordination with other public works projects.

All these criteria can be represented spatially in a GIS based tools with the pipe inventory.

### What is Catch Basin?

It is an engineered drainage structure, tasked with the function of collecting rainwater and snowmelt from streets and parking lots and transporting it to local waterways through a system of underground pipes, culverts, or drainage ditches. This drainage system is integral in the prevention of dangerous and damaging flooding events on local streets or roadways and in preventing damage to residential homes and other private property.

**Figure 1.1: Functional diagram of Catch Basin.**

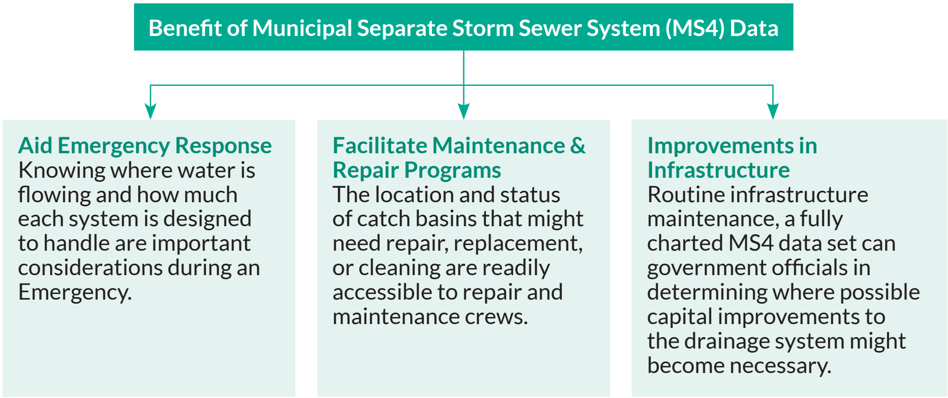



*Source: Mapping a storm water Drainage System, Joshua Robert & Camryn McGrath; 2018*

## Benefit of an effective Municipal Separate Storm Sewer System (MS4)

It prevents large amounts of untreated sewage from overwhelming existing wastewater treatment facilities, draining directly into local water bodies, and damaging local ecosystems. An MS4 system includes a variety of structures, including catch basins, curbs, gutters, ditches, man-made channels, or storm drains that work to collect, convey, and direct the flow of water to a desired location.

**Figure 1.2: Benefit of Municipal Separate Storm Sewer System (MS4) Data**

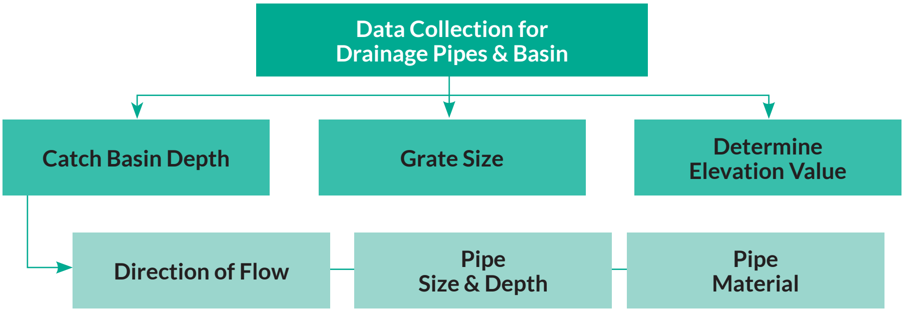



*Source: Author Expert*

## Need to Collect Data for Municipal Separate Storm Sewer System (MS4)

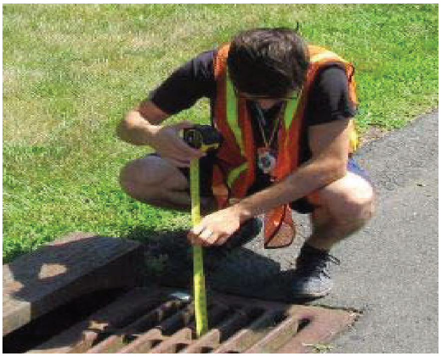
Collecting a variety of data about each catch basin will help ULBs in the development of its own comprehensive management plan. Data collection and measurement of the intricacies of storm water flow, direction, and quantity will be beneficial for Citizens, ULBs and lying departments. This system will help ULBs in displaying the effectiveness of MS4 system and the ability to reduce the discharge of pollutants and contaminants into local water bodies.

**Figure 1.3: Methodology**
**(Data Collection for Drainage Pipes & Basin)**



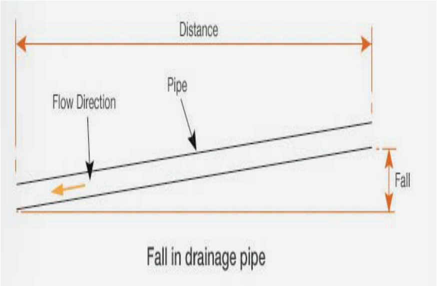

*Source: Author Expert*

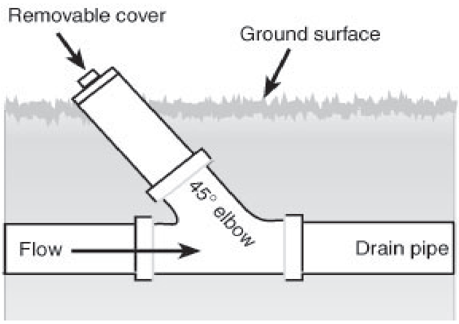
**Catch Basin Depth:** It should be measured from the surface of the grate to the bottom of the basin using a standard 25’ tape measure. The catch basins measured range should be approximately as little as 4 inches to over 200 inches in depth.



**Grate Size:** To collect grate size information, the length and width of each catch basin has to be measured and recorded. Most catch basins in the system are approximately 48 inches by 22 inches in size and include a metal curb box.

**Elevation Value:** Measured with the help of DEM or Lidar for calculating the depth



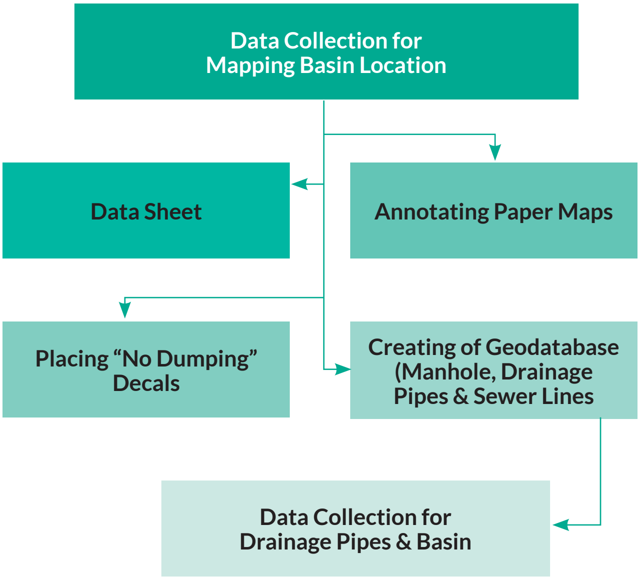




**Direction of the Flow:** Once the direction of water flow through pipes and which pipes are connected to which catch basins is determined using elevation values, a compass can be used to note the cardinal direction in which water would flow through the system.

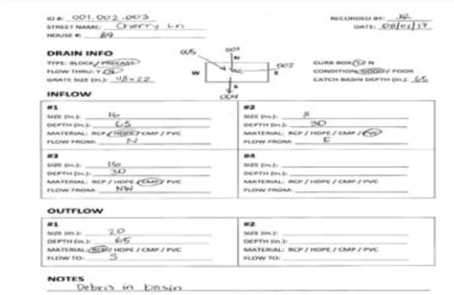
**Pipe Size & Depth:** Pipe size is measured by feeding the tape measure through the grate, and measuring the diameter of the pipe. The depth of the pipe, records as the distance from the bottom of the pipe to the surface of the grate.

**Pipe Material:** Pipe material is an important data value, because different pipes have different capabilities within the drainage system. Various type of pipe material include: High Density Polyethylene Pipe (HDPE), Corrugated Metal Pipe (CMP), Polyvinyl Chloride (PVC), & Reinforced Concrete Pipe (RCP).

**Figure 1.4: Methodology**
**(Data Collection for Mapping Basin Location)**




*Source: Author Expert*



ID #: 001.002.003
STREET NAME: Cherry Ln
HOUSE #: 89
RECORDED BY: JP
DATE: 08/01/17

DRAIN INFO
TYPE: BLOCK / PRECAST
FLOW THRU: Y / N
GRATE SIZE (in.): 48 x 22
CURB BOX: Y / N
CONDITION: GOOD / POOR
CATCH BASIN DEPTH (in.): 65

INFLOW

| #1 | #2 |
|---|---|
| SIZE (in.): 16 | SIZE (in.): 8 |
| DEPTH (in.): 65 | DEPTH (in.): 30 |
| MATERIAL: RCP / HDPE / CMP / PVC | MATERIAL: RCP / HDPE / CMP / PVC |
| FLOW FROM: N | FLOW FROM: E |
| **#3** | **#4** |
| SIZE (in.): 16 | SIZE (in.): |
| DEPTH (in.): 30 | DEPTH (in.): |
| MATERIAL: RCP / HDPE / CMP / PVC | MATERIAL: RCP / HDPE / CMP / PVC |
| FLOW FROM: NW | FLOW FROM: |

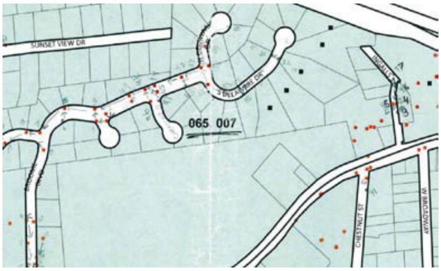
OUTFLOW

| #1 | #2 |
|---|---|
| SIZE (in.): 20 | SIZE (in.): |
| DEPTH (in.): 65 | DEPTH (in.): |
| MATERIAL: RCP / HDPE / CMP / PVC | MATERIAL: RCP / HDPE / CMP / PVC |
| FLOW TO: S | FLOW TO: |

NOTES
Debris in basin

**Data Sheet:** Blank data sheets are used to effectively record and organize data in the field. Each catch basin should be assigned its own unique identification number, based on its location within a particular section, subsection, and division within the municipal area.

**Annotation of Paper Maps:** In addition to filling out data sheets, paper maps with existing catch basin locations are manually annotated with parameters such as catch basin number, pipe layout, and flow direction.

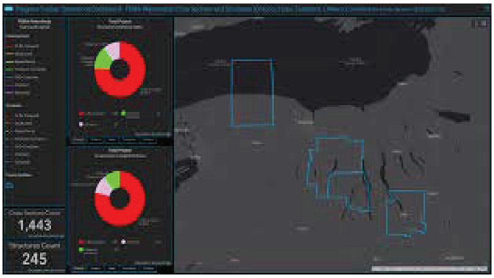




**Placing "No Dumping Decals":** Plastic "No Dumping" decals should be glued onto the curb box of each catch basin to inform residents and raise awareness of the fact that the storm drains in local neighbourhoods lead directly into local water bodies, and that any dumping into the catch basin will lead to undesirable contamination of the environment.

**Geodatabase:** Creation of Geodatabase include. Geotagging of Manhole using GPS equipment, Sensors and remote sensing techniques delineating pipes & sewer lines. One of the most important step in cataloging the collected MS4 data, is to plot each feature spatially using GIS software.

**Interactive Web Application:** Once data collection is complete, the next step is to transfer the data sets onto a Web platform. The geographic location of catch basins and pipes are drawn onto a base-map, along with a variety of accompanying measurements.



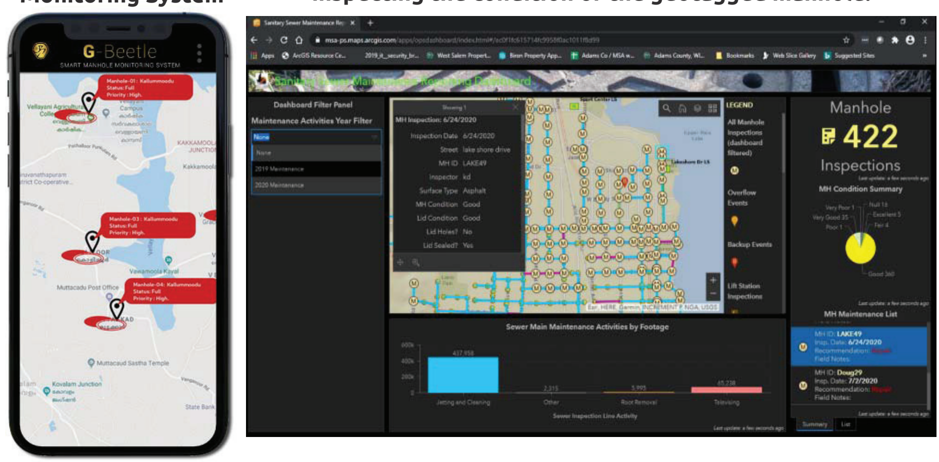

## 1.3. Mobile Application & Dashboard

After installation of sensors and creating a managing centre, alert message can be designed in case of, any problem related to manhole maintenance & infrastructure. In addition, a GIS Dashboard can be generated for the same.

**Figure 1.5:**

**(a) G-Beetle, Smart Manhole Monitoring System**

**(b) GIS Live Dashboard for inspecting the condition of the geotagged manhole.**




*Source: G-Beetle Smart Manhole Monitoring System; 2019*

Chapter

2

# Land Suitability for Waste Management

## Summary

The conventional methods of waste disposal prove to be inconvenient and expensive hence triggering the need of Geographical Information System (GIS) and remote sensing. It is not easy to monitor large areas routinely and systematically for waste dumping sites. GIS technology, which uses satellite data and algorithms to find unknown illegal sites, has proved to work extremely effectively and can pro-actively detect and stop illegal sites over very large areas, quickly, and cost-effectively.

## Training Objectives

- To understand the need of GIS Mapping for Solid Waste Management.
- To understand the concept of site suitability using GIS methodology

## Training Outcomes

- Gain importance of GIS Mapping for Solid Waste Management.
- Better Management of Solid waste management and Landfill site allocation

## Chapter Contents

## 2.1 Introduction

Due to increase in number of human and development activities, our cities/towns are producing enormous amount of solid waste without proper planning. This has led to both economic and environment sufferings. The conventional methods (generally municipal solid waste is collected and deposited in sanitary landfill which attract birds, rodents and fleas to the waste dumping site and result in the emission of carbon dioxide ($CO_2$), methane ($CH_4$) and other harmful gases) of waste disposal prove out to be inconvenient and expensive. Monitoring large areas routinely and systematically for waste dumping sites is a gigantic task for ULBs. GIS technology, which uses satellite data and algorithms to find unknown illegal sites, has proved to work extremely effectively and can pro-actively detect and stop illegal sites over very large areas, quickly, and cost-effectively.

