Proper Waste Disposal of Laboratory Wastes in Schools

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***Abstract*— Laboratory waste management in higher education institutions is pivotal for environmental sustainability and public health. This systematic literature review aims to assess the current practices of laboratory waste disposal in colleges and universities, emphasizing the challenges, strategies, and compliance with regulations. The study employs a qualitative research approach, synthesizing literature and studies on laboratory waste management from various databases. Inclusion criteria focus on full-text articles published in English within the past decade, indexed in reputable databases such as Scopus or Web of Science, and conducted in colleges and universities. Results and discussions reveal that educational institutions implemented diverse practices and initiatives for laboratory waste disposal. These include specific procedures for biological waste decontamination, chemical waste identification, radioactive waste storage, sharp waste segregation, and multihazardous waste disposal. Moreover, the study identifies common violations such as unlabeled chemical waste, improper storage of incompatible chemicals, and inadequate training of laboratory personnel. Further, the review underscores the importance of effective waste management policies and guidelines in higher education institutions to mitigate environmental pollution and health risks. It highlights the need for continued efforts in promoting awareness, training, and compliance with regulations to ensure responsible laboratory waste disposal practices. The findings contribute to the development of action plans for enhancing waste management in educational settings and serve as a reference for benchmarking effective practices in laboratory waste disposal.**

Keywords— Waste Disposal, Laboratory Wastes, Literature Review

I. INTRODUCTION

Many people believe the planet to be an infinite supply of food, water, and natural resources, even though many pollute its atmosphere, waters, and soil. As an effect, environmental problems are now one of the biggest issues that humanity is experiencing. One of the main causes of environmental degradation is improper management in the disposal of waste that results from human activities of development and survival. Waste management is the biggest challenge to the authorities of both small and large cities in developing countries (Qadir et al., 2010; Brown, Milke & Seville, 2011; Tsydenova & Bengtsson, 2011). It is a major cause of pollution and outbreak of diseases in many parts of the world. Based on waste properties, waste can be classified as inert (non-hazardous) or hazardous. Hazardous waste (HW) is a category of chemical waste that threatens humans and the environment if mismanaged (LaGrega, Buckingham & Evans, 2010). HW consists of liquid, solid, or gaseous materials. Manufacturing, forestry, water treatment facilities, construction, automobile garages, labs, hospitals, and other industries produce hazardous or harmful waste. Chemicals, heavy metals, radiation, and bacteria can be present in the waste, which may be liquid, solid, or sludge (Shankar, 2017). HWs are produced by different activities; one activity that should be considered in relation to global environmental problems is the production of chemical wastes from experiments by universities and similar analytical laboratories (Hassanvand et al., 2011; Saralegi et al., 2020; Clark & Funk, 2015).

Wastes from universities, such as laboratory wastes, would deteriorate the environment quality if they are discharged directly into the environment (Liu, Ren, Lin & Wang, 2015). It is important to note that schools and universities with science laboratories need guidelines and policies on laboratory waste disposal. Improper handling of wastes could also lead to problems such as corroding sewer equipment, generation of hazardous gases, treatment plant malfunction, and problematic sludge disposal (Elbeshbishy & Okoye, 2019). Laboratory waste is generated from laboratories in industry and educational centers such as schools and universities (Jimenez, Romero, Dominguez & del Mar Espinosa, 2015). This waste can be broken down into several categories: Hazardous, Clinical, Biological, Electrical, and other Laboratory wastes (Donald, 2010). In addition, the University of Florida Environmental Health and Safety (2018) also identified two typical laboratory hazardous wastes that often require proper disposal management: liquid hazardous wastes and solid hazardous wastes. Typical liquid hazardous wastes include organic synthesis liquids, liquid solvent waste, liquids associated with HPLC or TLC analyses, sample vials containing liquids for digestion and extraction including preservation, waste liquids associated with DNA extraction and cell lysis, specimen preservatives (Formalin, formaldehyde, paraformaldehyde, alcohol, etc.), photographic and X-Ray-related darkroom chemicals, unused portions of laboratory reagents which are no longer needed, and laboratory reagents which have been left behind or abandoned by previous users of the laboratory. Meanwhile, typical solid hazardous wastes include gloves used to protect workers when handling hazardous chemicals, absorbent or adsorbent materials used in chemical processes, weighing boats or papers used with chemical reagents, slides that have been used with or

contaminated with hazardous chemicals, paper towels and rags, vermiculite used to clean up chemical spills, disposable pipette tips used to measure or transfer chemicals, filters and ion exchange materials used during chemical processes, and electrophoresis gels containing Ethidium Bromide. Very often, the waste that laboratories dispose of is hazardous. Under health and safety regulations, this type of waste must be controlled and managed suitably and sufficiently (Elledge et al., 2018).

