

Article

Proposing a Framework for Ballistic Waste Management in the Context of the Public Security Institute

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Abstract: The aim of this research was to develop and validate a framework capable of enhancing the management of ballistic waste considering the context of the training activity of a Public Security Institute in Belém do Pará. A literature review was adopted as a method to provide the theoretical basis necessary to understand the context and develop the proposed conceptual framework, a questionnaire was developed and applied to security professionals, and the data were analyzed using the Lawshe-TOPSIS hybrid approach to validate the framework. The results make it possible to present, in an organized manner, a set of variables considering challenges and benefits for a framework for ballistic waste management. It is possible to conclude that ballistic waste management, especially in environments such as shooting ranges, is configured as a multifaceted challenge that demands a highly complex technical, normative, and operational approach.

Keywords: framework; ballistic waste; environmental management; sustainability



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1. Introduction

Currently, studies have highlighted the different negative impacts caused by ballistic waste, which is material left over from the use of firearms, such as projectile fragments, cases, cartridges, and gunpowder residue [1]. This waste, when accumulated in the environment, especially in military training areas, shooting clubs, or conflict zones, can release heavy metals such as lead, antimony, copper, nickel, and zinc, and the presence of these elements is associated with various environmental problems and risks to human health [2–4].

In this context, we consider, specifically, the dynamics of shooting ranges, where Public Security professionals are trained using live ammunition, which, according to Souza et al. [3], is generally made up of lead (Pb) projectiles, which, when fired, are deposited in ravines. According to Souza et al. [3], the dynamics of how a firearm fires involve various chemical elements. According to Borges [5], this is due to gaseous expansion occurring in the forward region of the gun barrel, although part of the gaseous mass flow is expelled from the rear region of the gun. Borges [5] points out that this flow contains gases from combustion (CO₂ and SO₂), as well as various inorganic compounds, such as antimony. Costa et al. [6] adds that Pb is a heavy metal that can have harmful consequences for living beings and the environment.

In this context, the National Solid Waste Policy (PNRS) establishes principles, objectives, guidelines, goals and actions, and important instruments, such as the National

Solid Waste Plan, which is in the process of being built and will cover the various types of waste generated, management alternatives that can be implemented, and goals for different scenarios, programs, projects, and corresponding actions [7].

Lisboa et al. [8] emphasize that it is important to research the control of residues from firearms discharges, as is the case with constant and exhaustive training carried out by Public Security professionals. In this context, it is worth highlighting some examples of projects and programs used to deal with this type of residue, such as the Ammunition Waste Management Program—Federal Police (Brazil), Recycling of Expendable Cartridges—São Paulo Military Police (PMSP), Project for the Recovery of Shooting Range Areas—German Army (Bundeswehr), and the “Green Ammunition” Project (USA/NATO).

In this dynamic, Oliveira Sousa et al. [9] show that this accumulation of heavy material waste, such as Pb, not only poses risks to the environment but also raises serious public health and safety concerns. It is therefore imperative to address this issue in a systematic and structured way through the development of a comprehensive framework for the management of these tailings.

In addition, Barroso et al. [10] point to the need to understand and contextualize the environmental and social impact of ballistic waste. Barroso et al. [10] also point out that cases and cartridges can contain heavy metals such as lead, cadmium, and zinc, which are harmful to soil, water, and wildlife. In addition, Haltenburg et al. [11] show that these materials are not biodegradable and can remain in the environment for long periods, contributing to environmental pollution. From a social perspective, the presence of ballistic waste in urban areas can foster a sense of insecurity, as well as potentially being reused for criminal purposes.

In this dynamic, in the specific case of shooting ranges, Public Security professionals are trained using live ammunition, which, according to Souza et al. [3], is generally made up of lead (Pb) projectiles, which, when fired, are deposited in ravines. According to Souza et al. [3], the dynamics of how a firearm is fired involve various chemical elements. According to Borges et al. [5], this is due to gaseous expansion occurring in the forward region of the gun barrel, although part of the gaseous mass flow is expelled from the rear region of the gun. Borges et al. [5] points out that this flow contains the gases from combustion (CO_2 and SO_2).

However, in view of the context presented, the literature is still limited in terms of proposing integrated actions that can enhance the mitigation of waste from firearms discharges. Most studies have focused on the chemical and analytical aspects of the elements present in ballistic residues, such as lead, barium, and antimony, leaving in the background approaches to environmental management, occupational exposure prevention, and control strategies in training environments, especially in the field of public security. This is therefore an important gap that jeopardizes the development of effective, sustainable, and applicable solutions for professionals who deal with firearms, such as police officers and security agents.

To this end, this gap highlights the need for research that can support the development of actions aimed at this context, where the challenges to be overcome and the benefits that can be achieved are still unknown. In this way, it becomes possible to contribute to the management of this waste and propose effective solutions to mitigate its impact on the environment.

In view of the above, this study sought to answer the following research question: “What should a framework capable of enhancing the management of ballistic waste from shooting range training look like?”. To answer this question, the study aimed to propose and validate a framework capable of enhancing the management of ballistic waste from the perspective of professionals who work in training activities in the area of public security.

The framework developed was validated with professionals working in the public security sector in the state of Pará, Brazil. The choice of this audience was justified by the relevance and frequency with which these professionals use firearms in operational training and are therefore directly exposed to ballistic residues generated during these activities. This condition makes them fundamental sources of practical knowledge for evaluating the applicability and effectiveness of the proposal, as well as for providing information on the challenges faced and opportunities for improvement in the management of this waste.

