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Strategies for use, treatment, management and final disposition of wastes in academic laboratories

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ABSTRACT

Laboratory higher education institutions can generate a wide range of wastes, many of which have hazardous characteristics. The uncontrolled accumulation of such wastes also has a significant impact on the environment, safety and health of the academic community. This work formulates strategies that allow the development of integrated solutions to mitigate the latent risk for the community at Institución Universitaria Colegio Mayor de Antioquia, Colombia, and its surroundings. Therefore, it is considered to quantify the generation of waste in the units of analysis of different experimental spaces and evaluate the factors involved in the implementation of strategies for diagnosis, waste recovery, treatment, and final disposition. Based on the diagnosis and characterization of wastes, alternatives are evaluated that help to prevent and, in other cases, mitigate the impacts that they can cause, in order to consolidate a protocol for waste management. Hazardous waste disposition strategies, treatment mechanisms and minimization strategies, such as microchemistry, precipitation recycling, encapsulation and immobilization methods, evaporation as well as solvent recovery, have been implemented.

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1. INTRODUCTION

Although the generation of hazardous and non-hazardous waste in many of the academic laboratories can be considered low, uncontrolled accumulation leads to significant impacts on both the environment, health and safety of the academic community. They are harmful to health and environment when there is prolonged exposure to high concentrations of waste. Nonetheless, even low concentrations of hazardous materials can alter ecosystem conditions reflected in pollution of water bodies (underground water, water sources, among others), caused by improper disposal of chemical and hazardous waste [1, 2]. Currently, there are global guidelines and policies for the classification of chemical waste generated in laboratories [3]. It is common to carry out corrective actions based on the evaluation of processes [4]. The aim of these treatments is to obtain monolithic solids with high resistance, either to compression (mechanical resistance) and above all to the leaching of contaminants (chemical resistance) [5, 6].

Reverse osmosis is another method of waste treatment which "is used to separate water from organic salts through a membrane that allows the passage of water, but prevents the passage of salt. The cost of membranes can represent 50 % or more of the cost of the equipment. Apart from the problems of dirtying, reverse osmosis systems are very sensitive to temperature" [7]. In addition, in [8] the authors propose a general management model for waste treatment in the search for solutions for management and control of this type of waste at Universidad Nacional de Río Cuarto, with a view to solving the problem of hazardous waste. In [9], the authors propose the program to progressively improve safety, and thus minimize the dumping of waste at Universidad Central de las Villas.

Additionally, in [10] the contingent valuation method for the determination of environmental benefits was used in order to evaluate the implementation of a management plan for substances discarded in the physicochemical laboratory at Universidad de Carabobo, through the cost-benefit ratio of two management plans with respect to waste recovery and storage. In [11], guidelines are proposed for the development of a Waste Management [12] Plan for the Instituto Tecnológico de Buenos Aires (ITBA) for both hazardous, domestic and similar waste generated in a chemical laboratory. In 2011, at Universidad Nacional de San Marcos, Perú, [13], studied the factors involved in the treatment and final disposition of toxic waste generated in the laboratories of that [14]. Institution, where it considered variables such as degree of hazard, degree of toxicity, and emissions. The results of the research allowed to develop: 1) a model for the treatment of laboratory waste, 2) a model for the identification of environmental impacts, hazards, and risks.

At Universidad Nacional de Costa Rica [15], inventories of chemical reagents used and stored in some laboratories were developed to establish distribution patterns, location and their handling in different academic spaces, where chemical agents and reagents are handled and used in greater quantity. In [16] describes detailed information on the management of hazardous chemical waste generated in the environmental OSP laboratory, focusing on the specific management of each type of hazardous chemical waste for the process of: generation, optimization, reuse, storage, processing and final disposition. Moreover, some methodologies were used in [17] such as: characterization of residual solutions, characterization of catalysts, pre-reaction processes and experimental reaction processes which led to the identification of a high concentration of oxidizable organic matter in the pure residual condition.

In [18] appropriate procedures were established from the generation to the storage of hazardous chemical wastes generated in laboratories at Universidad de Nariño, Colombia. To this end, a methodology was implemented aimed at the diagnosis, characterization, provisions for the minimization, treatment, appropriate management, and temporary storage of the chemical waste generated. At Universidad Tecnológica de Pereira Colombia [19], they developed the research work based on evaluating the degradation of 3.5-dinitrosalicyl (DNS) by homogeneous photocatalysis in a recirculation reactor and solar reactor CPC, concluding that homogeneous photocatalysis tested with ultraviolet light and solar energy is an effective method for the degradation of DNS in water. A method of treatment for the waste generated in chemistry laboratories at Universidad de Pamplona suggested by [20], indicates evaporation mechanisms for this purpose, this is due to the small volumes of chemical wastes that are usually generated during laboratory practices. The study was based on evaluating the process of evaporation in the open air for waste disposition, considering variables such as speed, volume, time and temperature of evaporation under ambient conditions of both temperature and pressure.

