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Analysis of Urban Waste Management Using System Dynamics Approach

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ABSTRACT

Nowadays, the increase in waste generated by citizens and its consequences, including environmental pollution, human and animal health endangerment, and depletion of natural resources, have become fundamental issues and challenges in Isfahan. The research proposes a comprehensive and systemic model to offer effective solutions for reducing waste volume by applying a system dynamics approach within Isfahan. In order to achieve this objective, the study first identified and localized the influencing factors on waste generation within the city by reviewing pertinent literature and research background, as well as consulting experts and officials from Isfahan. Subsequently, the relationships between these factors were delineated using insights from 32 experts and officials from Isfahan, who were selected through a snowball sampling. A causal loop diagram was constructed based on the identified relationships among factors affecting waste generation. Moreover, a stock-and-flow diagram was developed based on information extracted from municipal records of the identified variables' quantities and values. The results of this study demonstrate the significance of investing in waste collection equipment and advertising to raise citizens' awareness and reduce waste production in Isfahan. These efforts play a crucial role in decreasing the overall volume of urban waste. Moreover, they contribute to the saving and sustainability of resources while enhancing the city's beauty, ultimately attracting more tourists.

Keywords

Urban waste management, System dynamics, Urban waste, Isfahan municipality.

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1. Introduction

The focus on environmental protection and the conservation of natural resources has become a societal responsibility across all communities (Beyene et al., 2018; Zhang et al., 2023). In addition to the depletion of existing natural resources, the excessive utilization of these resources has not only disrupted biological and natural cycles (Smol et al., 2020) but has also had an impact on human life by causing various forms of pollution (Hosseinalizadeh et al., 2021). Over the past two decades, global consumption of products and natural resources has been rapidly increasing (Crutchik et al., 2023), leading to a significant rise in waste generation by humans and raising significant concerns about environmental degradation and human health (Sarigiannis et al., 2021).

In the past decade, urban waste management has emerged as a focal point that has garnered the attention of numerous researchers (Arifin et al., 2021; Qu et al., 2022). Urban waste management encompasses crucial aspects such as production, collection, transportation, recycling, and disposal of waste generated in urban areas (Das et al., 2019). Urban waste refers to the refuse and discarded materials individuals produce daily (Nanda and Berruti, 2020). In other words, urban waste encompasses waste originating from domestic, commercial, and construction activities conducted by humans (Xiao et al., 2020), collected by municipal authorities, and potentially recycled or reused (Karak et al., 2012). Currently, cities are grappling with the increasing volume of waste and urban waste, which puts significant pressure on waste disposal capacities and the environment (Jaligot and Chenal, 2018; Magazzino et al., 2020). Urban waste has become a critical concern in developing nations (Yao et al., 2019). Population growth is one of the factors driving the rise in urban waste production (Triassi et al., 2023). The urban population in developing countries is rapidly expanding, making urban waste one of the foremost challenges (Sharma and Jain, 2020). Among other factors contributing to increased waste production in urban areas, we can mention the need for more awareness among citizens about the importance of proper waste management, neglecting recycling materials, and disposing of them in nature (Zhang et al., 2010).

Neglecting the factors influencing waste collection and urban waste management can result in hazardous substances permeating communities, triggering explosions, and endangering human health and the environment (Ali et al., 2014). Moreover, disregarding waste and urban waste management can lead to resource depletion (Liu et al., 2015), hinder sustainable urban growth (Golroudbary and Zahraee, 2015), diminish the city's appeal to tourists (Pinha & Sagawa, 2020), and more.

Nowadays, waste and urban waste management are significant challenges in the country's major cities, such as Isfahan. Over recent years, waste generation has surged due to the population increase in Isfahan, negatively impacting the city's appearance and cleanliness. The growing waste production has also contributed to environmental pollution, leading to dissatisfaction among Isfahan's residents. Furthermore, the surge in waste production has resulted in the loss of valuable natural resources that could be conserved through recycling, ensuring their availability for future generations.

Due to the significance of urban waste and its impact on societal health, citizen satisfaction, the aesthetics of the city, and more, numerous studies have been undertaken in this field by researchers in recent years. These studies encompass a range of topics in urban waste management, including waste generation (Zanjani et al., 2012), identification and categorization of urban waste, waste segregation (Wang and Yu, 2021), methods and processes related to disposal and incineration (Magnanelli et al., 2020) and the role of urban waste management in preserving and sustaining resources and energy (Zhang et al., 2023). Additionally, attention has been given to the role of advanced technologies in waste volume reduction and proper management, among other areas. While most of these studies have focused on waste classification, recycling, and effective urban waste management outcomes, more have yet to concentrate on proposing viable solutions for reducing waste production and its associated consequences. Recognizing the existing research gap and the growing issue of increasing waste volumes in Isfahan, this research aims to present a systematic and comprehensive approach. It employs a system dynamics model to predict urban waste quantities and devise suitable waste volume reduction solutions, promoting and enhancing sustainable urban development and resource conservation.

2. Literature review

Urban waste inevitably impacts societies and nations, particularly in achieving environmentally sustainable lifestyles (Przydatek, 2020). Introducing effective waste management methods encompassing collection, recycling, and proper disposal is not only necessary but also vital (Tsoulfas and Pappis, 2006). Urban solid waste poses a significant environmental challenge within urban regions (Batool and Ch, 2009). Improper waste management releases greenhouse gases into the atmosphere (Rai et al., 2019) and impedes maintaining clean and aesthetically pleasing cities (Ferronato and Torretta, 2019). Mismanagement of waste and urban refuse contaminates soil, water, and air (Koda et al., 2016), potentially adversely impacting public

health (Seo et al., 2004).

Moreover, activities related to waste and urban refuse management, such as incineration (Boldrin et al., 2009) and landfilling (Figueroa et al., 2009), release greenhouse gases, including methane, nitrogen oxide, and carbon dioxide into the atmosphere (Mohareb et al., 2008). Additionally, uncontrolled waste accumulation can obstruct drainage systems (Rowe et al., 2000), contributing to flooding and waste entry into urban water bodies (Pervin et al., 2020). Municipal waste management poses a significant challenge for local authorities (Yukalang et al., 2018) owing to the exponential growth in waste volume alongside urban population expansion (Jha et al., 2013).

