We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

5,800
Open access books available

142,000
International authors and editors

180M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter

Application of Geographic Information System in Solid Waste Management

Elsai Mati Asefa, Kefelegn Bayu Barasa
and Dechasa Adare Mengistu

Abstract

The application of geographic information systems (GIS) to solid waste management (SWM) has been widely adopted in many cities around the world. Planning a sustainable waste management approach is complex, tedious, and time-consuming, and decision-makers are frequently subjected to conflicting factors. GIS has a crucial role in simplifying and facilitating the implementation of sustainable SWM. It is a powerful tool that can assist in minimizing value conflicts among preference and interest parties by providing better information. In this chapter, the basic principles of how GIS is utilized in SWM planning are discussed. The first few sections deal with sustainable SWM planning, its challenges, and problems with the poor performance of its planning. Furthermore, the principles of GIS, how it evolved in SWM, and its integration with multi-criteria evaluation were discussed. The final sections deal with the application of GIS in waste collection optimization and waste disposal planning. The primary aim of this chapter is, therefore, to aid decision-makers in the field so that they can apply it to the daily challenges of SWM.

Keywords: waste management, solid waste, GIS, MCDA, route planning, landfill, spatial analysis

1. Introduction

In recent decades, the application of geographic information systems (GIS) in solid waste management (SWM) has been widely adopted in many cities around the world, from developed to developing nations. Moreover, the utilization of GIS is not limited to the management of solid waste. It has been widely applied in agriculture, natural resource management, planning and economic development, disaster management and mitigation, public health, and related areas. In solid waste management, the primary objective for the adoption of GIS is to reduce cost and time (feasibility) and also to help planners make better decisions in designing solid waste management.

Essentially, planning a sustainable waste management approach is complex, tedious, and time-consuming, and decision-makers are frequently subjected to conflicting factors in SWM planning. Sustainable waste management, according to

the United Nations, is aimed at the integration of SWM at the national and local level, utilizing a life-cycle approach for resource efficiency and environmentally safe management of solid waste [1]. Waste reduction, resource reuse, recycling, and recovery are all part of sustainable waste management, which helps to reduce pollution while also extending the life of resources to be wasted. As a result, sustainable waste management should be economically feasible, socially acceptable, and environmentally effective upon implementation.

The geographic information system can be used to simplify the ease of implementation of sustainable SWM. Most often, due to the complex nature of SWM, there is poor performance in its technical functions and management functions (policy and legislation, financial, and stakeholders). Owing to this fact, there are different optimization techniques developed and implemented in different areas. Among the techniques used for spatial and non-spatial data information, GIS is common. In most cases, GIS is used with the integration of remote sensing and/or multicriteria decision-making analysis (MCDA). In spatial multicriteria analysis, the combination of GIS and MCDA capabilities is crucial. GIS allows for the acquisition, storage, retrieval, manipulation, and analysis of data to obtain information for decision-making. Whereas MCDA techniques provide tools for aggregating geographic data and decision-maker preferences into a single-dimensional value or utility of alternative decisions [2].

A brief description of how GIS is used in solid waste management was presented in this chapter. Our main goal was to show the fundamentals of GIS in SWM to individuals who have little or no experience with SWM planning, especially in developing countries. Furthermore, experts who specialized in GIS or SWM and have more experience with one than the other should understand the fundamentals of integrating the two to maximize efficiency. In addition, this chapter covers the concepts of sustainable waste management, GIS-based SWM, and MCDA. The application of GIS in solid waste collection optimization and waste disposal planning is discussed also.

2. Concepts of sustainable solid waste management

2.1 Solid waste management

Solid waste is defined as any waste discarded by households, commercial, mining, and agricultural operations, as well as the residue sludge from wastewater treatment plants, water supply treatment plants, and air pollution control centers, and it is other than liquids and gases [3]. Solid wastes can be categorized based on sources, reusable potential, degree of biodegradability, and potential impact on the environment, as shown in **Table 1**. Solid waste management (SWM) is a discipline related to the proper management of solid waste generation, storage, collection, transfer, transport, processing, and disposal of solid waste [5].

Solid waste management (SWM) consists of six functional elements, which include solid waste generation, collection, transfer, storage, processing, and disposal. It is a discipline related to the proper management of each of these functional elements. Waste collection is the process of gathering solid waste and recyclable materials and transporting them to a destination where the collection vehicle is emptied, such as a materials-processing facility, a transfer station, or a landfill, once they have

Classification	Type	Description	Composition
Source (based on [4])	Residential	From Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g., bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes.).
	Commercial	From stores, hotels, restaurants, markets, office buildings, etc.	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes.
	Industrial	From light and heavy manufacturing, fabrication, construction sites, power, and chemical plants.	Housekeeping wastes, packaging, food wastes, construction and demolition materials, hazardous wastes, ashes, special wastes.
	Institutional	From schools, hospitals, prisons, government centers.	Same as the commercial wastes
	Construction and demolition	New construction sites, road repair, renovation sites, demolition of buildings	Wood, steel, concrete, dirt, etc.
	Agriculture	Crops, orchards, vineyards, dairies, feedlots, farms.	Spoiled food wastes, agricultural wastes, hazardous wastes (e.g., pesticides).
Degree of biodegradability	Biodegradable	Can be decomposed easily by bacteria or any other natural organisms	Food wastes, garden wastes, paper, cardboard
	Nonbiodegradable	Cannot be decomposed or degraded by the biological process	Plastics
Potential impact	Hazardous	Wastes whose uses or disposal pose a threat to human health or the environment	Toxic, corrosive explosive, and/ or inflammable Pesticides, herbicides, paints, industrial solvents, fluorescent light bulbs, and mercury-containing batteries
	Nonhazardous	Wastes that are considered less harmful to the environment or human health	Paper, plastics, glass, metals

Table 1.
The categories and classification of solid wastes.

been collected [6]. Following the collection of these wastes, the wastes are sorted, processed, and reused to recover, recycle, or reuse them. Additionally, the waste could be treated to recover energy. After the recovery of products, the majority of the waste is compacted to reduce volume, weight, and size. Finally, the remaining waste is either disposed of through regulated methods such as landfilling or thrown in the open.

