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Assessing the Rate of Recyclable Plastic Wastes and Recycling Economic Value in Hospitals of Yazd in 2022

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A R T I C L E I N F O

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ABSTRACT

Introduction: Special and infectious wastes are the most significant wastes generated in hospitals, health centers, and similar facilities. Reducing and recycling such wastes at the source pose significant challenges to waste management. Therefore, this study assesses the components of healthcare waste in terms of their recyclability, emphasizing different types of plastic.

Materials and Methods: Data collection involved sampling normal and infectious waste in selected hospitals over three months using monthly checklists. The total waste generated in these hospitals was analyzed on a daily basis. Moreover, the average microbial load of infectious waste was determined through microbial strip tests and biological tests following patient companion. Tests were performed with the acceptable performance of safe hospital devices with the destruction of microorganisms.

Results: Average waste composition in the selected hospitals included 65-70% general waste and 30-35% infectious waste. The most common generated infectious waste was polyethylene (PE) sets (800 kg/month), while the predominant general waste was nylon bags for polyethylene terephthalate (PETE) packaging (520 kg/month). Hospital 1 had the highest per capita production of recyclable waste, generating 7,900 kg and 2,550 kg of normal and infectious waste per month, respectively. The total revenue generated from selling normal and infectious plastic waste was 1.4 and 0.2, respectively.

Conclusion: The mixing of waste can be prevented by properly segregating normal and infectious waste and adequate staff training. Given the escalating disposal costs of health-care waste (HCW) and the shrinking space in landfills, efforts to minimize waste generation are crucial for effective recycling and reuse processes.

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Introduction

The increased production of different types of wastes is one of the major consequences of changing human lifestyles and population growth. Following advancements in healthcare, waste production in healthcare has been increased [1, 2]. Hospitals, health centers, medical diagnostic laboratories, and similar facilities produce wastes classified as special and infectious according to national and international classifications. These wastes are categorized into two main groups: normal and infectious. General waste, similar to domestic one, constitutes 75% to 90% of the waste generated in healthcare centers and can be collected and disposed of along with municipal waste without requiring special regulations [3-5]. The remaining 10% to 25% of the healthcare waste is classified as special waste and includes

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pathological, infectious, genotoxic, chemical-pharmaceutical, and radioactive wastes. These wastes need special collection and disposal procedures [3, 6].

Health-care waste (HCW) is a major environmental concern due to its potential hazards, toxicity, and pathogenicity [3, 6]. Research conducted in 22 developed countries revealed that 18% to 64% of healthcare waste is improperly disposed of, leading to environmental pollution [2]. However, proper and efficient management practices can reduce waste generation by up to 15% [7]. Globally, hospitals generate 1-1.5 kg of waste per patient every day. In this respect, factors such as hospital size, range of general and specialized services, and the number of patients influence waste production [8, 9]. In Iran, a significant portion of municipal waste is disposed of in landfills, with only a small percentage recycled [8]. Developing countries increasingly adopt source separation and recycling practices in municipal waste management [10-12].

Regarding the significance of healthcare waste and the challenges in waste management, it is crucial to examine waste recyclability in healthcare centers. Since plastic waste is one of the major type of wastes generated in hospitals, recent studies have focused on its recyclability. Research conducted at the Department of Orthopedic Surgery at the University of Maryland in Baltimore demonstrated that proper separation of general waste from infectious waste and adequate staff training can facilitate the recycling of non-infectious recyclable waste [10]. In addition, studies conducted in Massachusetts hospitals have highlighted the importance of segregating and coding contaminated and non-contaminated waste, developing recycling infrastructure, and providing training for workers and managers to improve waste recycling opportunities [13]. Analyzing the potential for hospital plastic waste recycling is a crucial aspect of waste management in this sector. Plastic waste from laboratories, operating rooms, and hospital cafeterias has been identified as the primary source of plastic waste. According to the literature, segregating and coding at waste source, based on the infection possibility and the type of plastic material can enhance plastic waste recycling in hospitals [11].

Efficient waste management, including proper separating, recycling, and safe decontamination is essential for hospitals to adopt special strategies. On the other hand, improper segregation and inadequate employees' training lead to waste mixing and increased volumes of special waste, posing significant challenges to waste recycling management in these sectors [1]. Given the priority of recycling in hospitals and the importance of determining the recyclability of plastic waste, the present study aims to assess waste management status in public hospitals in Yazd and evaluate the economic aspects through an estimation of plastic waste recyclability.