2. Literature Review

Ballistic Waste and Its Impact on Health and the Environment

According to Krishna and Ahuja [12] and Burnett and Nunziata [13], ballistic residues, also known as gunshot residues (GSRs), consist of particles resulting from the deflagration of ammunition, composed of heavy metals such as lead (Pb), antimony (Sb), barium (Ba), copper (Cu), and zinc (Zn). These particles are generated from the components of the fuze, propellant, projectile, and case and are dispersed at the moment of firing and can be deposited on the shooter's hands, clothing, the victim's body, and the environment [12–14].

In the environmental context, GSRs represent a source of pollution. Based on the study carried out by Maia et al. [1], it was found that even ammunition considered non-toxic can release particles of metals such as zinc, copper, and lead, contaminating the air and soil of open shooting ranges. Such a scenario exposes shooters to the inhalation of dangerous particles, as well as contributing to environmental pollution, thus requiring more effective controls and safety protocols to reduce exposure.

The complexity of GSR also lies in its persistence and potential for bioaccumulation. Kim et al. [15] point out that lead, barium, and antimony present in waste have high toxicity and low biodegradability, making them harmful to the environment and human health. Continuous exposure to these metals can cause neurological, cardiovascular, and kidney diseases. In addition, growing concern about environmental impacts has encouraged the adoption of less toxic ammunition and the application of detection methodologies based on organic compounds as alternatives to traditional tests with inorganic elements [16,17].

Complementing this discussion, Witt et al. [18] demonstrated that cadavers exposed to the environment or buried for long periods did not show detectable levels of lead, barium, or antimony when analyzed by ICP-MS, reinforcing the specificity of ballistic residues as forensic indicators of shooting.

Ribeiro et al. [19] warn of the risk of industrial and occupational sources generating particles similar to GSR, as in the case of nail gun cartridges and fireworks. These similarities make forensic interpretation difficult and show that ballistic residues go beyond the criminal sphere, also reaching the field of environmental and occupational health.

From a broader perspective, Meireles [20] notes that accelerated urbanization, population growth and increased consumption have exacerbated the generation of solid waste in general, requiring more efficient responses from governments, industries, and civil society. Mendes et al. [21] and Abubakar et al. [22] also recognize that waste management has become a central issue on global agendas, involving concerns about the environment, public health, and sustainable development. In this logic, ballistic waste emerges as a category that deserves attention because it is classified as hazardous waste that can be harmful not only to the environment but also to health [23].

According to Gallo and Silva Augusto [24], solid waste covers a wide range of discarded materials and is classified, according to Mendes et al. [21], as organic, recyclable, non-recyclable, and hazardous—a category that includes ballistic waste. Its management therefore requires precise identification and specific treatment, given the toxicity of its components [25].

Because ballistic waste is hazardous to health and the environment, it is a growing challenge as society deals with the impacts of armed violence and environmental degradation [26]. According to Ferreira et al. [27], this issue must be understood in an integrated way, considering both the risks to public safety and environmental risks. An unused or improperly disposed weapon represents a double threat: social and ecological.

Hoch and Bruce [28] warn that during firing, metals such as lead and barium can be released into the environment, accumulating in the soil and potentially contaminating flora, fauna, and water resources. Silva et al. [29] explain that residues from gunshots contain burnt and unburnt gunpowder; fragments of the fuze, case, and bullet; and metal particles from the barrel of the gun. These materials disperse easily, affecting not only the shooter but also the surrounding environment.

The toxicity of lead is particularly alarming. According to the National Institute for Occupational Safety and Health—NIOSH [30], exposure to inorganic lead can cause hematological, neurological, endocrine, cardiovascular, reproductive, and renal damage. In this regard, Silva et al. [31] emphasize the need for awareness and education programs about the risks of lead since knowledge is a powerful tool in mitigating this pollutant.

In the Brazilian context, the existence of legislation that is a fundamental instrument and provides guidelines for this type of waste, such as CONAMA Resolution 357/2005, establishes water quality limits, including a maximum limit of 10 µg/L of lead, reinforcing the importance of regulation for the protection of public health and aquatic ecosystems [32]. The Ministry of Health, in turn, adopts the same limit in its water potability standard, showing a regulatory concern with human exposure.

Even so, as Souza et al. [3] have shown, there is a worrying contradiction: public security professionals, by qualifying through firearms training at shooting ranges, may be contributing to the contamination of soil and water with lead where specific environmental mitigation policies for these spaces are lacking. The necessary practice of professional activity clashes with the environmental risks it generates, revealing an ethical and environmental dilemma that needs to be addressed.

3. Research Methodology

This was an exploratory and descriptive study with a quantitative and qualitative approach.

This research was carried out considering the execution of five well-defined stages, namely: (a) literature review for the theoretical foundation necessary to understand the context and elaborate the proposed conceptual framework; (b) development of the questionnaire to be applied to the security professionals who use it; (c) execution of the survey; (d) treatment of the data collected via a hybrid Lawshe-TOPSIS approach for the validation of the framework; (e) elaboration of associated debates and conclusions.

In stage 1 of the literature review, the following scientific databases were consulted: Emerald Insight, Science Direct, Web of Science, Scopus, and MDPI. The search terms used in the scientific databases were the following: “Ballistic waste management”, “Environmental protection”, “Shooting range”, “Projectile”, and “Gunpowder waste”. These terms were also used in combination using the “AND” function in the searches of each scientific database. The references found served as the basis for the research context presented in the introductory section, the theoretical framework section, and the proposed conceptual framework, which considered the challenges and benefits of the literature on ballistic waste management.