In the work realized by [21], procedures were developed to design and implement educational strategies for the proper disposition and segregation of chemical waste. This makes it possible to minimize harmful effects on the environment and comply with regulations. The implementation of the proposed methodology allowed the qualitative characterization of wastes generated in the laboratory practices and implicit management processes as well. In the same vein, standard methodologies for international definition and classification of chemical waste were used in [1], which were adapted according to the needs and principles emanating from the University environmental policies. The result of the work allowed defining the management criteria for the identification, classification and proper treatment of chemical and hazardous waste generated in the academic activities of the Institution.

In the study "the use of new technologies in chemistry laboratories and the minimization of the impact on health and environment" [4] is framed in the prevention of risks associated with handling and final disposition of residual substances. As a result of the implementation of this technology, a "series of recommendations and protocols have been generated which should be followed at the time of final disposition of laboratory waste and especially at the chemistry laboratory" at Universidad Del Norte, (Barranquilla). The study undertaken at Universidad Industrial de Santander, by [22] which consisted of structuring "a protocol on transport routes and final disposition of hazardous chemical waste, generated in the chemistry school laboratories", focused on methods enabling the application of existing standards, by documenting procedures so that they can be incorporated into institutional arrangements and policies. In [23] the research exercise aimed at "contributing to the environmental management system for proper management of chemical solid waste generated at Universidad Nacional de Colombia, Bogotá campus, was implemented". The purpose was to "make the diagnosis of the current state of solid chemical waste in the different generating units at Universidad Nacional, Bogotá campus", for the implementation of strategies to mitigate adverse effects on both environment and human health. Methodologies were used for waste diagnosis, adaptation of laboratory spaces and protocols for waste management.

According to the literature consulted, it is necessary to know the levels of affectation or impacts generated by the inadequate disposition of chemical waste in laboratories. Inadequate storage, accumulation and incorrect final disposition of chemical and biological waste in a university institution, may pose a chemical risk and a negative environmental impact as well as detriment to human health not only for the institution but also for the surrounding community in general. In addition, the dumping and inappropriate disposition of chemical, toxic and hazardous wastes, generated during laboratory practices, can lead to contamination of water bodies (underground water, water sources, among others), soil and air; this if protocols or procedures for its management are not available.

Therefore, this paper focuses on carrying out the analysis of mechanisms for the management of hazardous waste, generated in academic practice spaces proposing strategies for recycling, treatment, proper handling, and final disposition. Moreover, characterize by type and volume the chemical waste generated in the institution's laboratories. Besides, evaluate alternatives for the diagnosis, utilization, treatment, proper management, and final disposition of chemical waste generated at Institución Universitaria Colegio Mayor. Furthermore, identify hazards, risks and controls associated with the generation of chemical waste in the Institution's laboratories. By developing a characterization and diagnosis of the current status of hazardous and no-hazardous chemical waste in the Institution's laboratories, and the consolidation of strategies for recovery, treatment and final disposition, an important tool will be obtained for the creation and execution of management alternatives that promote the care of the environment and protection of human health, of approximately 6000 people transiting the institution daily.

The rest of the paper is divided into three sections. Section 2 presents the research methodology, which develops the problem approach around the research question, highlighting the symptoms and causes of the difficulties associated with the generation and inadequate management of laboratory waste in the academic field. Section 3 sets out the analysis of the results obtained based on the alternatives implemented given their impact and relevance characteristics based on institutional dynamics. Finally, section 4 portrays the conclusions and recommendations arising from the investigative work.

2. RESEARCH METHOD

This research is of a quantitative nature with a level of descriptive and experimental research. The aim of the investigation is to identify a problem with relation to the management of laboratory waste at university level. Furthermore, the use of theoretical knowledge and developments for the application of mechanisms for diagnosis, recovery, treatment, and final disposition of chemical waste are considered.

2.1. Definition of waste

In this work the following laboratory wastes are considered: biological, chemical, toxic, hazardous, organic, hospital, special, among others. Whereas for the characterization of laboratory waste, it is considered: quantity generated by type of waste, frequency of rotation, storage, and final disposition. Institutional management protocols are carried out in the management of laboratory wastes. Policies and institutional arrangements for the management of laboratory waste, are implemented. The possible impacts generated by laboratory waste are evaluated: environmental: alterations in the environment, contamination of bio-systems, contamination of soils, water bodies and air. Human health: mutations, presence of carcinogenic or teratogenic substances, nervous and pulmonary disorders and pathologies, among others.

2.2. Sites for taking samples

Nine sampling laboratories are defined, two of them are located in the Architecture Faculty and Engineering and the other seven are located in the Faculty of Health Sciences. Table 1 shows the working areas of each laboratory and the capacity of students and professors attending each class. Each laboratory has a specific student capacity and has sufficient equipment and reagents. Furthermore, in the chemistry and bioanalysis laboratory teaching activities are carried out for undergraduate and postgraduate students in chemistry, biochemistry, genetics, immunology, biomedical instrumental analysis and extension and social projection activities for the general public.