Materials and Methods

This descriptive cross-sectional study was conducted in Yazd in 2020 to determine the recyclability of plastic waste generated in 3 public hospitals: Shohada-e-Kargar Hospital (hospital 1), Mohammad Sadegh Afshar Cardiovascular Hospital (hospital 2), and Shohada-e-Mehrab Hospital (hospital 3). The study focused on different types of wastes, including semi-domestic or general waste, sharp and infectious waste, chemical pharmaceutical waste, and infectious waste. The hospitals were selected based on their safety equipment and the objectives of the research, and monthly sampling was carried out during one season. It is noteworthy that the sampling was conducted during COVID-19 pandemic, which may have influenced the results. Table 1 provides a summary of the types of waste studied.

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Table 1: Types of the studied waste in health centers

Type of waste	Definition and example
Sharp and cutting waste	Used or unused sharp objects (e.g., subcutaneous injection needle, intravenous injection needle (IV), or other needles, syringe with needle (needle attached to the syringe and inseparable), infectious sets, surgical knife, pipette, knives, blades, broken glass
Infectious waste	Waste suspected of being contaminated with pathogens and waste carrying the risk of disease transmission (e.g., waste contaminated with blood and other secretions; laboratory culture media and microbiological stocks; waste such as feces and other materials in contact with an isolated patient with an infectious disease in an isolated ward)
Pharmaceutical and cytotoxic waste	Outdated drugs and unused drugs; items contaminated with drugs. Cytotoxic wastes are genotoxic wastes (toxic to genes) (e.g., wastes contaminated with cytotoxic drugs, which are often used in cancer treatment, and toxic chemicals that affect genes).
Safe or general waste	Waste that does not contain any biological, chemical, radioactive, or physical hazards.
Chemical waste	Waste containing chemicals (e.g., laboratory reagents, expired or unused disinfectants, solvents, waste containing significant amounts of heavy metals, including batteries, broken thermometers, and sphygmomanometers).
Intra venous (IV)	Needle Scalpels

General waste in the hospitals included waste from the kitchen, café, inpatient wards, and patients' companion areas. Infectious waste include waste from surgical, CCU (coronary care unit), obstetric, dialysis, operating room, pediatric, emergency, injection, pharmacy departments, etc. The total weight of the generated waste, including normal, infectious, sharp and infectious, and chemical pharmaceutical waste, was investigated in the selected hospitals. Average monthly and daily weights were estimated based on the collected data. During the sampling process, all normal and infectious wastes from the selected hospitals were labeled, collected, and separated on the same day. Recyclable plastic waste was separated from other types of wastes, and its total weight was estimated before and after separation. Additionally, the plastic types in normal and infectious waste were analyzed to assess the potential of recyclable materials.

In this study, the average weight of chemical pharmaceutical waste in the selected hospitals was estimated by calculating the weight of expired drugs, disinfectant residues, and other related waste. Similarly, the average weight of sharp and infectious waste was estimated by collecting safety boxes from each ward in the selected hospitals at the end of the day and analyzing their weight. The selected hospitals were equipped with an autoclave for waste decontamination. Microbial tests, including strip tests and biological tests were used in this study. Overall, the microbial load of waste after decontamination and the function of decontamination devices in hospitals were predominantly acceptable . The data obtained from estimating the average waste weights the variables were recorded in a monthly checklist and analyzed using Microsoft Excel version 2013. To this end, statistical measures such as mean and standard deviation were used.

Results

Average weight of total generated wastes

In this study, the average weight of total wastes generated by the selected hospitals was initially the average wastes generated by month/day in Kg. The highest weight belonged to hospital 1 regarding normal, infectious, chemical-pharmaceutical, and sharp-cutting wastes among the selected hospitals. According to Table 2, normal to infectious waste ratio in accordance with international standards was 65-70% to 30-35%.