Once the challenges and benefits had been identified in the literature, we moved on to stage 2, i.e., structuring and drafting the questionnaire to be applied to public security professionals in the state of Pará, Brazil. The questionnaire was made up of three parts, with the first corresponding to the respondent’s characterization data (length of experience

in the sector, academic qualifications, and position held in public security). The second part of the questionnaire corresponded to an analysis of the challenges and benefits for ballistic waste management. In this part, the professional respondents were asked to analyze each challenge using a three-point scale, where they had to judge whether overcoming that challenge was essential for promoting efficient ballistic waste management. The three-point scale used judged whether overcoming the challenge was essential; important, but not essential; or not essential for overcoming the challenges analyzed.

As for the benefits, for each one, the professionals had to judge, on a scale of 0 to 10, with intermediate scores being freely assignable, how decisive the benefit analyzed was for promoting ballistic waste management, where a score of 0 meant that the benefit was not decisive for promoting ballistic waste management and a score of 10 meant that the indicator was extremely decisive for efficient ballistic waste management. In total, 7 challenges and 6 benefits were considered in the survey.

Stage 3 consisted of applying the survey to the professionals by means of a data collection questionnaire. The questionnaire was sent to professionals working in the public security sector who practice shooting at the IESP range in the municipality of Marituba, a city located in the state of Pará, Brazil. The IESP in Marituba is one of the main training institutions for public security agents in the state and is a benchmark in weapons training and operational practices. The choice of the IESP as the study site was justified by the frequency and intensity of the ballistic activities carried out there, which increase the generation of contaminating waste such as heavy metals from the burning of ammunition [33]. The questionnaire was sent out by e-mail, social media chats, and messaging apps, with a deadline of 30 days to respond.

The survey was sent to a total of 160 public safety professionals and 41 responses were received, resulting in a return rate of 25.63%. The criteria for participating as a respondent included public security professionals who practiced shooting at the IESP stand. Of these 41 respondents, 56.1% had a specialization degree, 22.0% had a master's degree, 14.6% had a doctorate, and 7.3% only had an undergraduate degree. About length of experience in public security, 58.5% had between 21 and 30 years' experience in the area, 29.3% had between 11 and 20 years' experience, and 12.2% had between 1 and 10 years' experience.

Stage 4 then involved processing the data collected. To do this, the Lawshe and TOPSIS methods were used together. As the aim was to validate the challenges to be overcome in the context, the Lawshe method was applied considering the data collected. TOPSIS was used to analyze the indicators since the aim was to order them considering how decisive each benefit was for promoting ballistic waste management in the context of an IESP. The Lawshe guidelines were followed [34] and applied according to Moreira et al. [35] and Marinho et al. [36], and for TOPSIS, we used the guidelines of Singh et al. [37] and the application of [38]. The step-by-step applications of the Lawshe and TOPSIS methods carried out in this study are detailed below.

It should be noted that the Lawshe method is applied in analyses aimed at specialists in each context and that aim to validate items for the context under analysis. In the case of this research, the items corresponded to the challenges. Based on the questionnaires answered, the method was applied by initially calculating the CVR—Content Validity Ratio—for each challenge in the questionnaire, as shown in Equation (1).

Here, n_e : number of experts who consider the criterion to be “Essential” and N : total number of experts who took part in the survey. In this way, the CVR varied between -1 and $+1$ so that -1 characterized perfect disagreement while $+1$ characterized perfect agreement. The CVR was positive in the scenario in which 50% of the answers were “essential”, and on the other hand, the CVR would be negative when fewer than 50% of the experts indicated “non-essential”. When the CVR was equal to zero, this indicated that half of the experts

answered “essential” and the other half did not [34]. Values below the critical threshold could be excluded from the final version. To calculate $CVR_{critical}$, the average was first calculated according to Equation (2).

Here, “n” was the number of respondents and “p” was the probability of signing the alternative as essential. The variance and standard deviation were calculated from the mean, as shown in Equations (3) and (4). With the above calculations, it was possible to define $CVR_{critical}$, as shown in Equation (5). $v_{necritical} = \mu + z \times \sigma$, considering the value of $z = 1.96$ and the significance level of 5%, in the standard normal distribution.

Equation (1)—Content Validity Ratio

$$VR = \frac{ne - \frac{N}{2}}{\frac{N}{2}} \quad (1)$$

Equation (2)—Average

$$\mu = n \times p \quad (2)$$

Equation (3)—Variance

$$\sigma^2 = \mu \times (1 - p) \quad (3)$$

Equation (4)—Variance

$$\sigma = \sqrt{\sigma^2} \quad (4)$$

Equation (5)—Content Validity Ratio Critical

$$CVR_{critical} = \frac{necritical - \left(\frac{N}{2}\right)}{\frac{N}{2}} \quad (5)$$

Regarding TOPSIS, which was used to generate the ranking of the indicators considered in this study, this method is suitable for exploratory studies to broaden the debates in the context analyzed. Examples of the application of the TOPSIS method in exploratory research can be seen in [39,40].

The method was applied using the averages assigned by the groups of respondents considered in this study. Different weights were assigned to the groups and, consequently, the degrees of importance were varied, helping provide rationale and efficiency in decision-making. The weights assigned to each of the respondent groups were 0.50 for Group 1 (respondents with over 25 years’ experience), 0.30 for Group 2 (respondents with between 15 and 25 years’ experience), and 0.20 for Group 3 (respondents with up to 15 years’ experience).