Triassi et al. (2023) conducted a study to assess residual solid waste composition in rural and urban areas to optimize the waste management system. The study revealed that the highest proportion of organic waste was found in rural areas, accounting for 11.9%. Additionally, the study results indicated that plastic and paper collectively constitute approximately 50% of urban waste in Italy. The study conducted by Moreno Solaz et al. (2023) focuses on prioritizing action plans to achieve better resource savings and improved performance of key indicators in urban solid waste management. The research aims to identify and evaluate effective measures for properly managing urban waste, particularly to optimize financial resources. In a study, Mariyam et al. (2022) conducted a systematic review to enhance the waste management system in Qatar. The research findings revealed that food, plastic, and electronic waste constitute the primary types of waste generated in the country.

Furthermore, the study demonstrated that the attention and support of managers, as well as the awareness of employees regarding waste management processes and methods, significantly contribute to the reduction of waste production. In a study, Ferronato et al. (2021) evaluated urban solid waste collection in Bolivia to prevent unregulated disposal and enhance recycling efforts. The model outcomes could reduce household waste collection costs and capitalize on the economic and environmental advantages of recycling. Afshar et al. (2021) analyzed factors influencing social engagement in urban waste management. The findings highlighted the paramount importance of social, economic, educational, and cultural aspects and legal frameworks. Among social factors, lifestyle, and dietary patterns were of great significance. Valizadeh (2020) presented a mathematical model for waste collection and energy generation in Kermanshah. The proposed model minimizes costs and optimizes revenue through recycled materials and energy production. Bányai et al. (2019) explored urban waste routing optimization and the influence of Industry 4.0 technologies on environmental awareness and sustainability. This research aimed to allocate waste resources optimally to waste trucks,

minimizing operational costs and enhancing reliability. Ogundele et al. (2018) investigated the effects of urban waste disposal methods on community health, revealing that improper management leads to health issues such as skin infections, sore throats, abdominal pain, and typhoid. Nnaji (2015) assessed municipal solid waste production and disposal in Nigeria, showing that food waste constitutes around 50% of municipal waste. This study highlighted the rising trend in plastic, waterproof materials, and diaper waste. Due to inefficient waste management authorities, many cities grapple with open waste dumping, with over 50% of people in parts of Nigeria resorting to free waste disposal. This indiscriminate disposal has resulted in the prevalence of toxic heavy metals in agricultural soils, leading to bioaccumulation in plants and groundwater pollution.

3. Research method

This study adopts a descriptive-causal approach for its applied purpose and employs a survey method for data collection. The study's statistical population consists of experts and administrators of Isfahan Municipality, selected through the snowball sampling method, totalling 32 individuals. Information and documents available within Isfahan Municipality related to various investigated variables have been utilized to gather the necessary data.

In tackling issues concerning urban waste volume, this study employs the system dynamics approach. System dynamics was introduced by J. Wright Forrester in 1960 to address industrial challenges (Forrester, 1961). It is valuable in addressing linear and nonlinear interactions within large-scale, intricate, and dynamic systems (Kollikkathara et al., 2010). The system dynamics model comprehensively analyzes the structure, interactions, and behavior of complex systems, evaluating and forecasting their effects in an integrated manner (Jung, 2017). System dynamics aims to identify system variables and their temporal interplay (Wolstenholme, 1990). This approach adeptly handles the configuration assumptions and dynamic structures of systems, enabling the management of changes within subsystems and interrelationships across the complete system (Sukholthaman and Sharp, 2016).

System dynamics is a technique for analyzing intricate systems over time, facilitated by computer simulation software (Richardson and Otto, 2008a). Variables are perceived as system components interconnected through mathematical mappings established by differential equations, which are numerically solved via simulation (Kunc, 2017). The process of this research is outlined in Figure 1.

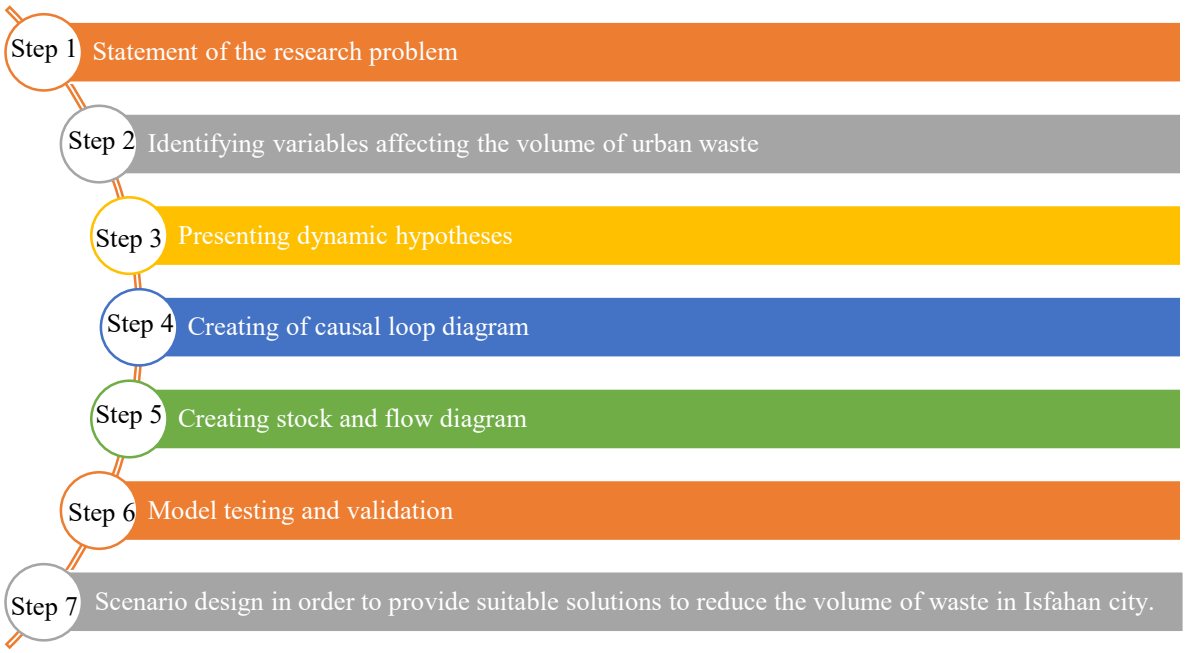

Figure 1. Research implementation steps

As shown in Figure 1, the research began by identifying the variables influencing the quantity of waste and urban refuse. These variables were identified based on existing studies in the field. Next, dynamic hypotheses were formulated grounded in the relationships established within the research context. Dynamic hypotheses represent robust theories that explain the causes and mechanisms underlying observed behaviors. After defining the dynamic hypotheses, the model's boundary diagram is designed. A model boundary diagram delineates the model's scope by listing the indigenous and exogenous variables and variables that are not included in the model. Next, a causal loop diagram was constructed, encompassing the identified variables. This diagram serves as a fundamental tool for illustrating the feedback structure of the system. It aids in formulating both system dynamic models and the mental models of developers (Sterman, 2000). Each causal link within the diagram is attributed to either a positive or negative sign. A positive sign signifies that the variables' changes align in the same direction, while a negative sign indicates opposing changes (Yao et al., 2018). After constructing the causal loop diagram, the stock and flow diagram is utilized to formulate relationships between the variables under study. It enables the examination of the system's behavior over time. Ultimately, the constructed stock and flow diagram has been evaluated through various tests, and different scenarios have been explored to investigate ways of reducing waste in the city of Isfahan.

