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Diverse Applications of Remote Sensing and Geographic Information Systems in Implementing Integrated Solid Waste Management: A Short Review †

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Abstract: The ever-growing global population, combined with the industrial revolution and increased consumerism, has led to an exponential surge in waste generation. The implementation of integrated solid waste management (ISWM) is crucial for addressing the challenges posed by increasing waste generation and limited landfill space. Remote sensing (RS) and Geographic Information Systems (GIS) have emerged as powerful tools to support ISWM strategies through their diverse applications. This short review explores the novel applications of RS and GIS in ISWM and highlights their potential for enhancing waste management practices. RS techniques, such as satellite imagery and aerial photography, enable the accurate mapping and monitoring of waste generation, disposal sites, and recycling facilities. GIS facilitates spatial analysis and decision-making, allowing for optimized waste collection routes, landfill site selection, and the identification of suitable locations for waste-to-energy projects. Furthermore, RS and GIS provide valuable insights into waste composition analysis, landfill stability assessment, and environmental impact evaluation. This review underscores the importance of leveraging RS and GIS technologies to improve waste management practices and offers valuable recommendations for future research in this field.

Keywords: remote sensing; waste management; integrated solid waste collection; optimization

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1. Introduction

Due to the ever-growing population, rising urbanization, industrialization, and changing lifestyles, there is now more waste being produced than ever before [1]. According to recent data, there were 2.24 billion tons of solid waste produced in 2020, and by 2050, that number is expected to rise to 3.88 billion tons [2]. Solid waste is a useless solid material that is produced by human activity in household, industrial, or commercial settings. It is produced either as a byproduct of manufacturing processes or as a result of objects or materials being thrown away after use in the home or commercial sectors [3]. An essential part of urban services is waste management, which covers everything from waste collection at homes, streets, and markets to disposal at landfills [4]. The general goal of an ISWM system is to achieve environmental benefit, economic optimization, and social acceptability. In this method, waste streams, collection methods, treatment methods, and disposal methods are combined. ISWM is a sustainable alternative to SWM in that it focuses on resource usage efficiency by integrating the creation, segregation, transfer, sorting, treatment, recovery, and disposal of waste [1]. The planning of waste collection (segregated waste), reuse and recycling, storage and transfer, transportation (primary/secondary), processing, and disposal all depend on the use of RS, GIS, and GPS [1]. The geospatial technologies used for route optimization, the best route, choosing a dumping site, and gathering trash generation data are GIS, GPS, and RS. GIS are used to identify sites, optimize routes, choose bin locations, and estimate garbage generation. The activities that are available with GPS include vehicle tracking, route planning, driver tracking, and collection monitoring. RS is used to aid in environmental assessment and environmental feature monitoring. This study examines the innovative uses of RS and GIS in ISWM and illustrates how they have the potential to transform waste disposal procedures everywhere. Using GIS and RS technology in solid waste management procedures offers a promising route to efficiency and sustainability. In addition, helpful suggestions for more study in this area will be provided, promoting ongoing waste innovation and the development of RS and GIS technologies in the waste management industry [3].

2. A Comprehensive Framework for ISWM

To effectively manage trash and protect both human and environmental health, a waste management framework known as ISWM combines waste prevention, recycling, recovery, and controlled and monitored disposal [5]. Sustainability in all of its dimensions, including environmental, social, and economic, is ISWM's primary objective. By promoting the reuse and recycling of waste materials, environmental preservation, pollution reduction, and waste generation reduction are all accomplished [6]. It is also important to set targets for waste collection and adopt appropriate approaches when designing new waste management facilities in order to build a sustainable future that balances the needs of the present and safeguards resources for future generations [7]. The flowchart for ISWM is shown in Figure 1.