Once the group weights had been defined, the seven TOPSIS steps were developed. Initially, a matrix D had to be structured with elements (xij), where (i) referred to the alternatives and (j) referred to the analysis criteria. For this study, the alternatives corresponded to the benefits of effective ballistic waste management identified in literature and considered in this study and the criteria corresponded to the averages assigned by each group of respondents.

The mathematical representation of Matrix D is shown in Matrix 1 of Table 1. The second step was to normalize the D matrix using Equation (6), resulting in a matrix called the R matrix.

Table 1. TOPSIS method matrices and equations.

Matrix 1	$D = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$	Equation (6)	$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^n x_{ij}^2}$
Matrix 2	$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}$	Equation (7)	$v_{ij} = w_j r_{ij}$
Matrix 3	$V = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1n} \\ v_{21} & v_{22} & \dots & v_{2n} \\ \dots & \dots & \dots & \dots \\ v_{m1} & v_{m2} & \dots & v_{mn} \end{bmatrix}$	Equation (8)	$s_i^* = \left[\sum_j (v_{ij}^* - v_j^+)^2 \right]^{1/2}$
		Equation (9)	$s_i' = \left[\sum_j (v_{ij}' - v_j^-)^2 \right]^{1/2}$
		Equation (10)	$c_i^* = \frac{s_i'}{(s_i^* + s_i')}$

Subsequently, the values in Matrix R were weighted using Equation (7), resulting in Matrix V. The ideal positive (v_j^+) and negative (v_j^-) solutions were then determined, i.e., the maximum and minimum values in Matrix V for each of the analysis criteria were calculated.

The positive and negative Euclidean distances of each alternative were then calculated using Equations (8) and (9) (Table 1). Finally, using the Euclidean distance values, the C_i^* indicator was calculated and, using this indicator, the 15 sustainability indicators were ranked. It should be noted that the C_i^* values had to be between 0 and 1. The C_i^* indicator was calculated using Equation (10) (Table 1).

In this way, a conceptual framework was proposed for the management of ballistic waste considering the context of a firing range at a Public Security Institute.

4. Results and Discussion

This section explains the indicators and challenges of ballistic waste management in the context of an IESP firing range. The suggested conceptual model, the analysis of the data obtained using the Lawshe and TOPSIS methodologies, the validation of the model, the relevant discussions, and the theoretical, practical, and political consequences involved are all addressed.

4.1. Challenges and Benefits of Ballistic Waste Management in the Context of a Public Security Institute Shooting Range

As a summary of the discussions resulting from the literature review carried out and presented in Section 2 of this article, Table 1 presents sustainability indicators and a description of each one, as well as challenges to be overcome in order to promote ballistic waste management considering the context of a shooting range at a Public Security Institute, which are already in the literature and which served as the basis for carrying out the survey among the professionals taking part in the research and were consequently taken into account when drawing up the proposed conceptual framework and also in the validated framework.

In general, ballistic waste management is a significant challenge for the Public Security Institute surveyed, given the increase in the use of firearms and the generation of waste

associated with their use. Waste can include, among other things, cartridges, unused projectiles, discarded gun parts, and packaging materials. The improper disposal of this waste can lead to serious environmental and public health problems, as well as legal implications for the institutions involved. In this context, a structured and well-founded approach is essential to ensure the proper management of these materials.

In the case of the proposal in this article, it is understood that once lead is taken into the body, according to Arnemo et al. [41], it is distributed throughout the body in the blood and accumulates in the bones. Depending on the level of exposure, lead can adversely affect the nervous system, kidney function, the immune system, the reproductive and developmental systems, and the cardiovascular system. Thus, it can be said that the efficient management of this waste is essential to mitigate risks and ensure that these objects are not misused. However, this is a field that presents multifaceted challenges, ranging from logistical and technical aspects to legal and ethical issues, as can be seen in Table 2.

Therefore, it is understood that the public security officers who work at the IESP firing range and the community around the institution may suffer various health problems due to the inhalation of Pb particles and soil pollution at the site. It is therefore important to research the proposal of a process that could be applied to reduce the damage caused by Pb exposure at the IESP.

In this way, we sought to identify the benefits (Table 3) of effective ballistic waste management by proposing the structuring of an Environmental Management System through a framework for ballistic waste management aimed at reducing the environmental impact of Pb, as well as at maintaining the operational efficiency of the IESP. Ultimately, the proposal for this framework will be aligned with the objective of identifying opportunities to bring benefits to the IESP's environmental performance.

Table 2. Challenges in ballistic waste management.

Code	Challenges	Description	References
D_01	Analyzing and confirming the presence of certain elements present in the formation of gunshot residues (GSRs).	Analyze the risks associated with the main firearms residues contained in military ammunition and the damage to human and environmental health.	[5,11,42–45]
D_02	Demonstrating the risks to which public security professionals are exposed when training to shoot from a stand.	Evaluate their possible impact on the environment and the risks to the health of public security professionals due to exposure to gunshot residues based on legislation.	[3,42,45,46]
D_03	Surveying the adverse effects of Pb on health and impact on the environment.	Identify the levels of Pb found in the soil at the Public Security Institute stand and compare them with the environmental and occupational safety legislation in force.	[4,10,31,47,48]
D_04	Analyzing and establishing the environmental conditions of the soils at the Public Security Institute's firing range and compare them with CONAMA Resolution 420/2009.	It is necessary to identify whether there is adequate environmental control of the waste produced by the training, considering that the greater the use is, the more disposal of ballistic waste will be necessary.	[43,49]

Table 2. Cont.