### Use of GIS in Solid Waste Management

GIS along with data captured from Remote Sensing Technique (aerial photography, videography, and optical, thermal, microwave or LiDAR sensors) is integrated with attribute and layers of prerequisite information which could make it easy to understand the area's waste generation nature and trend.

These trends are useful while planning waste management and provide remedies while dealing with such severe environmental issue. This technique is used to generate optimal route for collecting solid waste. GIS is a tool that not only reduces time and cost of the site selection, but also provide asset management services for future monitoring program of the site. GIS information can be related spatially, exchanged, compared, evaluated, and processed with a very good flexibility.

## 2.2. Methodology

### How is it done?

Solid Waste management using GIS involves steps like:

- Demarcating exact location of waste bins on base map by GPS or by surveying.
- Attributing record of the waste bins.
- Identifying the pre-existing waste disposal pattern.
- Locating the optimal waste dumping ground/landfill site and maintaining a record about the amount of waste being dumped at the landfill site.

**Figure 2.1: Simplified Representation of the Steps Involved in Creating a Model for Analysis**


*Source: Author Expert*

## Selection of suitable landfill sites

Selection of dumping site is essential for solid waste management as unplanned dumping and trenching of waste could be hazardous to environment and health of humans and wildlife.

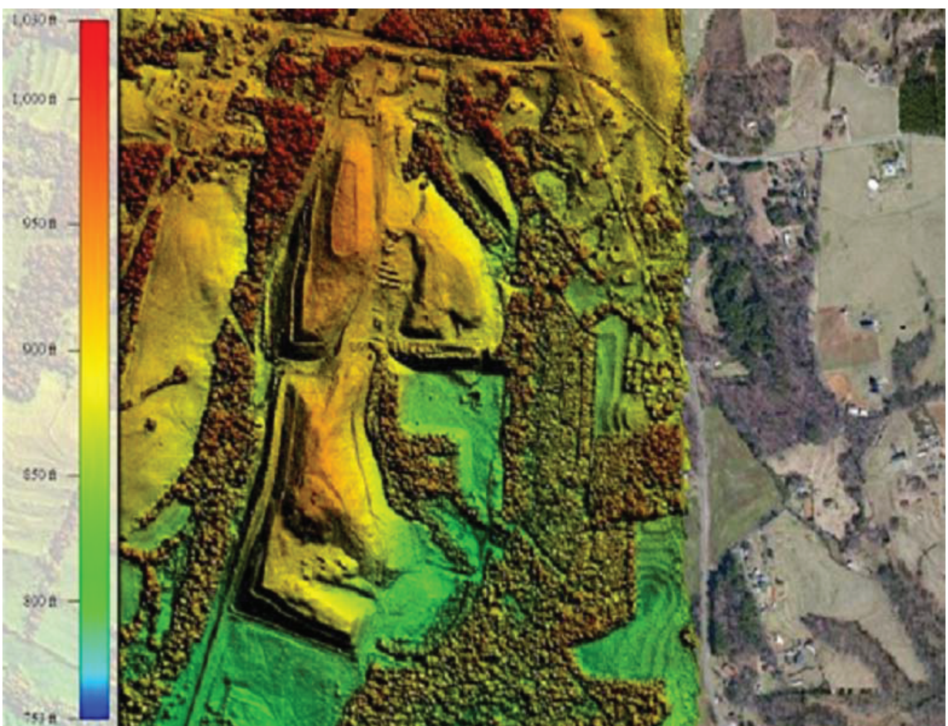
To analyze the suitability of a location for solid waste landfill, understanding the topography of the proposed site and its nearby surroundings is most important.

## Production of Digital Elevation Model (DEM) and its Role

The DEM generally is the 3D representation of the topographic surface demonstrating hill, valley, plain, slope, coastal and water areas, vegetation etc.

Furthermore, Slope and visibility analysis is performed to digital elevation model (DEM). Slope analysis expresses the elevations according to varying slope values, which can be beneficial for the movement of heavy vehicles for the transportation of heavy tonnage vehicles to the solid waste landfill site. Moreover, slope analysis helps to determine direction and the effects of dust and particulate matter originating from solid waste landfill site.

**Figure 2.2: Digital Elevation Model for Site Suitability Analysis**



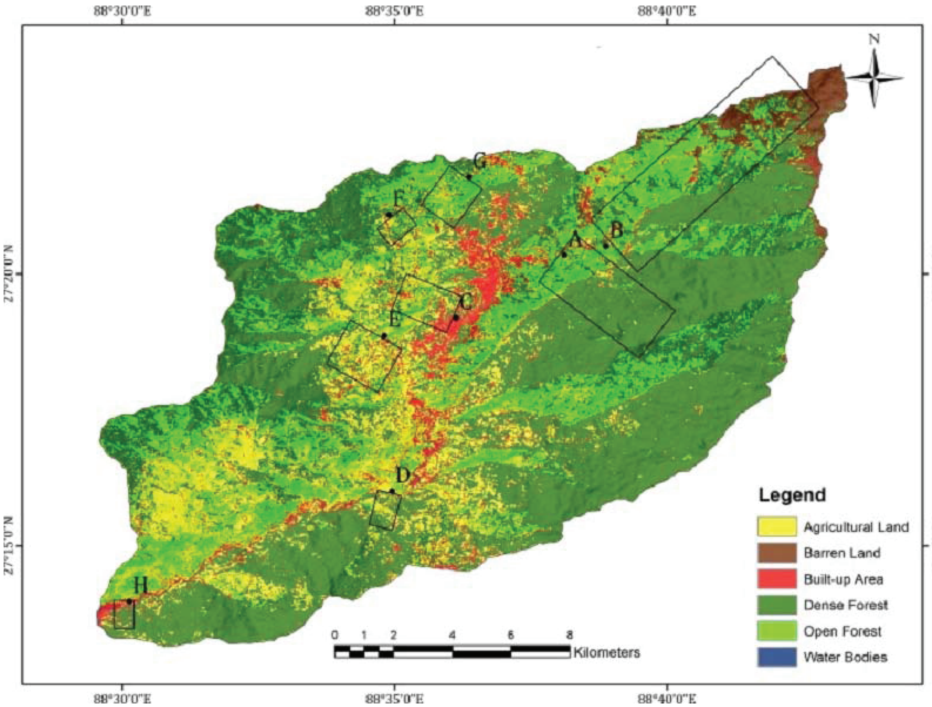

*Source: Land Suitability for Waste Management; 2016*

## Role of LULC Map of the Land Fill Site and its Surrounding Area (distances to settlement areas, road and proximity to water bodies)

To monitor the ongoing process LULC pattern over a period of time and time series satellite data can be used for preparation of Land use landcover map of the study area. The current and prospective use of land tends to be important criteria involved in selecting landfill site. Ideally, barren lands with less socio-economic, environmental and political value or cost is recommended as disposal site.

Commutation plays major role while locating landfill site. An ideal landfill site should neither be located too close to main road where the general public move as landfill can have harmful effect to health nor it should be located too far from main road as it can hamper transportation and access to the site. Proximity of a landfill site to water bodies poses extreme threat to environment as water can runoff and leach the landfill site. Hence, waste disposal should be placed away from water points.

**Figure 2.3: Land use & Land cover Map**




*Source: Land Suitability for Waste Management; 2016*

## 2.3. Summary

GIS and application of multi-criteria analysis can help in selection of suitable sites for solid wastes disposal, which is a vital component in solid waste management.

Global positioning system used for earth observation can track waste mainly by tracking vehicles, or paperwork chains. GNSS satellite technologies can also be deployed to physically track the waste itself. Further, this technology will also allow having confirmation on: where the waste has gone, rather than just potential movements. GIS, Remote Sensing, GPS along with other technologies are helpful in producing DEM, LULC etc. that plays a significant role in solid waste management.


TANA

Chapter 3

# Smart Real Time Manhole Monitoring System

## Summary

To mitigate the incompetency of manual monitoring of drainage manhole, a system using a wireless sensor network consisting of sensor nodes are designed. The proposed system is low cost, low maintenance, IoT based real time, which alerts the managing station through an email when any manhole crosses its threshold values. This system reduces the death risk of manual scavengers who clean the underground drainage and benefits the public.

## Training Objectives

- To understand the need of Smart Real Time Manhole Monitoring System
- To understand the working mechanism of the sensors
- To familiarise the audience with type of Sensor Network and Transmission Station.
- To familiarise the audience with mobile application tracking & GIS Dashboard for monitoring

## Training Outcomes

- Gain importance of Real Time Automated Manhole Monitoring over manual monitoring
- Understand working mechanism of sensors and transmission stations.
- Understand GIS Applications, Geotagging & Preparation of dashboard for monitoring.
- Identifying sensors purchase-ability in Indian market & Worldwide.

## Chapter Contents

## 3.1. Introduction

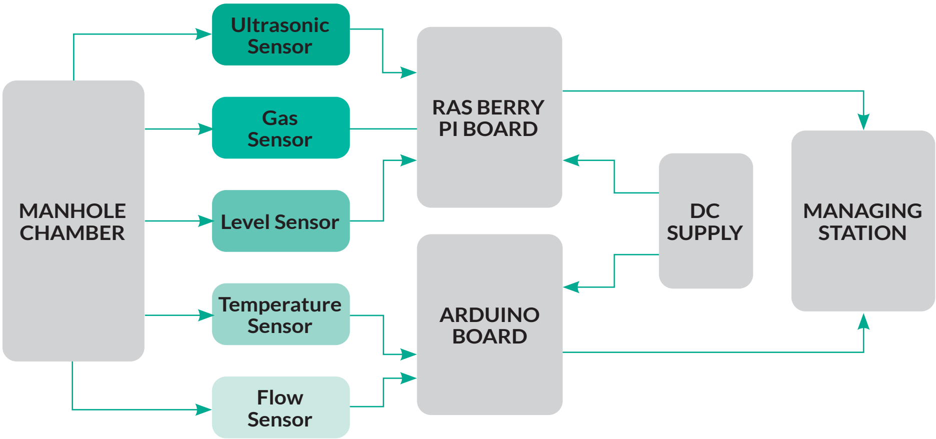
Drainage system monitoring plays a vital role in keeping the city clean and healthy. Since manual monitoring is incompetent, this leads to slow handling of problems in drainage and consumes more time to solve.

To mitigate all these issues, the system using a wireless sensor network, consisting of sensor nodes is designed. The proposed system is low cost, low maintenance, IoT based real time, which alerts the managing station through an email/trigger message when any manhole crosses its threshold values. This system reduces the death risk of manual scavengers who clean the underground drainage and benefits the public.

This model represents the implementations & design function of underground drainage & manhole monitoring system with separate transmitter & receiver models. Considerations of this design are low cost, low maintenance, fast deployment, and a high number of sensors, long lifetime and high quality of service.

This system helps in monitoring water level, atmospheric temperature, water flow and toxic gases. If drainage gets blocked and sewage water overflows, manhole lid opens, it is sensed by the sensors and this data is sent to the corresponding managing station via transmitter located in that area.

**Figure 3.1: Functional block diagram.**




*Source: SMART REAL TIME MANHOLE MONITORING SYSTEM; IRJET; 2019*

Maintenance of manholes manually is tedious, due to the poor environmental conditions inside, and therefore dangerous to go inside the manholes for inspection of its current state. To solve all the problems related to underground sanitation,a remote alarm system is necessary for transmitting data collected uses Wireless Sensor Networks (WSN) to implement this system. These nodes are composed of controller, memory, transceiver and battery to supply power.

## 3.2. Methodology

The functional block diagram describes the monitoring of manhole in underground drainage system. Any blockages, rise in temperature, explosion due to toxic gases, overflow, manhole lid left open is detected by the sensors. The signals from the sensors are fed to the controller, which is programmed to generate alerts.

The sensors will identify the clogging inside the drainage system and will give information about the location and further actions will be taken care by the municipal. This system consist of two *i.e.* Sensor Network & Transmission Station.

**Figure 3.2: Parts of a Sensor Network**

### Sensor Network

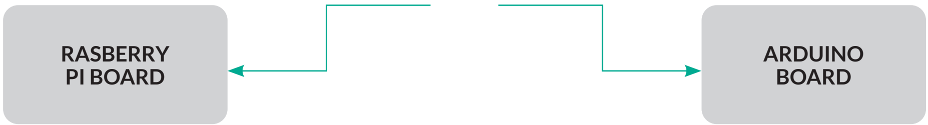
| | |
|---|---|
| **Ultrasonic Sensor** | Ultrasonic detection is most commonly used in industrial applications to detect hidden tracks etc. We are using it to detect the opening and closing of lid of manhole. |
| **Gas Sensor** | Gas sensor detects combustible gasses and smoke. |
| **Level Sensor** | Also known as, Float sensor is used to detect the level of water in the system. This can turn on tobe as a pump, alarm and indicator. We are using it to detect blockages in drainage. |
| **Temperature Sensor** | Temperature sensor is a device used to measure the hotness or coldness of an object.We are using this sensor to obtain the temperature underground |
| **Flow Sensor** | Flow sensors are mainly used to measure the quantity or the rate of flow of liquids or gases. We are using it to detect overflow. |

*Source: Author Expert*

### Transmission Station

This station helps to send signals from sensors. This station consists of Raspberry Pi model B and Arduino Uno which are the two microcontrollers that are interfaced. The signals received by the Arduino from the sensors is converted from analog signals to digital signals with the help of ADC located in the Arduino board and further is processed and sent to the cloud and Raspberry Pi, takes this as input data. An alert is displayed in the managing station and an email/message is sent to the respective authority.