The research laboratory of the Faculty of Science is intended for the activities of students and professors of the Institution and other institutions with which it has an agreement for the development of projects. In the Microbiology and Microscopy laboratory, teaching activities take place for undergraduate and graduate students in subjects of biology, mycology, hematology, microbiology, parasitology, bromatology, morphophysiology, histology, among others and extension and social projection activities for the public in general. There are also two spaces destined for central materials, a room for storage of reagents and another for storage of supplies.

Table 1. Analysis units [24]

Faculty	Laboratory	Area (m^2)	Capacity (Professors/Students)
Architecture and Engineering	Environmental	68.0	20
	Soils	85.0	25
Health Sciences	Quality Control LACMA	113.0	8
	Biotechnology Center	118.0	20
	Bioanalysis Laboratory (129 A)	77.5	30
	Chemistry Laboratory (129 B)	116.5	30
	Microscopy (144 A)	100.0	30
	Microbiology (144 B)	70.0	30
	Research	60.0	12

2.3. Collection of secondary information

This step involves the verification of the existence of waste management plans for the laboratories of the institution, and those that may be drawn up or updated. Activities developed in laboratories and operating processes are described for each of the laboratories. The information corresponding to the programming of practices developed by the academic programs that make use of this space is collected and analyzed in order to determine the possible supplies or reagents used (inventories, registers, among others). Furthermore, other information as the possible generation of waste and how each of these practice spaces operate are also considered.

2.4. Diagnosis of use and waste generation in each laboratory

A consultation tool (survey) is implemented with the people in charge of each of the laboratory spaces of the institution to consolidate information. Besides, verification of reagents supplies, laboratory equipment (liquid and solid reagents), reagent safety data sheets, and nature of reagents and supplies. Furthermore, other types of practices developed and procedures throughout the academic period, waste generation, handling and transitional disposition of waste, final disposition of waste, safety standards, and use of a form to implement as a poll (survey) are considered.

2.5. Waste characterization and classification

For purposes of study prior to the central purpose of the project, the diagnosis of the per capita production of the waste generated in each of the laboratories must be carried out, after identification and classification. In addition to this procedure, the following activities should be performed: physical chemical analysis of waste, collection and segregation of hazardous waste, identification of usable waste, identification of waste requiring treatment, and toxic and hazardous waste requiring inactivation. Hazardous chemical waste generated during academic practice should be classified on the basis of Decree 4741 of 2005 [25], established by the National Institute of Occupational Safety and Health and they can be classified as follows. Group I: Halogenated Solvents; Group II: Non-halogenated solvents; Group III: Aqueous Solutions with Heavy metals; Group III: Aqueous Solutions Free of Heavy Metals; Group IV: Acids; Group V: Oils; Group VI: Organic solids; Group VII: Inorganic solids; and Group VIII: Specials.

2.6. Strategy for the management of toxic and hazardous waste

The use of waste is proposed through recovery processes of non-halogenated solvents (group II) using fractional distillation. In the soil and materials laboratory, concrete, sand and stone materials waste are generated with which its use is considered by forming matrixes of waste encapsulation of groups I, III and VI based on the characterization and classification developed. Moreover, precipitation methods are established for aqueous waste with heavy metals (group III) and evaporation of halogenated solvents (group I). In the case of heavy metal precipitation as an alternative method to immobilization, a general procedure is established as describe in Figure 1.

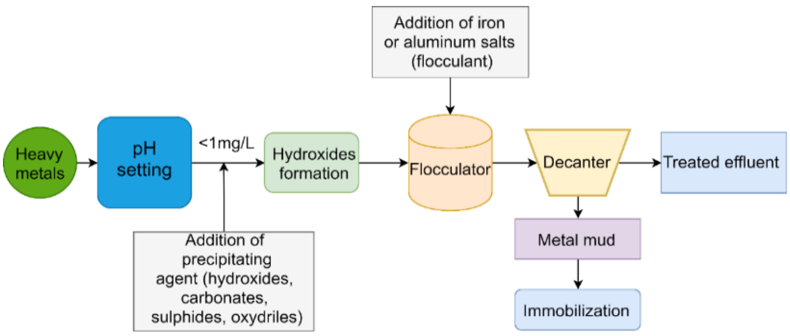


Figure 1. Heavy metal precipitation

For both inactivation and immobilization of waste, a process is proposed whereby waste is incorporated into a material that isolates it from the environment. In this case, the concrete matrices made of sand, cement and lime are used in a weight ratio of 3:1:1/2, respectively, after the identification and classification of the waste. For the determination of the degree of immobilization, Fourier transformation infrared spectrum (FTIR) tests are developed. And the monitoring of possible structural changes and chemical composition, due to mass loss with temperature, is done by thermo-gravimetric analysis (TGA) as shown in Figure 2.