Code	Challenges	Description	References
D_05	Preventing or reducing contamination with pollutants from firing firearms at the Public Security Institute's firing range.	Identify and analyze the rules for implementing the correct process of handling and disposing of them, as an important tool in the concept of sustainability, aimed at preserving the environment.	[31,42,45]
D_06	Adaptation of protection measures for Public Security professionals who work at the Public Security Institute's firing range and security workers and adaptation of legislation on tolerance limits and biological indices used in occupational health control.	Adapt the use of the Public Security Institute's shooting range so that it minimizes contamination and protects public security professionals from the health and environmental risks posed by the range.	[1,31,43,50]
D_07	Identifying the reverse logistics of unexploded ammunition used in training at the Public Security Institute.	Identify the contributions of reverse logistics to reducing the environmental and health impacts on public security professionals and the environment around the Public Security Institute.	[11,45,51–54]

Table 3. Benefits of effective ballistic waste management.

Code	Benefits	Description	References
B_01	Reuse of solid waste resulting from gunshots	The reuse of solid waste from firearms is an important practice for minimizing environmental impacts and promoting sustainability at IESP.	[2,3,41,55]
B_02	Guarantees business continuity	It will enable IESP to operate sustainably, meeting legal requirements and contributing to the health and safety of its professionals.	[5,31,56]
B_03	Reduced impact on health and the environment	Draw up procedures to minimize the adverse effects of lead exposure on human health and safety.	[29,57,58]
B_04	Compliance with legislation	Prioritize IESP's actions in accordance with the values, rules, and conduct established by Brazilian environmental legislation, as well as enhancing the use of resources with responsibility and transparency.	[2,3,41,55]
B_05	Improving the organization's image	Plan to improve information by adding value to IESP's corporate image.	[59,60]
B_06	Contribution to the preservation of the environment	Propose strategies to reduce the environmental and toxicological impacts of ammunition at the Public Security Institute's firing range.	[2,31,61]

Given this context, it can be concluded that lead contamination represents a serious threat to human health and the environment. The implementation of mitigation and

control strategies, together with the application of stricter legislation and regulations, are fundamental to minimizing the negative impacts. Furthermore, the need for future research is evident, aimed at deepening knowledge about the dynamics of lead contamination, the effects on specific ecosystems, and the development of more sensitive and effective detection methods.

Considering the complexity of lead contamination, it is crucial to direct efforts towards future research that addresses identified knowledge gaps, such as the investigation of new emission sources, the improvement of lead analysis techniques in different environmental matrices, the evaluation of impacts on aquatic ecosystems, and the identification of more efficient remediation strategies.

In addition, studies on the long-term effects of Pb contamination on human health and affected communities are essential to inform decision-making and the implementation of appropriate protection measures.

It is envisioned that the proposed Environmental Management Framework on Pb could be used as a powerful tool to manage environmental aspects and the negative impact that Pb can have on the research institution.

4.2. Proposed Conceptual Framework

The literature review showed that shooting practice at the Public Security Institute's training booths is essential for training professionals. However, the firearms generate gunshot residues (GSRs), made up of particles containing heavy metals such as lead (Pb), antimony (Sb), and barium (Ba), as well as other chemical elements. This waste poses potential occupational health risks to professionals who visit the stand, as well as having an adverse impact on the environment, especially the soil.

Considering the identification of stakeholders, challenges, and indicators derived from the literature review, the suggested conceptual framework was developed (Figure 1). The central objective was to present, in an organized manner, a set of variables for a conceptual framework for ballistic waste management considering the context of a shooting range at a Public Security Institute.

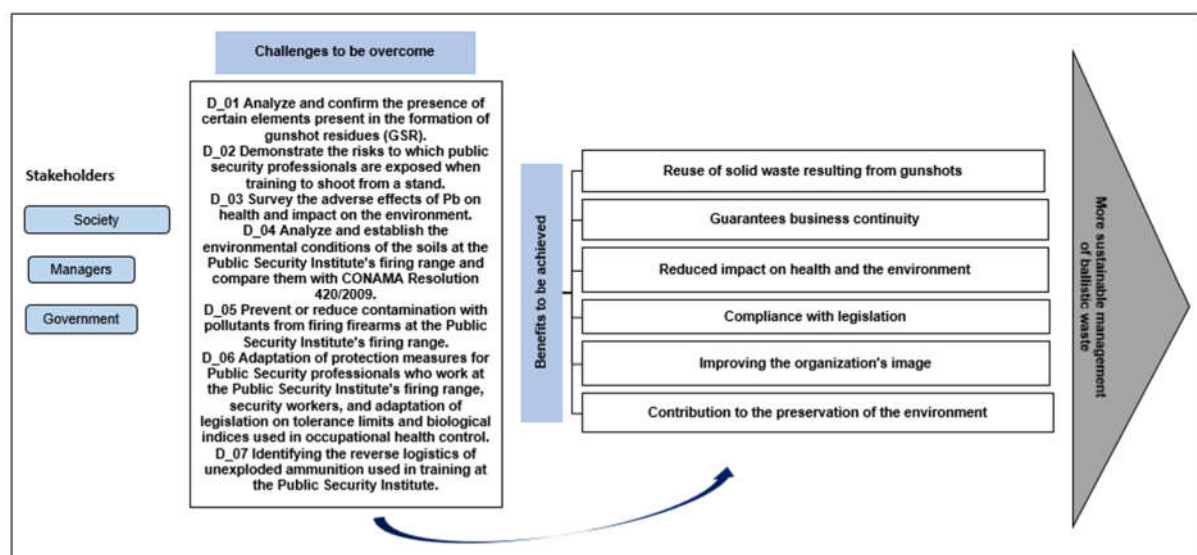


Figure 1. Proposed conceptual framework.