**Figure 3.3: Parts of a Transmission Station**

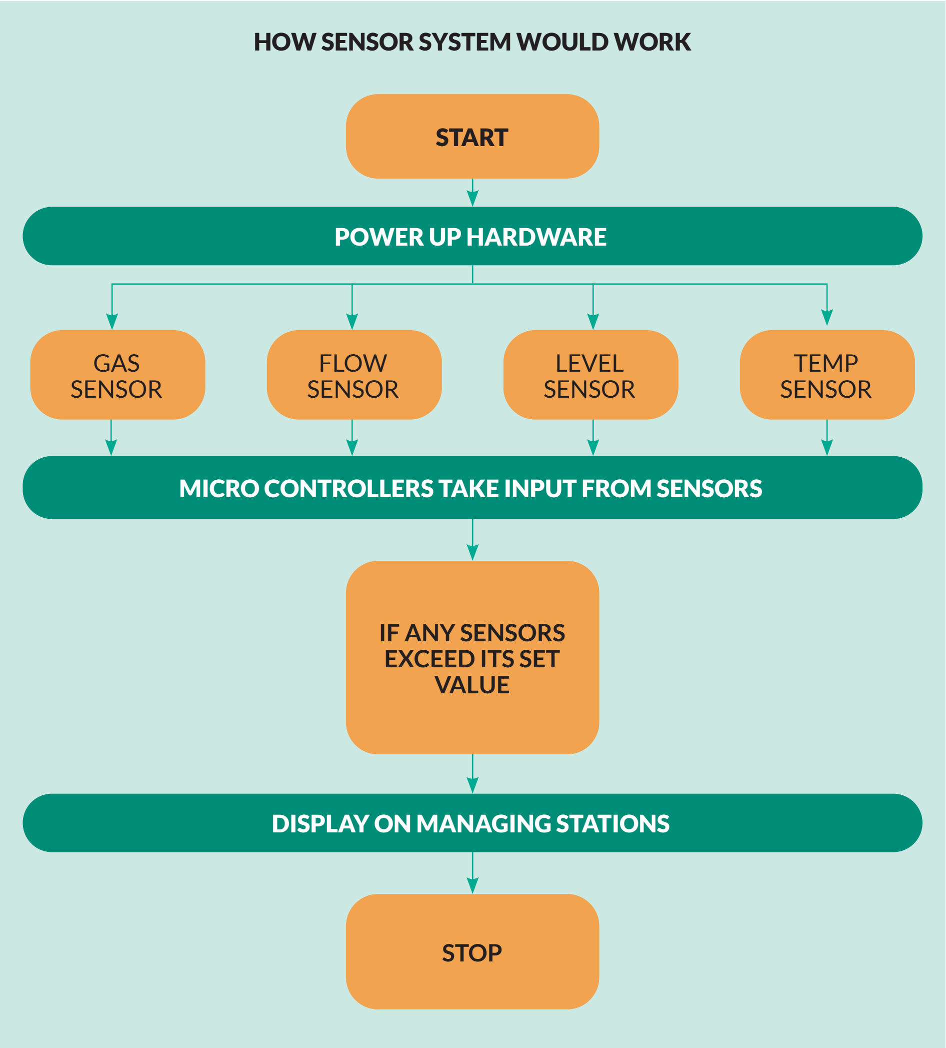



*Source: Author Expert*

## IoT Based System

IoT based system monitors atmospheric temperature, release of toxic gases, blockages, overflow in drains and manhole lid position. Maximum levels are set and sensors keep monitoring the changing conditions. As the levels reach a maximum set point, the sensors detect and send the signal to controller, where it commands the IoT network to generate alerts to the municipal corporation

**Figure 3.4: The Working Flowchart of the Unit**



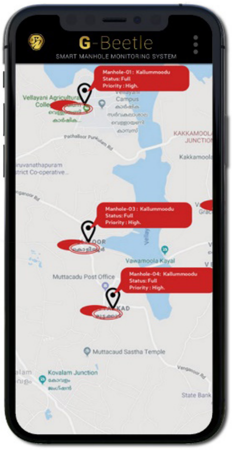

*Source: SMART REAL TIME MANHOLE MONITORING SYSTEM; IRJET; 2019*

## 3.3. Mobile Application & Dashboard

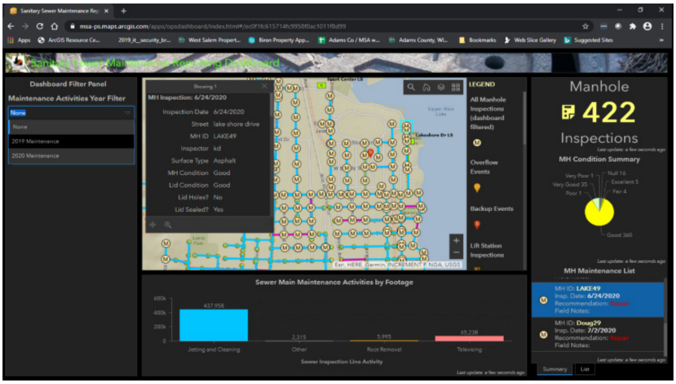
After installation of sensors and creating a managing centre, alert message can be designed in case of, any problem related to manhole maintenance & infrastructure. In addition, a GIS Dashboard can be generated for the same (Figure 1.5).

**Figure 3.5:**

**(a) G-Beetle, Smart Manhole Monitoring System**




**(b) GIS Live Dashboard for inspecting the condition of the geotagged manhole.**




*Source: G-Beetle Smart Manhole Monitoring System; 2019*

## 3.4. Accessibility & Specification of Sensors (World-wide & India)

### World-Wide

**a) Company : HYPER-TECH SYSTEM**

#### WSMS-125X321IS – MANHOLE COVER OPEN DETECTOR

The Manhole Cover Open Detector is designed to detect if the manhole cover is being tampered or tilted up. It protects against theft of the metal cover and/or the valuable assets down below (e.g. fiber cables, communication equipment, etc.). It communicates with the IoT AP/Gateway using a LoRaWAN protocol standard for long-range wide area (LPWAN) deployments. The Manhole Cover Open Detector integrates a 3-axis G-sensor and a temperature sensor. The detector reports battery level together with the other sensors data. It also sends a periodical keep-alive update messages.

**Main Features:**

- Rugged enclosure – IP68
- Tilt alert
- Low battery alert
- LoRaWAN – long range, low power, high sensitivity data link
- Power Supply – Internal battery, 2.2-2.3V
- Operating Temperature – -40°C ~ 70°C

## b) Company : HYPER-TECH SYSTEM

### OCTOPUS WATER LEVEL SENSOR

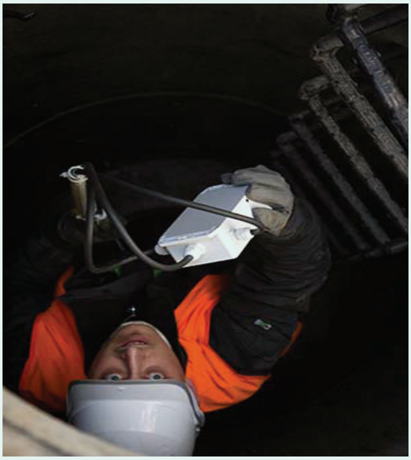
Sensoneo Octopus sensor is an enterprise class device intended as overflow warning system. It measures water level in a manhole. It is fully adjustable for different depths. Thanks to adjustable water level indicators (tentacles), Octopus can detect up to 3 different thresholds. When water level rises and reaches one of water level indicators (tentacles), you will receive immediate warning.If water levels are calm, sensor sends one maintenance message a day just for the record.Additionally, the sensor measures temperature.

### Octopus sensor consist of three parts:

Central unit processes the signal from water level indicators (tentacles). It secures communication with Sensoneo backend system via GSM network via external antenna.Water level indicators (up to three pcs) detect rising water level. They are placed using a mounting tube at a different levels (thresholds) within the manhole. Each indicator (tentacle) is a threshold. Once the water rises to the threshold (tentacle), Octopus sends a warning.

### Main Features:

- Real-time monitoring of up to 3 water levels' heights
- Operating Temperature: -30°C – +70°C
- Readings : once a day for keep-alive and real-time event driven for water level
- Connectivity: GSM / SMS
- Power Supply: Internal replaceable batteries, 2 x 3.6V 13Ah
- Enclosure: central unit IP65, indicators IP68



*OCTOPUS WATER LEVEL SENSOR*

### c) Company : WIIHEY

#### WIIHEY MANHOLE COVER OPEN DETECTOR

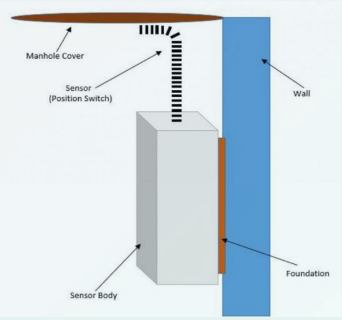
WiiHey's Manhole Cover Open Detector, you can deploy real-time monitoring and protection against metal theft, vandalism, and unauthorized access of manholes. The product utilizes a range of commercially available, off-the-shelf sensors to detect and prevent manhole related incidents. Signals are transmitted from the sensor device to a cloud platform via LPWAN (Low Power Wide Area Network) technologies, such as GPRS, NB-IoT, SigFox, etc. The sensors in combination with the cloud-based dashboard will allow you to monitor and well plan the maintenance of manholes.

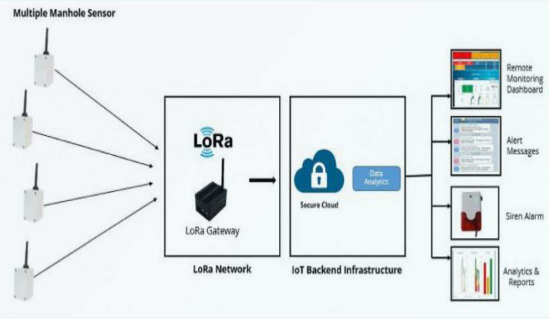
#### Key features

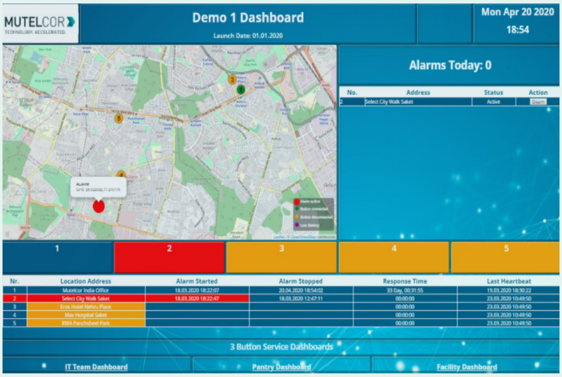
- Detect open/closed status of a manhole cover
- Easy to install, wireless communication and free maintenance
- Cloud based platform with GIS (Geographic information system) dashboard
- Automatic alarm and message notification support Benefits
- Monitor, report, predict and optimize your manholes
- Notice unauthorized activities and well plan maintenance schedules
- 24/7 monitoring with multiple status messages updated per day and instant alarm notification
- Total flexibility and reliability, can be deployed in urban or rural environments

#### Applicable to:

- Manhole cover
- Sewer cover
- Pipe hole cover
- Drain cover



### Indian Retailer

KERNELSPHERE

STANLAY

TRITECH Since 1997

GENROBOTICS

HACH

xylem Let's Solve Water

DETECTOR INDIA

## 3.5. Results

This system detects the blockages and water level in the manhole. It also monitors the continuous water flow rate. With the help of sensors temperature, humidity and gas leakage can be identified. The system also informs whether the manhole lid is open or closed by using the ultrasonic sensor. When a particular sensor reaches the respective threshold level, then that respective value of the sensor will be sent to the microcontroller. Microcontroller updates the live values of all the sensors using IoT. If any problem arises in the manhole, sensor senses it and sends that information to the microcontroller. Furthermore, the microcontroller sends the signal and the exact location of the manhole through IoT to the managing station. Then, an automatic mail is sent by Raspberry Pi. This alerts the person-in-charge to take the required actions regarding the problem occurring inside the manhole.

## 3.6. Summary

Sensor unit automatically senses and updates the live values of the physical parameters like temperature, humidity, water level and flow rate, blockages, and manhole cap is open or closed through IoT. This makes the system smart and automated. The deployment of Wireless Sensor Networks (WSN) helps in the implementation of the Smart cities in developing countries. This WSN can also be useful in designing of environmental monitoring systems, which helps in monitoring of volcanic activities, flood detectors and other system. By a small modification in the implementation, this project can be used in agriculture fields or other environmental fields to monitor and control the systems. With the integration of smart devices in a city infrastructure, can makes life in a city a lot easier.

Chapter 4

# Route Optimisation for Collection of Municipal Solid Waste

## Summary

Collection of solid waste in an urban area is complex as waste generation become more diffuse. Of the total amount of money spent for collection, transportation and disposal of solid waste, approximately 50 to 70 percent is spent on the collection phase. This fact is important as small percentage improvement in the collection operation can effect a significant saving in the overall cost. Therefore, interest in the analysis of solid waste collection systems arises to optimize the operation of existing systems and to develop data and advanced techniques to design and evaluate new systems for urban areas. Network Analyst for route optimization in Municipality has shown reasonable improvement in length of the routes and travel time minimization.

## Training Objectives

- To reduce the overall distance driven to collect and transport municipal waste from container bins
- To reduce the overall vehicle drive time to collect and transport municipal waste from container bins

## Training Outcomes

- Understanding the mechanism of Route optimisation for better management of Solid waste in municipal area.
- Familiarise with GIS Technologies “Network Analyst Tools” for Route optimisation

## Chapter Contents

## 4.1. Introduction

The frequency of collection helps to collect the waste in the stipulated time interval. The delay in transporting the waste causes the organic material to begin to deteriorate and makes the handling of the waste more difficult and delicate. Among the many routes available for the collection of MSW, the collection vehicle begins to move from one container to another in an indefinite route to collect the waste. In addition, the part of the waste is not collected in the streets. Many times the collection vehicles travel longer distances because the travel route is not scientifically identified. This leads to the consumption of more fuel and generates more pollution. There is also a delay in the collection of waste from all locations. To reduce the cost of fuel and contaminants emitted by collection vehicles and to ensure effective collection of MSW, optimized collection routes must be found. Therefore, Route optimization in solid waste management model based on GIS is proposed.

