Pilot Study On Pharmaceutical Waste Disposal and Its Role in Sustainable Management

Agnieszka Piekara
Wrocław University of Economics and Business, Wrocław, Poland
agnieszka.piekara@ue.wroc.pl

Significant attention is being given to waste management worldwide, with efforts to reduce waste volumes. While plastics receive the most focus, pharmaceuticals also pose a significant environmental threat. This pilot study on pharmaceutical waste disposal, conducted at a pharmacy in Poland, includes quantitative and qualitative analyses of medicines returned for disposal in two-week intervals. The research provides information about customer practices, revealing that many unexpired medicines are often found in disposal bins, further emphasizing the need for better education. The findings offer valuable insights into the role of pharmaceutical waste management in sustainable practices, addressing the environmental challenges posed by improper disposal. Furthermore, this study highlights the critical responsibility of pharmaceutical manufacturers to ensure the safe and sustainable disposal of their products. Additionally, the improper disposal of pharmaceutical waste generates a significant financial burden on national health systems, further underscoring the importance of responsible waste management practices.

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1 Introduction

Significant attention is being given to waste management worldwide, with efforts to reduce waste volumes. While plastics receive the most focus, pharmaceuticals also pose a significant environmental threat and financially burden national health systems (Rogowska & Zimmermann, 2022). The economic effects of pharmaceutical waste are multifaceted, resulting in increased healthcare costs, loss of financial resources, and broader impacts on public health systems. Such waste leads to the direct loss of financial investment in medications and exacerbates healthcare challenges through the need for additional treatments, putting pressure on already strained healthcare budgets. Non-adherence to prescribed medications contributes to pharmaceutical waste and results in increased overall healthcare expenditures. When patients do not follow their medication schedules, they often require additional medical attention, leading to repeated treatments or hospitalizations that incur extra costs. According to Alshemari et al., the costs associated with treating complications arising from non-adherence can significantly escalate, compounding the economic burden of wasted pharmaceuticals (Alshemari et al., 2020). Thus, addressing adherence improves health outcomes and serves as a mechanism for healthcare cost containment.

Inadequate pharmaceutical waste management systems can lead to indirect economic costs through environmental damage. Pharmaceuticals that enter the environment may cause pollution, necessitating costly cleanup operations and regulatory compliance in public health measures. Additionally, the rise of antibiotic resistance associated with improper disposal of pharmaceutical waste incurs significant expenses in directly treating resistant infections and the economic burden on healthcare systems globally (Alnahas et al., 2020; Mohammed et al., 2021) .

2 Theoretical Background

The disposal of unused drugs and pharmaceuticals is a significant public health and environmental issue. People often resort to various methods of disposal primarily due to a lack of awareness or understanding of proper practices. Research indicates that common disposal methods include throwing medications in household waste, flushing them down toilets, or returning them to pharmacies (Ling et al., 2024; Sarah & Lamyaa, 2016; Yu et al., 2019). When evaluating the motivations behind these

practices, several key factors emerge: knowledge, awareness of environmental risks, and accessibility of take-back programs. One of the most critical reasons for improper medication disposal is the lack of knowledge regarding proper disposal methods. Many individuals do not know that returning unused medications to pharmacies or designated take-back programs is the recommended approach. Studies show that a significant proportion of people dispose of their medications in household waste or sewage simply because they are not aware of safer alternatives (Albaroodi, 2019; Ong et al., 2020; Sarah & Lamyaa, 2016; Seehusen & Edwards, 2006). Additionally, research highlights that those who are educated about these recommended methods are more likely to use them, indicating an inverse relationship between knowledge levels and improper disposal behaviors (Ayele & Mamu, 2018; Ong et al., 2020; Rogowska et al., 2019). Furthermore, public awareness of the environmental consequences of improper disposal is surprisingly low. Although some individuals recognize the potential harm that pharmaceuticals can inflict on ecosystems, many still opt for less environmentally friendly disposal methods. Studies have documented instances in which individuals are aware of the detrimental impacts of such actions but choose to overlook them, possibly due to convenience or perceived low risk (Cook et al., 2012; Dohle et al., 2013; Ling et al., 2024). As noted in various studies, community campaigns aimed at raising awareness about the environmental impact of household pharmaceutical waste have had mixed effectiveness; thus, continued education is essential (Kasprzyk-Hordern et al., 2021; Kusturica et al., 2016; Rogowska et al., 2019). Additionally, accessibility to proper disposal methods plays a crucial role in shaping disposal behaviors. In regions where pharmacy take-back programs are scarce or poorly advertised, individuals are significantly more likely to dispose of medications improperly (Singleton et al., 2017). For instance, surveys indicate that in countries where organized medication return systems exist, like Sweden, a far higher percentage of the population returns medications to pharmacies than in countries with fewer or absent initiatives (Kusturica et al., 2016). The inconsistency of information provided to the public about disposal methods only compounds the issue (Yang et al., 2019).