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Table 2: The mean weight of the total waste generated in the hospitals in the summer

Hospital	Type of waste	Weight (kg) July	Weight (kg) August	Weight (kg) September	Daily average kg/day	Standard deviation (daily average)
Hospital 1	General	7800	7900	7950	265	± 6.5
	Infectious	2550	2600	2585	86.5	± 3
	Sharp	120**	130	110	40	± 5
	Chemicals	13	14	15	0.5	± 0.25
Hospital 2	General	2500	2550	2450	83.5	± 3
	Infectious	410	390	400	13.5	± 2
	Sharp	40	41	42	14	± 4
	Chemicals	10	12	11	0.4	± 0.25
Hospital 3	General	6150	6180	6200	206.5	± 5
	Infectious	1690	1680	1700	56.5	± 3
	Sharp	60	58	62	20	± 5
	Chemicals	21	19	20	75	± 0.25

Comparing the statistics of Iran's hospitals with normal to infectious waste ratio indicates that they are in the range of 70-90% to 10-30% [14], 41-56%, and 35-65% [15, 16] (Table 2). Proper separation of general wastes from infectious wastes and training the staff can prevent waste mixing and reduce the costs of disposing of general wastes. With increasing the costs involved in healthcare waste disposal and shrinking landfill space, efforts to minimize waste generation are important for recycling and reusing processes.

Average weight and plastic-type analysis of normal and infectious waste

Table 3 presents the average weight of recyclable infectious wastes in the selected hospitals after separating them from other wastes. In hospital 1, PE sets showed the highest percentage, with an average weight of 800 kg/month. This value was followed by HDPE distilled water tanks with an average weight of 300 kg/month, PETE oxygen masks weighing 250 kg/month, and HDPE test tubes weighing 100 kg/month. Syringes, angiocatheters, and airways had an average weight of 50 kg/month.

Table 3: Monthly average weight and type of infectious plastic waste in the selected hospitals

Type of waste	Monthly average weight (kg) (Hospital 1)	Monthly average weight(kg) (Hospital 2)	Monthly average weight (kg) (Hospital 3)	Plastic type
Airway[1]	50	10	30	PP
Angiocatheter[2]	50	20	30	PE
Distilled water tank[3]	300	50	100	HDPE
Types of syringes[4]	50	30	40	PE
Types of masks[5]	250	50	200	PETE
Types of test tubes[6]	100	50	120	HDPE
Types of sets[7]	800	120	750	PE
Total	1600	330	1270	-

[1] Nose-throat airway: A disposable plastic device used to maintain patient's airway open.
[2] Angiocatheter: A disposable plastic device designed to administer liquid medication to a patient.
[3] Distilled water tank: Plastic tanks and plastic injection vials used to store and distribute distilled water within the hospital.
[4] Types of syringes: Syringes with disposable plastic bodies in various sizes (0.5, 1, 2, 3, 5, 10, 20, 30, and 50 cc), including syringes specifically designed for insulin injection.
[5] Types of oxygen masks: Disposable plastic oxygen masks such as simple oxygen masks, oxygen masks with a bag, and nasal cannulas or nasal catheters. These masks are used to provide oxygen therapy to patients.
[6] Test tube: Plastic test tubes with lids typically made of PET/HDPE and commonly used in laboratory settings.
[7] Types of sets: Various sets made of plastic used in healthcare settings, including serum sets, blood sets, dialysis sets, and catheter sets (e.g., two-way Foley catheters, feeding tubes, nasal tubes, and suction tubes).

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The study revealed that PE sets demonstrated the highest percentage, with an average weight of 800 kg/month, among plastic wastes in hospital 1. In addition, HDPE distilled water tanks with an average weight of 300 kg/month, PETE oxygen masks with an average weight of 250 kg/month, and HDPE test tubes with an average weight of 100 kg/month ranked second. Syringes, angiocatheters, and airways had an average weight of 50 kg/month. In this research, the average weight of this type of waste was calculated by separating normal (semi-domestic) wastes with recyclability from other wastes in the selected hospitals. The highest percentage of normal plastic wastes was related to different types of PETE nylon bags, with an average of 520 kg/month in hospital 1. Plastic bottles made of HDPE/PETE with an average weight of 300 kg/month and plastic containers made of Polystyrene (PS) with a per capita consumption of 30 kg/month ranked the next.

Table 4 shows the average weight of recyclable normal (semi-domestic) wastes after separation from other wastes in the selected hospitals. The highest percentage of normal plastic wastes was attributed to different types of nylon bags made of PETE, with an average of 520 kg/month in hospital 1. Plastic bottles made of HDPE/PETE had an average weight of 300 kg/month, followed by plastic containers made of PS with a per capita consumption of 30 kg/month.