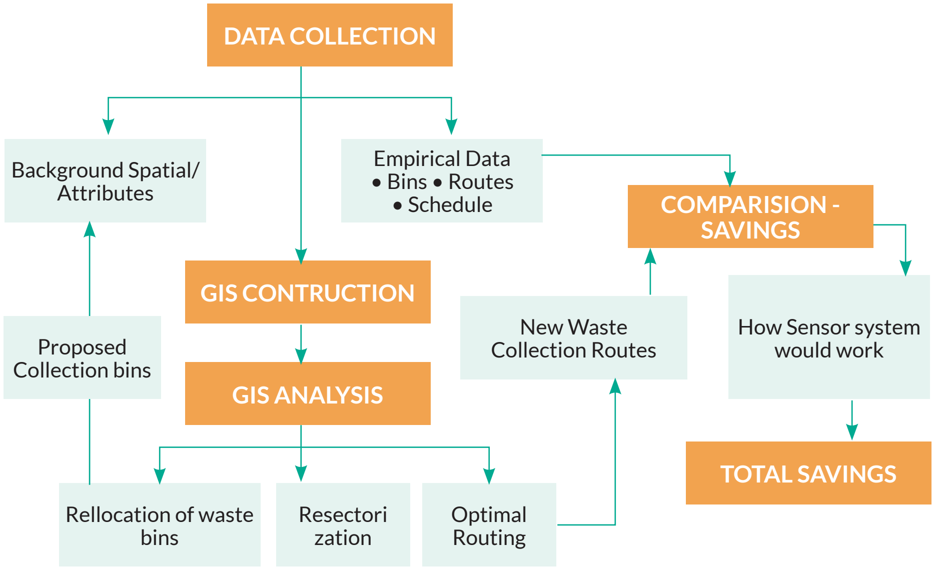
### Objective:

- Reduce the overall distance driven to collect and transport municipal waste from container bins
- Reduce the overall vehicle drive time to collect and transport municipal waste from container bins

## 4.2. Methodology

### Data Acquisition:

**Figure 4.1: Methodology for Route Optimisation**

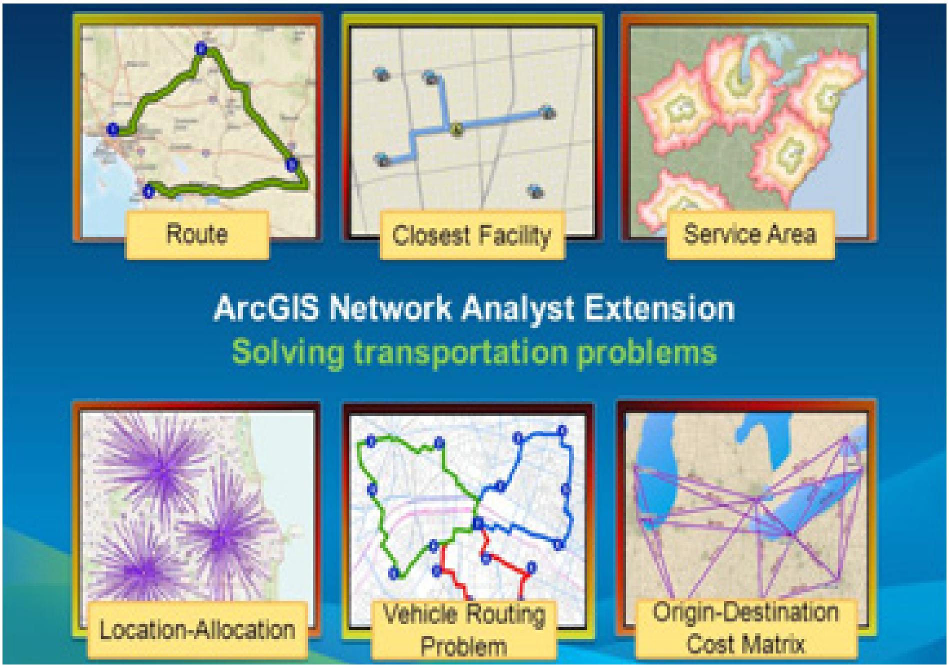



*Source: Author Expert*

**For generating the optimal routes for the solid waste collection, the following data are required :**

1. Study Area Boundary
2. Detailed & Updated Road Network
3. Traffic Volume details
4. No. of storage bin and their Locations
5. Capacities of the bins
6. Time taken for collection of solid waste per bin
7. Type of vehicle used and its capacity
8. Existing run route for the compactor vehicles
9. Fuel consumption of the compactors

**Figure 4.2: The different functions of Network Analyst Extension of ArcGIS**




*Source: Internet; Author Expert*

**Software used for Route optimisation :**

ArcGIS (Network Analyst Tool)

## Data Acquisition&Network Analysis:

The method used was deliberated based on

1. Territorial analysis
2. GIS analysis
3. Service design.

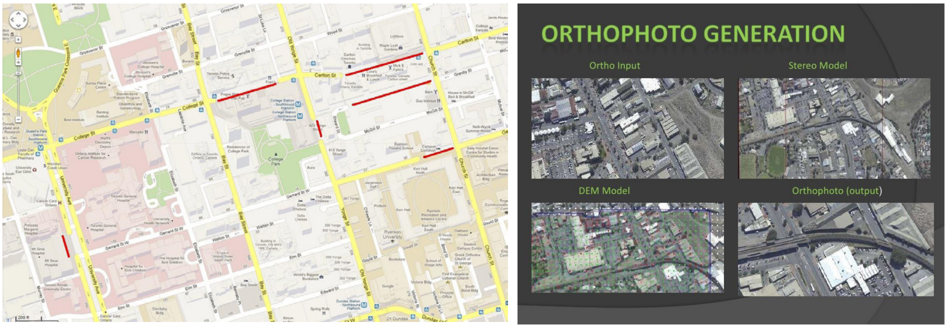
1. **Territorial analysis:**This analysis is based on the identification of the needs and/or restrictions in the collection service. Five routes in the area needs to be selected for the pilot study. Initially the selected routes are inspected according to topography, condition of the roads and other restrictions in the collection procedures. The selected routes are in the zones, which are nearer to the dumpsite compared to other zones.

   To process and analyze information that was the basis for the proposed methodology the following data were provided:

   - Street Plan in digital format (scale 1:6000)
   - Orth photos (scale 1:1500)
   - GPS; to locate the stop points (which in turn were placed with name and street number).

In order to efficiently manage the solid waste collection system, detailed spatial information is needed. These data involved the geographical background of the study area and the procedure of the waste collection process. The data including location of the trucks, waste generation rate, type of waste bins, the road network and related traffic has to be obtained.

**Figure 4.3: Territorial Analysis**

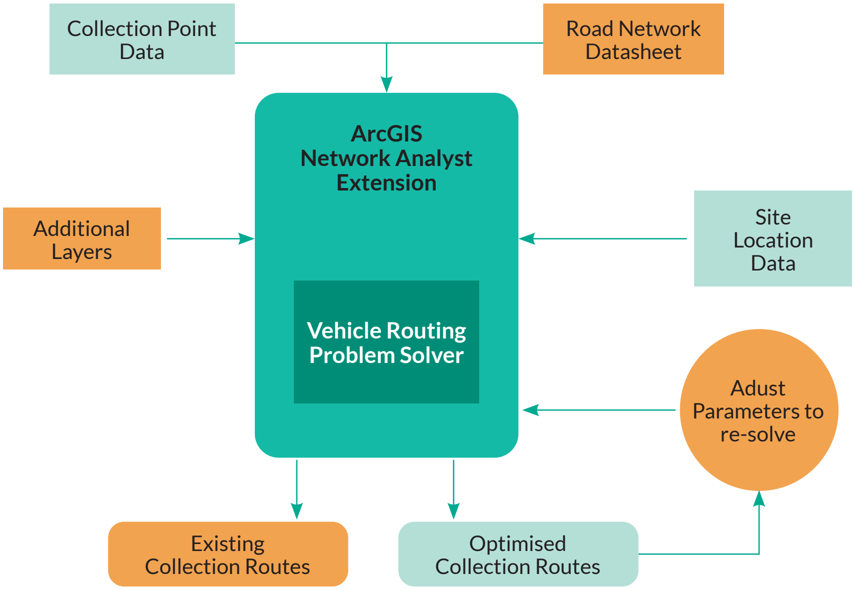



*Source: Internet; Author Expert*

2. **GIS analysis:** The use of the GIS allows the user to create, arrange, treat and analyze the geographical information, organized by means of graphic and alphanumeric data. The ArcGIS Software is used which enables the users to have a geographical reference of entire points on the digital street map. To analyze the information through ArcGIS the order tracked in the study are the following:

- **Data processing:** Initially, all the data in AutoCAD or other non-GIS formats were converted to GIS shapefile (.shp) format. All the layers such as road, drainage, elevation and contour layers are considered during the conversion. Then, the projected coordinate are used to standardize coordination system. The coordinate system is a reference tool used to represent the locations of geographic features, imagery, and observations, such as Global Positioning System (GPS) locations, within a common geographic framework.
- **Identification of the route:**The municipal solid waste trucks route are then identified by comparing the images of the Google Earth and drawing from AutoCAD. All required data for processing purposes such as length and name of the roads are inserted into the attribute table.
- **Identification of the layers:** In the base map, there may be many layers such as pipeline, contour, road and housing layers. With referencing with the Google Earth Image and Base Map, user can identify the road layers needed for data analysis. Finally, non-spatial data such as road name and length of each road can be added.
- **Creating network database:** A Network Dataset is created from the feature sources that participated in the network. It incorporates an advanced connectivity model that can represent complex scenarios, such as multimodal transportation networks. It also possesses a rich network attribute model that helps model impedances, restrictions, and hierarchy for the network.

**Figure 4.4: Methodology for Network Analyst ArcGIS Toolbox**




*Source: Author Expert*

- **Creating Network Database:** ArcGIS-Network Analyst is an extension that provides network-based spatial analysis including routing, travel directions, closest facility and service area analysis. This enables us to find efficient travel routes for the trucks during solid waste collection. In order to solve the route optimization, distance criteria and collection time by the truck (regardless to time spent in traffic) are considered and generated. By considering speed formula (v = ¨d/¨t) duration taken for each truck travelled throughout solid waste collection is obtained. The final output is an optimal solution in terms of distance criteria. After setting the stop points, the optimized routes for solid waste collection are produced. The stop-points are numbered automatically by Network Analyst in the order that are visited.

3. **Service design (definition of the routes):** Best possible routes for solid waste collection are identified based on the information obtained with the help of the GIS regarding the possible routes, and having taken into account the restrictions to the road conditions and topography. The routes are chosen in a way that the resources used for the collection, the length of the route and the time taken to complete the collection is minimized.

**Figure 4.5: Network Analyst ArcGIS Tool for Route Optimisation**

*Source: Internet; Author Expert*

## 4.3. Summary

Collection of unseparated and separated solid waste in an urban area is complex as waste generation become more diffuse. Of the total amount of money spent for collection, transportation and disposal of solid waste, approximately 50 to 70 percent is spent on the collection phase. This fact is important as small percentage improvement in the collection operation can effect a significant saving in the overall cost. Therefore, interest in the analysis of solid waste collection systems arises to optimize the operation of existing systems and to develop data and advanced techniques to design and evaluate new systems for urban areas.

Network Analyst for route optimization in Municipality has shown reasonable improvement in length of the routes and travel time minimization. In addition to cost deduction, as more and more communities are moving toward mandatory recycling of materials, the route optimization will provide opportunities for separate collection of recyclable waste using same logistic and equipment. This will reduce the reliance of city councils to disposal sites and increase disposal sites operational life.

# ANNEXURE-I
# Case Studies

## 1. Benefits from GIS Modelling for Municipal Solid Waste Management *(Christos Chalkias & Katia Lasaridi; 2011)*

Waste management issues are coming to the forefront of the global environmental agenda at an increasing frequency, as population and consumption growth result in increasing quantities of waste. Moreover, technological development often results in consumer products of complex composition, including hazardous compounds, which pose extra challenges to the waste management systems and environmental protection at the end of their useful life, which may often be fairly short (e.g. cell-phones and electronic gadgets). These end-of-pipe challenges are coupled with the deepening understanding that the Earth's natural resources are finite by nature and their current exploitation rate unsustainable, even within a midterm perspective. The self-cleaning capacity of the Earth systems is often also viewed as a «natural resource» under stress, with climate change being the most pronounced expression of this risk.

In the context of the above mentioned challenge a New Paradigm for waste management has emerged, shifting attention to resources efficiency and minimisation of environmental impacts throughout the life cycle of waste management, from waste prevention to safe disposal. This is best expressed, but not confined, in the relevant EU policy and legislation (e.g. the Thematic Strategy on the prevention and recycling of waste, the Thematic Strategy on the Sustainable Use of Natural Resources and the revised Waste Framework Directive, WFD-2008/98/EC). Especially the latter is of particular interest as it has a legally binding nature for all EU member states and sets a benchmark which is often also taken into consideration by the waste management systems of non-EU countries. The WFD reaffirms the need to move waste management higher in the so called "waste hierarchy", preferring, in this order, prevention, reuse, recycling and energy recovery over disposal. Separate collection for dry recyclables in municipal solid waste (MSW) should be implemented while separate collection of biowaste should be promoted (although no specific legislative requirements are set) (Nash, 2009).

Overall, EU and national waste management policies and legislation in many parts of the world are becoming increasingly demanding for the providers of these services, namely municipalities and their associations, demanding high recovery and recycling rates for a wide range of materials and goods, high diversion targets for the biodegradable fraction of the waste, advanced treatment processes, long after-care periods for existing and future landfills etc (COM, 2005; Lasaridi, 2009). Moreover, this increased level of service will need to be provided at the minimum possible cost, as the public will not be able to bear large increases in its waste charges and municipalities are increasingly being required to benchmark their performance, to ensure they offer their waste management services at the most efficient manner (Eunomia, 2002; Karadimas et al., 2007). The current economic crisis inevitably intensifies this need.

The need for improved performance at low costs is not restricted to developed countries seeking to apply increasingly complex separate waste collection, treatment and recovery systems. Under a different context, it also exerts its pressure to the municipal services of the developing countries, which strive to ensure waste collection and public health protection for the large populations of highly urbanised areas with severe infrastructure and economic limitations (Gautam & Kumar, 2005; Ghose et al., 2006; Kanchanabhan et al., 2011; Vijay et al., 2005).

Local authorities (LAs) constitute worldwide the main providers of municipal solid waste (MSW) management services, either directly or indirectly through subcontracting part or all of these services. Especially waste collection and transport (WC&T) are typically provided at the local municipality level and constitute the main interface between the waste generator and the waste management system. Assessing the different components of the solid waste management costs is a complex, poly-parametric issue, governed by a multitude of geographic, economic, organisational and technology selection factors (Eunomia, 2002; Lasaridi et al., 2006). However, in all cases WC&T costs constitute a significant component of the overall waste management costs, which may approach 100% in cases where waste is simply dumped. For modern waste management systems WC&T costs vary in the range of 50-75% of the total, which overall is significantly higher, as advanced treatment and safe disposal take their own, large share of the total costs (Sonesson, 2000).

Therefore, the sector of WC&T attracts particular interest regarding its potential for service most common problems associated with improper dumping includes; diseases transmission, fire hazards, odor nuisance, atmospheric and water pollution, aesthetic nuisance and economic losses. The effectiveness of solid waste disposal depends upon the selection of proper site and current global trend of waste management problems stems from unsustainable methods of waste disposal, which is ultimately a result of inadequate planning [2].

The aim of this chapter is to present a methodology for the optimisation of the waste collection and transport system based on GIS technology. The methodology is applied to the Municipality of Nikea (MoN), Athens, Greece based on real field data. The strategy consists of replacing and reallocating the waste collection bins as well as rescheduling the waste collection via GIS routing optimisation. The benefits of the proposed strategy are assessed in terms of minimising collection time, distance travelled and man-effort, and consequently financial and environmental costs of the proposed collection system.