Methods of neutralization and subsequent encapsulation are proposed for the treatment of acid and basic currents as shown in Figure 3. Given the dynamics of chemical waste management processes generated in the university environment in the international context, actions leading to the minimization and optimization of materials and reagents with microchemical procedures are carried out. Risks associated with human health, disposition in water bodies, soils and air are identified by considering environmental aspects and determining degrees of significance. Figure 4 features a summary outline with the management and treatment alternatives that are proposed in in the research work according to the established methodological design and the proposed objectives. In this case, characterization, classification, treatment, and a final process is considered to manage the wastes.

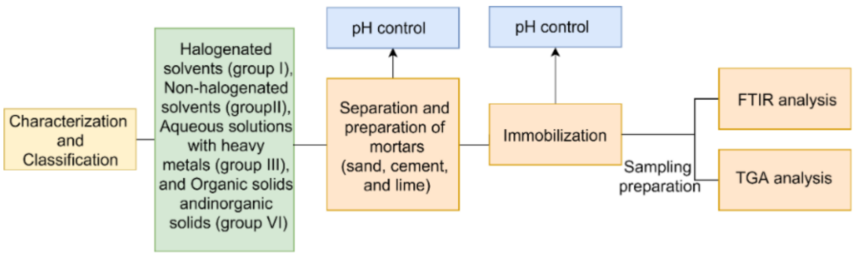


Figure 2. Waste immobilization

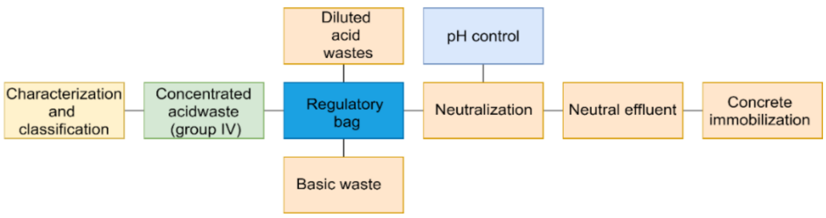


Figure 3. Recycling by neutralization of acid waste

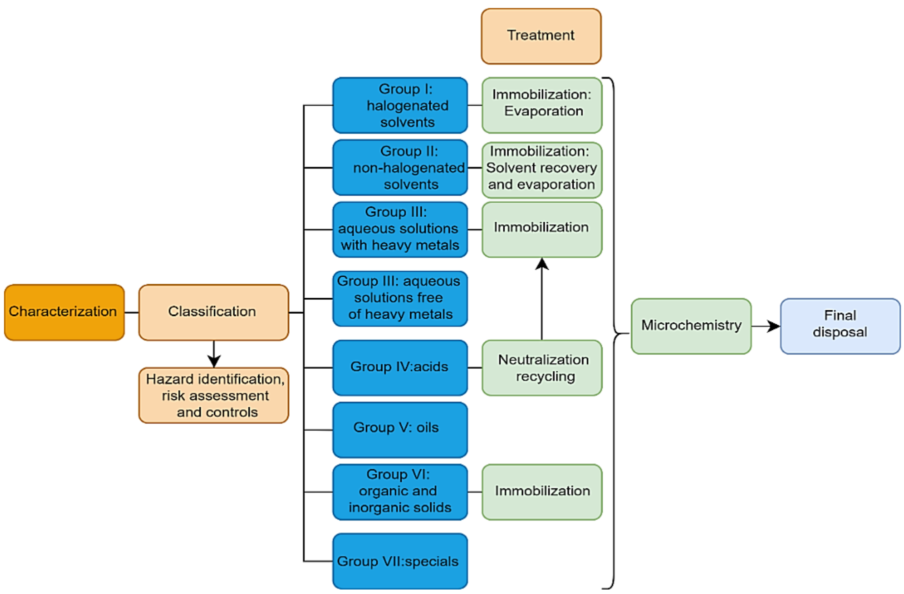


Figure 4. Alternatives for hazardous waste management in generating units

3. RESULTS AND ANALYSIS

3.1. Waste characterization

Table 2 portrays the monthly production of biosanitary, ordinary and recyclable waste found in the laboratories studied. It could be demonstrated that the laboratories that generates the most biosanitaries, reagent and ordinary waste are the microbiology laboratories, followed by the chemistry laboratories. The waste obtained from the quantitative characterization on average for 2018 indicate that 55% of the generated waste corresponds to hazardous sanitary waste, 29% to non-hazardous (ordinary) waste, 9% corresponds to reagent hazardous waste and 7% to recyclable (usable) waste.