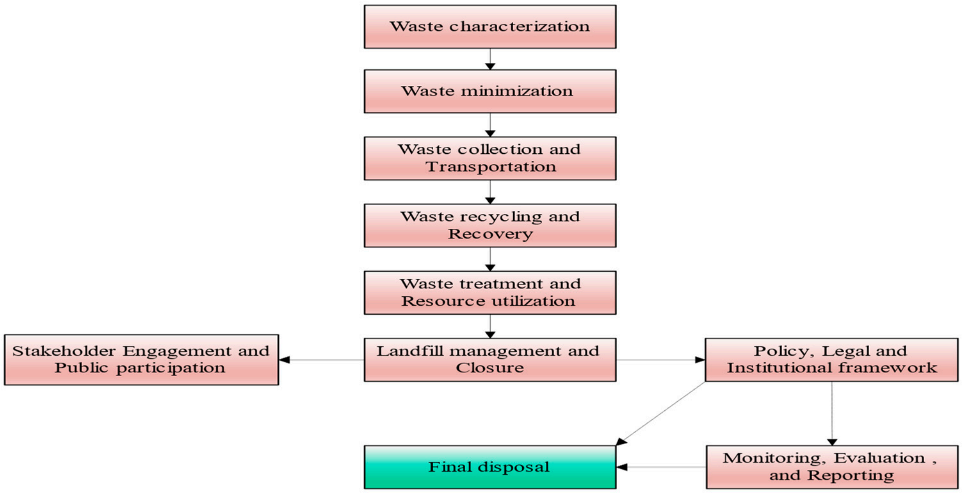

Figure 1. Flowchart for ISWM.

3. Application of RS and GIS in ISWM

RS and GIS play diverse roles in implementing ISWM. RS techniques, like satellite imagery and aerial photography, enable accurate waste generation mapping, monitoring of disposal sites, and recycling facilities [8]. GIS aid in optimizing waste collection routes, selecting landfill sites, and identifying locations for waste-to-energy projects. RS and GIS also provide valuable insights into waste composition analysis, landfill stability assessment, and environmental impact evaluation, enhancing overall waste management efficiency and sustainability [9]. Tables 1 and 2 below highlight the applications of RS and GIS in ISWM respectively.

Table 1. Applications of RS in ISWM [8,10,11].

RS Application	Uses	Data Sources	Technological Advancements	Cost–Benefit Analysis	Advantages	Challenges	Environmental Impact	Future Potential
Waste Generation Mapping	Municipal waste planning; resource allocation for recycling programs.	Satellite imagery; aerial photography.	Enhanced spatial resolution; real-time data acquisition.	Improved waste management costs.	-Enhanced resource allocation—improved hotspot identification.	-Data interpretation complexities—seasonal variations in waste generation.	Reduction in waste hotspots.	Integration with Internet of Things (IoT) for real-time monitoring.
Waste Disposal Site Monitoring	Landfill stability assessment; detection of illegal dumping activities.	Satellite imagery; aerial photography.	Advanced spectral bands; improved image classification algorithms.	Enhanced cost-efficiency in landfill management.	-Early risk detection—environmental impact assessment.	-Frequent data acquisition required—weather-dependent observations.	Reduced environmental risks.	Enhanced integration with unmanned aerial vehicles (UAVs).
Recycling Facility Monitoring	Recycling facility performance assessment; resource allocation for recycling.	Satellite imagery; aerial photography.	Hyper-spectral sensors; enhanced object recognition techniques.	Optimized resource allocation for recycling.	-Enhanced recycling efficiency—resource utilization assessment.	-Facility accessibility challenges—data accuracy and timeliness.	Increased recycling rates.	Real-time monitoring through advanced sensor networks.
Waste Composition Analysis	Resource recovery program optimization; reduction in waste sent to landfills.	Hyperspectral imagery; multispectral data.	AI-based spectral analysis; enhanced data fusion techniques.	Reduced waste in landfills.	-Informed resource recovery strategies—reduction in landfill waste.	-Spectral data processing complexity—limited spectral resolution.	Enhanced recycling rates.	Automated robotic sorting systems for recycling.
Environmental Impact Evaluation	Environmental impact assessments; policy development for sustainable waste management.	Remote sensing data; environmental models.	Enhanced machine learning algorithms; integration with environmental sensors.	Informed investment decisions for sustainable waste management.	-Environmental policy support—Data-driven decision-making.	-Data interpretation subjectivity—temporal data limitations.	Enhanced environmental sustainability.	Real-time environmental impact monitoring for rapid response.

Table 2. Applications of GIS in ISWM [1,8,12,13].