## The role of GIS for sustainable waste management

Geographic Information Systems (GIS) are one of the most sophisticated modern technologies to capture, store, manipulate, analyse and display spatial data. These data are usually organised into thematic layers in the form of digital maps. The combined use of GIS with advanced related technologies (e.g., Global Positioning System – GPS and Remote Sensing - RS) assists in the recording of spatial data and the direct use of these data for analysis and cartographic representation. GIS have been successfully used in a wide variety of applications, such as urban utilities planning, transportation, natural resources protection and management, health sciences, forestry, geology, natural disasters prevention and relief, and various aspects of environmental modelling and engineering (among others: Brimicombe, 2003). Among these applications, the study of complex waste management systems, in particular siting waste management and disposal facilities and optimising WC&T, have been a preferential field of GIS applications, from the early onset of the technology (Esmaili, 1972; Ghose et al., 2006; Golden et al., 1983; Karadimas et al., 2007; Sonesson, 2000). Nowadays, integrated GIS technology has been recognised as one of the most promising approaches to automate the process of waste planning and management (Karadimas & Loumos, 2008).

As mentioned above, the most widespread application of GIS supported modelling on waste management lies in the areas of landfill siting and optimisation of waste collection and transport, which are discussed in detail in the following section. Additionally, GIS technology has been successfully used for siting of recycling drop-off centres (Chang & Wei, 2000), optimising waste management in coastal areas (Sarptas et al., 2005), estimating of solid waste generation using local demographic and socioeconomic data (Vijay et al., 2005), and waste generation forecasting at the local level (Dyson & Chang 2005; Katsamaki et al., 1998).

## GIS-based modelling for landfill selection

The primary idea of superimposition of various thematic maps in order to define the most suitable location according to the properties of the complex spatial units derived after the map overlay, was first introduced in the late 60's (McHarg, 1969). This idea was applied next within the context of early GIS in many optimal siting applications (Dobson, 1979; Kieferand & Robins, 1973). The allocation of a landfill is a difficult task as it requires the integration of various environmental and socioeconomic data and evolves complicated technical and legal parameters. During this process the challenge is to make an environmentally friendly and financially sound selection. For this purpose, in the last few decades, many studies for landfill site evaluation have been carried out using GIS and multicriteria decision analysis (Geneletti, 2010; Higgs, 2006; Nas et al., 2010; Sener et al., 2006), GIS in combination with analytic hierarchy process (Saaty, 1980) – AHP (Vuppala et al., 2006; Wang et al., 2009), GIS and fuzzy systems (Chang et al., 2008; Gemitzi et al., 2007; Lofti et al., 2007), GIS and factor spatial analysis (Biotto et al., 2009; Kao & Lin, 1996), as well as GIS-based integrated methods (Hatzichristos & Giaoutzi 2006; Gómez-Delgado & Tarantola 2006; Kontos et al., 2003, 2005; Zamorano et al., 2008).

A large fraction of these applications produce binary outputs while most recent ones aim at evaluating a "suitability index" as a tool for ranking of the most suitable areas (Kontos et al., 2005). The main steps of a typical GIS – based landfill allocation model (fig.1) are as following.

- Conceptualisation of the evaluation criteria and the hierarchy of the landfill allocation problem. This step is dedicated to the selection of the criteria related to the problem under investigation. Creation of the spatial database. Here, the development of GIS layers for the modelling is implemented. These layers correspond to the primary variables.
- Construction of the criteria – layers within the GIS environment. Criteria maps are primary or secondary variables.
- Standardisation of the criteria – layers. This step includes reclassification of the layers in order to use a common scale of measurement. Most often, the ordinal scale is used.
- Estimation of the relative importance for the criteria. This estimation is implemented by weighting, e.g. with the use of Analytic Hierarchy Process (AHP) and pair wise comparison between variables.
- Calculation of the suitability index. A standard procedure for this step is the weighted overlay of the standardised criteria/layers.
- Zoning of the area under investigation is the next phase of the modelling. This classification action is based on the suitability index and reveals the most suitable areas for the application.
- Sensitivity analysis and validation of the model.
- Final selection – land evaluation

It should be noticed that for most of the aforementioned functions the geographic background (in digital format) of the area under investigation is required. Figure 1 demonstrates the data flow of the adopted procedure. Sumanthi et al. (2008) underline that the main advantages of applying GIS technology in the landfill siting process are: "the selection of objective zone exclusion process according to the set of provided screening criteria, the zoning and buffering function, the potential implementation of 'what if' data analysis and investigating different potential scenarios related to population growth and area development, as well as checking the importance of the various influencing factors etc., the handling and correlating large amounts of complex geographical data, and the advanced visualization of the output results through graphical representation."

Additionally, the incorporation of various spatial analysis methods, such as geostatistics, analytical hierarchy process, fuzzy logic modelling and many others, constitutes a major advantage of a GIS-based modelling approach. Finally, a particularly useful option of a GIS-based decision making model is the combination of experts knowledge with the opinions of citizens and stakeholders (Geneletti, 2010).

### GIS modelling for the optimisation of waste collection and transport

The optimisation of the routing system for collection and transport of municipal solid waste is a crucial factor of an environmentally friendly and cost effective solid waste management system. The development of optimal routing scenarios is a very complex task, based on various selection criteria, most of which are spatial in nature. The problem of vehicle routing is a common one: each vehicle must travel in the study area and visit all the waste bins, in a way that minimises the total travel cost: most often defined on the basis of distance or time but also fuel consumption, $CO2$ emissions etc. This is very similar to the classic Travelling Salesman Problem (TSP) (Dantzig et al., 1954). However, the problem of optimising routing of solid waste collection networks is an asymmetric TSP (ATSP) due to road network restrictions; therefore adaptations to the classic TSP algorithm are required, making the problem more complex.

As the success of the decision making process depends largely on the quantity and quality of information that is made available to the decision makers, the use of GIS modelling as a support tool has grown in recent years, due to both technology maturation and increase of the quantity and complexity of spatial information handled (Santos et al., 2008). In this context, several authors have investigated route optimisation, regarding both waste collection in urban and rural environments and transport minimisation, through improved siting of transfer stations (Esmaili, 1972), landfills (Despotakis & Economopoulos, 2007) and treatment installations for integrated regional waste management (Adamides et al., 2009; Zsigraiova et al., 2009).

## 2. The Nikea case study, in Greece

The total cost for waste collection and transport (WC&T) in Greece frequently accounts for more than 70% of the total municipal solid waste (MSW) management costs. Thus, it is crucial to improve the WC&T system through routing optimisation.

Here we present a general methodology for the optimisation of the waste collection and transport system, based on GIS, technology for the municipality of Nikea (MoN), Athens, Greece. This methodology was developed using standard GIS and network analysis procedures in order to improve the efficiency of WC&T in the study area via:

- the reallocation of waste collection bins; and
- the optimisation of vehicle routing in terms of distance and time travelled, via GIS routing.

The outputs of various different scenarios examined are finally compared with the empirical routing, which is the current vehicle routing practice. Benefits are assessed in terms of minimising collection time, distance travelled and man-effort, and, consequently, financial and environmental costs of the collection system.

In Greece Local Authorities (LAs) are by law responsible for waste management (Decrees 25/1975 and 429/1976). Waste collection and transport are provided at the individual municipality level, usually directly through their Waste Management Department. Currently, WC&T of commingled MSW in the country is responsible for a large portion of the total waste management cost (70% - 100%), which is considerably higher than the typical values, of between 50 and 75%, reported for modern waste management systems (Sonesson, 2000). This is observed because the largest fraction of the waste stream is currently landfilled at very low cost, without pre-treatment for materials and/or energy recovery, while in some cases illegal dumping may be still practiced (Lasaridi, 2009).

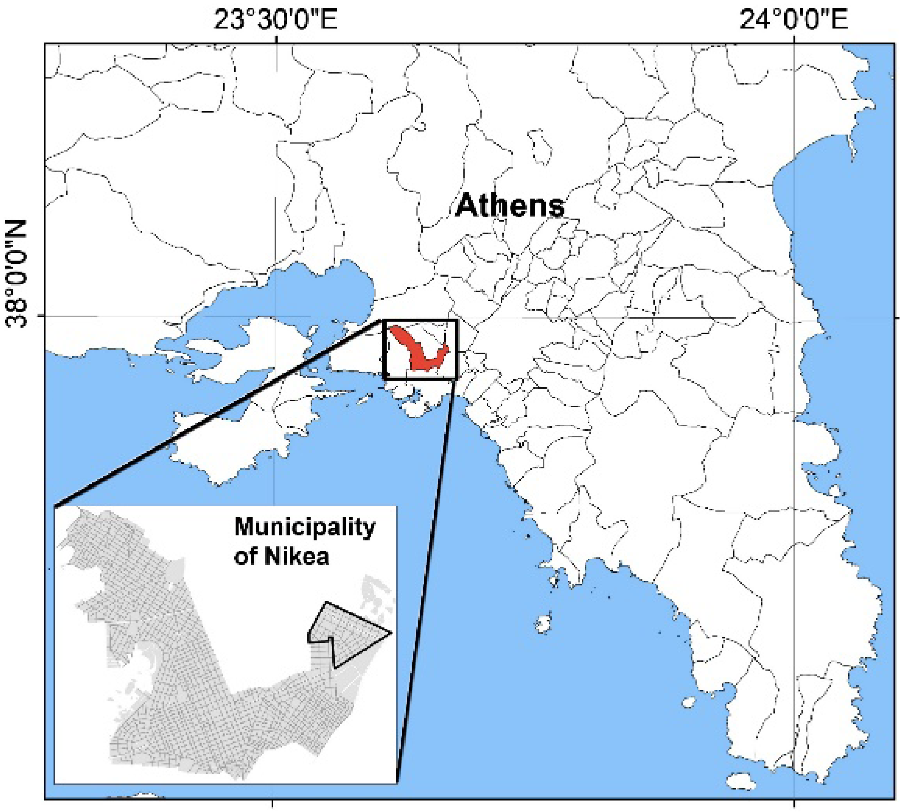
### The study area and the existing collection system

The MoN (Fig. 2) is one of the largest in the Attica Region, lying in the SW part of Athens metropolitan area. It has a permanent population of 95,798 habitants according to the 2001 Census (National Statistical Service of Greece - NSSG, 2001) and a total area of 6.65 km2. Nikea is a typical Greek urban municipality, characterised by multi-storey apartment buildings, combined by lower multiple dwellings (2-4 apartments) and mixed residential and commercial land uses in many neighbourhoods. The annual MSW production in MoN is estimated at 45,625 tn, or 1.30 kg/ca/d.

Waste collection is carried out mechanically, using 12,107 wheelie bins and 17 rear-end loaded compaction trucks with 9 tn average capacity. Most of the bins are small, of 120 and 240 L capacity, but a few larger ones exist in some central points. The total storage capacity of the bin system is 3.4 million litres. The crew size on the collection vehicle is three persons, a driver who never leaves the truck (as required by safety regulations) and two workers who move and align the bins with the hydraulic lifting mechanism of the truck.

Nevertheless, due to traffic restrictions and narrow roads, it is estimated that only 70% of the bins are really mechanically collected, with the content of the rest being manually transferred in other bins, by an extra worker walking ahead of the collection vehicle. The Municipality is empirically divided into 15 sectors (collection zones), each of which is further divided into two sub-sectors. Waste is collected in each sub-sector four times per week.

**Figure A.1: The study area: Municipality of Nikea, Athens, Greece.**




*Source: The Nikea Case Study, Greece*

This work applies the developed waste collection and transport optimisation methodology in a typical sector (Sector 1) of the municipality with mainly residential land uses. However, some commercial establishments, schools, stadiums and parks are also found in the area. The served equivalent population in Sector 1 (i.e. taking into account the MSW load created by non-residential land uses) is 6,790 people, divided in 63 parcels (building blocks). The total average waste production is 2,610 ton/yr, according to the weighing sheets of the collection vehicles in the period 2005-2007. This corresponds to an average daily commingled waste production of 1.053 kg/ca eq. This is not in contrast with the municipality average reported above, as the former is calculated on the basis of the 2001 census population, while the latter also takes into account the equivalent population corresponding to the non-residential land uses.

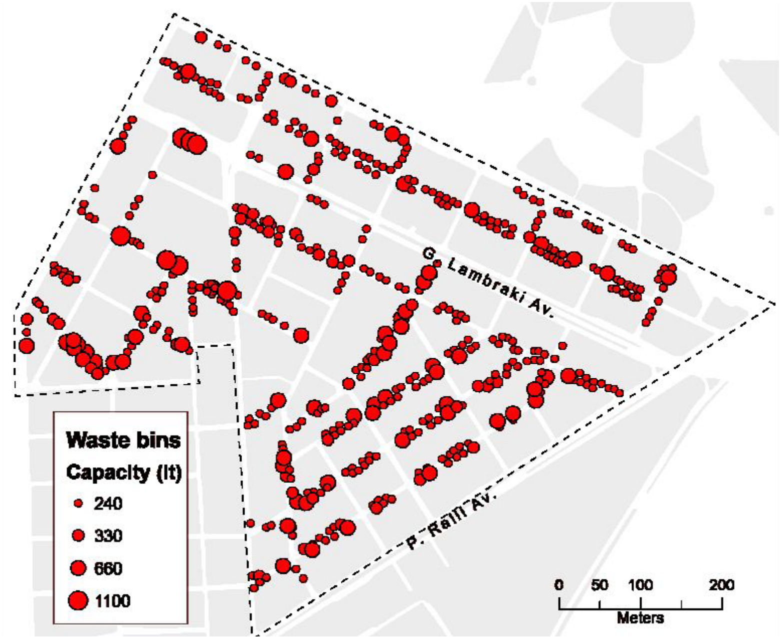
In the current waste collection system, 714 bins are located in Sector 1 (Fig.3), of which 501 are mechanically collected, with total capacity of 157,000 L. The content of the rest is manually transferred to the mechanically collected ones by the extra worker mentioned above. Since Sector 1 is rather flat (mean elevation ~ 50 m) it is assumed that fuel consumption and emissions are linearly related to collection time (Brodrick et al., 2002).

For waste collection purposes Sector 1 is divided into two sub-sectors both served by one waste collection vehicle. Waste in each sub-sector is collected four times per week, in alternate week days, resulting into eight collection trips per week. Collected waste is disposed of at the Fyli landfill site, about 25 km north-west from Sector 1. The key points to the proposed optimisation approach are:

- the replacement of the existing large number of small bins (120 and 240 L) with a reduced number of larger bins (1100 L);
- the resectorisation; and finally,
- the optimal routing.

