Implementing a waste management system using IoT: Systematic review

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***Abstract—* Environmental pollution represents a significant global challenge, with adverse effects on human health and ecological systems. Despite the existence of the PIGARS (Provincial Plan for Comprehensive Solid Waste Management), solid waste management in Ica City is inadequate. This results in the accumulation of garbage and the emergence of sanitary problems. The objective of this review article, which was carried out using the PRISMA methodology, is to analyze the various implementations of intelligent waste management systems using IoT's and to evaluate their impact on the efficiency of waste collection and their potential for sustainability depending on where it's implemented. A database search was conducted in Scopus, limiting the results to a maximum of five years old. A total of 23 articles were selected based on a pre-established criteria and classified into four categories: technological innovation, challenges and limitations and route optimization, sustainability. From the analysis it was observed that IoT-based solutions, such as smart containers and optimization of collection routes, can significantly improve efficiency and are sustainable in the long term to be implemented, however, challenges were identified such as initial costs and the necessary infrastructure for cities that do not have a certain level of technology.**

***Keywords—* Smart bin, IoT, PRISMA methodology, waste management, smart systems**

I. Introduction

At present, environmental pollution is a global challenge that affects the health of living beings and causes an imbalance of our ecosystems. Additionally, only 12.45% of the garbage is managed and the rest is poured into landfill, causing soil deterioration, underground water pollution and air pollution. Local urban organisms in our country spend more than 70% of their budget in nicely collecting waste, and the remaining 30% is intended for transportation [1]. This pollution occurs through the introduction of chemical or biological agents from external sources, altering the natural conditions suitable to ensure the well-being of living beings in their ecosystems. Both human-origin pollutants and natural-origin pollutants affect the environment, but the pollutants generated by human activities represent a large threat to According to studies conducted worldwide, the annual generation of solid waste is expected to increase, reaching around 3.40 billion tons by 2050, leading to an approximate cost of $635.5 billion in municipal waste management [2].

In the locality of Ica, there is evidence of poor management of solid waste. This frequently leads to the accumulation of waste at specific points in the city. This occurs for various reasons: the absence of temporary collection points in the city, a recycling culture in emerging stages, and inadequate waste management. This triggers additional problems such as: an increase in pests, areas of biological and chemical risk, environmental contamination, and high costs of urban cleaning operations.

For this issue in the management of solid waste in the Municipality of Ica, there is an interest in offering an effective solution through an intelligent waste management system using IoT. The aim is to use the results of the review to support and substantiate the design and development of the project, leveraging experiences, successful cases, and lessons learned from similar experiences. This document is written with the purpose of establishing a solid and documented basis that supports the proposed solution for the identified problem in waste management in Ica.

The order of this systematic review is structured as follows: in the methodology section, it discusses how the research articles were obtained using PRISMA; in the results section, the results obtained from the analysis of the selected articles will be observed; in the discussion section, the research and proposals of the authors will be presented, followed by the conclusions. Finally, the references used are listed.

II. Methodology

For the present research, the PRISMA methodology (Preferred Reporting Items for Systematic Review and Meta-Analyses) was used, which provides a framework for systematic reviews that allows documenting the reasons for the research, as well as how the studies were found and what was discovered in them. [3, p. 790]. Furthermore, a systematic review is a study and review of the existing literature conducted through specific and planned procedures, with the aim of answering a specific research question [4].

The database used to obtain the articles was Scopus, in which the search terms shown in Table I were used.

TABLE I. Search Terms

Mobile	Platform	IoT
Smart Bin	Solid Waste	Management
Technology	Implementation	Garbage
System	Municipal	Smart Cities

For the process of selecting the keywords to be applied in the equation of the selected articles, the PICOC methodology has been used which is shown in Table II.

TABLE II. RESEARCH QUESTIONS

Code	Questions
Major	What proposals developed using IoT could be implemented to improve solid waste management in the Municipality of Ica?
P	How is the concept of municipal waste management defined?
I	What other solutions with IoT-based waste management platforms have been implemented?
C	How sustainable have the existing proposals been in the long term?
O	How efficient have the implementations of the existing solutions been and what difficulties and limitations have they faced?
C	In what other cities that need to improve solid waste management can this system be implemented?

