Managing Chemical Waste Reduction Generated by Laboratory Activities in Educational Institutions

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ABSTRACT
Laboratories in educational institutions produce various toxic wastes that can harm the environment, safety, and human health. Unregulated disposal of these wastes has a severe impact on educational institutes. This study aims to identify alternative solutions to prevent and reduce the effects of laboratory waste by creating an eco-friendly waste management plan based on the identification and classification of waste. The examination of eco-friendly ideas from a different educational institution, centered on laboratory chemical waste management activities, was the review's main objective. As a novelty of this study, this review demonstrates the current waste disposal practices in educational institutes in India and the high volume of environmental effects, which may be decreased by implementing an integrated waste management framework, with source segregation as depicted in futuristic situations. The characterization investigation indicates that organic waste, which makes up 76% of all trash, is the most prevalent waste constituent. This discovery led to the discovery of anaerobic digestion as a practical therapeutic possibility. Additionally, it has been demonstrated that segregating waste at the origin enhances the efficiency of anaerobic digestion facilities. Therefore, institutions must always monitor environmental innovations for managing laboratory waste.

Keywords: Educational institution, lab activities, waste, environment, management

1. Introduction

Indian society was viewed as traditionally up until the initial half of the 20th century when modernization began to arise, because of a shift in social ideals that is linked to the development of new social structures and organizations. Despite the fact that modernity and scientific and technological growth raised the level of living for most individuals in the society, this also led to increased environmental pollutants and the misuse of environmental assets [1]. The Triple Bottom Line (TBL) of sustainability also says that the goals of social security, protecting the environment, and growing the economy must be met [2].

India has established approximately 20,000 colleges in the past ten years, bringing the total count of colleges from 12,806 in 2000-2001 to 33,023 in 2010-2011, a rise of higher than 150%. In addition to 52,627 colleges, India has around 1000 universities as of 2020, according to the MHRD. These institutions should offer an example of social and environmental responsibility since they are more than just educational settings, making it simpler to fulfil the overall sustainability aim [3]. A tremendous quantity of laboratory waste is constantly produced as a result of the growth of educational institutions, which is harmful to the ecosystem [4]. Institutions could be compared to "mini towns" due to their significant population volume and the variety of their administrative and scientific activities. These activities produce significant amounts of chemical and biomedical waste, which resembles the chemical waste produced by other urban areas, like cities and towns. By various technical implementation sustainable development achieved [5–10].

Even while the production of toxic and non-toxic chemical waste can be seen as being modest in several educational labs, the unchecked buildup has a considerable negative consequence on the atmosphere, human health, and academic community welfare. When exposed for an extended period of time to excessive waste levels, they are damaging to our well-being and the atmosphere. The inappropriate dumping of chemical and toxic waste, however, can affect water resources (including underground water and water resources) to become contaminated despite minimal levels of toxic elements [11].

Many chemical and biomedical labs, including those in numerous degree colleges and R&D facilities, discharge their chemical wastewater into neighboring waterbodies, which pollutes the environment and reduces the amount of aquatic life there (Prevention, 1996.). Since the requirement for sustainable growth has grown more apparent over the past few decades, colleges are required to teach students how to incorporate societal, environmental, and financial factors into the decisions they will make in the future. In an attempt to lower the hazards / mishaps due to human and natural exposure, many research organizations and labs throughout the globe have been focusing on the adoption of effective waste management techniques [13].

This paper emphasizes reviewing the environmentally friendly management of waste produced in Indian educational labs and suggests methods for recycling, treatment, appropriate handling, and disposal. Furthermore, it also focuses on types of wastes generated from the research labs of Indian educational institutions and their harmful effects. An essential platform will be acquired for the development and implementation of alternative approaches that encourage the care of the atmosphere and safeguard of human wellness, of individuals passing the educational establishment every day, by establishing a characteristic and diagnosis of the contemporary condition of toxic and non-toxic chemical waste in the educational institution labs, and the consolidation of approaches for restoration, management, and safe disposal.