The suggested conceptual model highlights the importance of society, administrators, government authorities, and public security managers as the main stakeholders in promoting a more sustainable organization. The structure of the model is made up of seven

challenges that need to be addressed to implement the proposed framework integrating technical, environmental, and occupational protection measures, promoting the efficient management of the ballistic waste generated at the IESP firing range.

With this model, it is hoped to achieve greater safety for public security professionals, compliance with current environmental standards, and a reduction in impacts on health and the environment, while, at the same time, contributing to the sustainability of the Institute's operations. Once the challenges have been resolved, the benefits identified in the model should be analyzed to assess the effectiveness of sustainable practices, ensuring continuous improvement actions in the sector and contributing to ballistic waste management.

It is important to note that the conceptual framework presented is based on the conclusions drawn from the literature review.

4.3. Application of the Lawshe-TOPSIS Approach

Initially, Lawshe's method was applied to the validation analysis of the challenges considered in this study. Therefore, according to the methodological procedures presented above, the CVR values for each challenge were calculated. The $CVR_{critical}$ (cut-off parameter) was then calculated. It is worth noting that the sample considered in the calculations for this study included 41 professionals working at the Public Security Institute. The $CVR_{critical}$ was 0.306.

Therefore, challenges with a coefficient greater than 0.306 were considered valid and, consequently, those with a lower value were considered not valid, in the specific case of identifying the reverse logistics of ammunition used in training. Please refer to Table 4 for the validation analysis of challenges using Lawshe's method.

Table 4. Validation analysis of challenges using Lawshe's method.

Challenges	Number of "Essential" Reviews	Content Validity Ratio (CVR)	CVRcritical Validation Reference: 0.306	Validated/ Not Validated
Determining elements present in firearms residues	28	0.366	✓	Validated
Demonstrating the risks of stand fire training	30	0.463	✓	Validated
Investigating the adverse effects of Pb on health and the environment;	27	0.317	✓	Validated
Establishing the environmental conditions of the firing range grounds	30	0.463	✓	Validated
Preventing or reducing contamination with pollutants from firearm discharges	31	0.512	✓	Validated
Adequate protection measures for public security professionals working at the shooting range	33	0.610	✓	Validated
Environmental education with regard to environmental management laws	32	0.561	✓	Validated
Identifying the reverse logistics of unexploded ammunition from training sessions	0	−1.000	X	Not Validated

In view of the results found, it can be seen in Table 4 that only the challenge "Identifying the reverse logistics of unexploded ammunition in training" was not validated.

Therefore, these challenges are considered in the validated framework presented below, where they are discussed and detailed in the light of the literature in the area.

The TOPSIS method was then applied to analyze and rank the benefits. Initially, the average (Table 5) of the scores attributed by each professional to each of the indicators considered in this study was calculated and these averages were normalized, resulting in the matrix shown in Table 6.

Table 5. Averages attributed to the benefits analyzed.

Benefits	Over 25 Years (0.50)	Between 15 and 25 Years Old (0.30)	Up to 15 Years (0.20)
B01—Effective reuse of solid waste	8.77273	9.285714286	7.80000
B02—Ensures business continuity	7.86364	8.428571429	8.80000
B03—Reducing impacts on health and the environment	9.00000	9.571428571	10.00000
B04—Compliance with legislation	8.95455	9.214285714	9.20000
B05—Improving the organization's image	9.31818	9.857142857	9.80000
B06—Contribution to the preservation of the environment	9.45455	9.785714286	8.60000

Table 6. R matrix with normalized values.

rij + 25 Years	rijentre15e25	rijaté15
0.402	0.405	0.351
0.360	0.367	0.396
0.412	0.417	0.450
0.410	0.401	0.414
0.427	0.430	0.441
0.433	0.426	0.387

It is worth noting that Group 1 (G1) corresponds to the most experienced respondents, Group 2 (G2) to those with intermediate experience, and Group 3 (G2) to those with the least experience, considering the interval in years as presented in the methodological procedures section.

Weights were then assigned to each group of professional respondents, with Group 1 having a weight of 0.50, Group 2 a weight of 0.30, and Group 3 a weight of 0.20. From this, it was possible to obtain Matrix V (Table 7).

Table 7. Weighted values of the V matrix.

rij + 25 Years $\times$ 0.50	rijentre15e15 $\times$ 0.30	rijaté15 Years $\times$ 0.20
0.201	0.121	0.070
0.180	0.110	0.079
0.206	0.125	0.090
0.205	0.120	0.083
0.214	0.129	0.088
0.217	0.128	0.077

The positive and negative ideal solutions (Table 8) were taken into account when calculating the Euclidean distances of the positive and negative ideal solutions (Table 9). The C_i^* coefficient was then obtained and used to generate the ranking of the benefits (Table 10).

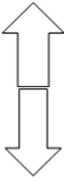
Table 8. Positive and negative ideal solutions.