The search equation used is the following: "waste management" AND (“smart" OR "smart bin”) AND (“IoT" OR "Internet of things”) AND "solid waste" AND “system” AND (“Smart Cities” OR “Municipal System”) with which a total of 117 results were extracted.

In this way, among the results found were: Conference papers, Articles, Journals, Book chapters, and Conference journals, as shown in Figure 1.

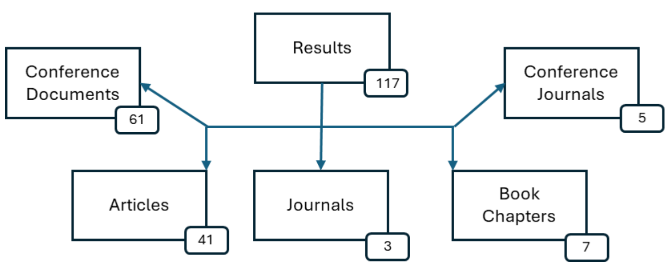

Fig. 1. Results by type of publication.

Regarding exclusion and inclusion criteria, the following were considered as shown in Table III.

TABLE III. EXCLUSION AND INCLUSION CRITERIA

EXCLUSION	INCLUSION
It has no relation to IoT on the management of slide waste. It has no relation to technological implementations in its development. Publications with more than five years of age.	Publications with information on IoTs applied in solid waste management. Publications within the range of the year 2019 to 2024. Articles in the Spanish and English languages.

In the search for publications, an interval of the last five years was established in the Scopus databases, resulting in a total of 98 articles published between 2019 and 2024.

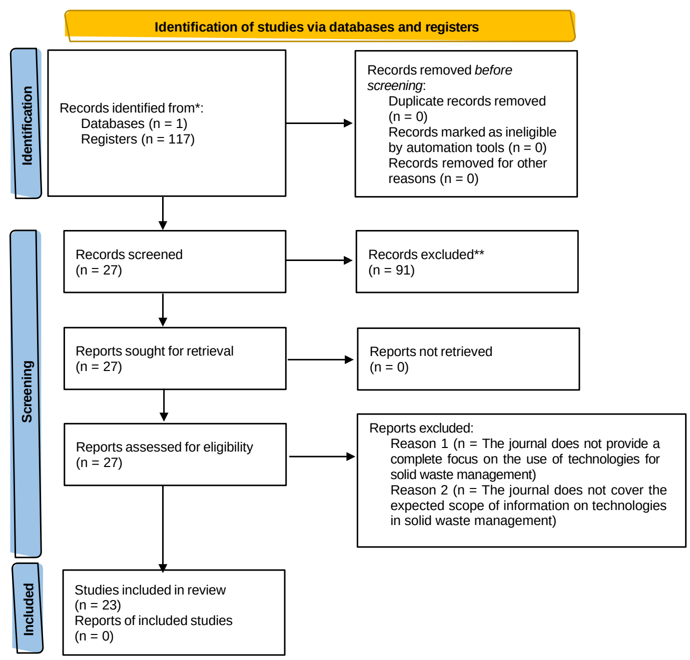

Fig. 2. PRISMA flowchart of the study

III. RESULTS

Based on the analysis of the previous search, 23 articles were obtained. These articles were obtained through research in the Scopus database, achieving a good distribution of topics as shown in Table IV.

TABLE IV. RESULT OF THE SELECTED STUDIES

Nº	Title	Year	Topic
01	Smart Waste Management and Classification Systems Using Cutting Edge Approach	2022	Technological Innovation