2.2 Integrated solid waste management and zero waste principle

Integrated solid waste management (ISWM) is a strategic approach to sustainable solid waste management in which solid waste generation, segregation, transportation, sorting, treatment, recovery, and disposal are all combined with the goal of resource efficiency. The US Environmental Protection Agency defines ISWM as the prevention, recycling, composting, and disposal of solid waste to protect public health and the environment, with a focus on reducing recycling, and managing waste [7]. Solid waste management that is integrated can provide both environmental and economic sustainability. No single waste management technology can deal with all waste products in an environmentally sustainable manner. A wide range of management options is ideal. As a result, any waste management system is made up of several interconnected processes. This method examines the entire waste management system and offers methods for estimating overall environmental and economic costs [8].

To bring about a sustainable world for present and future generations, besides the ISWM, there are many approaches to SWM today, including the "zero waste" approach and the life cycle inventory approach. The "Zero waste" approach has been defined in various ways by different individuals. Literally, zero waste is defined as the complete elimination and absence of waste. However, the generation of waste is inevitable as it is a result of extraction and manufacture, distribution, consumption, and other daily activities of human beings. As per the US Environmental Protection Agency, "zero waste" is defined as "the conservation of all resources through responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning or discharges to land, water, or air that endanger the environment or human health". It is an approach that aims to optimize waste recycling and reduction; products are designed in a manner that can be reused, mended, or recycled back into nature [9].

2.3 Sustainable solid waste management

The collection, transportation, treatment, and disposal of diverse types of waste in a manner that does not damage the environment, human health, or future generations is referred to as sustainable waste management. It encompasses all aspects of waste management organization, from production to final disposal [10]. To minimize irreversible negative impacts on human health and the environment, the sustainability concept suggests that industries and their operations be encouraged to become more efficient in terms of resource utilization, production of less pollution and process waste, and use of nonrenewable resources [11]. The waste management hierarchy, on the other hand, frequently necessitates more effort, invention, and creativity, as well as good regulations, stakeholders, and financial support, to achieve the "zero waste" goal.

2.4 Problems with solid waste management

2.4.1 Impacts of solid waste management

Solid waste management (SWM) has become a tough task for many cities around the world due to a significant increase in waste generation as a result of demo-technic growth, population growth combined with technological advancement [12, 13]. Waste collection, treatment, and disposal, among other issues, are crucial due to their costs [13]. Poor SW management has serious environmental implications and puts public health at risk. Moreover, the problem is worse in developing countries that lack basic infrastructure and are known for their less organized waste management practices coupled with a high waste generation rate [14]. According to Tan [12], in these countries, the collection rate is as low as 30–50%, and even the collected waste ends up in unmanaged landfills. Another major challenge is inadequate policy and legislation, lack of public commitment and awareness, lack of technical capacity, and poor financing in these countries [15].

Furthermore, gas and leachate generation are unavoidable outcomes of solid waste disposal in landfills, owing to microbial decomposition, climatic circumstances, refuse properties, and landfilling processes. The migration of gas and leachate away from landfill limits and their release into the surrounding ecosystem pose major environmental concerns at both existing and new sites. These concerns include but are not limited to, fires and explosions, vegetation damage, foul odors, landfill settlement, groundwater pollution, air pollution, and global warming, among others [16].

3. A new way of thinking

Recently, the implementation of integrated solid waste management (ISWM) has become popular for better management of growing MSW. It ideally proposes the waste reduction at source, before even generation of wastes utilizing different techniques, innovations, and optimal management practices [17]. In ISWM, there is effective management of waste at all levels, from generation to disposal. Despite its popularity, little is known about its technical operation, and it is also subjective from a management perspective.

Integrated solid waste management compromises the complex multi-objective criteria in each management element. This resulted in making the ISWM more subjective for decision-makers as uncertain solid waste generation, conflicting factors, and economic constraints are dealt with. To overcome these problems, there are some innovations in ISWM, including mathematical modeling, computer-based modeling, geographic information systems, and remote sensing, to name a few. Besides, Gaeta et al. [18] divided the innovations in ISWM grouping into four main typologies of innovations in the solid waste market system as follows: a traditional landfill-oriented system; a modern waste-to-energy incinerator-oriented system; a light recycling system; and a hard recycling system. In this chapter, the focus is on GIS, also detailed discussions on other approaches are presented by [14, 18–21].

To optimize solid waste management, there were some early attempts. For example, Anderson & Nigam [22] were the first to propose mathematical modeling in SWM. Followed by the development of models for technology selection, siting, and sizing of waste processing facilities in SWM [23–25]. On the other hand, geographic

information systems combined with remote sensing are becoming widely common in the area of SWM. GIS is preferred because of its simplicity, easy access, and low cost [26]. The use of GIS in solid waste management supports capturing, handling, and transmitting the required information promptly and properly, and it is a well-known, innovative technology that has contributed a lot to SWM in a short period.

4. GIS and SWM

4.1 History and evolution of GIS in SWM

Historically, early society relied heavily on spatial data to represent geographical locations. In the American War of Independence, at the Battle of Yorktown, the French cartographer prepared the map overlays of troop movements [27]. Also, in 1854, Dr. John Snow, in providing evidence for a water-borne cholera outbreak, mapped the incidence of cases with water supply sources. Even though there was a huge reliance on spatial data in early societies, the breakthrough was witnessed with the introduction of GIS after a century. The precise articulation of GIS's brief history is muddled at best. This is because most organizations involved in the use of GIS at the time of its inception refused to give up their data, and the early writers of GIS history were not practical users of the technology [28]. Even though the book did not give any description of the overlay processing with defined methodology, the publication of a book named "Design with Nature" by McHarg [29] is known to have been a crucial factor in the evolution of GIS. Many research articles, reviews, and books concur that the evolution of GIS over time is due to improvements in geography, environmental awareness, technology advancements, and the enhanced practical and technical skills of GIS users.

Geographic information arose as integrating and powerful technology in the context of these breakthroughs because it allowed researchers and geographers to include their methods and information in a variety of ways that supported traditional kinds of geographic analysis. For example, map overlay analysis and other forms of analysis and modeling that were previously impossible to achieve using manual approaches [30]. Researchers can now map, model, query, and analyze large volumes of data in a single database thanks to GIS [31]. GIS can play a part in SWM because it is complicated and the components are interconnected. As a result, the planning and monitoring operations are based on spatial data. Customer service, analyzing optimal transfer station locations, planning routes for vehicles transporting waste from residential, commercial, and industrial customers to transfer stations and from transfer stations to landfills, locating new landfills, and monitoring the landfill are all important aspects of SWM that GIS can help with.