2. Sources of Educational Institution Chemical Wastes

In various ways, educational institutions vary from the majority of other sources of hazardous chemical waste. High schools, universities, and colleges have different programs and student populations, which results in variations in the kinds and amounts of chemical and biomedical waste that these institutions produce. Chemical and biomedical discharges produced by laboratories of educational institutions comprise a wide range of substances, the majority of which are present in extremely small concentrations. Even while the majority of the stuff utilized at university labs is connected to investigation or teaching at a certain stage, it can still be dangerous (De, 2017.; Gamage et al., 2020).

Academic and research institutions promote contamination by producing hazardous waste, flushing away hazardous chemicals, allowing solvents to evaporate, and engaging in other environmentally destructive actions. Examples include chemicals, glassware, reagents, harmful product packaging, biological substances, damaged thermometers, outdated or old electronics, and apparatus that is out of service, defective, or antiquated. Less than 1% of the chemical waste produced nationwide is produced in educational institutions. Chemical Waste produced in these facilities is regarded as heterogeneity and potentially contains very dangerous substances. Since they are obligated by the Resource Conservation and Recovery Act (RCRA) to keep track of every single chemical, once it constitutes a waste, this makes educational institutions in a special classification. Many educational institutions merely don't follow the rules, perhaps because they're not conscious of laws or because they think the rules do not entail them. Educational institutions have quite different levels of insight.

Types of Wastes

Laboratory waste, often known as hazardous waste, must be traced from formation to clearance. Due to the fact that educational institution lab chemical waste primarily stems from teaching and research operations, pollutants or waste produced in these locations differs from waste produced in industries, homes, businesses, etc. Chemical wastes from educational institutions can be classified into solid, liquid, and mixed waste [16].

2.1 Solid Waste

Chemical waste in solid form can be detected at room temperature. Solid waste from the chemical labs of educational institutions is frequently generated, with the majority of it being metallic trash. Educational institutions frequently produce a variety of organic, inorganic, toxic, and electronic wastes. The primary supply of organic waste is from lab activities, whereas computer labs in other regions also supply electronic waste. These solid wastes can enter the atmosphere in a variety of manners, but they typically do so whenever they are discarded inappropriately or buried in landfills. Since the majority of solid wastes are made up of metallic waste, they may erode and combine with groundwater.

2.2 Liquid Waste

Educational institutions produce enormous amounts of chemical wastewater for hygienic purposes as well as for cleaning and washing. Acids, alkalis, and other liquid chemicals or reagents are typically released from educational, medical, and research establishments straight into the sewers. Natural factors, such as rainwater runoff and extra water from fields and gardens, contribute to the accumulation of chemical wastewater in addition to human actions. Common contaminants found in institutional chemical wastewater include toxic heavy metals, organic compounds, phenols, phosphorus, and nitrogen. Chemical oxygen demand (COD) and biological oxygen demand (BOD) measurements of liquid chemical waste allow for the identification of both the total organic composition and the biodegradable organic composition.

2.3 Biomedical Waste

One of the main types of hazardous waste produced by diagnosis, vaccination, management of people or livestock, and other relevant study and healthcare operations as biomedical waste. Biomedical waste is divided by the World Health Organization (WHO) into conventional, pathology, radioactive, chemicals, contagious, pointy, pharmacological, and pressurized vessel waste categories. According to the overall amount of laboratory waste emitted in India, the percentage of hazardous waste created by medical research labs varies from 15% to 35%.

2.4 Mixed Waste

Due to its potential for slow degradation and ability to remain in the atmosphere for extended periods of time, hazardous chemical waste constitutes a serious threat to people, creatures, and the ecosystem. These chemical wastes can be stored or exposed, solid, liquid, or gas. The production of hazardous chemical waste in the form of chemicals, radioactive materials, and microbes is also significant in biological lab activities (i.e., microbiological, pathology, veterinary, etc.).

2.5 Significant Issues with Institutional Laboratory Waste

In addition to spreading a bad stench and harmful effects across the environment, inappropriate chemical waste disposal in institutions is also to blame for a number of food, water, and air-borne illnesses. WHO estimates that each day more than 50,000 individuals lose their lives to infectious illness. Ineffective waste management is among the main causes of the development of contagious diseases. For instance, poor waste management contributes to infectious illnesses like pneumonia, TB, diarrhea, severe cough, etc. Cancer and respiratory illnesses can be brought on by exposure to the dangerous chemicals released during outdoor burning. Animals' digestive systems might become obstructed and other serious issues can arise when they consume garbage that contains polyethylene. Dioxins and furans, two dangerous compounds, can seriously disrupt birds and animals' wellness [17]. The additional characteristics of hazardous chemical wastes are listed below in **Table-1**.