Higher education institutions bear the ethical responsibility to promote sustainability and environmental awareness of people inside and outside universities. Hence, they should be responsible in the proper disposal of their laboratory wastes. Laboratory waste management practices refer to the discipline associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of wastes in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental consideration and that is also responsive to public health (Aung, Luan & Xu, 2019). Most of the wastes from school laboratories are considered hazardous, so the generation, storage, and disposal of these laboratory wastes must be given special consideration by the school administration (LaGrega, Buckingham & Evans, 2010; National Research Council, 2011). In addition, assessing how laboratory waste is managed within schools is crucial. The people who work and study in schools produce waste, and the amount of waste generated may be significantly higher than that produced at home, especially in small towns. Laboratory waste is one of the most critical environmental problems in developing countries, and it can lead to outbreaks of diseases and epidemics. Planning of laboratory waste management is necessary to prevent waste from adversely affecting human and environmental health. Moreover, documentation of practices on laboratory waste disposal is limited since most of the published articles and research focused on solid waste management (Sanjeevi & Shahabudeen, 2015; Allesch & Brunner, 2014; Chen et al., 2015; Paes et al., 2019). With the gaps presented, there is a need for a systematic literature review on laboratory waste disposal among colleges and universities. Hence, this study was conducted.

II. METHODS

This study utilized qualitative research to synthesize different literatures and studies related to laboratory waste management disposal among schools. A structured search was performed to identify journal articles related to school laboratory waste management disposal. The search took place in the whole month of May 2021 and included literature and articles published in the past 10 years (since 2010). The primary focus of the search was on the different activities and programs of schools toward laboratory waste management disposal.

Search Strategy

A database full-text search was performed to identify relevant peer-reviewed articles. Databases searched included Google Scholar, PubMed, Harzing's Publish or Perish, EBSCO-Host, Web of Science, and Elsevier. Keywords used to create database search strings included the following: laboratory waste management, school laboratory waste management, laboratory waste disposal, and school laboratory waste management practices.

Inclusion Criteria of Literature

The following were the inclusion criteria used by the researcher: (1) Only full-text articles published in English, (2) Articles must be published within the span of 10 years (2010 – present), (3) Articles were published in journals indexed either in Scopus (Elsivier) or Web of Science (Clarivate Analytics), and (4) Articles on laboratory waste management were only conducted among colleges and universities with emphasis on developed or first-world countries.

Data Analysis

The data gathered were analyzed using content analysis. By reading and coding textual information, content analysis is a research technique for making replicable and true inferences. Qualitative data may be translated into quantitative data by systematically analyzing texts such as records, oral conversations, and graphics (Luna-Reyes & Anderson, 2003). In this study, articles were categorized into relevant themes and are discussed within the context of these topics in the review paper.

III. RESULTS AND DISCUSSION

This section presents the different practices and initiatives on laboratory waste disposal of colleges and universities based on the available literature gathered by the researcher from different literature search engines. The presentation of activities was based on the standard practices and initiatives implemented by colleges and universities.

Common Laboratory Wastes and its Disposal

a. Sharps

These are items that present a significant threat to health and safety. This waste stream receives special handling and is decontaminated (for biological contamination) prior to landfill disposal. In addition, these are items designed to cut or puncture skin and sharp items with human blood and body fluids or bacteria. Some of its examples are Needles, Syringes with attached needles, Scalpels, Razor blades, Pasteur pipettes, pipettor tips, broken vials, and laboratory slides that are contaminated with biologically hazardous material.

Disposal Procedure:

1. When full, take to the red sharps collection hopper on the loading dock.
2. Custodians will not remove sharps containers from labs or hallways.

b. Hazardous Glass

These are items that could cut or puncture skin or trashcan liners. This waste stream must be boxed to protect custodial staff. It goes directly to the landfill without any treatment. Hazardous glass and plastic includes ems that can puncture, cut, or scratch if disposed of in normal trash containers. These also include pasteur pipettes, other pipettes and tips (glass or plastic), slides and cover slips, broken or fragile glass, including chemically contaminated glass unless the chemical poses a significant hazard, bags of miscellaneous plastic ware that has been autoclaved to remove bio-contamination, and syringe bodies (without needles).