4.2 Role of GIS in SWM

In the management of solid waste, a geographic information system is an excellent instrument as it is used in the planning of technical elements. Many researchers have used GIS principles in SWM to optimize the practice of SWM. For example, Chang et al. [32] used GIS in conjunction with a mathematical programming model to develop a multi-objective, mixed-integer programming model for collection vehicle routing and scheduling for solid waste management systems synthesized within a GIS environment and concluded the effectiveness of the model, as well as

recommendations for application to other environmental planning and management problems. In recent decades, efforts have been undertaken to shorten the distance between waste collection stations and landfills, hence reducing the number of trucks involved in waste collection and disposal [33–36].

GIS can be used to save costs and improve waste collection and transportation efficiency. Many elements influence route optimization, including the location of waste bins, collection details, vehicle kinds, trip impedances, and the road network's integrity [37]. Chang and Lin [38] used a GIS and a mixed-integer programming model to locate proper waste bin locations and waste transfer stations, which resulted in lower direct costs and more manageable operational programs. Even though the process varies, the technique has recently become popular. El-Hallaq & Mosabeh [39] used the GIS integrated location-allocation methodology to rebuild the existing waste bin sites and were successful in finding misplaced bins and recommending an equitable waste bin distribution.

Another key application of GIS in SWM is the selection of disposal sites. Muttiah et al. [40] used a GIS and a Markov-chain-based simulated annealing algorithm to find prospective waste disposal sites, and the simulated annealing method saved order of magnitude of time over an exhaustive search strategy. Multi-criteria coupled with GIS have recently become popular in SWM for assessing conflicting criteria.

Stages	Description	Principles/basics	Examples
Input	Identifying and gathering data related to SWM. Acquisition, reformatting, georeferencing, compiling and documenting these data.	Digitizing, scanning, remote sensing, GPS, internet	Daily waste generation rate, waste collection routes, landfill site location, type of waste, land use map, the elevation of the area.
Data storage and management	Includes those functions needed to store and retrieve data from the database can be thought of as a representation or model of real-world geographical systems	Geographical entity (towns, road network, and town boundary represented by point, line, and polygon). Object (spatial and nonspatial data)	Data model location of the existing landfill site (spatial) and types of waste dumped with the rate of dumping (nonspatial data).
Data manipulation and storage	To obtain information useful for waste collection optimization or waste disposal planning.	Fundamental analysis (measurement, classification, overlay operations, and neighborhood and connectivity operations) and advanced analysis (statistical modeling and mathematical modeling)	Vehicle route optimization, suitability analysis of landfill, optimal waste bin location
Data output	A way to see the analyzed SWM-related data or information in the form of maps, tables, diagrams.	Display monitors, pen plotters, electrostatic plotters, laser printers, line printers, and dot matrix printers and plotters	Optimal route for waste collection (map), schedule for waste collection (table), thematic map of a suitable landfill site.

SWM: solid waste management; GPS: global positioning service.

Table 2.
Basic principles of GIS.

Asefa et al. [41] used GIS in combination with the multicriteria decision-making method and the analytical hierarchy process to find the best landfill location by balancing competing environmental and socioeconomic concerns. In addition, Rahimi et al. [42] used GIS techniques and fuzzy Multi-Criteria Decision-Making methods in landfill site selection problems, where the criteria weights are determined using the group fuzzy Best-Worst Method, suitability maps are generated using GIS analysis, and the sites are analyzed and ranked using the group fuzzy MULTIMOORA method.

4.3 Basic principles of GIS

A geographic information system (GIS) has a broad area of application and is a computer-based system that helps in the manipulation of data about specific geographic areas. GIS, as presented by Rolf and Deby [43], is a georeferenced data entry, analysis, and presentation tool based on the computer interface. Data preparation and entry is the initial phase in GIS processing, which entails acquiring, preparing, and entering the data needed for information production into the GIS database system. The second stage is data analysis, which entails going over and analyzing the information that has been gathered and uploaded into the GIS system. Finally, during the data presentation phase, the analytical results are displayed and/or saved appropriately. Data input, data management, analysis, and final output are usually common processes in most GIS technique development for various purposes and applications, depending on the basic concept of the above-mentioned stages. **Table 2** summarizes and presents these stages, as well as their fundamental principles and instances.

5. Geospatial analysis

Geospatial analysis is the process of calculating data that has been entered or saved to generate new information that can be used to improve SWM decisions. The decision on which geographical analysis to use is based on the decision maker's needs and objectives. For example, when deciding where to build a new landfill, various conflicting environmental, social, and political variables must be considered. When these criteria are entered into the GIS interface, other geographical analyses, such as reclassification, overlaying, buffering, and so on, can be performed. As a result, GIS can assist in the computation of such cases using up-to-date criteria that are examined cost-effectively. The following are some of the most often used spatial analysis methodologies as discussed in [2, 43, 44].

6. Measurement, retrieval, and classification

It is usually used at the beginning of any analysis as it allows data exploration without making a significant change. In the measurement function, distances between features or along their perimeters, the counting frequency of features, and the computation of area size features are computed. The retrieval functions allow the selection of specific features based on logical functions and user preferences. Classification is the re-arrangement of specific features into a common data value layer. Usually, measurement, retrieval, and classification are performed using a single vector or raster data layer combined with non-spatial data, sometimes.

7. Overlay functions

The overlay capability, which allows disparate data layers to be joined to create new data, is considered the most important feature of GIS interfaces. It can be used for both vector and raster data types, however, it is most commonly employed for raster overlay computations. It includes operations of intersection, union, difference, and complement using sets of positions. Many GISs allow overlays using an algebraic language, which expresses an overlay function as a formula with data layers as parameters. Arithmetic, relational, and conditional operators, as well as a variety of functions, can be used to combine different layers [2].

8. Neighborhood functions and Network analysis

Neighborhood functions allow the evaluation of the surrounding areas of the location of the features and operate on the neighboring features of a given feature or set of features. It includes search functions to allow the retrieval of features, line-in-polygon and point-in-polygon functions to compute a given linear or point feature is located within a given polygon, and buffering functions which allow determining a fixed-width environment surrounding a feature. Network analysis is concerned with network computations in the GIS interface. A network is a series of interconnected lines that depict a geographic phenomenon, most commonly transportation. People, cars, and other vehicles can be transported along with a road network; commercial goods can be transported along with a logistic network; phone calls can be transported along with a telephone network, and water pollution can be transported along with a stream or river network. There are two types of network analysis functions: optimal pathfinding and network partitioning. Optimal path finding generates the least cost path on a network between two predefined locations using both geometric and attributes data. Network partitioning assigns network elements (nodes or line segments) to different locations based on predefined criteria.