Table 4: Average monthly weight of total normal plastic wastes in the selected hospitals

Type of waste	Average monthly weight (kg) (Hospital 1)	Average monthly weight (kg) (Hospital 2)	Average monthly weight (kg) (Hospital 3)	Plastic type
Plastic bottles [1]	300	75	150	PETE/HDPE
Plastic dishes [2]	30	35	50	PS
Nylon [3] bags	520	200	420	PETE
Total	850	310	620	-

[1] Plastic bottles: It includes all kinds of mineral water bottles, juice, bottles, containers related to dialysis fluid storage in the dialysis department, laboratory and radiography departments.
[2] Plastic dishes: It includes all kinds of plastic containers (cups, dishes) related to the patient's companion.
[3] Nylon: It includes all kinds of recoverable bags for accompanying patients and bags related to the packaging of drugs in drug stores and pharmacies.

Among the normal and infectious plastic wastes, PE sets (90% plastic content) and nylon bags (100% plastic content) had the highest ratio of waste. It is important to prioritize recycling these materials and consider alternatives to disposable plastics. The information provided in Tables 3 and 4 can determine the prioritizing of plastic products for recycling or substituting plastic with non-disposable materials. The use of Society of the Plastics Industry (SPI) codes in classifying and analyzing plastic waste can enhance waste recycling. In this context, programs incorporating various recycling processes and techniques such as mechanical crushing, decontamination, washing, and reprocessing are recommended to achieve recycled products [11].

Total per capita generated wastes daily in the selected hospitals per bed

According to Table 5 , hospital 1 (297 active beds), hospital 3 (177 active beds), and hospital 2 (48 active beds) generated 0.9, 1.1, and 1.7 kg.day/bed of general wastes, respectively. The estimated production of infectious waste was 0.3 kg.day/bed. Hospital 1, with the highest number of active beds, generated more normal and infectious wastes compared to the other two hospitals (hospitals 3 and 2). However, hospital 1 received the lowest rank in terms of daily per capita waste production per bed.

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Table 5: Total per capita wastes generated daily in the selected hospitals per bed

Hospital	Type of waste	Weight (kg.day/bed)July	Weight (kg.day/bed) August	Weight (kg.day/bed) September
Hospital 1	General	0.89	0.92	0.95
	Infectious	0.29	0.32	0.30
Hospital 2	General	1.70	1.75	1.65
	Infectious	0.30	0.25	0.28
Hospital 3	General	1.10	1.12	1.15
	Infectious	0.29	0.26	0.31

Figure 1 presents the mean weight per capita regarding total infectious and general wastes in the selected hospitals throughout the study period. Previous studies showed a weak correlation between normal and infectious waste generation per capita per day and the number of beds [15]. Waste generation rate varies in different countries and cities based on hospital conditions, available facilities, and the range of services provided to patients [17].

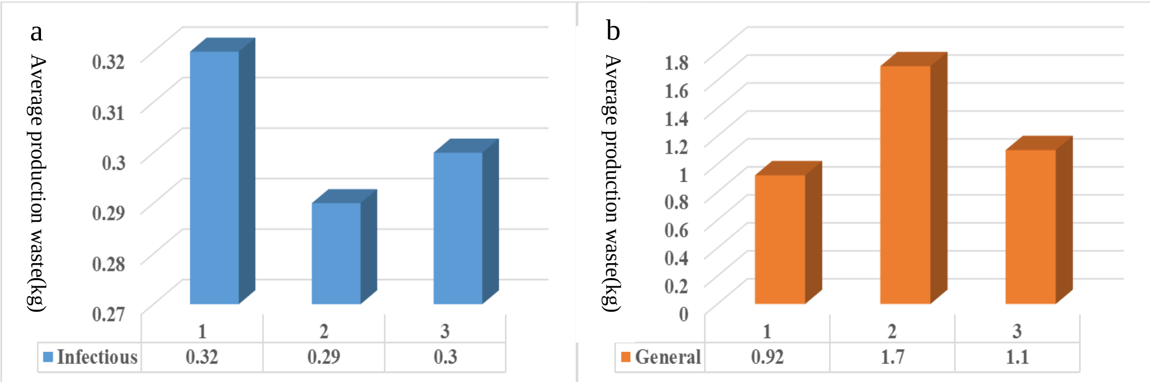

Figure 1: Average weight per capita of total waste generated in selected hospitals (a: infectious waste b: generated wastes)

The total cost from decontamination (by autoclave) to the final landfill stage, including staff salaries, autoclave calibration, and final disposal costs, was estimated for the generated waste in the selected hospitals. The revenue from the sale of decontaminated recyclable plastic waste was also considered. Table 6 shows the average recycled value of generated plastic waste on a monthly basis.