Table 1: Characteristics of hazardous chemical wastes

S. No.	Types of Hazardous	Potential hazards on living animals/environment
1.	Flammable/explosive	This kind of garbage may affect the environment by generating dangerous gases at high temperatures and pressures or by posing a fire risk.
2.	Oxidizing	Byproducts that might make oxygen and start or help other things to burn.
3.	Poisonous (Acute)	If these wastes are swallowed, breathed in, or come in contact with the skin, they have a high chance of killing, hurting, or making people sick.
4.	Infectious substances	Dangerous waste, which can contain microorganisms and their poisons, can make people or animals sick.

5.	Corrosives	These wastes are chemically active and may seriously harm other materials or the flora and animals if they come into touch with them.
6.	Eco-toxic	Because of bioaccumulation, these wastes may have negative effects on biotic systems as well as immediate or delayed negative effects on the environment.
7.	Toxic -Delayed or chronic	If these wastes are breathed in, eaten, or absorbed through the skin, they may have long-term or chronic effects, such as causing cancer.
8.	Organic peroxides	These are bivalent O-O-structured organic wastes that may decompose exothermically and quickly.

Urban regions were the first to adopt waste management procedures, however, semi-urban and rural regions haven't yet followed suit. The origins of chemical waste formation should receive extra attention since they affect the features and content of the chemical waste in different ways. When recommending a waste management approach, the origin of chemical waste production, features, and recycling industry situations should all be considered into account.

Also, any harmful or dangerous item must be disposed of in accordance with current federal, provincial, state, and municipal laws. Unless the technique may be regarded as a component of the reaction being carried out at the bench, on-site disposal may need licensure as a treatment facility. Wastes should undergo chemical treatment so that the material may be transformed into harmless, ecologically friendly goods. The techniques should also fit into a number of categories, such as neutralizing acids and bases, oxidizing or reducing substances, and precipitating hazardous ions as insoluble solids.

Alongside chemical waste gathering and transportation, various plans like chemical waste reduction, segregation, and valorization that could aid operators in bettering their waste management procedures must be implemented.

2.6 Solid Waste Management

Research by Rajiv Ganguly describes the current solid waste management procedures in 4 significant regions in Himachal Pradesh, India. It has been determined that the localities have to take action plans and remedial actions to effectively enhance solid waste management. These include buying new machinery for separation and recycling centers, maintaining waste gathering vehicles properly, and putting in place a platform for leachate gathering and abolishment [18]. Sukha Ranjan and Pooja have conducted research to assess any potential environmental effects of the area of Dhanbad's current chemical waste handling. In order to maximize the recycling of chemical waste, official and informal institutions for gathering and segregation must cooperate, and recycling enterprises must switch from thermal energy to alternate resources in order to create the recycling activity more environmentally friendly [19]. Research on the advancements in the field relating to biosorption for the treatment of nuclear waste was undertaken by Nishesh Kumar. For the retention of heavy metals, bio sorbents of algal, bacterial, fungal, animal, and plant origin are utilized. Its widespread utilization is anticipated eventually since it is among the most cost-effective approaches to managing nuclear waste [20]. The replicable model of waste management in campuses involve segregation of wastes generated at source, and systematic and scientific management for transformation of trash into treasure. Which can be achieved through composting and biogas generation, and the creation of livelihood opportunities. Christ University, Bangaluru displays a decentralized solid waste management system in the campus. Their goal of 'zero-waste' campus propagates the message of 'Trash to Treasure' [21].