Nº	Title	Year	Topic
02	Application of Smart Waste Management Strategies for Sustainable Waste Management	2019	Route Optimization
03	An IoT-based bin level monitoring system for solid waste management	2021	Sustainability
04	Designing an effective two-stage, sustainable, and IoT based waste management system	2022	Challenges and Limits.
05	Sensor-Based Solid Waste Handling Systems: A Survey	2022	Technological Innovation
06	Internet of things enabled smart solid waste management system	2023	Technological Innovation
07	Role of wireless aided technologies in the solid waste management: A comprehensive review	2021	Challenges and Limits.
08	RFID and IoT Enabled Framework to Make Pune City an Eco-friendly Smart City	2023	Technological Innovation
09	Optimal Management of Solid Waste in Smart Cities using Internet of Things	2020	Technological Innovation
10	Internet of things-based urban waste management system for smart cities using a Cuckoo Search Algorithm	2020	Technological Innovation
11	An intelligent waste removal system for smarter communities	2020	Challenges and Limits.
13	IoT cloud-based cyber-physical system for efficient solid waste management in smart cities: A novel cost function-based route optimization technique for waste collection vehicles using dustbin sensors and real-time road traffic informatics	2020	Challenges and Limits.
14	IoT-Enabled Smart Waste Management Systems for Smart Cities: A Systematic Review	2022	Technological Innovation
15	Smart city solutions: Comparative analysis of waste management models in IoT-enabled environments using multiagent simulation	2024	Technological Innovation
16	IoT-Based Smart Waste Bin Monitoring and Municipal Solid Waste Management System for Smart Cities	2020	Technological Innovation
17	IoT-based smart solid waste management system a systematic literature review	2019	Technological Innovation
18	Smart Bin and IoT: A Sustainable Future for Waste Management System in Nigeria	2024	Route Optimization
19	Smart waste management paradigm in perspective of IoT and forecasting models	2022	Challenges and Limits.
20	A sustainable smart IoT-based solid waste management system	2024	Technological Innovation
21	IoT-enabled solid waste management in smart cities	2021	Technological Innovation
22	Smart waste management using internet-of-things (IoT)	2019	Technological Innovation
23	Smart Solid Waste Management System Using IOT	2019	Technological Innovation

A greater amount is evidenced in 2020 and 2022 (see Figure 3), coinciding with the beginning and end of the contingency of Covid-19. It is important to highlight that none of the revised articles explicitly mentions the pandemic as a cause or factor related to the production of these works. The management of slide waste is a persistent problem that has existed since many years, which reinforces that contingency is not a relevant point to highlight in the origin of the articles investigated. Therefore, a direct relationship cannot be established between the contingency of Covid-19 and the increase in the number of publications during these years.

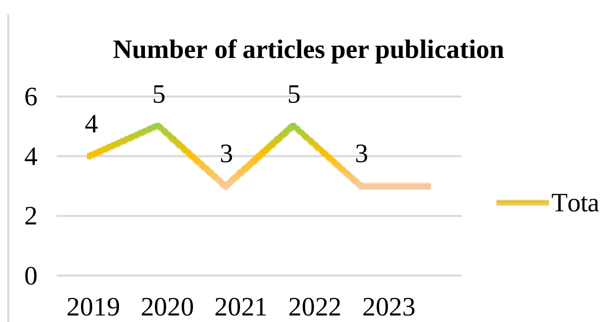

Fig. 3. Number of articles for publication.

The articles that demonstrate having a greater amount are on Technological Innovation and Challenges and Limitations respectively with 14 and 5 articles (see figure 4). Having this large number of articles on these topics evidence that the previous analysis is correct regarding innovations with technologies such as IoT, Geospatial, GIS, RFID, and what are the challenges and limitations they present, such as costs, infrastructure, integration, and testing.

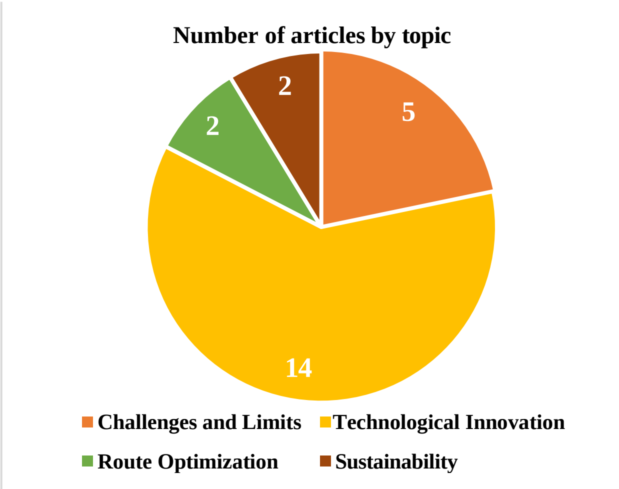

Fig. 4. Number of items per topic

The analysis with the VOS viewer software used the abstract and the title of the selected articles to find the keywords related to the various articles, resulting in clusters (figure 5).