Ideal Solution A+		
Over 25 Years Old	Between 15 and 25 Years Old	Up to 15 Years
0.217	0.129	0.090
Negative solution A+		
Over 25 Years Old	Between 15 and 25 Years Old	Up to 15 Years
0.180	0.110	0.070

Table 9. Positive and negative ideal solution distances and Ci* coefficient.

Calculation of Si+	Calculation of Si−	Ci
0.026	0.024	0.47333
0.042	0.009	0.17537
0.011	0.036	0.76476
0.016	0.030	0.65180
0.004	0.042	0.92133
0.013	0.041	0.76504

Table 10. Ranking of indicators.

More decisive for solid waste management at the IESP shooting range	Position	(Ci*)	Code	Benefits
	1°	0.921328023	B05	Improving the organization's image
	2°	0.765035798	B06	Contribution to the preservation of the environment
	3°	0.764763943	B03	Reduced impact on health and the environment
	4°	0.651799461	B04	Compliance with legislation
	5°	0.473328356	B01	Effective reuse of solid waste
	6°	0.175368324	B02	Guarantees business continuity
Less decisive for solid waste management at the IESP shooting range				

Therefore, by analyzing Table 10, it is possible to see that the three benefits ranked highest in the ranking generated, i.e., those that, in the opinion of the professionals taking part in the survey, are essential for aligning the operation of stands with environmental sustainability, the protection of human health, legal compliance, and operational efficiency.

It promotes a structured and planned approach to dealing with the specific challenges associated with hazardous waste management, contributing to the long-term viability of shooting activities and reducing negative impacts on the environment and society: improving the organization's image, contributing to the preservation of the environment, and reducing impacts on health and the environment.

These benefits are then considered and presented in rank order in the validated framework, where they are discussed and detailed in the light of the literature.

4.4. Validated Framework and Associated Discussions

As a result of the treatment of the data collected in the survey using the Lawshe and TOPSIS methods, a validated conceptual framework was obtained for the management of ballistic waste considering the context of an IESP firing range (Figure 2). The validation considered the opinion of public security professionals who work in this organization.

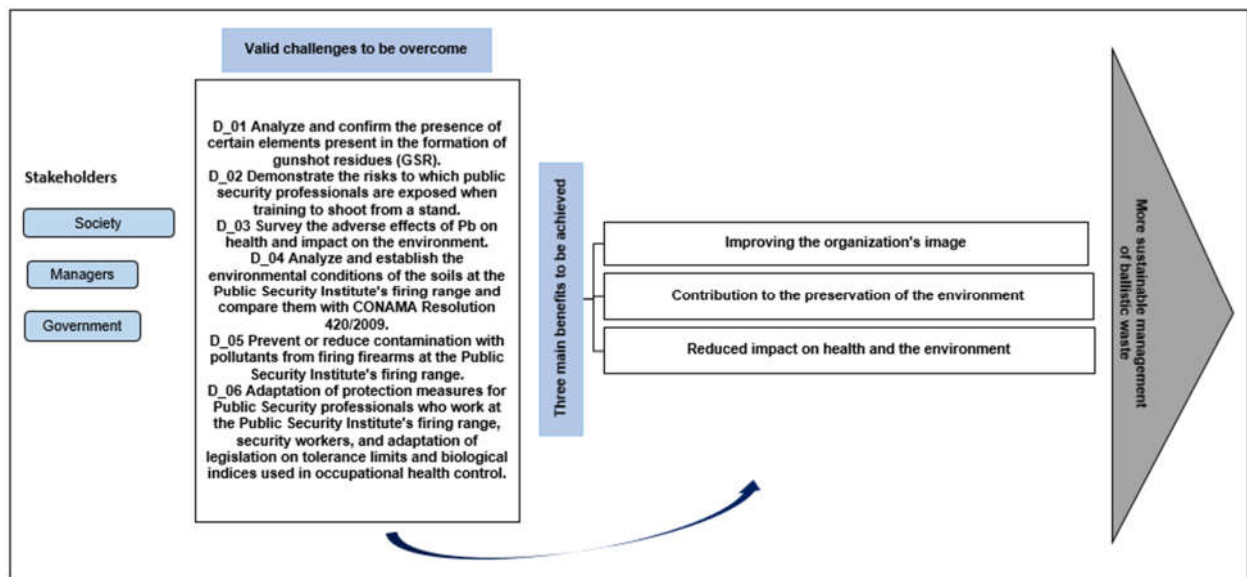


Figure 2. Validated conceptual framework.

According to Figure 2, in relation to the conceptual framework proposed (Figure 1), six challenges were validated for the context of solid waste management as being the essential ones to be overcome by the researched organization.

About the analysis of the benefits seen in the previous figure, the ranking generated by data processing shows the three most decisive indicators for promoting the efficient management of ballistic waste generated at the IESP firing range.

Looking at the validated framework, it is worth highlighting the importance of overcoming the challenge of ballistic waste management as it is necessary to develop a strategy to align the organization with sustainable principles, reduce legal risks, and enhance its reputation.

Silva et al. [31] state that occupational exposure is the main way in which excessive lead absorption occurs in adults. Silva et al. [31] also state that preventive measures have reduced the number of cases of lead poisoning in developed countries, but the consequences of long periods of exposure in asymptomatic workers are not fully understood.