Using the collected data and the analytical tools of the GIS software, specific proposals are developed regarding the optimisation of the existing WC&T system of commingled MSW. For results assessment both the vehicle trip within the sector and travel to and from the landfill are considered.

**Figure A.2: Waste bins in the study area.**




*Source: The Nikea Case Study, Greece*

## Data collection and spatial database description

To efficiently manage the municipal solid waste system, detailed spatial information is required. This information is related to the geographical background of the area under investigation, as well as to spatial data related to the waste collection procedure. A large amount of waste management data for the period 1998-2007 has been collected and statistically analysed regarding the static and dynamic data of each existing collection program: population density; waste generation rate for mixed waste and for specific waste streams; number, type and positions of waste bins; the road network and the related traffic; the current routing system of the collection vehicles; truck capacities and their characteristics; and the geographic boarders and characteristics of the waste collection sectors. The range of data acquired and utilised is illustrated in Table1.

For the optimisation of the collection process a spatial geodatabase was constructed, in a standard commercial GIS environment (ArcGIS, ESRI). This choice ensures compatibility with the available data from the municipality and access to many network analysis routines available from the software. The content of the spatial database is summarised in Table 2.

Background spatial data for road network, existing routes, bins and building parcels were obtained from MoN. These data were updated with field work and other non spatial data such as road name, road type, vehicle average speed, travel time, road slope, bin number, bin type/capacity, bin collection time were added. Furthermore, special attributes of road network were registered. These attributes include traffic rules, traffic marks, topological conditions and special restrictions (e.g. turn restrictions) in order to efficiently model the real world road network conditions.

**Table A.1: Data collected and their source.**

| Data | Source |
|---|---|
| Study area boundary | (MoN Corporation) |
| Detailed urban plan of the municipality | (official toposheet plan) |
| Population density distribution | (National Statistical Service of Greece: NSSG) |
| Land use of the study area | (NSSG) |
| Satellite image of the municipality | (Google Earth) |
| Road network of the study area | (official toposheet plan, , field work) |
| Road class information: restrictions and traffic volume details | (official toposheet plan, MoN Corporation, field work) |
| Location of waste bins | (MoN Corporation, field work) |
| Capacities of bins | (MoN Corporation, field work) |
| Time schedule for the collection process | (MoN Corporation, field work) |
| Existing collection routes | (MoN Corporation, field work) |
| Vehicle speed, fuel consumption, CO2 and other gas emissions of the compactors | (MoN Corporation, field work, literature). |

### Methodology

The key point of the proposed analysis is GIS technology. GIS provides a powerful context to import, manage and analyse spatially based data. The typical bin type used in most Municipalities in the wider Athens area.

- The required number of bins (N) was calculated to cover the waste production of the sector for a five trips per week schedule (D=7/5), assuming a waste density in the bin of $\rho$=110 kg.m$^{-3}$, and a coefficient of filling the bin, $\varepsilon$ = 0.80 of its capacity, according to the equation (1):

  $N = WD x D / (V x \rho x \varepsilon) N = WD x D / (V x \rho x \varepsilon)$

  E1

where WD (kg) is the daily waste quantity and V (m$^3$) is the bin capacity. A 10% safety margin was added to this number (Panagiotakopoulos, 2002).

Thus, instead of the existing 501 bins of various sizes (§2.2) Sector 1 is covered by 142 large bins (1100L).

- Next, these bins are allocated in the study area according to the following rules:
  - allocate bins on the road network (intersections are preferable);
  - install proposed bins near an existing bin location (in a buffer zone of 60 m radius); and,
  - allow the placement of more than one bin in the same intersection. The number of bins sharing the same intersection point is related to the land use and population of the covered area.

**Figure A.3: Reallocation of waste collection bins in the new sector**


*Source: The Nikea Case Study, Greece*

The definition of the new sectors is restricted by the capacity of the available waste collection vehicles. Thus, the size (in terms of the number of bins) of a new sector was estimated at the 2/3 of the existing sector. Therefore, instead of 4 routes per week for each of the two subsectors (total: 8 routes per week) we designed smaller sectors and schedule 5 routes per week in these new sectors.

As a result of the above mentioned approach, each new sector should contain 95 bins, which can be collected in one vehicle trip. The reallocation of bins was based on travel distance from each residence to the nearest bin and the general intention to decrease the total number of bins. A maximum travel distance of 60 meters from each resident to the proposed new site of the bin was allowed. Moreover, the introduction of new bins with larger capacity, to accommodate for the same waste quantity, ensures the decrease in the total number of bins and collection stops. A higher priority for the allocation of the new bins was given to locations of bins in the existing system and to crossroads in order to facilitate social acceptance and collection vehicle travel.

Summarising, we assume a new waste collection planning: the MoN is divided into 22 new sectors and each collection vehicle should make 5 collections per week in each of these sectors. Thus we propose an improved collection schedule for the study area, as the vehicle collects each bin 5 times per week instead of 4, according to the existing situation. For this study we did not proceed to the full re-sectorisation for the total area of the municipality, but limited our approach within Sector1. Thus, we assumed a new sector (Sector_N1) within Sector1, with the properties described above (2/3 of the size of Sector 1, 5 collections per week). The evaluation of the results of the proposed modelling approach was based on the comparison between Sector_N1 and corresponding part of Sector1.

### Routing – Network Analysis

After the reallocation of the waste collection bins and the definition of Sector_N1 the optimisation of waste collection vehicle routing was performed, using the ArcGIS Network Analyst modelling package. The optimal path finding algorithm of NA is an alteration of the classic Dijkstra's algorithm (Dijkstra, 1959) which solves the problem of optimal route selection on an undirected, nonnegative weighted graph in a reasonable computational time.

**Figure A.4: Optimal waste collection route.**


*Source: The Nikea Case Study, Greece*

In the literature, many modifications and new algorithms have been used for the incorporation of the aforementioned restrictions. In the context of ArcGIS Network Analyst commercial GIS software, this algorithm is improved further, using effective data structures such as d-heaps (ESRI, 2006). To use it within the context of real transportation data, this algorithm must be modified in order to respect real problem restrictions, such as one-way roads, prohibited turns (e.g. U-turns), demand at intersections (nodes) and along the roads, and side-of-street constraints while minimising a user-specified cost attribute. The key point is to build a cost matrix containing the costs between origins and destinations. These points correspond to pairs of vehicle stops (waste bins).

The total vehicle travel time is the sum of the travel time for each road segment plus the collection time for emptying of the bins. The user can define all the relevant traffic restrictions described above, the time delay for each stop for bin collection, as well as the first and last collection stop within the sector. The final output is the optimal solution in terms of distance or time criteria (fig. 6).

### Results and discussion

- The method described above was applied to simulate the waste collection procedure of the study area. Based on the methodology presented in the previous sections and the criteria and restrictions introduced in ArcGIS Network Analyst, different routing solutions were created for the collection of the new bins (95 bins of 1100 L) in their new location within Sector_N1. Evaluation of the results of the developed methodology is based on the comparison of the proposed waste collection scenario (Sp) with the existing one (Se). The time needed during waste collection has three distinct components: time for hauling; (assumed as 25+25 km with average speed 50 km/h);
- time for driving during collection; and,
- time for emptying the bins.

The parameters input to the model were based on real data provided by the MoN and verified by field studies. More specifically, the time for emptying of the bins (bin loading, emptying and unloading – component 3) is 30 sec for bins with capacity up to 330 L and 60sec for bins with capacity equal to or larger than 660 L. The time for driving during collection (component 2) is determined by the average speed of the collection vehicle in the travel between stops and the total distance travelled in the collection segment of the route. For MoN the average speed is 5, 10 and 15 km/hr for 1-way, 2-way and central roads, respectively.

Both parameters are not readily available and default literature values are scarce. Sonesson (2000) reports values for the time required for bin emptying from empirical data for the wider Uppsala area in Sweden, as follows: 68.4 sec for inner city, 43.2 sec for suburbia and 57.4 sec for rural areas. Although the bin size is not defined, these values are in good agreement with the observed figures in the MoN. The author also reports an average collection speed of 20, 30 and 50 km/h for inner city, suburbs and rural areas, respectively. This is higher than the values achieved in MoN (conditions comparable with the inner city in Uppsala). Possible explanation is twofold:

- different conditions of the road network and traffic in the two cities; and,
- a denser matrix of collection points, due to a higher population density, allowing for shorter distances travelled between collection points and therefore lower speed.

Nevertheless, the vehicle speed used for central roads in Nikea (15 km/h) compares well with the inner city collection speed in Uppsala (20 km/h).

The comparison of results, on a weekly basis, between the existing collection scenario (Se) and the proposed one (Sp) is illustrated in Table 3. The optimal solution expressed in Scenario Sp (Fig. 6) corresponds to 287 km of distance travelled by the waste collection vehicle on a weekly basis. This provides a 3% improvement when compared to the existing equivalent empirical route (Se). The improvement is more significant if assessed in terms of the total travel time in the optimal route, defined as the runtime of the collection vehicle plus collection time for the waste bins. The total travel time, on a weekly basis, for the optimal route (Sp) is estimated to be 1225 minutes (18% reduction compared to the empirical route (Se). For the calculations the hauling time to the Fyli landfill (~25 km from Sector 1) should be added. Assuming an average speed of 50 km/h, the travel time to and from Fyli is about one hour.

Restricting the discussion to the collection phase only of the WC&T cycle, it is expected that fuel consumption relates more to time of operation and number of stops than distance travelled, as most of the collection time is spent for bin loading and emptying. Fuel consumption and corresponding gas emissions are functions of work performed for stopping and accelerating, actual driving, traffic related stops and lifting and compacting the waste (Sonesson 2000).

## Conclusions

GIS technology supports the optimisation of municipal solid waste management as it provides an efficient context for data capture, analysis and presentation. Two main categories of GIS-based waste management applications can be identified in the international literature. In the first, GIS is used for the selection of waste disposal landfills, and to a smaller extent, other waste treatment facilities. Most of these applications benefit from map overlay GIS functions and spatial allocation modelling methods. The final output of an application of that type is the suitability map of the area under investigation. This map could be the core of a spatial decision support system for a landfill site / waste treatment facility selection problem.

The second, more complex category of GIS supported waste management applications is related to waste collection. There are several applications for route optimisation, reallocation of waste bins and complete redesign of the collection sectors. The main aim of these applications is to reduce the collection distance and/or time of the collection vehicle fleet. The implementation of GIS-based modelling for waste collection optimisation in many countries with different socioeconomic conditions and technological background shows that significant savings could be achieved in most setups. The optimisation of routing has a direct positive impact on cost savings (reduction of fuel consumption and maintenance costs) as well as significant environmental impacts due to the lower levels of sound pollution within the urban environment and the reduction of greenhouse gases emissions. The application of GIS-based waste collection modelling should consider the following aspects, in order to provide reliable results:

- Accurate and up to date information about the road network of the area under investigation.
- Detailed capture of the spatial properties of the existing collection system (collection routes, location and attributes of waste bins, existing time schedule). Most often, especially in developing countries, the research team has to acquire this information with field work.
- Installation of a modern GIS facility within the municipality enriched with network analysis functions. Advanced training of the staff is a very important factor for the efficient operation of this system.
- Validation of the outputs from GIS-based modelling in order to ensure the applicability of the proposed routes in real life conditions.

Nowadays, although GIS-supported waste collection modelling is a mature scientific field the general diffusion of this technology is hampered by factors such as the absence and the poor quality of digital spatial data, the high cost of spatial data capture and the lack of personnel with the proper technological background to operate such modelling.

The methodology developed in this study and its application to the Municipality of Nikea, Athens, resulted in significant savings, especially in terms of time (18%), fuel consumption (13.8%) and $CO_2$ emissions (12.7%). The study demonstrated the value of GIS technology as a waste collection optimisation tool, capable of supporting decision making, in the context of a Mediterranean, densely populated city. The adoption of this technology could provide significant financial and environmental benefits for local communities.

## 3. GIS Application for Estimating the Current Status of Municipal Solid Waste Management System: Case Study of Chandigarh City, India *(A. Khajuria*, T. Matsui and T. Machimura; 2011)*

Rapid growth of urban population in developing Asian countries in recent years has made MSWM an important issue. India is facing serious environmental problems in MSWM that is really threatened by a number of problems; some of which include inadequate management, lack of technology and human resources, a shortage of collection and transport vehicles, and insufficient funding. In general, an effective MSWM system should include one or more of the following options: waste collection, transportation and transfer; intermediate treatment, reduce- reuse-recycle (3R) activities and disposal. The waste collection, transport and transfer methods depend on the specific site, waste generated, distribution road network, work force, vehicles, treatment methods, etc. It is ensured that MSWM is environmentally safe and sustainable disposal (Khajuria et al., 2010).

Geographical Information Systems (GIS) is an information system for capturing, storing, analyzing, managing and presenting data which are spatially referenced. It consists of a geo-referenced spatial database and it also includes all required parameters for MSWM. These parameters involve city maps, collection points, transfer stations, collection and transportation road network, as well as the location and capacity of disposal sites (Sharholy et al., 2007). ArcMap software has the capability to input and store the geographic (coordinate) and tabular (attribute) data, to find specific features based on location or attribute value regarding the interaction between multiple datasets, to visualize geographic features using a variety of symbols and to display the results in a variety of formats such as maps and graphs. In addition, it can be used to display, edit, create and analyze GIS data; browse, find and present geographic information of management system.

Recently, there has been an increase in research that uses GIS application as a tool for data collection, data analysis and result display. Ghose et al. (2006) found that GIS application used an optimal routing model that was proposed to determine the minimum cost/distance efficient collection paths for waste collection and transport. Wilson and Vincent (2008) used the Global Positioning System (GPS) to estimate the delay time of waste transfer stations. Sharholy et al. (2007), noted that GIS application has been used to analyze existing maps and data, was generated to give the efficient information concerning static and dynamic parameters of MSWM problems; and the emission control with route optimization in solid waste collection process used GIS application (Apaydin and Gonullu, 2008).