Table 2. Qualitative and quantitative characterization of waste generated in health sciences laboratories and medical offices

Area	Quantity (Kg)/month by type of waste			
	Biosanitaries	Reagent	Regular	Recyclable
Doctor's office	19.7		17.6	
Biotechnology	27.1		37.6	6.6
Chemistry Lab.	64.6	7.3	23.2	16.1
Microscopy Lab.	102	35	36.5	6.7
Research	31.2		12.9	1.3

3.2. Waste classification

With regard to the collection and transport of characterized waste, the route of ordinary and recyclable waste took place jointly within the Institution's facilities so as not to present incompatibility with respect to risk. They are then taken to the storage plant or collection center, where they are collected by the companies that manage their treatment and final disposition. In no case is the collection carried out simultaneously with the waste generated in health care and academic activities and using the same elements of personal protection. This is done separately and exclusively for hazardous waste.

The waste generated is collected in rolling-type containers, in rigid material, with rounded edges, washable and waterproof, for that purpose only and fully identified and then taken to the central storage or collection center within the hazardous waste cell. The collection of biological risk waste (external management), is the responsibility of the company EMVARIAS-ASEI, which, with the collaboration of the staff of the Institution, go to the central storage (in the collection center, cell of hazardous waste), take the wastes generated in the health care and other activities and take them to the transport vehicle in compliance with Decree 1609 of 2002 [26], for the transport of dangerous goods. For this activity, the personnel of the hospital route have the elements of personal protection necessary to accomplish this activity.

3.3. Deactivation of hazardous waste

Infectious wastes are deactivated by means of low efficiency chemical process with 2.5% of glutaraldehyde, in each of the areas where they are generated within the Institution to neutralize their infectious characteristics. It is deposited in the temporary storage area and not more than 7 days to be subsequently delivered to the collection company. The sharpened wastes are not deactivated since they have a safe container (guardian); these are sealed with tape at the edges of the lid and thus delivered to the company in charge of their collection.

3.4. Internal movement

The Institution in the practice spaces has areas for the temporary storage of waste. Collection of ordinary waste and recycling are included in the processes of the institution. The collection of waste generated in health care and other activities is then collected independently. The Institution has a suitable place to store, wash, and disinfect containers and other implements used as shown in Figures 5 and 6. There is a separate area for washing toiletries and enough space to place brooms, rags, soaps, detergents, and other implements used for the same purpose. An example of the evacuation routes established within the Institution is shown in Figure 7. All the laboratories have this disposal route for waste management.

3.5. Intermediate and/or central storage of waste

The collection of the central storage of the institution is located in an area far from the usual circulation of the university community, thus minimizing any possibility of contamination. The institution has only the main storage plant, since the collection of the waste after its deactivation at the places where it is generate is done once a day (less than 60 kilograms/day), to be taken to the collection center within the hazardous waste cell, within the space indicated for waste generated in health care and other activities, and finally be delivered to the collecting company that makes the final disposition. The anatomopathological waste generated is immediately deposited in the freezer located in the chemistry laboratory and on the day intended for collection by the hospital route, they are delivered by the personnel of the central of materials in red bag. The central storage in the waste collection center is divided into three sections: One for ordinary waste, another for hazardous waste (biosanitary–sharpened, anatomopathological, medications, “chemicals”), and another for recyclable and/or recoverable waste.

Figure 5. Internal hazardous waste management [24]

Figure 6. Waste collection center [24]

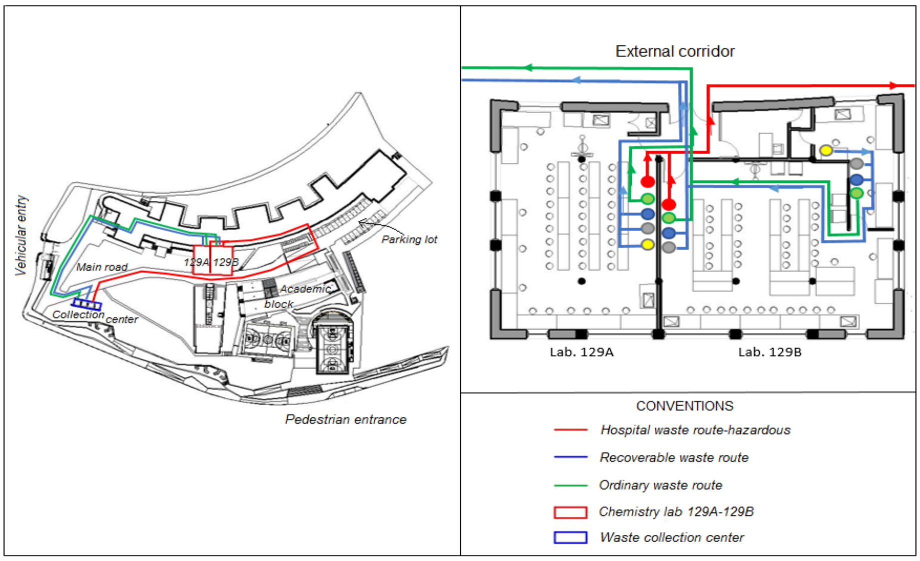


Figure 7. Chemical laboratory waste disposal route [24]