GIS Application	Examples of Use	Data Sources	Technological Advancements	Cost–Benefit Analysis	Advantages	Challenges	Environmental Impact	Future Potential
Waste Collection Route Optimization	Optimal waste collection route planning, Fleet management	Geographic data, traffic data	Real-time traffic data integration; Integration with mobile apps for route optimization.	Lower operational costs.	-Reduced operational costs—improved route planning.	-Data accuracy dependencies—initial setup costs.	Reduced vehicle emissions.	Autonomous waste collection vehicles with AI-driven routing.
Landfill Site Selection	Sustainable landfill site selection, Land use planning	Environmental data, socioeconomic data	Advanced environmental modeling; stakeholder engagement platforms.	Optimized land use and site selection.	-Minimized environmental impact—comprehensive site assessment.	-Regulatory compliance challenges—stakeholder engagement complexities.	Reduced environmental footprint.	AI-driven predictive modeling for site selection.
Waste-to-Energy Project Identification	Site selection for waste-to-energy facilities, Energy resource optimization	Geographic data, energy infrastructure data	Integration with energy grid data; enhanced energy generation modeling.	Enhanced energy production and revenue.	-Energy generation optimization—landfill waste reduction.	-Land use conflicts—technological integration complexities.	Reduced waste sent to landfills.	Advanced waste-to-energy technologies for efficient resource recovery.

3.1. RS Applications in ISWM

The use of RS techniques, such as satellite imagery and aerial photography, enables the accurate mapping and monitoring of waste generation and disposal sites, as well as the recycling of waste. A number of critical aspects of ISWM are assisted by these technologies:

- Waste generation mapping: maps based on satellite imagery and aerial photography enable planning and resource allocation by identifying hotspots and trends in waste generation.
- Waste disposal site monitoring: monitoring waste disposal sites using RS techniques permits detection of changes, assessment of potential environmental impacts, and assessment of landfill stability.
- Recycling facility monitoring: recycling facilities are monitored and assessed with RS, allowing waste diversion efforts to be optimized.
- Waste composition analysis: solid waste composition can be analyzed using RS data to guide resource recovery initiatives.
- Environmental impact evaluation: The RS performs environmental assessments of waste management practices in support of sustainable policy development and decision-making.

3.2. GIS Applications in ISWM

GIS complement RS by facilitating spatial analysis and decision-making in ISWM:

- Waste collection route optimization: GIS-based spatial analysis can help improve waste management efficiency and reduce fuel consumption through the design of optimal waste collection routes.
- Landfill site selection: The use of GIS leads to the identification of appropriate landfill sites based on factors such as environmental, social, and economic factors.
- Waste-to-energy project identification: In addition to maximizing energy recovery, GIS tools identify potential waste-to-energy sites and reduce landfill burden.

4. Overall Contribution of RS and GIS in ISWM

A wide range of aspects of ISWM can be enhanced with RS and GIS. Tables 1 and 2 show the substantial contributions that RS and GIS make to the ISWM framework when combined. The use of satellite imagery and aerial photography are two RS technologies that significantly contribute to waste management (Table 1). The data can be used for the purpose of mapping waste generation, detecting environmental risks early at disposal sites, optimizing recycling facility operations, and advising on resource recovery strategies. In addition, RS fosters data-driven decision-making for sustainable waste management practices through environmental impact assessments. RS is enhanced by GIS applications (Table 2), which provide spatial analysis capabilities that are critical to ISWM. GIS facilitate waste collection route optimization, leading to reduced operational costs and lower emissions. The selection of a sustainable landfill site optimizes land use and minimizes environmental impacts. Furthermore, GIS are vital for identifying suitable waste-to-energy sites, which can reduce landfill waste and increase energy generation. It is not only possible to optimize operations but also to benefit the environment through the integration of RS and GIS technologies. In addition to contributing to reduced environmental risks, improved recycling rates, and a reduction in waste sent to landfills, these technologies also improve the level of environmental sustainability. Low operating costs and informed investment decisions enable them to facilitate cost-effective waste management. In conclusion, the RS and GIS technologies, as shown in Tables 1 and 2, provide a comprehensive solution to the complex challenges posed by the growing number of waste generators and the limited amount of landfill space in the world. ISWM practices are significantly enhanced by their combined contributions in terms of efficiency, sustainability, and environmental impact. ISWM will become more environmentally friendly and cost-effective in the future as these technologies continue to evolve and integrate.

5. Conclusions

GIS and RS have proven invaluable in advancing ISWM strategies. By using these technologies in a variety of ways, we have been able to overcome the challenges posed by growing waste production and limited landfill space. The use of RS techniques, such as satellite imagery and aerial photography, has enabled accurate mapping of waste generation and disposal sites, while GIS has enabled spatial analysis for waste collection route optimization, landfill site selection, and waste-to-energy projects. Additionally, RS and GIS have contributed to waste composition analysis, landfill stability assessment, and environmental impact evaluation. Waste management practices have been significantly enhanced through the combination of RS and GIS technologies. Due to the exponential growth of the world's population, these technologies offer valuable insights and recommendations for future waste management research, which makes them imperative to shaping the future of this field.

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