2.7 Laboratory waste management in educational institutions

Initially, the trash produced in an educational institute lab can be divided into hazardous and non-hazardous waste. The majority of non-hazardous materials can be thrown away in regular waste. Hazardous chemicals must be properly labeled and handled, and they can always be discarded at disposal sites that have been authorized. The waste that because corrosion can be neutralized to make them safe. Acids are best neutralized by certain carbonate substances, like sodium or potassium carbonate. Utilizing carbonate prevents neutrality from being overrun to the basic end. To neutralize basic flows, it is better to use a moderate acid like boric acid. To prevent confusion about the components placed in the container, don't forget to completely label any waste products. These items will be regularly gathered and delivered to a certified location for clearance. Exotic or aggressive solvents ought to be kept in their own, unique container until they are in time to be disposed of. Forming sulfide precipitation of the heavy metals and decanting the aqueous part are two ways to reduce the quantity of accumulated aqueous metal wastes. To precipitate all the metals from a neutralized metal solution, sufficient sodium or iron sulfide might be introduced. If any of these components is put into an acid solution, hazardous emissions of hydrogen sulfide gas will be produced, thus make sure to neutralize. To ensure that proper maintenance is a real element of the lab research and not just a collection of guidelines on writing, constant monitoring and verification must be established. A vast array of hazardous substances that are out-of-date, unsuitable, poisonous, aggressive, flammable, or unidentified, are present in many educational environments and labs. These substances are frequently bought in bulk, kept poorly, and discarded inappropriately, endangering students, staff, and the surroundings. Numerous institutions also keep chemical waste from laboratory studies for ages in regard to these useless substances. Lab waste management procedures are regularly started, such as performing a chemical inventory to remove outdated chemicals, inspecting, and lowering the number of dangerous chemicals for indicators of leaking, corrosion, and torn labels, and building spill containment in chemical storage rooms [22].

In RUC campus Kharagpur, depending upon the waste characteristics, a chemical waste management plan was created [7]. Figure 1 depicts the system limits of the planned and current chemical waste management approaches.