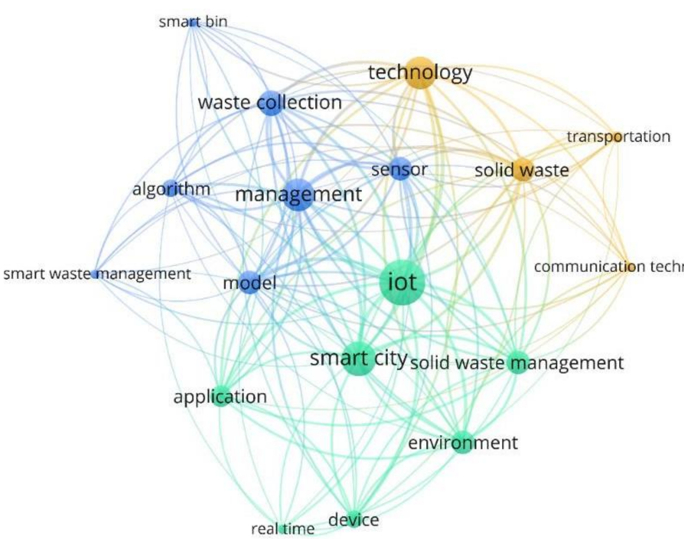

Fig. 5. Word network visualization

The words were grouped into 3 clusters: IoT technology (green), garbage collection (blue), and communication (yellow).

The key words that appear most frequently in the selected articles can be seen in the keyword cloud (figure 6), these are "waste", "smart", "management system" in order from most to least, additionally, words like "algorithm", "monitoring", and "intelligent", among others, can be observed.

Fig. 6. Keyword cloud

In this section, the research questions will be answered based on what was found in the analyzed articles.

P1. How is the concept of municipal waste management defined?

According to the researched articles, they agree that municipal waste management is the collection, transportation, and disposal of waste to minimize harmful effects on the environment and humans [5], [6], [7], [8], [9], [10]. Furthermore, this is necessary to achieve sustainable metropolitan development [7]. These agreements in the definition are expanded in Table V.

TABLE V. RESULTS THAT ANSWER THE QUESTION 1

Keyword	Result
Storage	Various methods of garbage storage are used, the most highlighted among all articles are smart garbage containers, which allow to calculate and send in real time through non-human data transmission solutions information about their capacity, filling, location, among others.
Collection and transportation.	The collection and transportation of garbage is always carried out by collection trucks. In the articles, the implementation of algorithms and technologies is mentioned to optimize the collection routes, with the aim of reducing costs and increasing the efficiency and speed of the process.

P2. What other solutions with IoT-based waste management technologies have been implemented?

It has demonstrated the use of Geospatial technologies such as GIS, GPS, and remote sensors; also, non-human data acquisition technologies such as ultrasonic, optic, infrared and marine sensors; technologies such as long-range and short-range non-human data communication such as Zigbee, Bluetooth, Wi-Fi, NB-IOT, Sigfox, GSM/GPRS and LoRa; and the emerging use of the Blockchain [5] In addition, these technologies were applied with the use of microcontrollers such as R5f100LEA, Atmega 328P, Arduino Uno, Raspberry Pi, WEMOS, SAM L21 and independent chips [5].

These technologies are used to create more specific solutions such as:

Smart containers: Smart containers are an IoT solution that is widely mentioned, a smart bin is described as a garbage container that uses sensors to detect its fill level. On the other hand, to send this information, various wireless technologies mentioned earlier are used, and this information is sent to cloud or on-premises servers that allow processing of this data and making informed decisions.