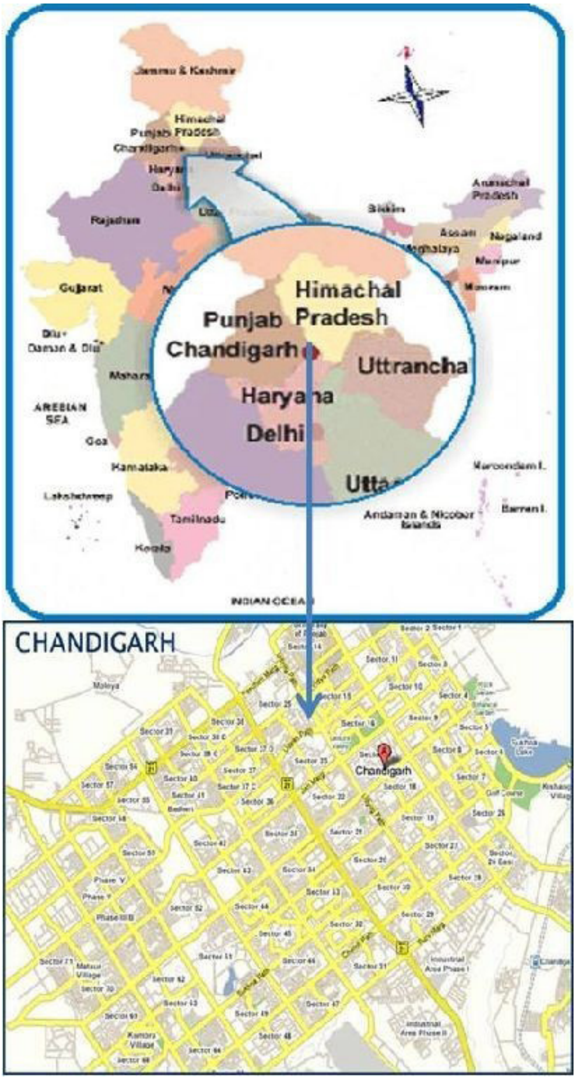
Optimization of the operational efficiency for collection, transport and transfer becomes an important component of an effective MSWM system. In this study, an assessment to estimate the operational efficiency of waste collection, transport and transfer system is conducted; and the MSWM model using GIS application as a decision support tool by municipal authorities for the efficient management in waste collection, transport and transfer system, load balancing within vehicles, managing fuel consumption, and generating work schedules for the workers and vehicles are proposed.

### Study area and current status

Chandigarh is located near the foothills of the Shivalik range of the Himalayas in Northwest India. It covers an area of approximately 44 $m^2$ or 114 $km^2$ and shares its borders with the states of Haryana in the east and Punjab in the north, west and south (Fig. 1). Chandigarh city is an urban area directly under the state government and is regarded as a "Chandigarh Capital Region (CCR)", with a population of 1,064,711 (2010), and geographic area of 13,256 $km^2$.

Solid waste includes garbage, sewage sludge and other materials which are in solid state. Broad categories of solid waste may include: food waste such as vegetable, fruit or meat residues; rubbish such as waste papers, broken crockery, used cans, discarded house material, leather or furniture items; ashes such as wood, coal, and dung cakes; construction waste such as dirt, stones, concrete and bricks from demolished buildings; industrial wastes from factories; plant wastes from trees or pruned hedges; sewage from toilets and special wastes such as animal dung and dead animals (Krishna, 1996).

Chandigarh 'the city beautiful' is one of the cleanest cities of India. It produces around 350 TPD of solid waste, which is 0.4 kg/c/day, out of which, major amount is of biodegradable substances (40-50%) consisting of organic matter like vegetable peels, and leftover foodstuffs. Combustible fraction accounts for 20-25% of waste and rest is the inert fraction which includes sand, dust, glass and others.




*Source: GIS Application for Estimating the Current Status of Municipal Solid Waste Management System: Case Study of Chandigarh City, India (A. Khajuria*, T. Matsui and T. Machimura; 2011)*

**Materials and methods:** This case study was carried out to estimate the waste collection, transport and transfer system to find out problems from those activities and then purpose the solutions by using GIS application. For collection and transport system, surveys were conducted on waste collection vehicles as handcrafts and waste transport vehicles as trucks by using manual GIS application. ArcGIS was used to create maps for MSWM. The original map of Chandigarh was scanned and registered/geo-referenced to specify its location. Thereafter, the collected data for various sanitary wards, collection routes, depots locations, and disposal sites were given as input parameters for the generation of MSWM maps for Chandigarh city using ArcGIS applications. The sanitary wards were drawn and input properties such as name, number, generation rate, and the disposal site (Fig. 2). The location of distribution in each ward, collection sites are determined (Fig. 3). Then, the properties of each disposal site, such as name, capacity and amount of MSW disposed daily (Fig. 4).

## Proposed model

Waste may be defined as useless, unwanted and discarded material which results from a number of activities going on in the locality. It may include left over from kitchen, old newspaper, broken crockery or other home materials, worn out clothes, plastic/glass bottles, tree shedding/leaves, sewage from toilets, ash from hearths, emission from chimneys/ vehicles, effluents from industries, and so on. It may be in solid (garbage from homes), liquid (polluted water from industries) or gaseous (smoke from thermal plants) state. Municipal solid waste includes the following elements; waste generation, waste storage, waste collection, transfer and transport, waste processing, waste recovery/ recycling, and waste disposal. Solid waste management is of paramount importance in the context of urban areas/ cities. In urban India, per capita solid waste of about 0.5 kg is produced daily, which varies from 0.3 kg in small towns to around 1 kg in metro cities. Chandigarh 'the city beautiful' is one of the cleanest cities of India.

Waste collection and storage are inter- related functional elements of MSWM system. Collection of waste includes gathering of wastes and hauling them to the location, where it is collected by emptying the collection vehicle. It may be disposal site, transfer station, or a processing unit. On the other hand, storage is a key functional element because collection of waste never takes place at the source or at the time of its generation. Onsite storage is of primary importance due to aesthetic consideration, public health, as well as economics involved in it. Depending upon the type of waste as well as the frequency of waste generated in the locality, storage size, form and material of storage containers is utilized. The proposed model for Chandigarh Administration will started its MSW plan according to proposed model for save money and manpower.

The proposed model includes different pathway of proper and safe management system. The thickness of the lines represents the amount of waste (kt). Indication points of (1, 8, 10) is source separation method, (2, 9, 11) is mixed waste (3) is compostable, (4) is residue, (6) is compostable waste, (7) is compost, (12) is recovered material (13) is residue, (14) is compostable waste, (15) is ash sludge (16) is after remaining 3R technology waste which is increased the specific land filling costs (40% is centrally separated when running the scenario without the landfill limitations) (Fig. 5)

## Results and discussion

The result of the analyze shows that MSW contains 45.3% organic matter and 40% miscellaneous materials (bricks, fine dust, rubber, wood, leather, wastewater, etc.). The percentage of recyclable materials (glass, paper, plastic, metals) has been found to be very low. This may be due to rag pickers, who collect and segregate recyclable materials from collection points and disposal sites.

The results from the survey reveal that the per capita MSW generation rate is

0.39 kg/capita/day. The per capita generation rate for various areas in Chandigarh city. It is also revealed that 88±3.6% of people living in houses dispose of their garbage daily, in which 53.4±4% are disposing waste in containers, whereas 46.4±4.2% are disposing on the streets. Further, 20.4±6.8% of houses are segregating their solid waste (biodegradable/ non-biodegradable), 39.5% are using polyethylene bags for storage and 63.5±5.9% of houses are fully aware of government's policy (government bans the using of plastic and polythene bags because they are not easily biodegradable and they create many problems to the environment).

The collection frequency of MSW is shows that 42.7±5% of houses are paying for solid waste collection services to local sweepers, and 45.6±3.5% are willing to pay for the improvement of solid waste services. About 23±3.6% of houses have complained of poor services and others (39.7±5.4%) have been satisfied by the complaint office. The survey also reveals that 34.8±4.1% of the people are satisfied with solid waste collection services.

Figure A.5: Sanitation zones in Chandigarh ward wise (Kaur et al., 2010).

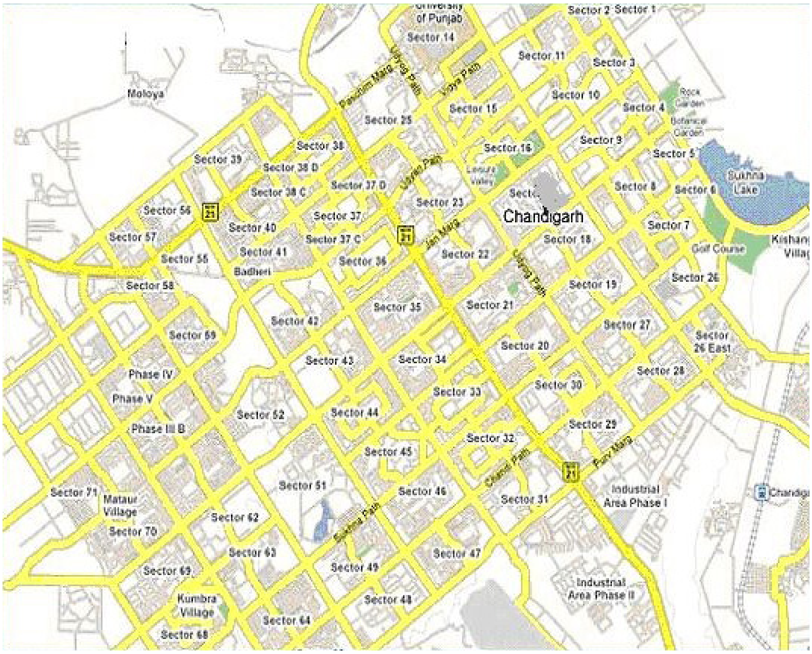



Figure A.6: Distribution of location and collection site of MSW in Chandigarh city (Kaur et al., 2010).

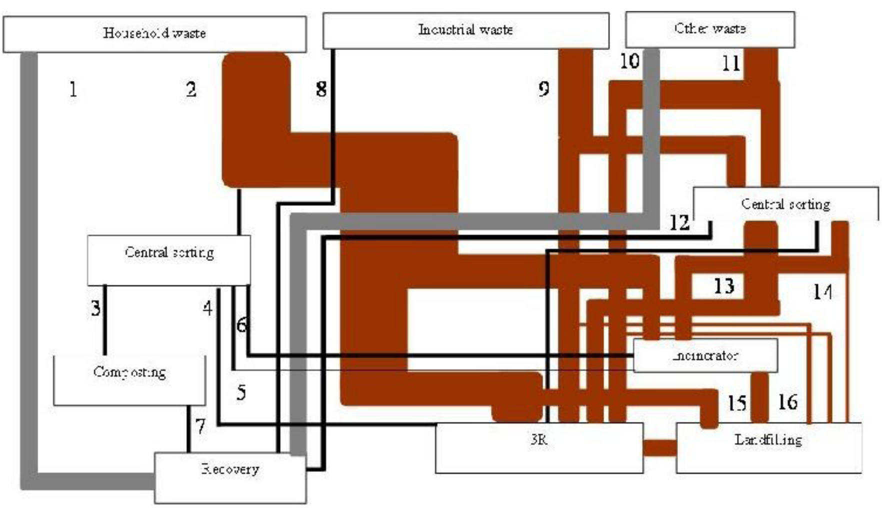
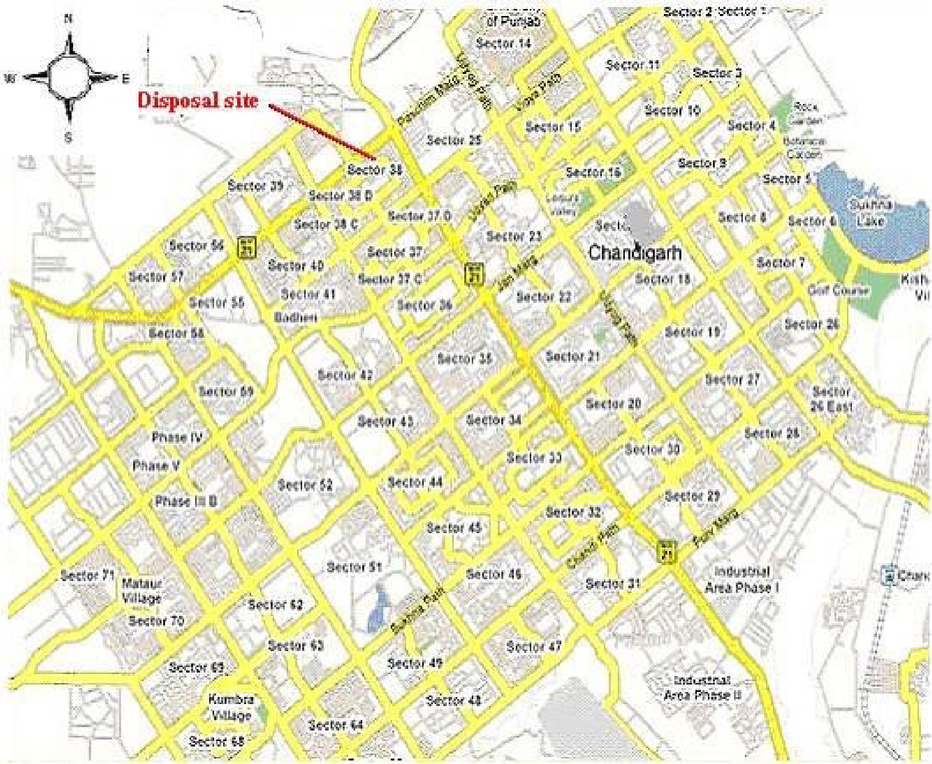


**Figure A.7: Existing MSW disposal site of Chandigarh city (Ministry of Urban Development, 2001).**




The results from data analysis in GIS are products of the appropriate format maps concerning static and dynamic parameters of the MSWM problem, such as the productivity of MSW in the different wards, collection point locations, types of MSW transport means and their routes, and the number of disposal sites and their attributes. The locations of these distribution are scattered, unplanned and cover only about 50% of total area. The information clearly indicates the poor MSW services of Chandigarh city having scant attention in establishment of depots for different prime locations of the city.

The sector 38 disposal site serves the maximum number of wards, whereas other site serves the minimum. This can be balanced by diverting MSW from a few wards towards other sites, but the enhancement of capacity of these sites is required. The MSWM data obtained from ArcGIS maps are responsible for the retrieval, update and visualization of the information required. The produced maps can provide Chandigarh Municipal Corporation, environmental engineers and decision makers with data about the present MSWM system, which is required for improvement of the existing system and for future planning.

## Conclusion

The segregation of waste at source and promotion of recycling or reuse of segregated materials reduces the quantity of waste and the burden on landfills, and provides raw materials for manufacturers. The composition of MSW shows mostly organic matter, so composting is a good method for the treatment and production of soil amendment. The rapid increases in the quantity of MSW but its inability to provide daily collection service cause a nuisance and health hazards. The study presents the current scenario of MSWM, which will be helpful in creating awareness among the people. The MSWM data obtained from ArcGIS maps are responsible for the retrieval, update and visualization of the information required. The produced maps can provide environmental engineers and decision makers with data about the present MSWM system, which is required for the improvement of the existing system and for future planning.