9. GIS-based Multicriteria decision analysis in SWM

9.1 Overview of GIS-based MCDA

We have seen that the capability of GIS is reliant on spatial analysis functions such as overlay, connectivity, and proximity. These functions, however, always do not provide the best decision alternatives when there are complex and conflicting sets of criteria presents. For instance, in siting a new waste disposal site, the overlay function can be used to combine different factors such as proximity to a road, surface water, and groundwater, or site slope, elevation, and soil type. However, this function does not provide enough analytical support because of the limited capabilities for incorporating decision makers' preferences into the GIS-based decision-making process. Thus, the combination of geographic data and the decision maker's preferences into analysis for better output is required.

As a result, GIS can assist in minimizing value conflicts among conflicting interest parties by giving more and better information, whereas multicriteria decision-making

analysis (MCDA) methodologies can aid in lowering factual disagreements [2]. MCDA is a strategy for assisting decision-makers through the essential process of establishing evaluation criteria and determining relevant values in a choice circumstance. Based on literature MCDA has six components as a primary goal, the decision-maker(s), set of criteria, decision alternatives, decision environment, and outcome. Furthermore, the components of MCDA can be achieved through the steps shown in **Figure 1**. As it is shown in the figure, any spatial decision problem can be structured into three major phases according to [45]; intelligence which examines the existence of a problem or the opportunity for change, design which determines the alternatives, and choice which decides the best alternative. The components and steps of MCDA were discussed in detail by [2, 46, 47].

9.2 Multi-Criteria Decision Aid Methods

According to a recent study aimed to present a literature review of MCDA applications used in SWM, the top five and most commonly used MCDA methods are Analytic Hierarchy Process (AHP), Simple Additive Weighting (SAW), Elimination and choice expressing the reality (ELECTRE), and Preference Ranking Organization Method for Enrichment (PROMETHEE) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). **Table 3** shows the commonly used MCDA
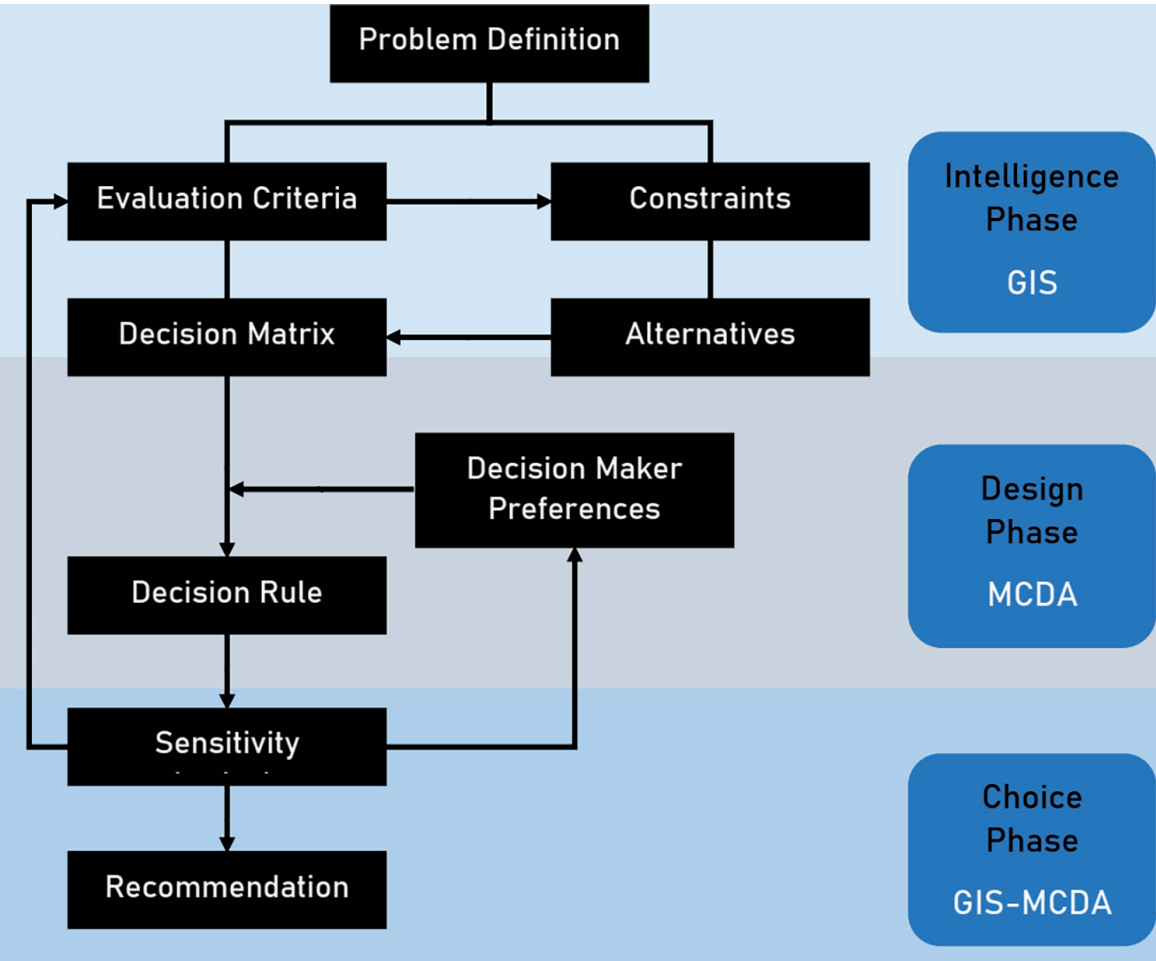

Figure 1.
Framework for spatial multicriteria decision analysis based on [2].