4. The proposed model

Combining insights from research literature and input from experts and managers in Isfahan Municipality, the interrelationships among the identified variables were explored, constructing a cause-and-effect diagram.

4.1. Dynamic hypothesis

The dynamic hypothesis is a conceptual model proposed by the researcher based on the key variables of the problem. It involves drawing basic reinforcing and balancing loops using the main variables, facilitating reasoning and knowledge extraction from the expanded model. The dynamic hypothesis serves as a crucial starting point for model conceptualization. One of the main advantages of the dynamic hypothesis is that it enhances readers' understanding of the model's complexity. The verbal description of the dynamic hypothesis for this problem, using signals H1 through H5, is as follows:

H1: Investment in waste collection has a positive impact on waste collection performance.
H2: Waste collection performance has an impact on the volume of waste.
H3: Volume of waste has an impact on saving resources.
H4: Save resources have an impact on sustainable urban growth.
H5: Sustainable urban growth has an impact on the beauty of the city.
The dynamic hypothesis of the problem under study is depicted in Figure 2 below.

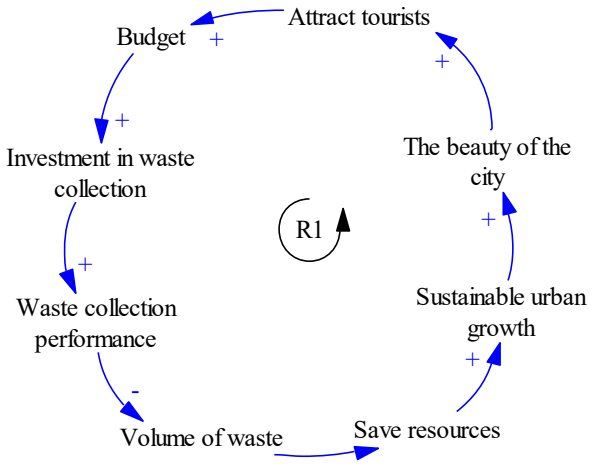

Figure 2. The feedback loop

As depicted in Figure 2, a positive feedback loop has been established. The efficiency of waste collection is enhanced through the allocation of funds for investments in waste collection, including procuring equipment, transportation means, hiring personnel, and covering salaries. The heightened performance in waste collection leads to a reduction in the volume of waste within Isfahan. Consequently, the conservation of resources and their efficient utilization is

promoted. As resources are preserved and managed efficiently, the prospects of sustainable growth and resource availability for future generations are amplified. Furthermore, preserving the city's aesthetic appeal is upheld due to reduced pollution safeguarding recreational and historical sites from damage. The improved attractiveness and beauty of Isfahan foster increased tourist engagement, ultimately contributing to an augmented budget for Isfahan.

4.2. System's boundary diagram

After analyzing the dynamic hypotheses, these have proceeded to create the boundary diagram of the model and identify the indigenous and exogenous variables. The findings of this examination are summarized in Table 1.

Table 1. Classification of factors into indigenous and exogenous factors

NO	Factors		References
1	Indigenous factors	Volume of waste	(Fadda et al., 2018; Kumar et al., 2017)
2		Waste production	(Leal Filhoet al., 2016; Sufian and Bala, 2007)
3		Waste collection equipment	(Mbina and Edem, 2015)
4		Environmental pollution	(Chen et al., 2010; Mian et al., 2017; Tirkolaee et al., 2020)
5		Population	(Kumar and Agrawal, 2020)
6		Quality of Life	(Zorpas, 2020)
7		Investment in waste collection	(Jouhara et al., 2017; Vassanadumrongdee and Kittipongvises, 2018)
8		Advertising	(Romano et al., 2022; Xiao et al., 2017)
9		People's awareness	(Almulhim, 2022)
10		Budget	(Anuardo et al., 2022)
11		Attract tourists	(Anuardo et al., 2022; Ridho et al., 2023)
12		The beauty of the city	(Fidowaty et al., 2022)
13		Sustainable urban growth	(Abubakar et al., 2022; Chen et al., 2022)
14		General health	(Adeniran and Shakantu, 2022)
15		Citizen satisfaction	(Corrente et al., 2023)
16		Save resources	(Nelles et al., 2016; Tutunchian and Altınbaş, 2023)
17	Exogenous factors	Citizen cooperation	(Rodić and Wilson, 2017)
18		Citizen culture	(Almasi et al., 2019; Rodić and Wilson, 2017)

4.3. Causal loop diagram

According to the determination of dynamic hypotheses and the identification of indigenous and exogenous variables of the model, the causal loop diagram is shown in Figure 3.