Routes of collection: Another of the most treated points in the revised articles is the way in which the emptying of the smart containers that are full will be carried out, the most appropriate route to be able to carry out this process in the most efficient way and that can reduce costs and time, generally, to be able to trace these routes are used known and/or proprietary algorithms, can be used in combination or in solitary, the data used always tend to be in real time about the state of the containers and even traffic.

Centralized servers: The data obtained in real-time from the containers or other devices is sent to a server in the cloud or on-premises to facilitate processing, sharing, and real-time monitoring, this is to make decisions for optimized routes, apply algorithms, among others.

P3. How sustainable were the existing long-term proposals?

By using the technologies shown in the articles it can be achieved that there is sustainability, since, in the articles analyzed it can be observed that the proposals showed an improvement in the time of collection of garbage, this allows to reduce the environmental impact. Using third-party technologies such as SensoNeo this reduction was much greater [11]. These reductions in the use of resources and costs allow governments to use this money in improving these proposals generating more sustainability.

P4. How efficient have the implementations of existing solutions been and what difficulties and limitations have they encountered?

Efficiency: In the analyzed articles, it was found that the implementations have been efficient enough to be considered for use; this is possible in cities that are considered "Smart Cities." This term means that a city can utilize IoT technology and other emerging technologies to provide its citizens with a better quality of life [12]. However, in cities that are not considered "Smart Cities," it is possible to encounter quite considerable difficulties, as explained in the following point.

Difficulties and limitations: Based on several articles, difficulties emerge from a city's ability to implement the necessary technologies and infrastructure to operationalize these solutions for solid waste management. This is due to the high initial costs. required to implement IoT technologies, adapt existing systems, among others.

P5. In which other cities that need to improve solid waste management can this system be implemented?

In the first place is India with 10 articles, followed by Saudi Arabia with 2 articles and the other countries with 1 article each (Figure 7).

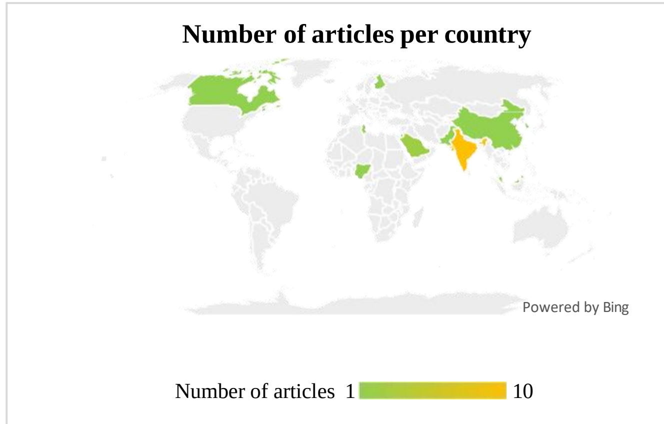

Fig. 7. Number of articles per country

From this figure, it is analyzed that India is the country that has produced the most of these articles to solve a growing problem, which is the rapid population growth; this brings with it an increase in waste generation, as well as to cities that already have a high population density.

Based on the questions answered, the main question can be answered.

P6. What proposals developed using IoT could be implemented to improve solid waste management in the Municipality of Ica?

The management of solid waste, as has been evidenced, is a critical challenge in growing urban areas. The implementation of IoT technologies offers an innovative solution to improve the efficiency and sustainability of waste management systems. That is why the adoption of IoT platforms is proposed in the Municipality of Ica, Peru; to monitor in real-time the fill levels of containers, optimize collection routes, and reduce operational costs.

Real-time container monitoring: The integration of ultrasonic sensors and IoT technologies into garbage containers enables continuous monitoring of filling levels. This facilitates a fast and efficient response, avoiding container overflow handling a clean urban environment.[6].

Optimization of Collection Routes: Using real-time data on the filling of containers, optimal routes can be planned for collection trucks, minimizing the distance traveled and operational time. This not only reduces fuel and maintenance costs but also decreases greenhouse gas emissions [14]. For example, "the optimal route planning for selective waste collection in smart cities has shown a significant reduction in operating costs and CO2 emissions" [15].