According to data from the Polish Ministry of Health, in 2023, the total sales value of all prescription drugs amounted to PLN 26.1 billion (PLN 4.2 billion more than in 2022), while the value of reimbursements reached PLN 10.5 billion (PLN 1.9 billion more than in 2022). Patients spent PLN 15.6 billion of their funds on prescription drugs (PLN 2.3 billion more than in 2022). In 2023, reimbursements

accounted for 40.4% of the value of prescription drugs sold (compared to 39.3% in 2022). In 2023, the highest share in the value of sold medicines was held by drugs related to the cardiovascular system (19.2%), the digestive system and metabolism (18.9%), and the central nervous system (13.5%).

This pilot study aims to analyze the scale, structure, and characteristics of pharmaceutical waste returned to a community pharmacy in Poland, with a particular focus on the presence of expired versus unexpired medicines, their therapeutic classification, and the broader implications for environmental sustainability, and pharmaceutical industry responsibility.

3 Methodology

The research methodology was adapted from Romanelli and Lucente (2022). This descriptive study examined a sample of packaged medicines returned by customers to a pharmacy for disposal. In Poland, patients' collection of unused and expired medicines primarily relies on designated pharmacies with special disposal containers. The PSZOK (Selective Municipal Waste Collection Points) is a second option, where patients can bring their pharmaceutical waste. While pharmacies provide convenient and widely accessible drop-off locations, PSZOK facilities offer an alternative for the disposal of larger quantities of pharmaceutical waste alongside other hazardous household waste. When disposing of medicines at pharmacies, it is recommended that they be brought without their cardboard packaging and accompanying leaflets. As a result, the collection containers typically contain only blister packs, bottles, and other primary packaging. The entire study was conducted with precautionary measures in place, using a protective apron, face mask, and disposable gloves.

The analysis occurred in a „Apteka Rodzinna Iwaszko Pawel“ pharmacy located in Dzierżoniów, a city with 30,000 residents in the Lower Silesian Voivodeship, Poland, between the beginning of January and the middle of March 2025. For each collected medicine, the following details were recorded: (1) product name, (2) active ingredient(s), (3) number of remaining dosage units, and (4) expiration date. Based on these records, additional data were derived, including (5) pharmacological classification (according to the 1st or 2nd level of the ATC classification system) and (6) remaining shelf life (in months). The study excluded medicines that could not be

quantified, such as multi-dose liquid formulations (non-transparent bottles) and semi-solid preparations (gels, creams, ointments, etc.). The study concerned one pharmacy and was a pilot study. It aimed to confirm whether the methodology adopted from the cited studies is adequate for the situation in Poland and for collecting unused medicines. All collected data were entered into an Excel file, and descriptive statistics were generated.

4 Results

During the pilot study, 69 kg of waste was analyzed. The average amount of waste collected over two weeks was 11.5 kg (SD 1.2 kg). Analyzed samples comprised 10.71% of dietary supplements and 89.29% of pharmaceuticals. Among pharmaceuticals, 80.67% were past their expiration date, while 19,33% were unexpired at the time of disposal (in the case of dietary supplements, 87.78 % were expired). Full blisters or bottles accounted for as much as 58.40% of all discarded medicines. The sample included unused drugs representing almost all classes according to the Anatomical Therapeutic Chemical classification (table 1).

Table 1: The distribution of unused pharmaceuticals according to the Anatomical Therapeutic Chemical classification.

The Anatomical Therapeutic Chemical (ATC) classification system*	%	% of expired
A Alimentary tract and metabolism	24.13	17.38
B Blood and blood forming organs	3.07	2.50
C Cardiovascular system	15.33	7.86
D Dermatologicals	2.67	2.38
G Genito urinary system and sex hormones	2.93	1.67
H Systemic hormonal preparations, excl. sex hormones and insulins	2.80	1.5
J Antiinfectives for systemic use	5.87	3.33
L Antineoplastic and immunomodulating agents	0.13	0.00
M Musculo-skeletal system	11.20	6.90
N Nervous system	21.20	12.98
P Antiparasitic products	0	0
R Respiratory system	10.53	7.5
S Sensory organs	0.13%	0
V Various	0	0

*WHO Collaborating Centre for Drug Statistics Methodology, Guidelines for ATC classification and DDD assignment 2024. Oslo, Norway, 2023

The most commonly represented categories were Alimentary tract and metabolism (A), accounting for 24.13% of all unused medicines, and Nervous system (N) drugs at 21.20%. These groups include medications for gastrointestinal conditions, diabetes, depression, and chronic pain—indicating challenges with long-term treatment adherence and possible overprescription.