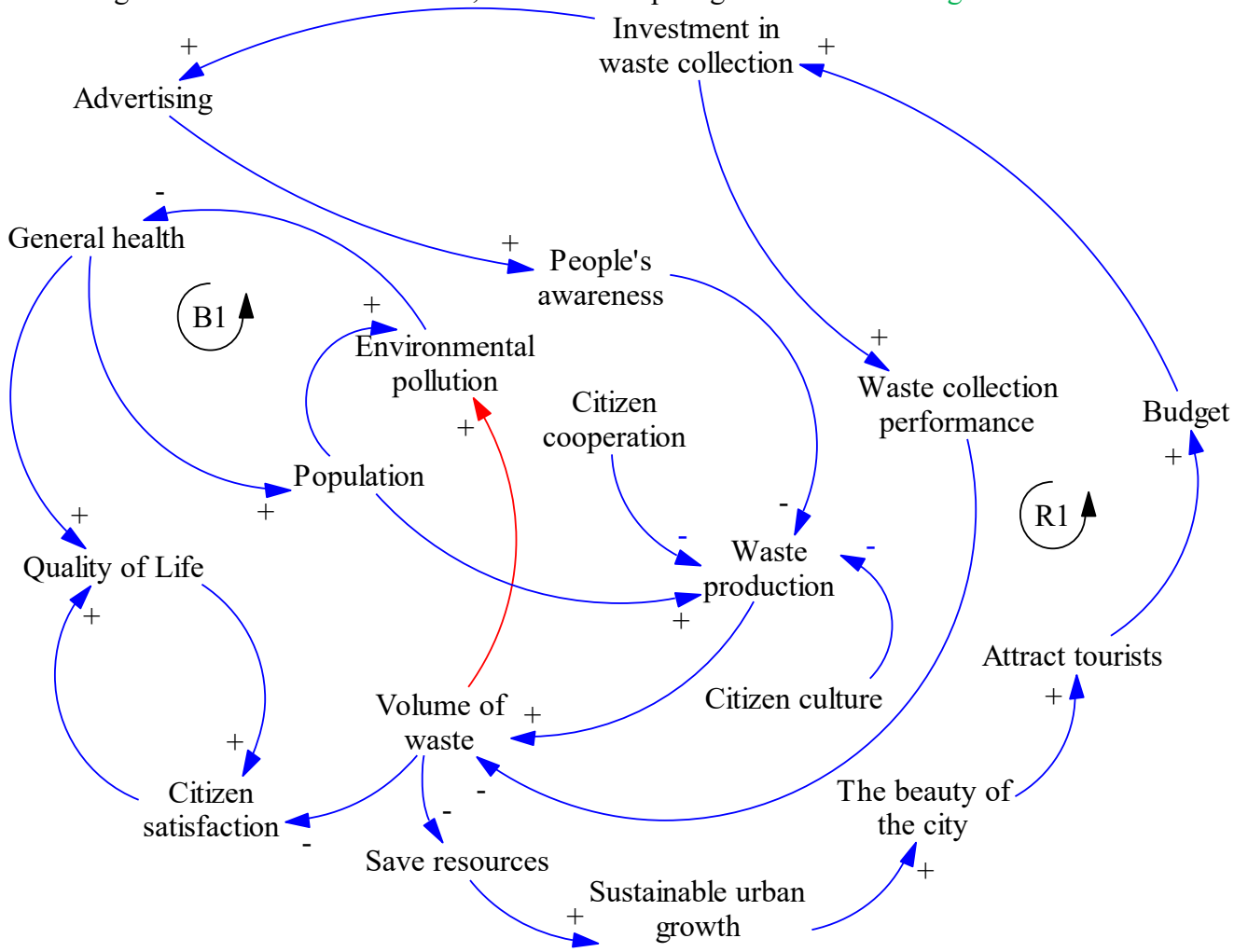

Figure 3. Causal loop diagram

4.4. Stock and flow diagram

After creating the causal loop diagram, the stock and flow diagram has developed by establishing relationships and mathematical equations among the variables under investigation. In the appendix, we outline several key relationships among variables in the current research. In Figure 4, the stock and flow diagram are drawn.

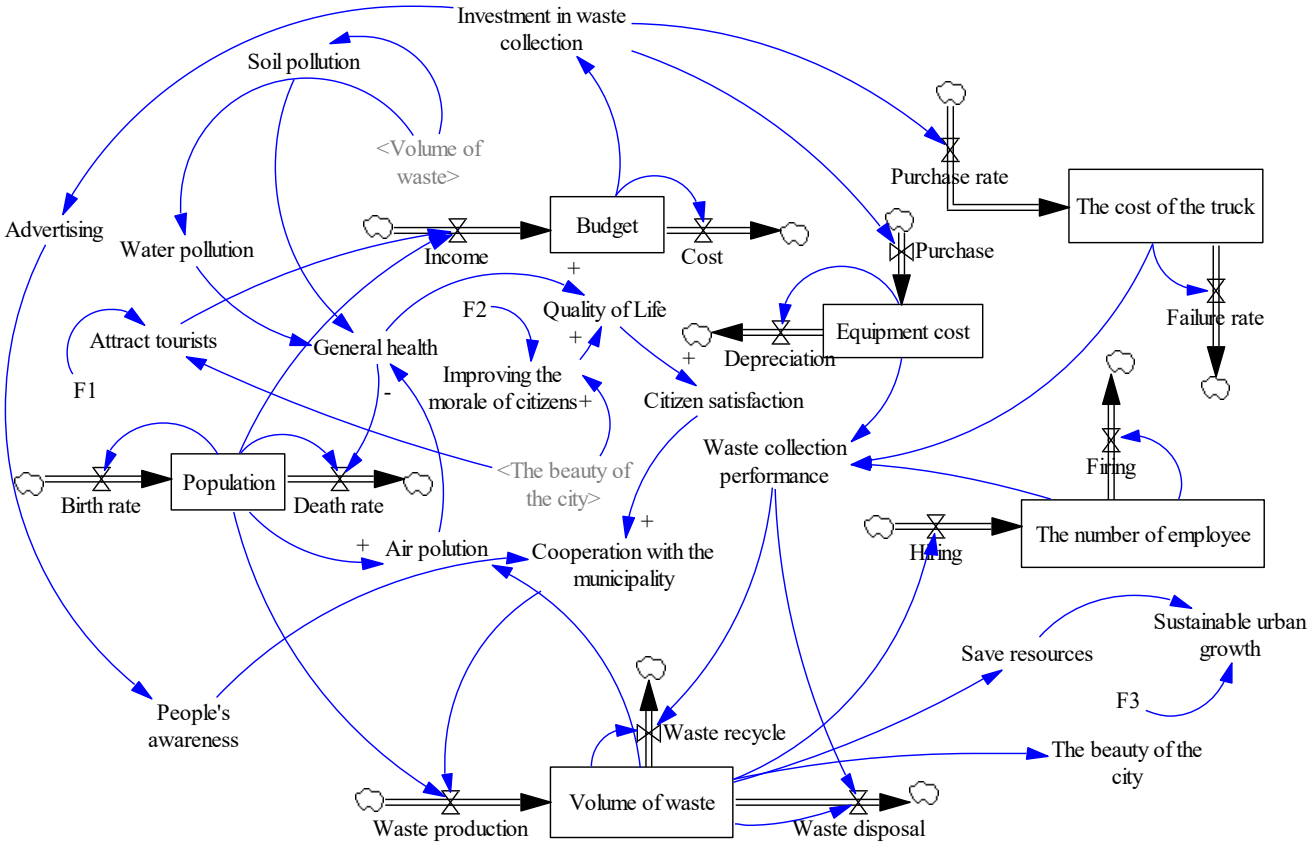

Figure 4. Stock and flow diagram

The presented diagram illustrates the interactions of Volume of waste and forms the foundation for constructing a quantitative model. The development of the stock and flow diagram involved utilizing quantitative and qualitative relationships and numerical functions. The stock and flow diagram, as demonstrated in Figure 4, encompasses a total of 35 variables, out of which six are stock variables. A 10-year timeframe was chosen, evaluated, and analyzed at 12-month intervals to imitate the study.