Table 6: Average recycled value of generated plastic waste per month

Hospital	Type of waste	Total waste (kg)	Total cost [1] ($)	Total recyclable plastic waste	Total income[2] ($)	Cost to income ratio[3] ($)
Hospital 1	General	7900	263.33	850	188.88	1.4
	Infectious	2550	85	1600	355.55	0.23
Hospital 2	General	2500	83,33	310	68.88	1.2
	Infectious	400	13.33	330	73.33	0.2
Hospital 3	General	6150	205	620	2.22	1.5
	Infectious	1700	56.66	1270	282.22	0.2

[1] Total cost from decontamination to final disposal (Rials) = amount of not segregated (in kilograms) waste generated (infectious or normal) × Cost spent for decontamination per kilogram of waste (15,000 Rials)
[2] Income from sales of plastic waste (Rials) = amount of generated plastic wastes (infectious or normal) separately (in kilograms) × Income from sales of per kilogram of waste (100,000 Rials)
[3] Cost-to-income ratio (Rials) = total cost from decontamination to final disposal (Rials) ÷ Income from the sale of plastic wastes (Rials)

Decontamination cost per kilogram of generated wastes, taking into account all the mentioned factors, was estimated to be an average of $0.2 at the time of the study (summer 2020). Moreover, the cost of each kilogram of waste delivered to municipalities and private agencies for final disposal was estimated at $0.01. Decontamination, and the total cost of decontamination and final disposal of normal and infectious wastes were calculated at $0.03 per kilogram. The revenue from the sale of non-hazardous plastic waste, based on the estimated value of recycled plastic, was $0.22 per kilogram in this study.

Microbial load of infectious wastes after Safeguarding

To measure microbial waste, at least 3 microbial tests, test strips, and biological tests were performed to confirm the accuracy of the performance of waste-free devices in the hospitals. In this test, the test strip changed from yellow (before autoclave) to black or dark (after autoclave), indicating the high vapor pressure of indigestion (autoclave) and performance. The top of the autoclave machine is in the waste disposal of hygienic, the higher the steam pressure of the autoclave machine becomes, the darker the color of the test strip will be after the autoclave. Microbial test Biological test The purple color (before autoclaving) is visible after spending 72 hours in the drying machine (autoclave) with the original purple color and the visible jelly state.

This state and the lack of color change indicated the accuracy of the experiment. Due to the high probability of infection, recycled infectious plastic wastes in operating room, laboratories and other places were ignored and removed from plastic pile of waste with recyclability[11]. Through performing microbial tests and high performance of riskless devices in the hospitals regarding the reduction of infectious wastes all the infectious plastic wastes can be used for recycling. To confirm the correctness of the operation of drying devices in health care centers, the monitoring tape and biological test were performed at least 3 times with the acceptable performance of safe hospital devices with the destruction of microorganisms.

Discussion

In the present study, the average weight of total wastes generated by the selected hospitals was initially measured on monthly and daily basis in kilograms (kg). Hospital 1 generated the highest amount of normal, infectious, chemical-pharmaceutical, and sharp-cutting wastes among the selected hospitals. The normal-to-infectious-residues ratio following the international standards was found to be 65-70% to 30-35%. Generally, the statistics of Iran's hospitals showed a normal-to-infectious waste ratio of 70-90% to 10-30%[14], 41 to 56%, and 65 to 35%[15, 16]. Comparing these findings with other studies and global standards revealed that the lack of proper separation and simultaneous disposal of normal and infectious wastes increased the volume of infectious wastes. The average weight of recyclable infectious wastes was measured by separating them from other types of wastes in the selected hospitals.

Based on the obtained results, incorporating the costs and implementing proper waste management practices from initial stages to the final disposal allows for creating a favorable platform for the sale of recyclable plastic waste. This approach also provides a basis for the return of raw materials to the production cycle and cost recovery [18].

Among normal and infectious plastic wastes, sets with the highest plastic content (about 90%) and nylon bags (100%) had the highest ratios of waste production, it is noteworthy that all types of sets and packaging bags were primary materials for recycling. Other studies have also analyzed different types of normal and infectious recyclable waste, and syringes were found to have the highest plastic content (approximately 85%) compared to other plastic waste [11]. Proper waste management should follow the codes of Society of the Plastics Industry for plastic waste classification and analysis to increase recycling. Given the high quality of recyclable plastic wastes and the significant volume of generated waste, recycling programs can be implemented using various

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processes and techniques such as mechanical crushing, decontamination, washing, and reprocessing to recycle products [11].