3.6. Characterization and diagnostics

For the purposes of research and analysis of the information obtained in this waste generation unit (environmental laboratory of the Faculty of Architecture and Engineering) the annual generation was identified for each type of reagent used in this practice space in teaching and research activities. To this end, the organization of academic activities was verified, as well as the recording of inventories, practice programming, entry, exit and rotation of reagents, the nature of the reagents, handling and transitory disposition. Table 3 features the classification based on Decree 4741 of 2005 [25], used annually in the development of teaching and research practices in the environmental laboratory in subjects such as: chemical (organic and inorganic), biochemistry, microbiology, water diagnosis, physical chemistry, and research. These include the consumption and production of liquid waste with a high content of strong acids, with an average annual production of 2226 ml, ethanol with an average consumption of 11300 ml, 700 ml of hexane (saturated oil derived from petroleum) and consumption of commercial grade acetate and reagent with a production greater than 3257 ml per year.

Table 3. Waste characterization based on Decree 4741 of 2005 [25]

Decree 4741 of 2005	Average annual amount in gr	Average annual amount in ml
Group I: Halogenated Solvents	-	-
Group II: Non-halogenated solvents		16215.4
Group III: Aqueous Solutions with heavy metals		0.62
Group III: Aqueous Solutions free of heavy metals		127.6
Group IV: Acids	36	2308.75
Group V: Oils	-	-
Group VI: Organic solids	274.9	
Group VI: Inorganic solids	3647.5	
Group VII: Specials	-	-

Based on the consumption of reagents of solid nature, the annual production of basic waste with sodium standing out as the main constituent through the consumption of sodium chloride (897 gr), sodium hydroxide (614.7 gr) and sodium thiosulfate (297 gr). When considering the aforementioned quantities, although they are not alarming; it is important to indicate that, from an environmental point of view, even low concentrations of hazardous materials can alter the conditions of ecosystems reflected in the contamination of water bodies (underground water, water sources, among others), soil and air pollution, caused by improper disposition of chemical and hazardous waste, in addition to the health effects it may have. The production of waste with acid nature is highlighted, in this case considering both the consumption of strong acids and organic acids, there is an annual generation of waste with a load of 2308.75 ml of acids. In the same way the generation of non-halogenated solvents (approximately 16 liters a year) and a large amount of inorganic solids (3647.5 gr per year) represented in waste with metals such as aluminum, barium, calcium, copper, iron, mercury, manganese, magnesium, silver, potassium, sodium and zinc. Based on the above, it is borne in mind that some of these inorganic solids constitute heavy metals, after consumption, they generate aqueous solutions with chromium, copper, mercury and zinc charges representing the following quantities as shown in Table 4. Furthermore, Table 5 shows the characterization of waste based on its nature.

Table 4. Amount of heavy metals in annual waste production

REAGENT	TOTAL annual average–mass in gr
Copper powder	14.5
Metallic copper	1.5
Mercury sulfate	33.3
Potassium chromate	5.82
Potassium dichromate	14.32
Zinc in Metallic Shotguns	7.75
Zinc powder	10.5
TOTAL ANNUAL	87.69

Table 5. Characterization of waste based on its nature

Nature of reagents	TOTAL annual average–mass in gr	TOTAL annual average–volume in ml
Fuels		700
Metals	181.1	
Organic solvent	6.25	15543
Corrosive		2280.4
Oxidizing	21.14	
Chlorinated	1354.5	

3.7. Recycling by precipitation

Given the large amount of acetate waste produced annually in the environmental laboratory (3257 ml approximately) and sulfuric acid (1173 ml), these mainly aqueous solutions have been neutralized, promoting their treatment by the following chemical mechanism, in which the following equilibrium is established: $CH_3COONa + H_2O$ ===== CH_3COO (-) + Na (+), $H_2SO_4 + H_2O$ ==== HSO_4 (-) + H (+); $CH_3COONa + H_2SO_4 + H_2O$ ===== $CH_3COOH + NaHSO_4$. From this chemical reaction and technical considerations, of temperature and relevant catalysis, it was possible to produce about 740 gr of sodium bisulphate (a yield close to 38%) with which it is complicated the possibility of using it for gardening for pest control, however, its dangerousness to plants and soils would be studied. At the time, its acid behavior (generates sulfuric acid in aqueous solution) is used to reduce the pH of waste with an alkaline nature prior to inactivation and final disposition by means of immobilization mechanisms in concrete mortars.