5. Model validation

The model's validation process is conducted in three phases, as outlined below.

5.1. Model structure evaluation test

This evaluation aims to align the model's structure with the existing knowledge within the system. In this research, urban waste management was initially identified based on the research context and subsequently refined through insights from experts and administrators in Isfahan. Ultimately, the structure of the designed model was validated by incorporating the feedback and opinions of Isfahan's experts and administrators.

5.2. Parameter evaluation test

The parameter evaluation test ensures the congruence between parameter values and their counterparts. Since the variables in this study were derived from the research context, related literature, Isfahan Municipality's documents, and expert opinions, the values align with those presented in pertinent documents and research.

5.3. The limit condition test

The assessment was conducted to evaluate the logical behavior of model variables under extreme scenariosIn this test, the value of a specific model variable gradually decreases toward zero while observing the resulting behavior of other variables that are influenced by the changed variable. For this research, the income variable has been selected to be reduced to zero, and the subsequent behavior of certain impactful variables from the budget is illustrated in Figure 5.

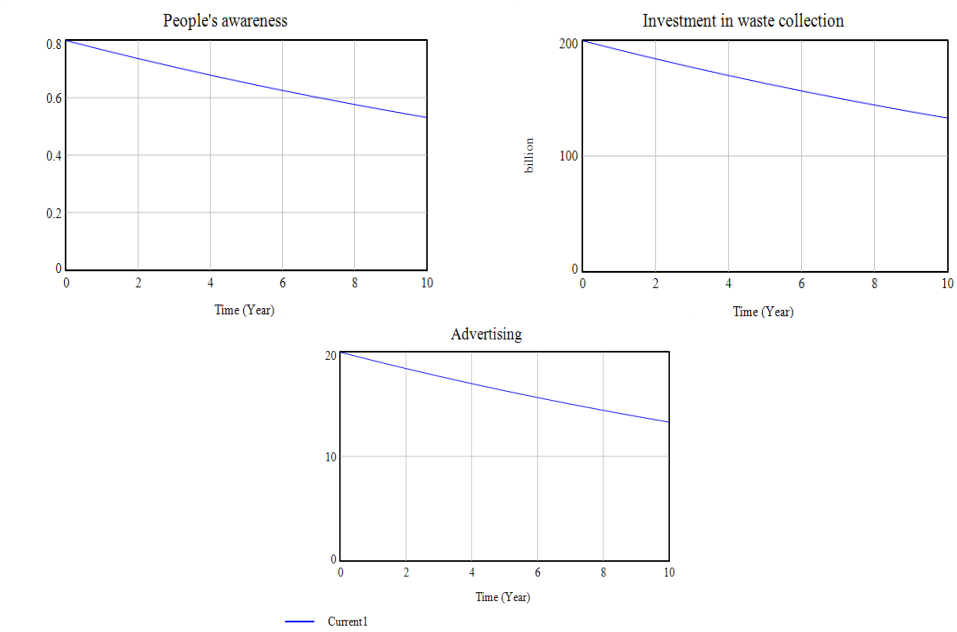

Figure 5. Model testing and validation

As shown in Figure 5, if the income amount approaches zero, the waste collection, advertising, and public awareness investment will gradually diminish over time. It demonstrates how changes in income can directly impact the allocation of resources towards waste management activities and initiatives.

5.4. Behavior reproduction test

In order to verify the correctness of the model's behavior, this test will compare the simulation results with actual data. The figures' findings demonstrate how well the researched variable may be replicated. The results are shown in Figure 6.

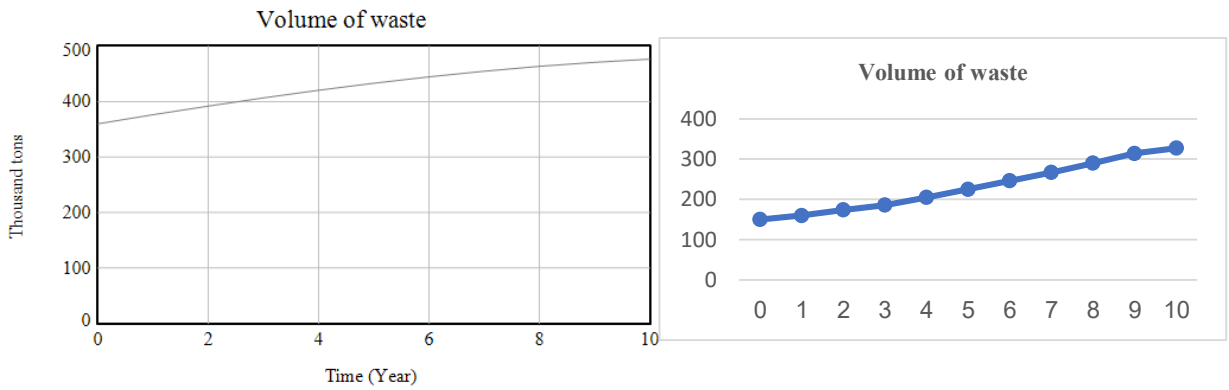

Figure 6. Comparison test with reference behaviour

6. Simulation results

The model has produced the following results as a consequence of the behavior of the key factors and key indicators in the volume of waste by the relationships between the model's variables that were indicated.

6.1. Implementation and evaluation of policies

This section presents the simulation results and analysis of three carefully designed scenarios. It is worth noting that in this research, three specific scenarios are developed: one that increases investment allocation in the equipment sector, another that enhances investment in advertising to boost people’s awareness of waste management and urban waste, and a third scenario that simultaneously increases investments in both advertising and equipment.