Disposal Procedure:

1. Empty any chemicals into a suitable chemical waste container and dispose via surplus chemicals pickup.
2. Autoclave before boxing if contaminated with infectious agents, recombinant organisms, or human blood.
3. Seal container closed.
4. Place it in the hallway next to your lab door for custodians to remove, or take it to the labeled hopper on the loading dock.

c. Other Non-hazardous Trash

These are items that are neither sharp nor contaminated. This waste stream is handled directly by custodians and goes to landfill without further treatment. Items that present no hazard if disposed of as normal trash, unbroken glass and plastic that has been washed or decontaminated to present no chemical or biological hazard, such as petri dishes and plastic laboratory ware, weighing boats sturdy test and centrifuge tubes, washed and uncapped empty bottles, and paper towels and gloves that have no significant contamination.

Disposal Procedure

1. Place waste in the lab trash can for custodians to dispose of in the dumpster.
2. Place large (≥ 2 liters) bottles next to the trash can.

Laboratory Waste Disposal among Schools and Universities

a. Biological Waste Disposal

Biological waste in school laboratories includes the following: (1) liquids such as used cell culturing media, supernatant, blood or blood fractions (serum), etc., which contain viable biological agents; (2) materials considered pathological, including any part of the human body, tissues and bodily fluids, but excluding fluids, extracted teeth, hair, nail clippings and the like that are not infectious; (3) any part of an animal infected [or suspected to be infected] with a communicable disease; (4) non-sharp, solid laboratory waste (empty plastic cell culture flasks and petri dishes, empty plastic tubes, gloves, wrappers, absorbent tissues, etc.) which may be, or is known to be, contaminated with viable biological agents; (5) all sharp and pointed items used in medical care, diagnosis, and research, including the manipulation and care of laboratory animals, which should be considered potentially infectious; and (6) laboratory glassware which is known or suspected to be contaminated with hazardous biological agents (Mohammed, Sanyi & Al-Rayahi, 2019; DiBerardinis, 2020; Wang, Wang & De Michele, 2017).

Most of the gathered literature revealed that colleges and universities' management and disposal of biological wastes are anchored on either national standards set by their health department or ministry or other ISO-9001 accredited standards and procedures such as the Biohazardous Waste and Sharps Disposal Policy, U.S. Environmental Protection Agency, Environmental Health and Safety Guidelines, and other important bodies and agencies. In addition, schools and universities have extensive guidelines and procedures for biological waste disposal.

The University of Toronto in Canada has three (3) specific biological waste disposals for its laboratories. These include: (1) Following steam sterilization or chemical disinfection, innocuous liquids may be disposed of via the laboratory drainage system. Flush with sufficient clean water to purge the drain immediately after disposal of all liquids; (2) Do not pour melted agar into sink or floor drains. Allow it to cool and solidify for disposal as bio-waste unless produced in a Containment Level 1 lab where it can be placed with non-hazardous waste. However, Containment Level 1 labs should use UNMARKED autoclave bags, available from Medstores; and (3) Some buildings with a Central Storage Area can have the pails moved to where more supply pails are stored. In addition, the university has a special pick-up and disposal schedule for untreated biological laboratory waste (Waked et al., 2019).

Meanwhile, the biological waste disposal of the University of Idaho is in accordance with the Biohazardous Waste and Sharps Disposal policy. This policy ensures compliance with institutional, local, state, and federal mandates for handling biological waste and sharps. The main procedure for their disposal is decontamination. All biological wastes must be properly decontaminated prior to disposal, including liquid waste, solid waste, and sharps waste (Chen, de Haro Marti, Moore & Falen, 2011).

In addition, the University of Connecticut, through its Division of Public Safety, has its Regulated Waste Guide. Biological and regulated medical solid waste shall be disposed of through the Biological Solid Waste Stream established by the Department of Environmental Health and Safety. Processes include the following: disposal procedures for sharps wastes and non-sharps, transport and storage of biological waste, labeling of biological waste, and steam sterilization processes (Environmental Health and Safety, 2019). Furthermore, the biological waste disposal management of the University of Wollongong is implemented in order to minimize risks associated with the disposal of

laboratory waste. The policies should consider specific procedures such as general considerations, laboratory procedures, disposal for particular biological waste, and waste disposal routes (Talebian & Foroughi, 2019).

Furthermore, the biological waste disposal of the University of Pittsburgh stresses the need for all biological, infectious, and chemotherapeutic wastes that are generated at the University to be decontaminated and disposed of properly. No infectious wastes are permitted to leave the premises or control of the Principal Investigator without first being decontaminated to ensure that they present no harm to others or the environment. All biological wastes must be placed in a red biological waste bag. Once full, seal/close the biological waste bag and place it into a biological waste box. All biological waste boxes must be labeled with a University biological waste label (Homer et al., 2011).