Cardiovascular system (C) drugs comprised 15.33% of the waste, many of which are prescribed for chronic conditions such as hypertension and heart disease. Musculo-skeletal system (M) medications, including anti-inflammatory and pain-relieving agents, accounted for 11.20%. In comparison, Respiratory system (R) drugs made up 10.53%, reflecting episodic use and potentially unnecessary stockpiling of treatments for seasonal illnesses.

Drugs from other therapeutic areas appeared less frequently: Antiinfectives for systemic use (J) represented 5.87%, raising concerns due to the implications of leftover antibiotics on antimicrobial resistance. Genito-urinary system and hormonal treatments (groups G and H) comprised approximately 2.9% and 2.8% of the waste, respectively. Dermatologicals (D) accounted for 2.67%.

Some categories were nearly absent from the waste stream, including Antineoplastic and immunomodulating agents (L) and Sensory organs (S), each representing only 0.13%, and Antiparasitic products (P) and Various (V), both with 0%.

The proportion of expired medications within each ATC group also varied. A notable percentage of expired items was found in categories A (17.38%), N (12.98%), and R (7.5%). These results suggest that many patients do not complete their treatments, discontinue medications due to side effects, or accumulate excess supplies due to therapy adjustments.

Table 2: The distribution of 13 of the most common unused pharmaceuticals according to ATC classes.

ATC Class*	ATC classification	% of collected drugs
Paracetamol OR paracetamol with caffeine	N	3.73
Pantoprazole	B	2.67
Diclofenac	M	2.40
Metformin	A	2.40
Ibuprofen	M	2.00
Tramadol + Paracetamol	N	2.00
Drotaverine	A	1.60
Captopril	C	1.47
Bilastine	R	1.47
Betahistine	N	1.20
Naproxen	M	1.20
Acetylsalicylic acid	B	1.20
Ramipril	C	1.20

*according to the WHO Collaborating Centre for Drug Statistics Methodology, Guidelines for ATC classification and DDD assignment 2024. Oslo, Norway, 2023

Among the most frequently discarded pharmaceutical substances identified in this study were drugs commonly used to treat chronic and widespread medical conditions. Pantoprazole, a proton pump inhibitor, is routinely prescribed for acid-related disorders such as gastroesophageal reflux disease (GERD) and peptic ulcers. Paracetamol and ibuprofen—both widely available over-the-counter analgesics—are used for the treatment of mild to moderate pain and fever, and were frequently found among unused medications, often reflecting over-purchase or precautionary use. Similarly, diclofenac and naproxen, both non-steroidal anti-inflammatory drugs (NSAIDs), are prescribed for musculoskeletal and inflammatory conditions such as arthritis and back pain. Metformin, one of the most commonly used medications for type 2 diabetes, and ramipril or captopril, used for hypertension and cardiovascular disease, represent cornerstone therapies in chronic disease management. The presence of these drugs among unused items may indicate issues with long-term adherence or dosage adjustments made during treatment. Tramadol combined with paracetamol is used for moderate to severe pain and may be discarded due to side effects or resolution of acute symptoms. Drotaverine, frequently used in abdominal or menstrual cramps, and betahistine, used to treat vertigo, suggest the presence of symptom-based prescribing for episodic conditions. Also notable was the disposal of bilastine, an antihistamine used for allergic rhinitis, and acetylsalicylic acid (aspirin), often prescribed in low doses for cardiovascular prevention.

5 Discussion

In the present study, 80.67% of the pharmaceutical items documented in the database were past their expiration date, while 19,33% were unexpired at the time of disposal. This finding aligns with international data on the composition of pharmaceutical waste returned by consumers. A study in Italy reported that 28% of the medications returned to pharmacies had not yet expired, a figure that is remarkably consistent with the proportion observed in our dataset. Comparable percentages of unexpired medicines were also reported in earlier studies conducted in Birmingham (UK) (Mackridge & Marriott, 2016) and Southern California (USA)(Law et al., 2014), suggesting a recurrent trend across different healthcare systems and cultural contexts. In a separate study analyzing residual household waste in Vienna, Austria, the proportion of unexpired medications was slightly higher, at 36% (Vogler & Rooi, 2018). The convergence of these findings suggests that almost one-quarter of pharmaceutical waste may involve medicines still within their shelf life. This phenomenon has important implications for pharmaceutical policy and waste prevention. It reflects a persistent over-prescription, suboptimal adherence, or precautionary stockpiling, particularly without financial or behavioral incentives to complete prescribed regimens.