6.1.1. The policy of increases investment allocation in the equipment sector

Figure 7 illustrates the behaviors of variables associated with waste volume when there is an increase in investment in the equipment sector for waste collection.

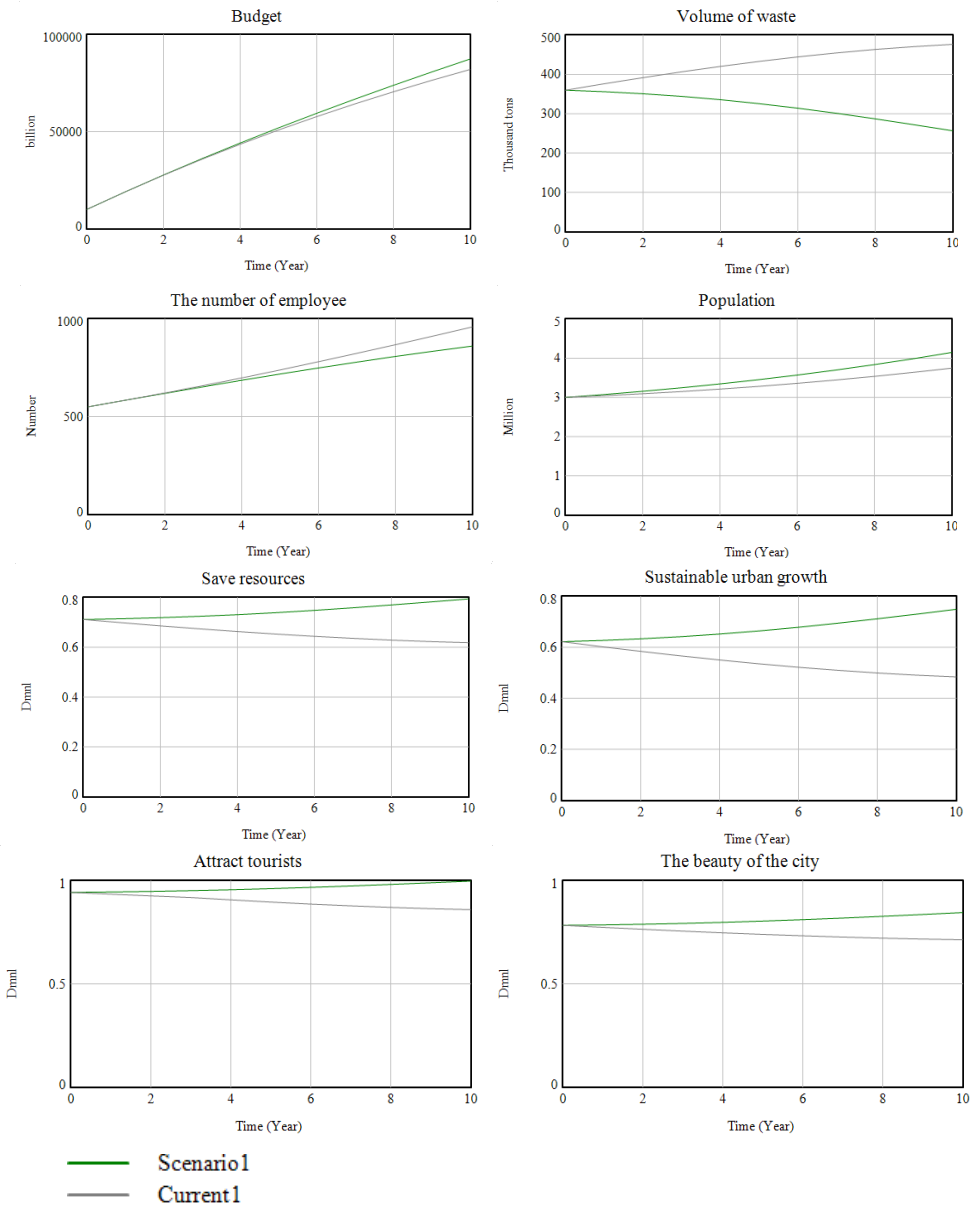

Figure 7. Result of policy of increases investment allocation in the equipment sector

Figure 7 shows that the amount of urban waste in Isfahan will gradually decrease as investment in the sector of waste collection equipment rises. Consequently, the demand for employees in waste collection will decrease gradually, leading to increased budget allocation due to reduced investment needs in the waste collection sector. Moreover, the increased investment in the equipment sector for waste collection and pollution reduction is a foundation for enhancing public health. As a result, the mortality rate due to environmental pollution will decrease over time, fostering population growth. Furthermore, the outcomes of increased investment in waste collection equipment indicate that other aspects will also witness improvement. These include the storage and sustainability of resources, the aesthetics of the city, and the attraction of tourists.

6.1.2. The policy of increases investment allocation in advertising

Figure 8 illustrates the behaviors of variables associated with waste volume when there is an increase in investment in advertising.