In general, biological waste can be extremely dangerous and has the potential to seriously harm students, teachers, the public, and the environment. Therefore, it is essential that school laboratories have an efficient waste disposal system in place.

b. Chemical Waste Disposal

Chemical waste includes solids, liquids, or gases containing or contaminated with any of the following: flammable solvents (e.g., acetone, alcohols, acetonitrile); leachate toxic materials (e.g., heavy metals, pesticides); corrosives (e.g., hydrochloric acid, potassium hydroxide pellets); reactives such as oxidizers, cyanides, sulphides, explosives, unstable materials and water-reactive materials (e.g., sodium metal, benzoyl peroxide); toxic materials including mutagenic, carcinogenic, acute, or chronic toxicity materials (e.g., chloroform, ethidium bromide); polychlorinated biphenyls (> 50 ppm concentration); and non-returnable gas cylinders (Chartier, 2014). Most of the schools and universities are producing chemical wastes because they offer health-related and applied sciences programs which are required for the course of students. With this, one significant challenge emerges, which is properly managing chemical wastes in school laboratories. Previous literature suggest that chemical inventories found both in high schools and tertiary schools contain a vast array of chemicals ranging from safe and suitable for education to extremely hazardous, unsuitable and inappropriate for those unknowledgeable or untrained in their use, and potentially harmful to the environment (Sakhi et al., 2019; Gross & Birnbaum, 2017).

At the University of Florida, all laboratory workers have three basic responsibilities when it comes to properly managing the chemical wastes being generated within the laboratory. These responsibilities include: (1) Proper identification of all wastes that require management as Hazardous Waste, (2) Once identified, proper accumulation (or storage) of all Hazardous Wastes, and (3) Proper Hazardous Waste disposal via the EH&S Chemical and Radioactive Waste Disposal group. Environmental Health and Safety's Chemical and Radioactive Waste Disposal group is available to assist with all of these important responsibilities (University of Florida, 2018). In addition, proper chemical management and disposal is necessary to protect the health and safety of the University, surrounding communities, and the environment, according to the University of Delaware. The disposal of chemical waste depends on the kind of chemicals. It is reflected in their University Policy 7-18, which states that all University of Delaware personnel must manage all chemical and hazardous waste in compliance with these federal and state regulations and in accordance with procedures set up by the Department of Environmental Health & Safety (Cramer et al., 2016).

Meanwhile, the University of Chicago also has an existing policy that deals with the disposal of hazardous chemical waste. All hazardous wastes shall be managed in accordance with federal, state, and local regulations. The university has extensive polices with regard to authority and responsibility, chemical waste disposal, storage, labeling, packaging, scintillation vials, controlled substances, provisions of refrigerators and freezers, empty chemical containers, glass containers, metal containers, secondary containers, and hazardous waste minimization (Zinn et al., 2020). On the other hand, Case Western Reserve University also has its procedures for disposing of chemical waste. Chemical waste is regulated by the Environmental Protection Agency (EPA) through the Resource Conservation and Recovery Act (RCRA). It cannot be disposed of in regular trash or in the sewer system. Most chemical wastes must be disposed of through the EHS Hazardous Waste Program.

c. Radioactive Waste Disposal

Radioactive waste is any liquid, gas, or solid containing a radioactive nuclear substance for which there is no foreseeable use. Common waste management methods for low-level radioactive waste from laboratories include storage for decay and indefinite on-site storage, burial at a low-level radioactive waste site, incineration, and sanitary sewer disposal. The University of Iowa generates radioactive waste from teaching, research, and patient care activities. The University's Environmental Health & Safety (EHS) manages radioactive isotope use through its Radiation Protection Program and radioactive waste disposal through its Radiation Waste Management Program. EHS provides technical assistance and training to individuals and departments who generate waste so they can comply with rules and regulations that direct waste generation activities. Radioactive waste disposal is regulated by the Iowa Department of Public Health (IDPH), Nuclear Regulatory Commission (NRC), and Environmental Protection Agency (EPA) (Brookins, 2012). Meanwhile, at the University of Florida, all chemical and radioactive waste disposal must be managed per Environmental Health and Safety policies. Chemical and Radioactive Waste Disposal staff within EH&S provide training, technical support, and compliance assistance to all University of Florida faculty and

staff who generate waste. Furthermore, at the University of Buffalo, all radioactive waste must be collected in containers supplied by Environmental Health and Safety. They also have important policies to consider, such as radiation dosimetry, safe handling of radioactive material, and radiation emergencies. For the University of Oakland, two major processes were developed for radioactive disposal, which include the following: waste segregation and packaging and waste handling and disposal.