Given that unexpired medicines often remain pharmaceutically viable, their disposal represents economic loss and a missed opportunity for recovery, redistribution (in regulated contexts), or prevention of waste at source. These insights support the need for targeted interventions such as improved patient education, digital adherence tools, more precise prescribing practices, and potentially take-back systems with eligibility for redistribution where legally and ethically permissible.

Analysis of unused medications according to the Anatomical Therapeutic Chemical (ATC) classification system (Table 1) revealed that certain therapeutic groups are disproportionately represented in pharmaceutical waste. The observed distribution may be partially influenced by recent policy developments—specifically, the introduction of free drug entitlements, effective September 1, 2023, and access to free medications for specific population groups (Act of 13 July 2023). Under this regulation, individuals aged 65 and above are entitled to receive prescribed medications free of charge, provided two conditions are met: the patient has a diagnosed condition that falls within the scope of reimbursement indications, and

the medication is included in the official list of reimbursed drugs. This entitlement has also been extended to children and adolescents under 18. Similarly to seniors, eligible young patients must have a confirmed diagnosis aligned with the reimbursement criteria, and the prescribed medication must be listed in the national reimbursement register. The list of medications available free of charge to children and adolescents includes a broad spectrum of therapeutic categories, such as antihistamines, hormonal agents, immunostimulants, antibacterial, antifungal, and antiviral drugs, as well as analgesics, anticonvulsants, anti-infectives, and vaccines. Importantly, the list of free medications is dynamic and subject to regular updates—potentially several times per year—reflecting changes in therapeutic standards, market availability, and health policy priorities. This measure aims to reduce economic barriers to pharmaceutical access among vulnerable age groups and support adherence to prescribed therapies in chronic and acute conditions.

The data (Table 1) indicates that waste is not solely associated with acute therapies. Many of the most wasted medications are used for chronic or age-related conditions, aligning with the therapeutic needs of older adults, particularly those over 65, who are newly entitled to free medications in Poland. While the policy increases access, it may unintentionally contribute to stockpiling or reduced adherence without adequate monitoring and patient support. Introducing a policy providing free pharmaceuticals to specific patient groups could significantly impact the disposal practices of unused drugs brought to pharmacies. Such initiatives often lead to increased availability of medications, which may result in a higher surplus of unused drugs if patients do not adhere to prescribed regimens or receive a greater quantity than necessary. This scenario could exacerbate the issue of drug waste, thereby heightening the environmental risks associated with improper disposal practices. One study highlights that unused medications contribute to household waste, with many individuals discarding these drugs improperly by throwing them into regular garbage or flushing them down toilets (Vogler et al., 2014; Ayele & Mamu, 2018). In environments where free drug policies are implemented, an influx of pharmaceuticals without adequate patient education about responsible use and disposal may increase the volume of drugs requiring safe disposal. Research indicates that many households lack awareness about the appropriate means of disposing of medications, often resorting to unsafe practices that can lead to contamination of local environments. For instance, household disposal practices have been shown to lead to significant levels of pharmaceutical contaminants in landfills and water

sources (Insani et al., 2020; Kahsay et al., 2020). Moreover, take-back programs are central to mitigating this waste issue. Evidence suggests that when consumers are provided with accessible take-back options—such as designated drug disposal sites within pharmacies—they are more likely to return unused medications (Kahsay et al., 2020; , Alghadeer & Al-Arifi, 2021). Countries like Sweden and the USA, which have established structured drug take-back systems, demonstrate how convenience can enhance participation in safe disposal practices (Abuassonon et al., 2019). However, if free drug policies are not accompanied by public educational campaigns about the environmental impacts of drug waste and the importance of utilizing these take-back systems, the effectiveness of these programs may be compromised. Research shows how specific disposal education can bolster public participation in drug take-back schemes, revealing that individual knowledge directly influences proper disposal behavior (Amoabeng et al., 2022). This situation underscores the importance of a comprehensive approach combining the provision of free drugs with robust educational initiatives aimed at promoting both medication adherence and environmentally responsible practices. Additionally, it should be noted that perceptions of responsibility towards proper disposal also play a crucial role. Studies indicate that a significant percentage of the public believes they should take responsibility for drug disposal, yet they often lack the necessary information or systems to facilitate proper behavior (Bean et al., 2016; , Alghadeer & Al-Arifi, 2021). Thus, as free drug policies expand access, it becomes paramount to integrate educational efforts about safe disposal and implement accessible return systems to ensure that increased supply does not translate to elevated environmental harm.