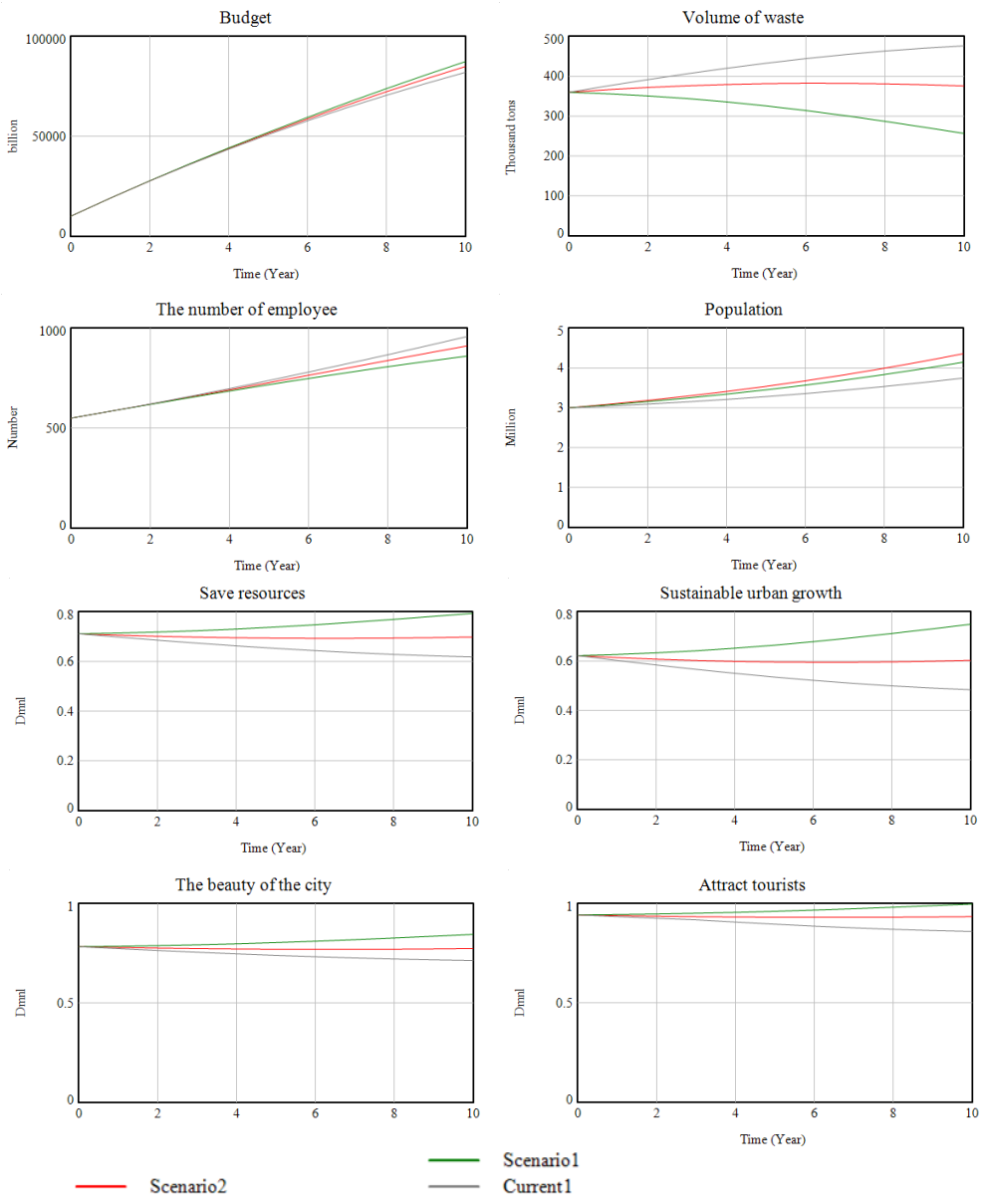

Figure 8. Result of policy of increases investment in advertising

According to Figure 8, increased advertising investment reduces waste volume and requires employees. Additionally, increased investment in advertising and citizens' awareness of the waste disposal process results in an increased budget allocation for waste collection. It is due to citizens' compliance and improved waste production practices. Moreover, reducing waste production and pollution will contribute to population growth. Furthermore, increasing the investment in advertising improves resources and sustainability, enhances the city's beauty, and attracts more tourists.

6.1.3. The policy of increases investment allocation in the equipment sector and advertising simultaneously

Figure 9 illustrates the behaviors of variables associated with waste volume when there is a simultaneous increase in investment in the equipment sector for waste collection and advertising.

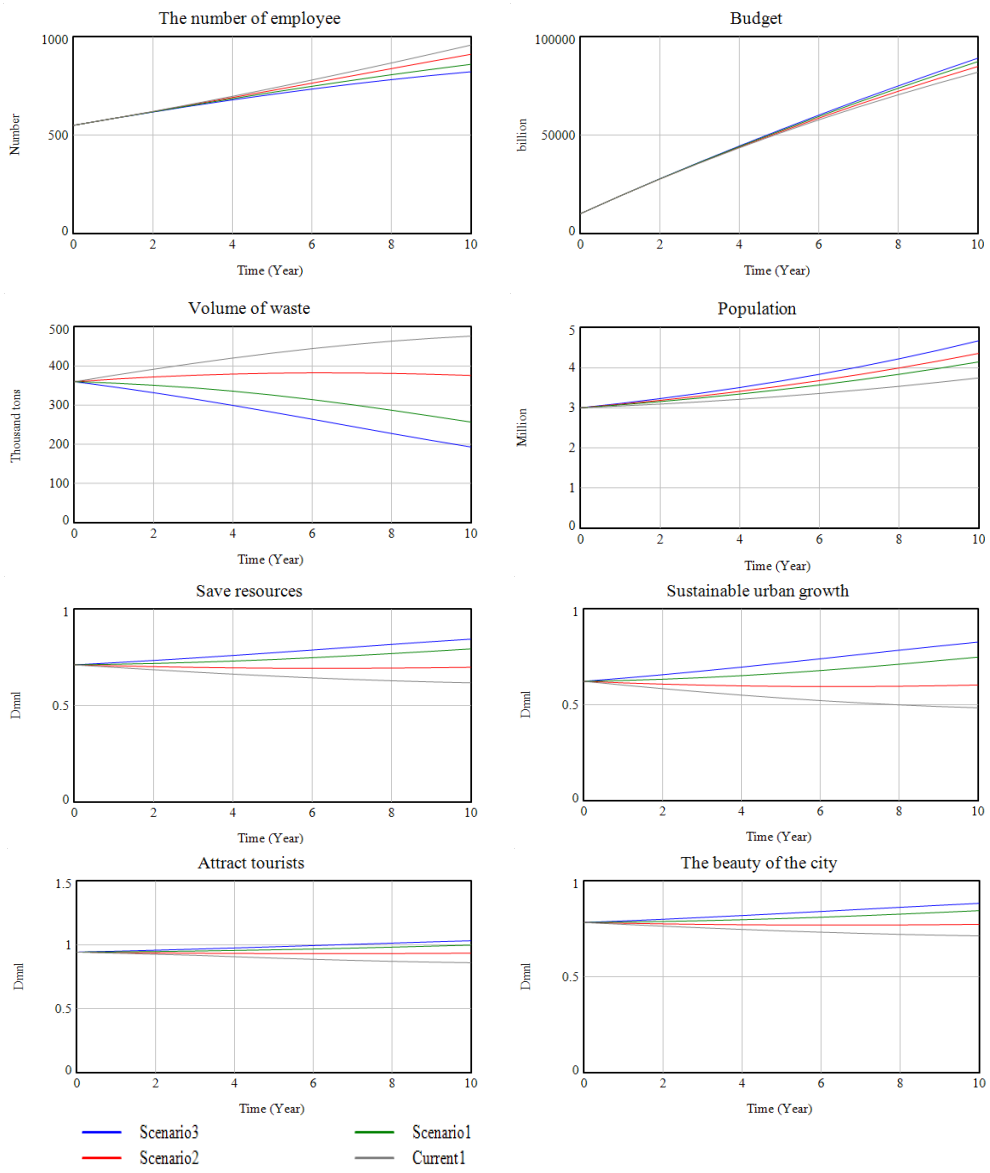

Figure 9. Result of policy of increases investment allocation in the equipment sector and advertising simultaneously

As shown in Figure 9, the simulation results indicate that increasing the investment allocation for waste collection equipment and advertising initiatives in Isfahan decreases the urban waste volume and the required employees while bolstering the budget. Furthermore, the behavior of city beauty, population, saving resources, urban sustainable growth, and tourist attraction variables is investigated. Furthermore, the simultaneous increase in investment in equipment

and advertising will result in significant growth and improvement in various aspects. It includes the population, the beauty of the city, the saving and sustainability of resources, and the attraction of tourists.