The proposed model customized to Indian Municipal Solid Waste involves the conversion of waste (mainly combustible fraction) into densely packed fluff/pellets with the calorific value, which is free from any harmful by-products and effluents. The practice activity resulting in reduction of methane emission, a potent green house gas by avoiding anaerobic decomposition of untreated MSW in unsecured landfill sites, which was the earlier practice of disposal of MSW in Chandigarh, the 'city beautiful'. In the absence of this green-tech fuel processing plant, dumping of MSW in open/unsecured landfill site in Chandigarh would have continued and there would have not been any reduction in green house gas emissions. Thus it kills two birds with one stone-environment friendly waste disposal and power generation. With the starting of this MSWM processing unit, Chandigarh the city beautiful has also emerged as a green and environment friendly city.

## 4. Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia (*Amjad Kallel,[1,2] Mohamed Moncef Serbaji,[1] and Moncef Zairi[1,2; 2016)]*

Technological development, globalization, and population growth have accelerated the dynamics of urbanization pro- cesses in developing countries, which contributed to the generation of increasingly large quantities of solid waste (SW) in more or less concentrated areas. Therefore, problems related to solid waste management (SWM) remain at the forefront of the global environmental policy for sustainable development. Indeed, an effective SWM system is necessary to ensure better health and human security.

The process of SWM is very complex as it involves many technologies and disciplines associated with the control of generation, handling, storage, collection, transfer, transportation, processing, and disposal of SW [1]. SWM practices vary with the economical/social conditions and with the regulatory framework.

The collection/transport component is the showcase for any SWM system whose implications are straightforward to evaluate the success of the system and its costs. The operation involves the removal and transfer of waste from production or assembly points to transfer station or from transfer station to processing or to final landfill site. It is therefore the most influential and most costly component as it absorbs the biggest fraction of the budget allocated by municipalities for SWM in detriment of other operations in the waste man- agement system [2, 3]. The challenge is therefore to achieve optimal waste collection and transport operation (hauling, equipment, manipulation, etc.). However, the development of an optimal collection/transportation system for SW involves the determination of a number of selection criteria, which is a very complicated task for a planner to do manually. The use of Geographic Information System (GIS) is recognized as one of the most promising approaches to analyze complex spatial phenomena. GIS has been successfully employed for a wide range of applications, such as geology, protection and management of natural resources, risk management, urban planning, transportation, and various modeling aspects of the environment [4, 5].

Nowadays, integrated GIS technology provides an ad- vanced modeling framework for decision makers to analyze and simulate various problems related to SWM. Indeed, the GIS tool has been used to model various applications in waste management such as siting of transfer stations and landfill, optimizing the collection and transportation, and local forecasting of waste [7–9].

The use of spatial modeling tools and GIS for collection and transportation optimization can provide economic and environmental gains by reducing travel time, distance, fuel consumption, and pollutant emissions [10]. Several models for the collection and transport of SW have been developed based on appropriate software for route optimization. A 3D GIS modeling was used by Tavares et al. [11] in Cape Verde and helped to achieve up to 8–12% of fuel savings even by traveling a longer distance compared to the shortest path. ArcGIS Network Analyst application was used by several authors to optimize the collection and transportation of waste: Ghose et al. [17] who developed a GIS model for calculating optimal route in the state of West Bengal, India, and have shown that its application would allow colossal savings over a period of 15 years; Chalkias and Lasaridi [10] proposed various scenarios developed upon field real situation in the municipality of Nikea, Greece, allowing reductions of up to 17% for working time and 12.5% for the distance traveled. Thus, in the present work, an optimization was developed using the ArcGIS Network Analyst tool in order to improve the efficiency of the collection and transportation of waste in Cité El Habib district of Sfax city, Tunisia, by means of waste bins reallocation and optimization of vehicle routing in terms of traveled distance and operating time while taking into consideration all the required settings parameters, that is, population density, waste generation rate, bins locations, road network and traffic/circulation, collection vehicles capacity, and so forth.

### Background of SWM in Sfax City

The case study in this work relates to a district in the Sfax city, which is the economic heart and the second largest city of Tunisia. It has a very disperse agglomeration with 300,000 inhabitants resulting in a density of 48 persons per hectare. The town of Sfax is divided into 7 districts: El Medina, El Boustane, Sidi Mansour, Sfax Nord, Errbadh, Merkez Chaker, and Cite´ El Habib (Figure 1). Each of these districts involves one or more municipal communities.

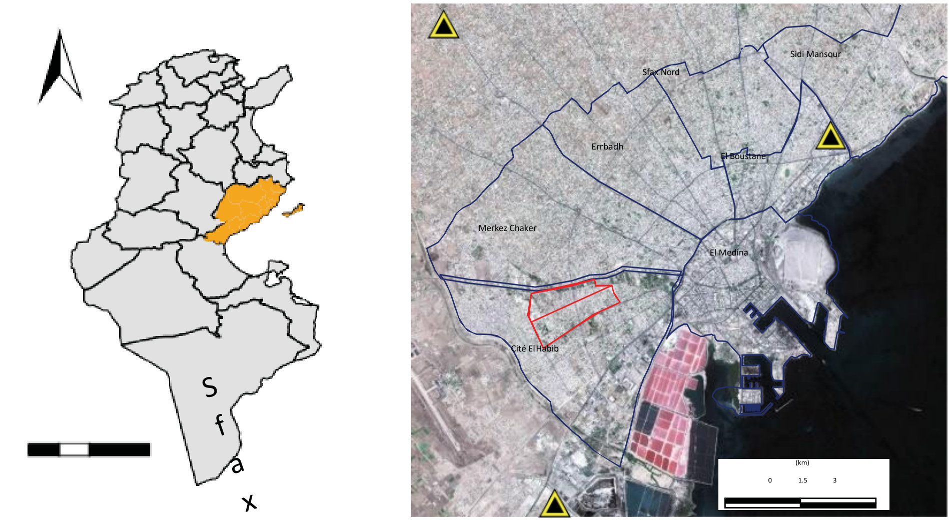
The amount of municipal SW collected by the munici- pality of Sfax was 74501 t in 2010, but it decreased to 53455 t in 2013 due to the social and political events in the country during the last five years. Based on 2010 data, the correspond- ing average of collected waste is 0.68 kg/capita/day (projected average being 0.71 kg/capita/day). It should be pointed out that the municipal SW is characterized by a high level of organic matter (68%) and thus a high rate of water content ranging between 65% and 70%. Besides individual citizens, potential producers of waste are schools, kinder gardens (227); hospitals, clinics, drugstores, and fuel stations (118); touristic areas (4); cafes, restaurants, bakeries, and other businesses (3934); and hotels (18) and shopping centers (24). Citizens dispose off their waste in plastic bags, plas- tic/metal dustbins (buckets and half steel drums), or polyethylene or metal containers of different capacity or simply in bulk left on ground (Figure 2).

The municipality of Sfax makes 400 metal waste bins of 770-liter capacity available in some areas. Waste collection is carried out manually and/or mechan- ically. The vehicles available in the municipality for the collection are 4 packer trucks of 12 m3 capacity, 14 rear-end loaded compaction trucks of 16 m3 capacity, 10 dump trucks of 7 t capacity, 13 tractors of 5 m3 capacity, 2 pickup trucks of 3 m3, and 3 mini tractors. Multidump trucks (30 m3) are also available to evacuate the anarchic dumps and ensure transfer of waste to the municipal landfill.

The communal area is swept by a total of 44 circuits, including 19 circuits of collection operated by rear-end loaded compaction trucks, 15 by dump trucks, and 10 by tractors [6]. Besides, laborers carrying hand cart ensure the collection of waste from hardly accessible places and unload it into trucks at certain predefined gathering places (Figure 2(d)).

The staff ratio is about one collection agent per 600 inhabitants in the district of El Medina to reach up to one per 2200 inhabitants in the district of Merkez Chaker, knowing that the crew of each collection vehicle consists of a driver and two workers. The collected waste is split between two transfer stations before being transferred to the municipal landfill site in the absence of any source separation process or sorting at transfer stations.

Multiple expenditures (direct and indirect expenses) are required to handle one ton of waste from collection until landfilling operations. These expenses are as shown in Figure 3(a) where it is noted that the sum of salaries and equipment costs exceeds 70%. In Figure 3(b) is presented the cost of collection and transport of one ton of waste (based on 2012 data in [6]) for the districts of Sfax city. The average is 76 TND/t (therefore an annual allowance




*Conditions and equipment for waste collection.*
*(Amjad Kallel,1,2 Mohamed Moncef Serbaji,1 and Moncef Zairi1,2; 2016)*

per capita of around 19 TND/cap/year) showing huge gaps between different districts. On the other hand, the costs are nearly 45% lower for the districts whose collection is ensured by private companies than by municipal service, as the case of El Boustane and Sfax Nord whose costs are 41 and 51 TND/t, respectively. In comparison to the national average (53–73 TND/t) these values are excessively high and suggest that an exceptional quality of service is offered!

It should be noted that the recovery of expenses by revenues from municipal taxes does not exceed 30% and the deficit (70%) would be borne by the state (recovery of other taxes and subsidies).

### Methodology and Tools

The current case study concerns one of ten collection routes in the district Cite´ El Habib, Sfax city (Figure 1).

The approach for optimizing the collection system relies on GIS which provides an effective means to import, manage, and analyze spatial data. The methodology followed in this work consists mainly of two procedures (Figure 4): the design of the geodatabase and analysis of the results.

Data Collection and GIS Design. A geodatabase was prepared using the GIS environment "ESRI ArcGIS" from maps, municipal and statistical services data, satellite images, monitoring and field work, and literature data. The required data are related to geographic/urban characteristics of the study area as well as characteristics of the waste collection procedure.

The following data were obtained and processed in suitable forms (vectors, tables, and raster): delimitation of the study area; detailed land use plan of the municipality; population distribution and density; satellite image (Google Earth); road network; and information on roads (traffic, restrictions, and signs).

We have been tracking the collection route with a GPS (Global Positioning System) to take all relevant data and facts: location of the starting point, starting time, number of workers, itinerary and coordinates of collection points, condition of waste on site, condition of container and bins, odometer reading before departure and after collection, time of arrival at the transfer station, amount of waste collected, and quantity of energy consumed.

Once our database is established, the optimization model is performed with the use of the Network Analyst (NA) tool on ArcGIS. This work was carried out considering the actual scheme of collection and transportation as well as other proposed scenarios.

GIS Analyses: ArcGIS NA. ArcGIS NA is a user-friendly powerful ArcGIS extension that provides easily and directly the most efficient route solutions. The optimal path searching algorithm solves the problem of selecting the optimal route on a nonnegative weighted undirected graph in a reasonable computing time. This is mainly to build a cost matrix containing costs (length) between origins and destinations. These points correspond to pairs of vehicle stop point (location of the bins) [10].

In ArcGIS NA, routes can be calculated according to the distance and time criteria where total travel time is the sum of the vehicle operating time plus the time of waste loading/unloading.

The user is able to set or modify all the dynamic factors needed to create an initial scenario. By changing these par- ticular parameters, other scenarios can be generated leading to several solutions. Finally, the solution is identified by a function that refers to various parameters, such as the shortest distance, the road network, and the social and environmental implications [18].

## Results and Discussion

The current study for the chosen collection route is based on the actual real state (initial scenario, S0) along with three other suggested scenarios (S1, S2, and S3). The main results of analyses are shown in Table 1.

**Scenario S0:** Current Route. In Figure 5 we illustrate the tracing of journey made by rear-end loaded compaction trucks during collection, the meeting places of the truck with hand cart, and anarchic points that show waste accumulation areas. The collection is made by a team of 5 persons: the driver and two collectors in the truck and two collectors with hand cart. The distance traveled by truck from the starting point (the municipal garage) to the transfer station is 37 km and lasts 7 hours including 2.5 hours of driving, 4 hours to load/unload bins, and 30 min break. The amount of waste collected duringa trip is around 3 to5 tons.

**Scenario S1:** Optimized Route Using the Same Work Method. For this scenario we kept the same work method as in S0 (equipment and number of workers) and therefore the same stop points. Only the route and the sequencing of stoppages differ. The truck goes through all the anarchic points and it meets with hand cart allowing the workers enough time to collect the waste from those areas as well. The driver should not backtrack in order to minimize the risks of accident. The vehicle does not pass twice through the same route.

We notice, though with the same equipment and the same staff, that waste collection is performed with decreased distance (31 km) and therefore with less fuel consumption (21 L) and less working hours (6 hours).

**Scenario S2:** Optimized Route with a Change of Vehicles. The passage of rear-end loaded compaction truck in tight areas hinders traffic. Besides, it is not cost effective to carry out door to door waste collection with such a vehicle. Therefore, we proposed the use of a tractor or pickup truck- type vehicle (Figure 6).

For this scenario the work will be divided into a part made by compaction truck and the other by the tractor or pickup as the following instructions:

- zones with large quantity of waste must be collected by the compaction truck besides collection ensured with hand cart;
- zones with low quantity of waste will be collected door to door by the tractor;

the path made by the compaction truck does not overlap that performed by the tractor as shown in Figure 6;

- truck meets the hand cart only twice;
- residents in areas not covered by hand cart should be informed so that they carry their waste until the placed containers.

We found out that the travel distances of the truck and the tractor are short (19 km and 13 km, resp.), so this allows increasing the perimeter of working area performed by the same team for the same workingsession.

Scenario S3: Optimized Route with Modified Collection Method. This scenario consists of an optimized path with a modified collection mode, that is, change of vehicle and reallocation of waste bins. This scenario assumes enough containers and imperatively requires the cooperation of citizens to make the effort of bringing their waste until allocated containers.

## Conclusions

In this study, an optimization was developed using the ArcGIS NA tool in order to improve the efficiency of the collection and transportation of waste in the Cite´ El Habib district of the municipality of Sfax, Tunisia.

Three scenarios were generated and analyzed for the identification of optimal routes: S1—optimized route using the same work devices (change of sequencing stops only); S2—optimized route with change of vehicles; and S3— optimized route with a change of collection mode (changing the transportation equipment and reallocation of containers). Compared to the current situation, the results showed that Scenario S3 allows savings of about 40%, 57%, 40.5%, and 48% in the number of workers, working time, traveled dis- tance, and fuel consumption, respectively, and hence a gain of about 60,000 TND/year, in addition to other benefits related to $CO_2$ emissions, hours of work, vehicles wear/maintenance, and so forth. These findings indicate that GIS-based opti- mized scenarios can provide significant improvements to the collection/transportation system of SW and consequently to its financial and environmental costs.

These results could be further enhanced by optimizing the location of containers and subsequently this could be tried to be applied for the whole city of Sfax

Notes:

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