3.8. Strategies for waste minimization

To this end, some principles of "microchemistry" are laid down: a method used for the optimization of reagents used in the development of laboratory practices, in which small amounts of materials can achieve the initial purposes. To evaluate this strategy, the laboratory guides are restructured, with the aim of using fewer reagents in each of the practices without affecting academic purposes and procedures in each case. The percentage of consumption reduction and annual generation of waste generated in the environmental laboratory are shown in Table 6. It should be noted that the consumption of reagents and therefore the production of waste also depends on the rotation of groups, the number of students per session and, in general, the academic programming as well as the percentage of occupation of the generating units. It should also be considered that in some cases the consumption of reagents is not only due to the development of academic practices; research activities are carried out in these spaces for which it is not possible to determine a specific quantity of reagent to be used.

Table 6. Percentage of consumption reduction and annual generation of waste generated in the environmental laboratory

REAGENT	Total annual quantity QUANTITY MASS (gr)			Percentage reduction	Total annual quantity QUANTITY VOLUME (ml)			Percentage reduction
	2016	2017	2018		2016	2017	2018	
Acetone	-	-	-		1380	390.4	50.42	87 %
Hydrochloric acid	-	-	-		1930.14	245	753	61 %
Nitric acid	-	-	-		120	100	10	90 %
Sulfuric acid	-	-	-		1684	1120	717.7	36 %
Benzoic Adehyde	-	-	-		120	230.8	170.9	26 %
Ammonium Hydroxide	-	-	-		71.5	40	50	30 %
Manganese Dioxide	14	8	1	88 %	-	-	-	
Industrial ethanol 96%	-	-	-		-	14220	4700	67 %
Ethanol	-	-	-		2620	1480	1420	4 %
Ethyl ether	-	-	-			230	15	93 %
Hexane	-	-	-		450	1000	650	35 %
Iron III Chloride	-	132	4	97 %	-	-	-	
Iron III Sulfate	7.5	-	3.73	50 %	-	-	-	
Magnesium sulfate	134.5	261.1	172.8	34 %	-	-	-	
Mercury sulfate	33.3	-	-	100 %	-	-	-	
Nitrate silver	10.1	55	23.1	58 %	-	-	-	
Sulfate silver	5.5	10.1	5.5	46 %	-	-	-	
Potassium chloride	81	102.2	91	11 %	-	-	-	
Potassium dichromate	16.88	-	11.7	30 %	-	-	-	
Potassium iodide d	1.94	12.53	2.63	79 %	-	-	-	
Sodium chloride	729	1493.8	469.1	69 %	-	-	-	
Sodium hydroxide	156	1424	264.2	81 %	-	-	-	

3.9. Encapsulation and immobilization methods

By this process, the waste is incorporated into a material that isolates it from the environment, without the components of the waste being chemically fixed to the material used. In this case, concrete was used as an encapsulation material. For this purpose, 6 samples were prepared in mortars of three parts of sand, one part of cement and a half part of lime (ratio of 3:1:1/2) using a standardized diagonal cut mold of 50 mm (cubes of 5 cm on the side). Figure 8 shows the preparation of mortars for waste immobilization test. Figure 8 (a) shows the standardized model according to the ASTM C87–H2823, Figure 8 (a) shows the cement and lime mortar conformation, Figure 8 (b) cement and lime mortar conformation and Figure 8 (c) shows the waste mortar samples. Finally, Table 7 shows the results of the mortar for hazardous waste immobilization test.

(a) (b) (c)

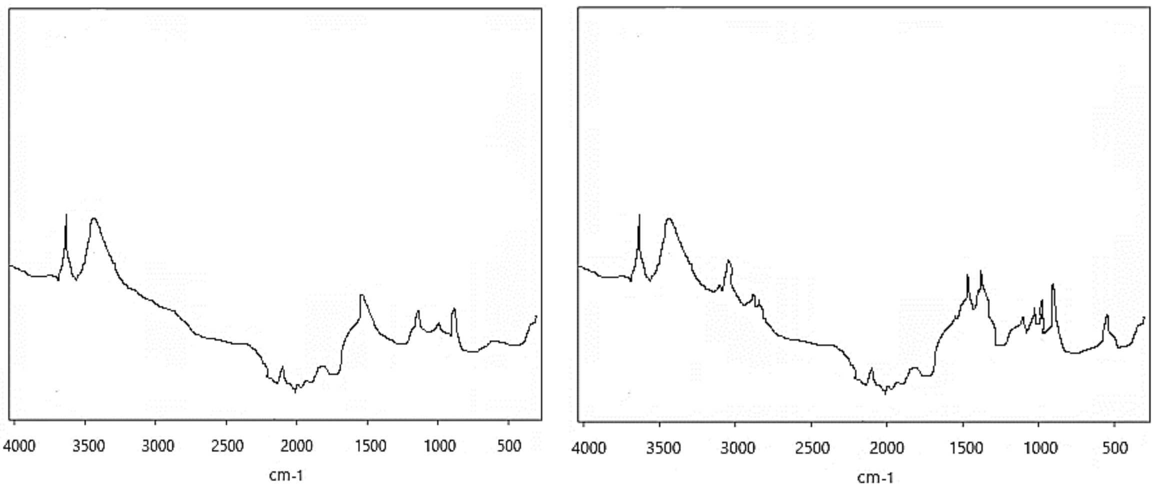
Figure 8. Preparation of mortars for waste immobilization test; (a) standardized mold ASTM C87–H2823, (b) cement and lime mortar conformation, (c) waste mortar samples