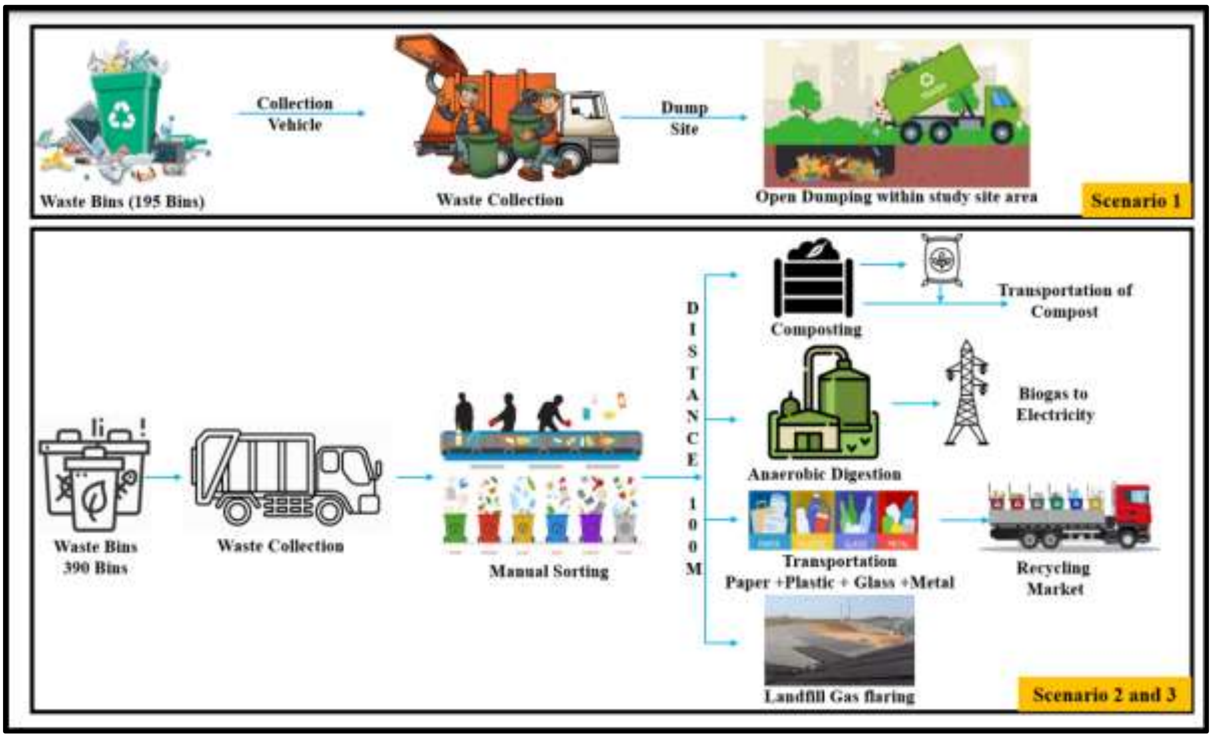

Figure 1: Environmentally friendly Waste Management Plan in Kharagpur, India

2.8 Open Dumping-(Scenario 1)

The RUC campus of Kharagpur, West Bengal, India currently disposes its chemical wastes using this scenario. The sanitation council's employees collect trash, which is then dumped in unlined landfills on campus. A significant amount of greenhouse gases (GHGs) is released as a result of the waste's breakdown. Methane gas emissions from the anaerobic breakdown of the garbage cause GHG to be created. The anaerobic breakdown of methane (CH_4) results in around 5% of the world's methane emissions. Leachate, a poisonous liquid, is produced when the waste reacts with precipitation and humidity.

2.9 Waste Sorting System with 50% and 90% Integration of Waste Management-(S2 & S3)

An organized approach to chemical waste management that promotes eco-friendly integrated waste management. In this procedure, chemical waste, the leachate mechanism, and the gas collecting system are all dumped into the landfill. Before releasing the gas into the atmosphere, it is additionally gathered and flared. As recommended by the IPSS, a first-order degrading scenario is used to determine the overall landfill gas (LFG). The exterior oxidation effectiveness of CH4 by the fugitive emission is predicted to be between 15% and 20%, whereas the collecting rate is roughly 60%. Around 25 to 30 kWh/ton of total electricity is used for the leachate treatment. This procedure involves separating the chemical waste's organic component and delivering it to the anaerobic digestion plant. No energy is retrieved during the constructed landfill's disposal of the residual waste. The techniques for treating leachate and gathering gas are also taken into account in this approach. The gas is flared prior to being released into the atmosphere. A third of the biogas is discharged, which is created during the anaerobic breakdown and used to produce power. In this instance, the collection efficiency is reported to be around 95%. Leachate was treated using the same procedure, and the same procedure is utilized to treat biogas slurry. As a substitute for mineral fertilizer, digestive waste is spread on the ground [23,24,33,25–32] .

The National Institute of Technology Rourkela, the Indian Institute of Technology, and the Jaypee University of Information Technology are research and educational institutions and that specialize in waste management. The Department of Civil Engineering of the Jaypee University of Information Technology does an investigation on solid waste management. This institute also comprises the Division of Bioinformatics and Biotechnology, which conducts studies on the bioremediation of solid chemical waste and electronic waste [34].

The Center of Societal Mission has been run by the Indian Institute of Technology Indian School of Mines since 2015. This facility is a portion of the National Initiatives of the Indian administration, which links universities and local regions to promote sustainable development. It makes utilization of chemical wastewater, plastic, and biodegradable waste. The Department of Civil Engineering at the National Institute of Technology Rourkela creates remedies for India's major environmental problems. Studies on solid chemical waste management, air pollution, and chemical wastewater management are conducted in this unit [35].

A service-learning approach to trash management has been devised by Nancy Jaba Priya of Madras Christian College. It entails dealing with impromptu recyclers and chemically recycling garbage made of polyethylene terephthalate (PET). The PET trash was turned into solid terephthalic acid, which makes a lot of money for the recyclers. This contrasts with PET bottles, which would only bring in a quarter of the money [21]. Advanced oxidation processes (AOPs) were also used to produce a large number of active and non-selective free inorganic radicals in the reaction, which were also applied to the removal for organic pollutants [36].

In order to lessen its environmental impact and provide a safe and healthy working environment for teaching and non-teaching staff, students, and visitors, Maharshi Dayanand University, Rohtak, recognizes the need of sustainable and comprehensive waste management. In an effort to better manage waste, MDU is putting the Hazardous Waste Regulations into practice. Under these rules, the University is only allowed to store hazardous waste for a maximum of 90 days and must keep a record of all sales, transfers, storage, recycling, and reprocessing activities unless the State Pollution Control Board in question has extended the time limit. The university will investigate ways that nonhazardous trash can be reused, recovered, and recycled in a way that is good for the environment. Paper waste will be recycled to create packaging materials and paper board. Environmentally safe enzyme technology will be used to treat the paper's harmful inks and colors [37].