MCDA method	Description	Advantage	Disadvantage
SAW	Value based method Use of measurement of the utility of an alternative	Easy to use and well understandable. Applicable when exact and total information is collected. Well-proven technique. Good performance when compared with more sophisticated methods.	Normalization is required to solve multidimensional problems
AHP	Use of value-based, compensatory, and pairwise comparison approaches. Use of Hierarchical structure to present complex decision problem	Applicable when exact and total information is collected. A decision problem can be fragmented into its smallest elements, making evidence of each criterion applied. Applicable for either single or multiple problems, since it incorporates qualitative and quantitative criteria. Generation of inconsistency index to assure decision-makers	Due to aggregation, compensation between good scores on some criteria and bad scores on other criteria can occur Implementation is quite inconvenient due to the complexity Complex computation is required Time-consuming
TOPSIS	Use of the value-based compensatory method Measures the distances of the alternatives from the ideal solution Selection of the one closest to the ideal solution	Easy to implement the understandable principle Applicable when exact and total information is collected Consideration of both the positive and negative ideal solutions Provision of a well-structured analytical framework for alternatives ranking Use of fuzzy numbers to deal with uncertainty problems	• Normalization is required to solve multidimensional problems
ELECTRE	Use of outranking method Use of pairwise comparison, compensatory Use of indirect method that ranks alternatives utilizing pairwise comparison	Applicable even when there is missing information Applicable even when there are incomparable alternatives Applicable even when the incorporation of uncertainties is required	Time-consuming without using specific software due to complex computational procedure May or may not reach the preferred alternative

MCDA method	Description	Advantage	Disadvantage
PROMETHEE	Use of outranking method, pairwise comparison, and compensatory method Use of positive and negative preference flows for each alternative in the valued outranking Applicable even when simple and efficient information is needed Generation of ranking with decision weights	Applicable even when there is missing information	Time-consuming without using specific software When using many criteria, it becomes difficult for decision-makers to obtain a clear view of the problem

Table 3.
Comparison of MCDA methodologies applied to SWM based on [48].

methodologies in SWM, their description, advantages, and disadvantages of these methodologies.

As mentioned in **Table 3**, we have to understand that each MCDA available has its strength and drawback, and also there is no general rule in adopting one. Therefore, in SWM the decision-maker decides to depend on the criteria and alternatives available. This also depends on the decision-maker's previous experience and the availability of adequate software [47].

9.3 Criteria for SWM planning

As discussed in previous sections, GIS-based MCDA is used to overcome complex and conflicting criteria in SWM. In fact, in MCDA methodology development there are goals and alternatives where decision outputs are made based on the decision-maker preferences. In addition, in sustainable waste management or ISWM, the aim is to reduce waste generation, improve reuse, recycle, and recovery, and otherwise properly manage these wastes. So, without any compromises, there are always environmental, economic, political, and social considerations in ISWM. Due to these facts, ISWM planning has been a challenge for the decision-makers as different criteria are taken into consideration under the specific goal of sustainable solid waste management. For instance, [49] used sixteen criteria for landfill site selection, including topography, urban and rural settlements, highways and village roads, railways, airports, wetlands, pipelines, and power line infrastructure, slope, geology, land use, floodplains, aquifers, and surface water. In general, the criteria used in ISWM planning can be categorized as environmental criteria, political criteria, financial and economic criteria, hydrologic and hydrogeologic criteria, topographical criteria, geological criteria, availability of construction materials, and other criteria as shown in **Figure 2**.
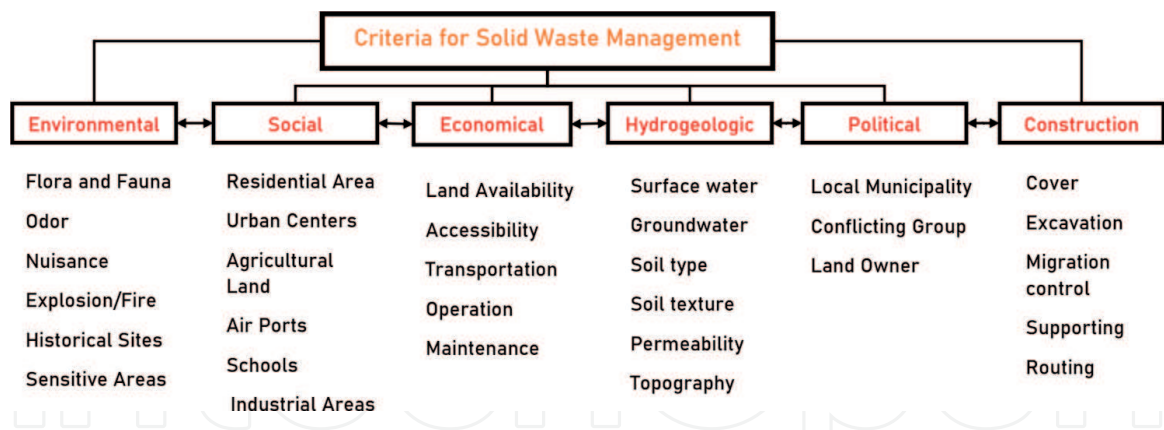
Figure 2.
Criteria used for decision making in SWM.

10. Application of GIS in optimizing solid waste collection

10.1 Routing and waste transportation

Routing in solid waste collection entails planning and specifying routes for trucks to follow during the collection process [50]. When it comes to SWM optimization, routing is crucial. The rate of solid waste collection is frequently determined by the efficiency of transportation in the SWM component. Due to their complicated structures, transportation of solid waste to the final disposal or treatment facility is a major problem in many cities. As a result, more emphasis should be placed on optimizing waste collection routes, as failure to do so would result in exorbitant costs. As a result, defining the routes reduces waste collection costs while delivering the best service to the community. Routing is essentially the process of choosing a path for traffic within a network, as well as between or across various networks. The five basic steps of route planning are as follows, and they are accomplished in GIS utilizing the previously mentioned principles: (a) Identifying the potential location, (b) Identifying the storage capacity and volume to be collected, (c) Grouping the potential locations for a single truck cover, (d) Planning the shortest route between different groups, (e) Choosing the optimum route that is a shorter distance, less traffic volume, and less expensive.

11. Strategies for route optimization

Over time, routing has been applied in varying ways in solid waste management, giving rise to many models and strategies. According to EPA categorization, these models can be divided into macro-routing, districting and route balancing, and micro-routing [51]. The major difference is that macro-routing aims to optimize the use of the waste collection in daily and long-term capacity by minimizing round trip and haul time. While districting and route balancing divide the workload between the workers, micro-routing considers the details of each daily waste collection so that unnecessary truck movements will be reduced [51]. Among the many identified strategies for route optimization, heuristic routing, right turns, onboard computers, and round trips were presented in **Table 4**.

Strategies	Description
Heuristic Routing	Heuristic routing is a system used to describe how deliveries are made when problems in a network topology arise. In heuristic routing, routes should not be fragmented or overlapping
Right Turns	Using only right turn during the collection of solid waste. This helped not only reduce cost by reducing fuel consumption but promoted the safety of drivers.
Computer-based	This allows the collectors to track routes in realtime. It is also GPS-based and every detail of the route is presented.
Dump trips	Scheduling the collection trips for the full containers twice per week. This also involves when the containers are full, they should be taken by the nearby truck.