7. Discussion

In today's world, effective urban waste management holds significant importance for various societies. Neglecting waste management and urban conditions can have numerous consequences, including escalated environmental pollution and compromised citizen health. Additionally, it can diminish the beauty of the city and attractiveness, resulting in citizen dissatisfaction, resource depletion, and a decline in tourist attraction, among other issues.

This research aims to develop a simulation model that predicts the volume of urban waste in Isfahan over the next ten years and assesses its consequences. In order to achieve this goal, the research literature was analyzed to identify the factors influencing the volume of urban waste. Subsequently, the identified factors were adapted to the local context of Isfahan through the valuable insights of experts and administrators. The research investigated the dynamics and behavior of each identified factor in urban waste management through the system dynamics approach.

The outcomes of the system dynamics simulation revealed that the growth of Isfahan's population in the upcoming years will increase both the quantity and volume of waste generated within the city. This rise in urban waste volume poses a threat, leading to the wastage of valuable and reusable materials such as metals, glass, plastic, and others, which could otherwise be recycled, thus conserving resources. In essence, the surge in urban waste will diminish the resource-saving rate and ultimately impact the sustainability of resources for future generations. This research finding aligns with the conclusions drawn from Lehmann's (2011) and Frata et al.'s (2019) studies. On the other hand, the rise in urban waste volume impacts the population growth rate. In other words, as the volume of waste increases, population growth is expected to occur at a lower rate in the coming years due to the amplified pollution and the resulting increase in deaths caused by the waste produced.

Additionally, the rise in urban waste volume impacts the population growth rate. In other words, as the volume of waste increases, population growth is projected to occur slower in the forthcoming years. It is attributed to the elevated pollution levels and associated health issues resulting from the increased waste production, which can lead to increased mortality rates.

Furthermore, the escalating urban waste levels in Isfahan have negatively impacted the city's attractiveness and aesthetics. It triggers dissatisfaction among citizens regarding the municipality's performance and diminishes the city's appeal as a tourist destination. Consequently, it can lead to a decline in the number of tourists visiting the city.

In this research, three scenarios have been proposed to offer viable solutions for reducing waste in Isfahan. The findings of the first scenario indicate that allocating the budget towards waste collection equipment, such as containers and automated separation devices, as well as safety and health equipment, like gloves, masks, and disinfectants, along with implementing management software, will result in an improvement in waste collection performance. The urban waste could be reduced through effective recycling and proper disposal methods. This finding aligns with Santos et al.'s (2022) research. Moreover, increasing investments in equipment will contribute to the city's aesthetics, resource conservation, urban sustainability, tourist attraction, budget enhancement, and population growth by reducing environmental pollution and mortality rates.

The findings of the second scenario in this research reveal that allocating a higher budget for advertising efforts aimed at raising citizens' awareness about waste and urban waste management can effectively reduce both individual waste generation and the overall waste volume in Isfahan. Several positive outcomes can be achieved by increasing citizens' understanding of waste management. These include enhancing the city's beauty, reducing the need for additional employees, improving resources by avoiding the disposal of recyclable and reusable containers, ensuring resource sustainability, and ultimately attracting more tourists. Moreover, this scenario highlights other notable results, such as an increased municipal budget due to reduced waste collection costs and enhanced tourist attraction. These findings are consistent with the findings of (Magazzino et al., 2020).

Comparatively, the first scenario's investment in waste collection equipment holds a more pronounced effect on reducing urban waste volume. It underscores the pivotal role of equipping the city with ample containers, employing waste management software, and automating waste separation processes. However, it is imperative to acknowledge that citizen awareness still significantly influences waste volume, as demonstrated by the second scenario. The analysis demonstrates that investing in waste collection equipment tends to have a more substantial impact than advertising initiatives for enhancing citizen awareness.

The third scenario encapsulates the most comprehensive approach. Simultaneously directing resources towards advertising and equipment, Isfahan municipality can substantially reduce urban waste volume. This integrated approach enhances awareness and triggers notable improvements in variables such as city aesthetics, resource conservation, urban sustainability, tourist attraction, and budget allocation compared to the first two scenarios. The steeper slope over ten years illustrates the potential for more significant improvements in this holistic approach.

This research underscores the contemporary significance of effective urban waste management. It illuminates the potential consequences of neglecting waste management and offers actionable scenarios to mitigate waste volume. By emphasizing investment in equipment and raising citizen awareness, Isfahan can better manage its waste and engender positive transformations across various urban facets.

8. Conclusion

This research employed the system dynamics approach to develop an effective model for optimizing waste and urban waste management in Isfahan. The study commenced by identifying the variables influencing waste volume through an extensive review of the literature and research background. These factors were refined and localized by integrating insights from experts and city administrators in Isfahan. Subsequently, dynamic hypotheses and causal loop diagrams were constructed based on the amalgamation of literature findings and expert opinions.

The study developed a stock and flow diagram by designing the causal loop diagram, delving into the quantitative relationships among the identified variables. The research established a comprehensive framework to curtail waste volume in Isfahan by formulating various scenarios. The research outcomes indicated that waste production and volume could be effectively controlled within the city while enhancing resource conservation and sustainability growth.

It is recommended that future research extend the scope beyond the factors examined in this study. It could encompass investigating additional aspects, such as the impact of immigration on waste production, considering waste generated by newcomers, and analyzing the potential role of government assistance in aiding the municipality's waste control efforts. By expanding the research focus, a more holistic understanding of waste management dynamics can be attained, enabling the development of even more comprehensive strategies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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