The pharmaceutical substances most frequently identified in the collected waste suggest distinct age-related usage patterns. Several medications are strongly associated with older adults, particularly those used to manage chronic conditions (Atella et al., 2019). For example, pantoprazole, ramipril, captopril, metformin, and acetylsalicylic acid (aspirin) are commonly prescribed for patients over the age of 50, particularly for managing hypertension, type 2 diabetes, cardiovascular disease, and gastrointestinal conditions (Cena et al., 2020; Glossmann et al., 2019; Reid et al., 2018; Salvatore et al., 2020). The high presence of these drugs in the waste stream may reflect issues such as polypharmacy, non-adherence, therapeutic substitution, or discontinuation due to side effects—factors particularly relevant in older populations. Other medications, such as tramadol with paracetamol and diclofenac, are also commonly used among older adults and middle-aged individuals for

managing chronic pain, osteoarthritis, and post-operative conditions (Findikli & Altun, 2016; Scott & Perry, 2000). The disposal of these agents might result from changes in pain management strategies or concerns about long-term use and safety in older patients.

As a key stakeholder in the pharmaceutical supply chain, industry actors must not only prioritize access and efficacy but also address the environmental and social consequences of product disposal. This includes supporting take-back programs, investing in eco-design of packaging and formulations, and collaborating with public health agencies to promote responsible medicine use. The study may indicate that the pharmaceutical industry's responsibility is not only the scope of developing and delivering safe and effective medicines, but also participation in ensuring the responsible disposal of unused and expired products. In line with the European Commission's definition of ESG and corporate social responsibility (CSR)—which frames CSR as the duty of enterprises to manage their societal impacts—pharmaceutical firms are uniquely accountable, given the direct consequences of their operations on human and environmental health. CSR in the pharmaceutical sector increasingly includes mechanisms like product take-back programs, improved distribution forecasting, and consumer education to reduce over-prescription and waste (Tat et al, 2021, Sabbaghnia et al, 2024).

Despite growing attention to these initiatives, the current data demonstrate persistent inefficiencies in medicine use, with a significant percentage of drugs being disposed of before their expiration. This trend contributes to environmental pollution, risks to public health, and unnecessary financial burdens on healthcare systems. Moreover, studies such as Droppert and Bennett (2015) highlight that CSR strategies often emphasize health systems strengthening and local partnerships, but rarely integrate structured pharmaceutical waste management as a core business responsibility. As pharmaceutical companies evolve from philanthropic models toward shared value strategies, a more explicit integration of waste reduction and circular economy principles is warranted. Addressing medicine waste must become a pillar of the pharmaceutical industry's CSR agenda, aligned with sustainable development goals and stakeholder expectations in high-income and low- and middle-income countries. In addition, there is a direct link to at least two sustainable development goals, i.e., ensure healthy lives, promote well-being for all ages (SDG 3), and ensure sustainable consumption and production patterns (SDG 12).

6 Conclusions

Conducting research following the adopted scheme may be further continued and scaled up to a broader level, allowing for more comprehensive data collection and deeper analysis. Building on these initial findings, future research should explore several complementary areas. First, longitudinal studies could track seasonal or policy-related variations in pharmaceutical waste volumes and composition. Second, comparative studies across different pharmacy settings—urban vs. rural, public vs. private—would offer broader insights into patient behavior and disposal practices. Moreover, qualitative research involving patient and pharmacist interviews could deepen the understanding of motivations behind improper disposal, medication non-adherence, or precautionary stockpiling. Special attention should be paid to the impact of public reimbursement policies, such as the free drug entitlement for seniors and minors, on drug overuse and wastage.

From the circular economy perspective, increased pharmaceutical waste undermines the principles of resource efficiency and responsible consumption. Medicines are complex, high-value products involving intensive raw material usage, energy consumption, and emissions throughout their lifecycle—from production to disposal. An increase in unused medicines translates to increased demand for new production and intensifies the environmental footprint of the pharmaceutical supply chain.

Furthermore, medicine disposal programs' logistics and financial burden fall largely on health systems and local authorities. As the volume of returned medications grows, so do the costs of collection, sorting, and high-temperature incineration—often the only environmentally acceptable method for safe pharmaceutical waste treatment. These factors necessitate integrating waste prevention strategies into pharmaceutical policy, including more personalized prescribing, improved patient education, and systematic analysis of disposal trends.

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