Table 4.
Strategies to optimize the routing in the solid waste management.

12. High-Density Routing and Point-to-Point Routing

Residential collections are often routed using arc routing or side-of-street routing in high-density routing. This enables the software to arrange automatic collection with two passes on a street segment, as well as a semi-automated collection to serve both sides of a street segment at the same time. Point-to-point routing can be done on a variety of software and web-based platforms. When using point-to-point, the collected side of the roadway is usually ignored. Point-to-point routing can be used to develop commercial routes for solid waste collection as well as for routing calls for services like cart or bin delivery.

13. Waste bin location

For waste to be collected efficiently, proper waste bin allocation and distribution are critical. It simplifies waste sorting, recycling, and transportation at the source. As a result, the second functional element of solid waste management is waste storage at the source. The waste is usually placed in bins on both sides of streets, close to buildings and other sources of waste generation. As a result, due to health concerns, attention should be exercised when storing hazardous material near residential areas. Wastes should also be stripped away regularly. GIS can be used to appropriately place waste storage containers or waste bins so that they are no longer a menace, are evenly distributed among the households, and the cost is decreased.

Several criteria were used to determine where the waste bins should be placed, including proximity to a road and a waste-producing source, land usage, sensitive areas, and so on. Using GIS, the criteria are integrated with the preferences of the decision-makers to obtain optimized waste bin sites using spatial analysis such as buffering. For example, a decision-maker could choose a buffer zone that is 20 meters away from a waste-producing source, 10 meters away from roadways, but 100 meters away from sensitive places such as hospitals, historical sites, and schools. The number of waste bins allocated can also be decided based on the waste generation rate and dispersed evenly. Furthermore, one of the most common strategies for arranging waste bins is using Location-Allocation models to determine the best position. The p-median model is used in several investigations. Because it averages the locations of multiple points, this model decreases the distance and expense of the facility from the source.

14. Application of GIS in waste disposal planning

In waste disposal planning, a geographic information system plays an important role. GIS is used in waste disposal for a variety of reasons, including decision support for locating suitable landfills and temporal monitoring of disposal locations, including landfills. Due to the competing criteria illustrated in **Figure 2**, solid waste landfill siting is a complex and time-consuming operation in the traditional method of SWM. Furthermore, the primary purpose of the landfill site selection procedure is to ensure that the disposal facility is located in the best possible area, with the least amount of detrimental influence on the environment and population. Furthermore, a thorough review process is required to determine the best possible disposal place that complies with government standards while also minimizing costs.

Typically, landfilling is the least preferred method of ISWM according to the waste management hierarchy. But proper management of residue from reuse, recycling, and recovery, as well as the ashes from incineration, is a must. Therefore, the GIS-based MCDA approach is common in landfill site selection analysis. The basics and principles of GIS-based MCDA have been discussed in previous sections, so in this section, an overview of how GIS can be applied to landfill suitability analysis is presented. **Figure 3** depicts the methodology for adopting GIS, MCDA, and waste
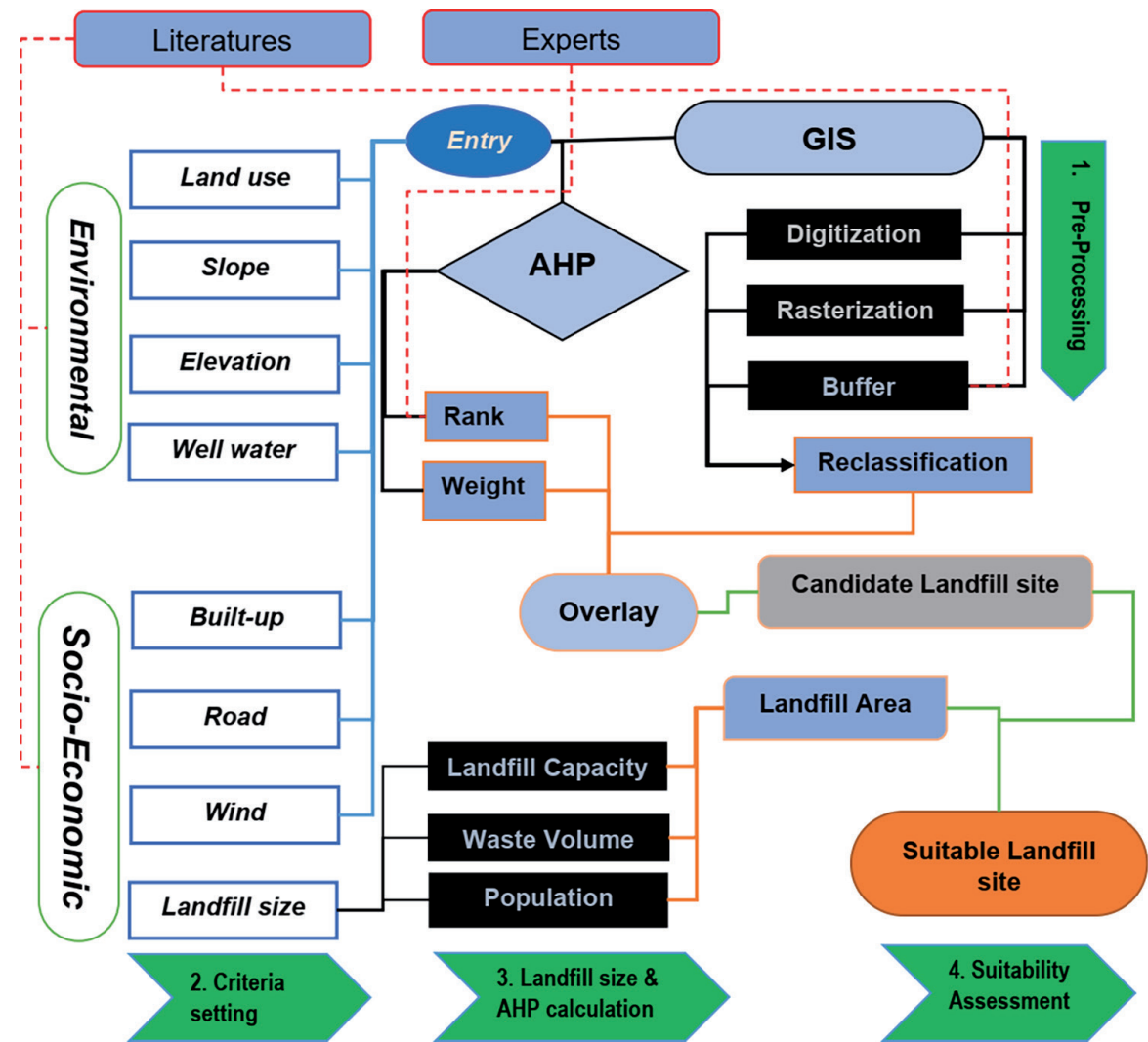

Figure 3.
Framework of the study to select a suitable sanitary landfill site, adopted from [41].

disposal site analysis. Also, as presented in **Figure 2**, the process always starts with setting a goal (suitable landfill site). Then, after defining a set of criteria, GIS functions are combined with decision makers' preferences to produce the final, most suitable landfill site.