The present study showed that the estimated production of total waste regarding general wastes per bed per day was 0.9, 1.1, and 1.7 kg in hospital 1 (297 active beds), hospital 3 (177 active beds), and hospital 2 (48 active beds), respectively, while infectious wastes were 0.3 kg per bed per day. Thus, hospital 1, with the highest number of active beds, generated more normal and infectious wastes than the other two hospitals (3 and 2). However, hospital 1 ranked last in terms of per capita production of waste per bed daily. Weak correlations between normal and infectious waste generation per capita per day and the number of beds were observed in other studies [15]. Moreover, several studies reported varying quantities, such as 4.72, 3.4, 3.12, 2.4, 3.48, 7.5, 5.6, and 14 kg/day [8, 18-24].

Overall, hospital 1, with its higher number of active beds, generated larger quantities of both normal and infectious wastes compared to the other two hospitals (3 and 2). However, Hospital A ranked last in terms of per capita waste production per bed per day. This observation was consistent with the findings from other studies regarding weak correlations between normal and infectious waste generation per capita per day and the number of beds[15]. Notably, the hospital waste generation rate can vary across different countries, cities, and hospitals, depending on factors such as hospital conditions, facility availability, and the range of services provided to patients [24].

Various factors were considered for calculating the total cost of waste management from decontamination (using an autoclave) to the final disposal stage. These factors included staff salaries, autoclave calibration (garbage bags for normal and infectious wastes, autoclave device, and purchase and replacement of worn parts), and the final disposal cost. These costs, incurred by relevant authorities such as municipalities and private waste disposal centers, were estimated based on the average weight of normal and infectious wastes in this study. Additionally, revenue from the sale of decontaminated recyclable plastic waste was taken into account. This revenue was the amount paid by relevant agencies to health centers in exchange for receiving recyclable waste.

The cost of specifying per kilogram of the generated waste was an average of $0.2 during the study period (summer 2023). Furthermore, the cost of each kilogram of waste delivered to municipalities and private agencies for final disposal was $0.01. Consequently, the total cost of decontamination (from the initial stages to the final disposal of normal and infectious waste) was calculated as $0.03 per kilogram. The revenue from the sale of non-hazardous plastic waste, based on the estimated value of different recycled plastic types, was determined to be $0.22 per kilogram in this study. Another study conducted by thenon-governmental organization of Nepal Health Care Foundation demonstrated that autoclaving is an effective method to recycle blood-contaminated plastic waste, including blood bags and dialysis kits. This center also implements recycling practices for paper, plastic, and glass (general waste), covering approximately 40% of the waste management costs through recycling revenue. They use autoclaves to decontaminate infectious waste safely. Overall, examining the costs associated with waste management and implementing appropriate practices from initial stages to the final disposal allows for establishing a suitable platform for selling recyclable plastic waste. This approach contributes to the return of raw materials to the production cycle and enables cost recovery [18].

Conclusion

This research is designed to ,first, determine the amount of plastic wastes generated in hospitals, and second, consider the high value of plastic wastes, whether it is possible to recycle some of these wastes or not. It can be said that this study is the first of its kind in the country.

The present paper offers a comprehensive review of previous studies and an analysis of

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normal and infectious wastes which can be recycled in the selected hospitals. Therefore, normal and infectious plastic wastes made of PE/HDPE possess the highest potential for recycling. Generally, recycling this type of waste is feasible. Furthermore, based on the cost-benefit analysis, appropriate measures can be implemented to facilitate waste recycling.

Proper segregation of general wastes from infectious wastes, along with comprehensive staff training, is crucial to prevent waste mixing and reduce the costs associated with disposing of general wastes. As the costs of disposing of hazardous waste continue to rise and landfill space becomes limited, efforts to minimize waste generation become increasingly important for promoting recycling and reusing processes.

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Conflict of nterest

The authors declared no conflict of interest.

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Ethical considerations

All authors have read, understood, and complied as applicable with the statement "Ethical Responsibilities of Authors" as found in the Instructions for Authors; they are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

Code of Ethics

The present study was approved by the Ethics Committee of Shahid Sadoughi University of Medical Sciences, Yazd (Ethic code: IR.SSU.SPH.REC.1399.064)

Authors' contributions

All the authors contributed to the study's conception and design. Masoumeh Bagheri did the research and wrote the original draft;

Ehsan Abouee Mehrizi validated, reviewed and edited the manuscript.

Roghayyeh Koupal was involved with methodology and conceptualization.Mehdi Mokhtari was involved with project administration and editing

All the authors read and approved the final manuscript.

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