Table 7. Mortar forming for hazardous waste immobilization test

Mortar	Immobilized waste	Volume of waste	Initial pH	
1	Test mortar (white) without waste	N/A	12	
2	Aqueous solution with mercury waste	10ml	10	Soil and materials laboratory
3	Wastes from halogenated organic solvents	10ml	10	
4	Wastes of potassium permanganate ($KMnO_4$)	5ml	11	Temperature: 24 °C
5	Wastes of aqueous solution without metals	20ml	1	Moisture R.: 67 %
6	Halogenated organic solvent wastes + solution (4 ml) of $KMnO_4$ at 2 %	10ml	10	

3.10. FTIR test

It is worth keeping in mind what Fuhrmann describes in [27] “encapsulation technologies may involve a combination of physical enclosure through solidification and chemical stabilization with precipitation, adsorption or other interactions”. In this sense, the processed matrices are subjected to Fourier-transform infrared spectroscopy (FTIR) tests to determine the possible interactions of remaining functional groups in the mortar. Figure 9 (a) shows the test for the mortar without waste. Elongations between 3400 cm-1 and 3600 cm-1 correspond to hydroxyl group (OH) bonds due to the aqueous phases of the mortar and waste. Vibrations around 1000 cm-1 correspond to silicates, the area close to 1500 cm-1 corresponds the presence of carbonates and in elongations below 1000 cm-1 represents the presence of Al–O bonds. Figure 9 (b) portrays the test for the mortar with the halogenated organic solvent waste. The appearance of vibrations in the spectrum between 1400-1500 cm-1 are indicating C–H tensions. Besides, vibrations close to 3000 cm–1 confirm the presence of hydrocarbon compounds. Furthermore, the presence of carbonyl compounds can be established due to elongations between 900 cm-1 and 1100 cm–1. Finally, vibrations close to 500 cm-1 may correspond to the presence of halides.



(a) (b)

Figure 9. FTIR tests for (a) mortar without waste and (b) mortar with the halogenated organic solvent waste

4. CONCLUSIONS

This paper presented the formulation of strategies that allow the approach of integrated solutions that mitigate the latent risk for the community at Institución Universitaria Colegio Mayor de Antioquia, Colombia, and its surroundings. It was considered to quantify the generation of waste in the analysis units of different experimentation spaces and evaluate the factors involved in the implementation of strategies for diagnosis, use, treatment, and final disposition of waste. Through the process of recycling by precipitation it is possible to neutralize a considerable amount of acid steam and the corresponding production of sodium bisulfate for possible use in gardening for pest control.

Through minimization strategies, it is possible to optimize the use of reagents such as acetone, HCl, HNO3, ethanol, ethyl ether, mercury sulfate, potassium iodide, chloride, sodium hydroxide, AND others, with reductions in consumption greater than 60%. It is an economically and environmentally viable alternative given the nature of the Institution's academic programs. In the international context, based on the background analyzed, it is common to implement strategies that lead to waste minimization through policies that promote the use of substances with less degrees of danger in academic activities, in the same sense, in recent years in the organization of academic activities in higher education programs, the principle of sustainability has been relevant in the programming of laboratory practices based on mechanisms involving a lower consumption of reagents. Immobilization strategies achieve the inactivation and encapsulation of waste consisting of heavy metals and halogenated semi-volatile and non-volatile organic compounds. The behavior of volatile organic waste immobilized in concrete matrices should be evaluated using thermo-gravimetric analysis techniques that allow the evaluation of the quantity and kinetics of the change in the amount of matter as a function of temperature and time changes in order to analyze thermal stability and decrease in mass due to the effects of decomposition of waste in mortars formed by the action of oxidation processes, absorption, desorption, evaporation, among others. To assess the effectiveness of the encapsulation method it is important to determine its degree of resistance to contact with leaching agents such as water. In the FTIR analysis test, the absence of stresses and vibrations indicating the presence of aromatic compounds demonstrates the probable volatilization of this type of compound and the effectiveness of the method of incrustation and immobilization of wastes with components of this nature. For final disposal of hazardous waste generated in practice spaces in university institutions, it is important to bear in mind the normative provisions at the local, regional, national and international levels, as well as considerations such as knowledge of the waste to be discarded (due to the presence of "orphan and mixed" wastes), these must not be classified as explosives, must not be made up of toxic components and cannot present radioactive behavior.

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