15. Conclusion

This chapter deals with the application of geographic information systems to solid waste management. GIS is a powerful tool that can assist in minimizing value conflicts among conflicting interest parties by giving more and better information. Essentially, planning a sustainable waste management approach is complex, tedious, and time-consuming, and decision-makers are frequently subjected to conflicting factors in SWM planning. There is an increasing trend of waste generation worldwide, and the situation is worse in developing countries owing to poor infrastructure, finance, and political reasons. To cope with the high waste generation and different problems in SWM, integrated solid waste management is widely used as a sustainable waste management practice. ISWM is a complex and tedious process to implement. Following the challenges in ISWM, many researchers came up with many innovations, like mathematical modeling and computer-based modeling, to mention a few. GIS is a computer-based spatial analysis method applied to SWM, enabling decision-makers to make better judgments by combining the alternatives and their preferences. In this chapter, the basics, and principles of how GIS works, what multicriteria decision making is, how to apply it to GIS, and the utilization of the GIS-based MCDA method in SWM was discussed. Also, information on how to apply GIS to waste collection optimization (routing and waste bin allocation) and waste disposal planning (landfill) was presented. Furthermore, the key principles of GIS-based MCDA method development were supported with references for further reading. Finally, we hope the readers will get some insights and, with some digging, be able to solve problems with SWM in their area easily.

Conflict of interest

The authors declare no conflict of interest.

Acronyms and abbreviations

GIS   Geographic information system
SWM   Solid waste management
ISWM   Integrated waste management
MCDA   Multicriteria decision making analysis

Author details

Elsai Mati Asefa*, Kefelegn Bayu Barasa and Dechasa Adare Mengistu
Department of Environmental Health, College of Health and Medical Science,
Haramaya University, Harar, Ethiopia

*Address all correspondence to: elsyyymati@gmail.com

IntechOpen

References

[1] UNEP. Guidelines for National Waste Management Strategies: Moving from challenges to opportunities. Nairobi: United Nations Environment Programme. UNEP, Nairobi; 2013

[2] Leake C, Malczewski J. GIS and Multicriteria Decision Analysis. Vol. 51. Hoboken, New Jersey, U.S.: John Wiley & Sons; 1999. p. 247

[3] USEPA. Criteria for the Definition of Solid Waste and Solid and Hazardous Waste Exclusions. In: What is a Solid Waste? US EPA; 2021. pp. 1-12. Available from: https://www.epa.gov/hw/criteria-definition-solid-waste-and-solid-and-hazardous-waste-exclusions

[4] Hoornweg D, Thomas L. What a waste: solid waste management in Asia. The World Bank; 1999

[5] Tchobanoglous G. Solid waste management. In: Environmental Engineering Environmental Health Safety Municipal infrastructure L use planning. New Jersey: Ind Wiley; 2009. pp. 177-307

[6] Tchobanoglous G, Frank K. Handbook of solid waste management. New York: The McGraw-Hill Companies, Inc; 2002

[7] US EPA. What Is Integrated Solid Waste Management? Vol. 6. Washington DC: United States Environmental Protection Agency; 2002. pp. 1-4. Available from: www.epa.gov/globalwarming

[8] McDougall FR, White PR, Franke M, Hindle P. Integrated solid waste management: A life cycle inventory: Second edition. New Jersey: John Wiley & Sons, Inc; 2008. pp. 1-513

[9] ZWIA. How Communities Have Defined Zero Waste | US EPA [Internet]. Washington DC: Zero Waste International Alliance; 2018. Available from: https://www.epa.gov/transforming-waste-tool/how-communities-have-defined-zero-waste

[10] Conserve Energy Future. Sustainable Practices in Waste Management [Internet]. New York: Conserve Energy Future. 2021. Available from: https://www.conserve-energy-future.com/sustainable-practices-waste-management.php#:~:text=Sustainable waste management is a, source of energy and resources

[11] Hussain CM. Concepts of Advanced Zero Waste Tools Present and Emerging Waste Management Practices. Moscow, US: Electronic Green Journal; 2020

[12] Munguía-López A d C, Zavala VM, Santibañez-Aguilar JE, Ponce-Ortega JM. Optimization of municipal solid waste management using a coordinated framework. Waste Management. 2020;**115**:15-24

[13] de Souza V, Melaré A, Montenegro González S, Faceli K, Casadei V. Technologies and decision support systems to aid solid-waste management: a systematic review. Waste Management. 2017;**59**:567-584

[14] Kundariya N, Mohanty SS, Varjani S, Hao Ngo HWC, Wong J, Taherzadeh MJ, et al. A review on integrated approaches for municipal solid waste for environmental and economical relevance: Monitoring tools, technologies, and strategic innovations. Bioresource Technology. 2021;**342**:125982

[15] Sibanda LK, Obange N, Awuor FO. Challenges of Solid Waste Management

in Kisumu, Kenya. Urban Forum. Switzerland: Springer; 2017. pp. 387-402

[16] El-Fadel M, Findikakis AN, Leckie JO. Environmental impacts of solid waste landfilling. Journal of Environmental Management. 1997;**50**(1):1-25

[17] Wang Z, Lv J, Gu F, Yang J, Guo J. Environmental and economic performance of an integrated municipal solid waste treatment: A Chinese case study. Science of Total Environment. 2020;**709**:136096. Available from: https://www.sciencedirect.com/science/ article/pii/S0048969719360929

[18] Gaeta GL, Ghinoi S, Silvestri F, Tassinari M. Innovation in the solid waste management industry: Integrating neoclassical and complexity theory perspectives. Waste Management. 2021;**120**:50-58. Available from: https:// www.sciencedirect.com/science/article/ pii/S0956053X20306255

[19] Hafid HS, Omar FN, Abdul Rahman N, Wakisaka M. Innovative conversion of food waste into biofuel in integrated waste management system. Critical Reviews in Environmental Science and Technology. 2021;**51**:1-40