Data analysis and prediction of waste generation patterns: The implementation of data analysis tools allows us to identify patterns in waste generation, facilitating long-term planning and resource allocation. “Sensor data analysis can provide valuable information to predict peak waste generation and adjust collection operations accordingly” [11].

DISCUSSION

In this review article, the difference in time spent on waste collection using traditional methods averaged 55 minutes with a 72% success rate in finding full containers compared to the use of technologies where a decrease of more than 67.2% was observed, resulting in an average of 18 minutes with an 89% success rate in finding full containers [6]. This difference clearly represents how the use of IoT technologies contributes to more efficient and effective collection.

Furthermore, it was also found that when talking about IoT technologies, there is a significant variance when only these technologies are used without the integration of algorithms that reinforce these technologies, where the difference is recognized in the average collection time and efficiency, as applying specialized algorithms shows a reduction to an average of 15 minutes and an effectiveness of 98.4% [16]. It was also found that the technique of periodically checking containers has a higher rate of finding them full, being 3.2 per day compared to when IoT is used, which has a rate of 2.16 per day; however, using technology results in a shorter collection time while traditional methods, despite having a higher rate, have much longer times, which are associated with extra costs.

In this regard, it is evident that when technologies are used, the distance traveled is less than when using traditional techniques, being 413.7 km using IoT and 593.4 km in a traditional manner [17]. This can be applied to the district of Ica, which has an area of 887.51 km, where the proportion of the distance traveled using IoT technologies (413.7 km) relative to the area of the district of Ica is approximately 2.15, and if we consider that the travel time per area is 15 minutes applied to 413.7 km, it can be estimated that the time per route is about 32 minutes, compared to over an hour as would be the case using traditional methods in Ica [17], [18].

Likewise, considering the annual expenditures of S/. 695,402.10, the implementation of IoT technologies could translate into a significant reduction in these costs, relating the success of finding full containers, which would be 72% using traditional methods, giving us a cost of S/. 9,658.36 for every 1% of success, in contrast to the use of IoT technologies with an 89% success rate estimated at S/. 7,814.63, and applying algorithms increasing this success rate to 98.4% where there would be a saving of S/. 7,068.93 concerning the current solid waste management expenditure in just the district of Ica [6], [16], [18].

IV. CONCLUSION

In conclusion, in this systematic review of the literature, in which 23 articles were reviewed and analyzed following the PRISMA methodology, an analysis of the effectiveness and sustainability of using IoT technology for solid waste management was carried out.

The solutions that were observed were based on smart containers, optimized collection routes with algorithms, and technological infrastructures, which proved to be efficient if implemented correctly. By monitoring the fill status of the containers in real time using sensors, it becomes possible to employ route optimization algorithms for timely and efficient collection, and furthermore, this reduces operational costs and greenhouse gas emissions. Likewise, the mentioned advantages make this solution sustainable in the long term due to the reduction in resource use, resulting in governments being able to allocate funds to other areas.

However, despite the various benefits, significant challenges were identified for the implementation of these technologies in cities that do not have a certain level of technological infrastructure, or in other words, cities that are not considered 'Smart Cities'. This is because the initial costs and the need to adapt existing (or non-existent) systems represent significant barriers. Furthermore, the integration of advanced technologies such as IoT requires an appropriate regulatory and logistical framework to ensure their effectiveness and sustainability, which becomes more complicated to implement in cities that do not have an initial infrastructure.

In the context of the city of Ica, where solid waste management is currently inadequate, the adoption of IoT platforms could offer a viable and effective solution. However, the city of Ica does not have the appropriate infrastructure for the implementation of these solutions; the investment needed for the adoption of such platforms is justified by the benefits of optimizing routes by changing the current collection model to one based on algorithms that analyze waste generation patterns. Likewise, technological advances allow us to have access to a wide use of mobile devices and websites, which will enable us to overcome existing limitations.

Finally, it is anticipated that these technologies will continue to improve over time, allowing more cities to adopt them and advance towards the transformation into “Smart Cities,” improving the quality of life for citizens, and establishing the use of IoT as a paradigm in urban innovation.

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