In addition to Souza's assertion [4] that bullets are mainly made of materials that are harmful to the environment and living organisms, such as lead, antimony, and arsenic, these metals contained in the projectiles end up remaining in the ground, posing a risk of polluting the soil, surface water, and groundwater, and environmental management at the IESP firing range should be carried out by managing and minimizing the environmental impacts resulting from gunfire during shooting practice at the range.

Another challenge worth highlighting in the context of environmental management at the IESP shooting range is the reuse of solid waste from shooting ranges, which not only helps minimize the environmental impact but can also serve as an important educational tool in sustainability, promoting a culture of environmental responsibility among users. Implementing this process requires commitment and a collaborative approach between the IESP administration, the shooters, and the local community.

In this sense, Souza et al. [3] state that in most firing ranges, the most significant problems over time have been noise pollution and soil contamination. Souza et al. [3] also state that soil contamination by Pb can occur naturally or geologically, as well as through activities carried out by human beings (mining, industry, and transportation). Souza et al. [3] add that the Pb content in soils varies from region to region: in regions

close to high-traffic roads and industries, Pb levels are much higher than those found in isolated areas.

In the case of the IESP, it can be said that in order to combat the environmental impacts generated by Pb, it is necessary to comply with Brazilian legislation, which, according to Silva et al. [31], through Regulatory Standard NR-7, Ordinance No. 24, of the Occupational Health and Safety Secretariat (SSST), establishes how complementary examinations should be carried out for the Occupational Health Medical Control Program. In the case of Pb, the parameters for the biological control of occupational exposure are compliant.

From the point of view of practical actions, it is important to highlight some actions that converge to enhance the achievement of the sustainable management objectives present in the framework. About this, it is understood that it is necessary to establish the systematic and continuous monitoring of contaminants, for example, through the implementation of a permanent environmental monitoring program in the shooting range areas. Another important point is the mapping and management of occupational risks; in this sense, it is worth carrying out periodic ergonomic and toxicological assessments and creating protocols for rotation and scheduled breaks.

In addition, two other key points are regulatory adequacy and legislative updating and the training and awareness raising of stakeholders. In this sense, it is important to form an inter-institutional working group to review and propose adjustments to the limits of occupational exposure to lead and to promote educational campaigns and regular training for managers, shooters, and support staff, highlighting health risks and good environmental practices.

Therefore, the proposal aims to bring benefits in the implementation of an Environmental Management framework for ballistic waste. It is believed that the proposal could minimize both the sources of human exposure to lead in the IESP as well as issues involving residents of the areas surrounding the IESP since there are no data on this type of contamination and no study has been carried out to date in the location chosen for the research.

4.5. Theoretical, Practical, and Political Implications

Considering the results achieved, it is worth noting that these results can serve as a basis for further debate in this context: the implementation of efficient ballistic waste management at a shooting range, such as the IESP, can have various theoretical, practical, and political implications.

Ballistic waste management relates to theories of sustainable development and the circular economy, emphasizing the need to minimize the environmental impact of shooting activities.

Public health literature can be used to understand the risks associated with exposure to toxic materials such as lead and other heavy metals present in ammunition.

Waste management can be a field of study in environmental management courses, environmental engineering, and other areas, promoting research and training in sustainability practices.

As for the practical implications, it is essential to develop clear protocols for the collection, storage, and final disposal of ballistic waste, guaranteeing the safety of users and workers, as well as implementing training programs for stand users on the importance of proper waste management and its consequences for health and the environment.

In the case of the political implications, it is envisaged that environmental policies can comply with local, state, and federal environmental rules and regulations relating to the management of solid waste and contaminants and promote awareness campaigns on

the importance of ballistic waste management and its impacts, seeking to mobilize the community and public authorities.

5. Conclusions

The aim of this study was to propose and validate a framework capable of improving ballistic waste management in the context of the Public Security Teaching Institute (IESP) in the state of Pará, Brazil. To achieve this goal, a literature review was carried out to support the construction of the conceptual model, followed by the application of a questionnaire to public security professionals working at the IESP, whose data were analyzed using the Lawshe-TOPSIS hybrid approach.

The analysis revealed that ballistic waste management is a challenge to be faced, involving technical, regulatory, environmental, and occupational health aspects. Six of the seven challenges initially proposed were validated as essential, and the most relevant benefits pointed out by the professionals were as follows: improving the institutional image, contributing to environmental preservation, and reducing impacts on health and the environment. These elements made up the validated framework, the structure of which seeks to offer an integrated and sustainable approach to the management of waste generated at shooting ranges.

The problem-question “What should a framework capable of improving ballistic waste management in shooting ranges look like?” was answered by constructing and validating a model that articulates critical environmental management and health protection variables, offering guidelines applicable to the institutional context studied. By considering the challenges and benefits from the perspective of the professionals involved, the framework represents a practical tool aligned with the local reality.

Thus, structured planning and the application of technical and scientific knowledge are fundamental to transforming this problem into an opportunity for innovation and socio-environmental responsibility. Only through this cooperation will it be possible to balance training and safety activities with the commitment to preserve the environment and protect public health, guaranteeing a sustainable and responsible model for ballistic waste management.

However, the study had a limitation, especially in relation to the size of the sample. With a total of 41 respondents, the return rate was 25.63%, which may restrict the generalization of the results to other contexts or institutions. As a suggestion for future research, we recommend extending the study to other public security institutes in Brazil to test the applicability of the framework in different contexts, developing a strategic plan that integrates reverse logistics and consequently the management of this waste, and developing and testing mitigation protocols and environmental remediation technologies adapted to ballistic training environments.

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