[20] Colangelo F, Farina I, Travaglioni M, Salzano C, Cioffi R, Petrillo A. Eco-efficient industrial waste recycling for the manufacturing of fibre reinforced innovative geopolymer mortars: Integrated waste management and green product development through LCA. Journal of Cleaner Production. 2021;**312**:127777

[21] Paul K, Chattopadhyay S, Dutta A, Krishna AP, Ray S. A comprehensive optimization model for integrated solid waste management system: A case study. Environmental Engineering Research. 2019;**24**(2):220-237

[22] Anderson LE, Nigam A. A mathematical model for the optimization of a waste management system. Vol. 1. Berkeley, USA: University of California, Sanitary Engineering Research Laboratory SERL Rep.; 1968. p. 68

[23] Fiorucci P, Minciardi R, Robba M, Sacile R. Solid waste management in urban areas: Development and application of a decision support system. Resources, Conservation and Recycling. 2003;**37**(4):301-328

[24] Costi P, Minciardi R, Robba M, Rovatti M, Sacile R. An environmentally sustainable decision model for urban solid waste management. Waste Management. 2004;**24**(3):277-295

[25] Abou Najm M, El-Fadel M. Computer-based interface for an integrated solid waste management optimization model. Environmental Modelling & Software. 2004;**19**(12):1151-1164

[26] Singh A. Remote sensing and GIS applications for municipal waste management. Journal of Environmental Management. 2019;**243**:22-29

[27] Waters N. GIS: History. In: International Encyclopedia of Geography. Vol. 15 Volume Set: People, the Earth, Environment and Technology. New Jersey: John Wiley & Sons, Inc.; 2018. pp. 1-13

[28] Coppock TJ, Rhind WD. The history of GIS. Geographic Information System Vol 1 Princ. 1993;21-43.

[29] McHarg IL. Design With Nature. New York: American Museum of Natural History; 1969. pp. 7-17

[30] By RA d, Huisman O. Principles of geographic information systems. In: TS-WorldCat T4-An introductory

textbook. Vol. 1. Atlanta, Georgia: ITC Educ Textb Ser; 2009. p. 258. Available from: http://www.worldcat.org/oclc/700395896

[31] López AJV, Aguilar Larrucea M, Fernández-Carrión Quero S, Jiménez del Valle A. Optimizing the collection of used paper from small businesses through GIS techniques: The Leganés case (Madrid, Spain). Waste Management. 2008;**28**(2):282-293

[32] Chang N-B, Lu HY, Wei YL. GIS technology for vehicle routing and scheduling in solid waste collection systems. Journal of Environmental Engineering. 1997;**123**(9):901-910

[33] Hina SM, Szmerekovsky J, Lee ES, Amin M, Arooj S. Effective municipal solid waste collection using geospatial information systems for transportation: A case study of two metropolitan cities in Pakistan. Research in Transportation Economics. 2020;**84**:100950

[34] Dao-Tuan A, Nguyen-Thi-Ngoc A, Nguyen-Trong K, Bui-Tuan A, Dinh-Thi-Hai V. Optimizing vehicle routing with path and carbon dioxide emission for municipal solid waste collection in Ha Giang Vietnam. Lect Notes Inst Comput Sci Soc Telecommun Eng LNICST. 2018;**221**:212-227

[35] Vu HL, Ng KTW, Bolingbroke D. Parameter interrelationships in a dual phase GIS-based municipal solid waste collection model. Waste Management. 2018;**78**:258-270

[36] Van Mai C, Nguyen SH, Dao CD, Van LT, Phan HA. A GIS application in optimizing the collection and transportation route of domestic solid waste in Hue city Vietnam. In: Global Changes and Sustainable Development in Asian Emerging Market Economies. Vol. 2. Cham: Springer; 2022. pp. 599-609

[37] Chaudhary S, Nidhi C, Rawal NR. Gis-based model for optimal collection and transportation system for solid waste in allahabad city. Advances in Intelligent Systems and Computing. 2019;**814**:45-65

[38] Chang LYT. Optimal siting of transfer station locations in a metropolitan solid waste management system. Spectroscopy Letters. 1996;**30**(3):601-623

[39] El-Hallaq MA, Mosabeh R. Optimization of municipal solid waste management of bins using GIS. A Case Study: Nuseirat City. Journal of Geographic Information System. 2019;**11**(01):32-43

[40] Muttiah RS, Engel BA, Jones DD. Waste disposal site selection using gis-based simulated annealing. Computational Geosciences. 1996;**22**(9):1013-1017

[41] Asefa EM, Damtew YT, Barasa KB. Landfill site selection using GIS based multicriteria evaluation technique in Harar City, Eastern Ethiopia. Environ Health Insights. 2021;**15**:117

[42] Rahimi S, Hafezalkotob A, Monavari SM, Hafezalkotob A, Rahimi R. Sustainable landfill site selection for municipal solid waste based on a hybrid decision-making approach: Fuzzy group BWM-MULTIMOORA-GIS. Journal of Cleaner Production. 2020;**248**:119186

[43] Rolf A, de By RA. Principles of geographic information systems. Vol. 99. Netherland: Int: Inst Aerosp Surv Earth Sci (ITC) Hengelosestraat; 2001

[44] Aronoff S. Geographic information systems: A management perspective. In: Geographic information systems: A management perspective. Vol. 4. 1989. p. 58

[45] Simon HA. The new science of management decisions. New York: Harper & Row; 1960

[46] Malczewski J, Rinner C. Multicriteria decision analysis in geographic information science. Vol. 1. Switzerland: Springer; 2015

[47] Pires A, Martinho G, Rodrigues S, Gomes MI. Sustainable solid waste collection and management. Switzerland: Springer; 2019

[48] Pires A, Bin CN, Martinho G. An AHP-based fuzzy interval TOPSIS assessment for sustainable expansion of the solid waste management system in Setúbal Peninsula, Portugal. Resources, Conservation and Recycling. 2011;**56**(1):7-21

[49] Sener B, Süzen ML, Doyuran V. Landfill site selection by using geographic information systems. Environmental Geology. 2006;**49**(3):376-388

[50] Sulemana A, Donkor EA, Forkuo EK, Oduro-Kwarteng S. Optimal Routing of Solid Waste Collection Trucks A Review of Methods. Journal of Engineering. 2018;**2018**:56

[51] Shuster KA, Schur DA. Heuristic routing for solid waste collection vehicles. Vol. 45. Washington DC: USA EPA; 1974