d. Sharp Waste Disposal

Sharp is defined as any object that could readily puncture or cut the skin of an individual, including, but not limited to, needles, syringes, knives, razor blades, lancets, capillary tubes, metal shavings, etc.; glass or plastic pipettes and pipette tips; any broken glass, glass slides, cover slips, plastic, metal, pottery with sharp edges, etc.; and anything that could puncture through a garbage bag causing the bag to rupture and spill, or risking injury and exposure to personnel (Hasan et al., 2019). Sharps include, but are not limited to, the following (when contaminated): glass pipettes, broken glassware, specimen tubes, blood culture bottles, and microscope slides (Janjua, 2013). For the University of Washington, the rules for packaging and disposal of laboratory glass and plastic waste differ depending on whether or not the items are contaminated. There are four processes in handling sharp wastes, which include identification, packaging, decontamination, and chemotheraphy. Meanwhile, for the University of Toronto, sterilization, disinfection, or decontamination of needle and blade waste may be required prior to disposal. The filled yellow plastic container of needle and blade waste must be closed by securing the attached cap over the top opening. The yellow container should be placed with the other biological waste pails for disposal. The Environmental Protection Technicians will collect them during their scheduled pickup. When there are containers with chemically contaminated needles and blades, they must also be called for a pickup as only permitted Biosafety laboratories are on a regular schedule. In addition, for George Washington University, all sharps must be disposed of in puncture-resistant, impervious rigid containers with self-closing lids. It must also be placed in a red sharp container with a biohazard label, which will be disposed of as biological waste (filled containers should be locked and placed in the biohazard waste box). Furthermore, the University of Missouri has laboratory practices for sharps waste. All sharps must be disposed of in authorized Sharps containers indicating the kind(s) of sharp waste contamination present. Once containers are filled, biohazardous contaminated sharps must be autoclaved (if feasible) and disposed of through the Environmental Health & Safety Biohazard Waste Disposal program. Laboratory sharps cannot be placed with regular trash. Care must be taken to follow these procedures to prevent serious injury and violation of regulations.

e. Multihazardous Waste Disposal

Multihazardous waste contains any combination of chemical, radioactive, or biological hazards. Examples of laboratory mixed wastes include used flammable liquid scintillation cocktail; phenol-chloroform mixtures from the extraction of nucleic acids from radiolabelled cell components; certain gel electrophoresis waste (e.g., methanol or acetic acid containing radionuclides); and uranium compounds used in electron microscopy. Mixed wastes produced at universities and medical research laboratories are typically a mixture of low-level radioactive and chemically hazardous wastes. Disposal options for mixed waste are usually costly. For many types of mixed waste, there are no management options other than indefinite storage on site.

Common Violations with Regard to Laboratory Waste Disposal

Another important theme that was transcribed from the different gathered literature and related studies is the common violations concerning laboratory waste disposal of schools and universities. This study identified six (6) common violations supported by relevant literature sources (Liao & Ho, 2014; Gibson, Schroder & Wayne, 2014; Peng, Bilal & Iqbal, 2018; Hill & Finster, 2016):

1. Unknown / Unlabeled chemical waste
2. Mixing or storage of incompatible chemicals
3. Chemical containers that are left uncapped / open
4. Laboratory personnel who are inadequately trained in proper waste management
5. Liquid containers stored outside of secondary containers
6. Waste Containers Stored In and/or Near Sink Areas and Floor Drains

IV. CONCLUSION AND RECOMMENDATIONS

Proper laboratory waste management of colleges and universities protects the health and safety of everyone, especially students and teachers, and prevents or minimizes pollution. Laboratory waste disposal services require strict adherence to applicable policies and procedures. It is a joint effort between laboratory personnel, teachers, students, and school administrators. This study concludes that universities and colleges from developed countries already have effective and efficient guidelines and policies for proper laboratory waste disposal and management. In addition, each of the different laboratory waste, such as biological, chemical, radioactive, sharp, and multihazardous wastes, has its own special methods and guidelines for disposal. Finally, despite the different policies and guidelines for laboratory waste disposal, violations were still being made that may have negative effects and impacts to the university and school, students and teachers, and most especially, the environment.

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