In order to promote the scientific and lab infrastructures in academic institutions, university departments, and research institutions, the Government of Kerala's Department of Science and Technology has established a research fund [38]. Additionally, it helps emerging scientists carry out tasks and initiatives in the fields of science and technology. The UGC is a legal agency of the Indian government that administers funding as well as plans, chooses, and upholds the preservation of high academic levels in Indian educational institutions. For colleges to develop practices and policies to substitute chemical waste with highly environmentally friendly resources, this commission has provided guidance [39]. Due to the complexity of India, it is crucial that educational institutions look for ways to segregate waste management while also educating the students about the importance of reducing chemical waste.

The biomedical waste management plays a significant role in sustainable development [40]. The biomedical waste management regulations of 2016 are followed by AIIMS, India's top medical school, as society moves toward more environmental awareness and responsibility. The first institution in India to get approval to operate and a renewal of its permit to dispose of biomedical waste under the new regulations is AIIMS [41,42]. The goal is to make occupiers and operators of common biomedical waste treatment facilities more accountable while also emphasizing the need to reduce, recycle, and reuse. The phase-out of chlorinated materials, training, vaccination, bar-coding of waste, pre-treatment of laboratory waste, and higher standards for treatment and disposal are all efforts in this direction. A section that explains such requirements for disposal via incinerators and autoclaves and to be followed by common biomedical waste treatment and disposal facility operators has been included as a much-needed boost to environmental protection [43,44].

For practical reasons, the AIIMS's whole bio-medical waste system is separated into the three parts listed below. The selection and collection of garbage at the point of creation are the topics of the first part. The second or middle segment and final segment are related to NDMC central collection facility and final disposal respectively (**Figure 2**).

First Segment	Middle Segment	Last Segment
Segregation and Collection of waste at the site of generation (ward/lab/ Blood bank/user/areas etc.) and transportation to the collection points i.e., sluice room/ common corridor etc.), This service is carried out by outsourced sanitation firms.	1. Collection and transportation of biomedical waste from the collection points to Central temporary collection and storage facility. 2. Collection and transportation of biomedical waste from the collection points at laboratories and blood banks and microwaving of these wastes. Subsequently these wastes are transported to central temporary collection and storage facility. 3. Transportation of general wastes from Collection points to NDMC central collection facility. These services are also carried out by outsourced sanitation firms	Transportation of Bio-Medical waste from the Central temporary collection and storage area/ central, treatment and final disposal. This segment of service is being rendered by the DPCC authorized CBWTF operator M/S Biotic Pvt. Limited.

Figure 2: Three segment biomedical waste management in AIIMS

The following five step process explains about the biomedical waste (BMW) generation and its disposal in AIIMS (Figure-3 and 4).

Step-1-Collection of BMW from various sites and location.

Step-2-Use of different colored coded bins and bags to load in the trolleys.

Step-3-Trolley collects waste all over the institute and transfers the waste into temporary transport storage unit.
Step-4-Bar coded the bags.
Step-5-All collected waste transport to common BNW treatment facility.

Figure 3: BMW collection in AIIMS

Figure 4: BMW transportation from AIIMS

Special pretreatment is done in microwave for some specific hazardous lab waste before sending them in the temporary transport unit (Figure-5). At the common treatment site incinerable and autoclavable wastes are separated out. Flow chart depicted in figure-6 showing the process for disposal of BMW at common treatment site. Biotic Waste Solutions Pvt. Ltd. New Delhi is authorized CBWTF of AIIMS. Insight of common bio-medical waste treatment facility (CPWTF) for incinerable and autoclavable waste disposal in greener way (Figure-7 and Figure-8). Chemical liquid waste generated throughout is also collected and inclined into sewage treatment plant (STP) of the institution (Figure-9).

Figure 5: Special pretreatment in microwave for some specific hazardous BMW lab waste

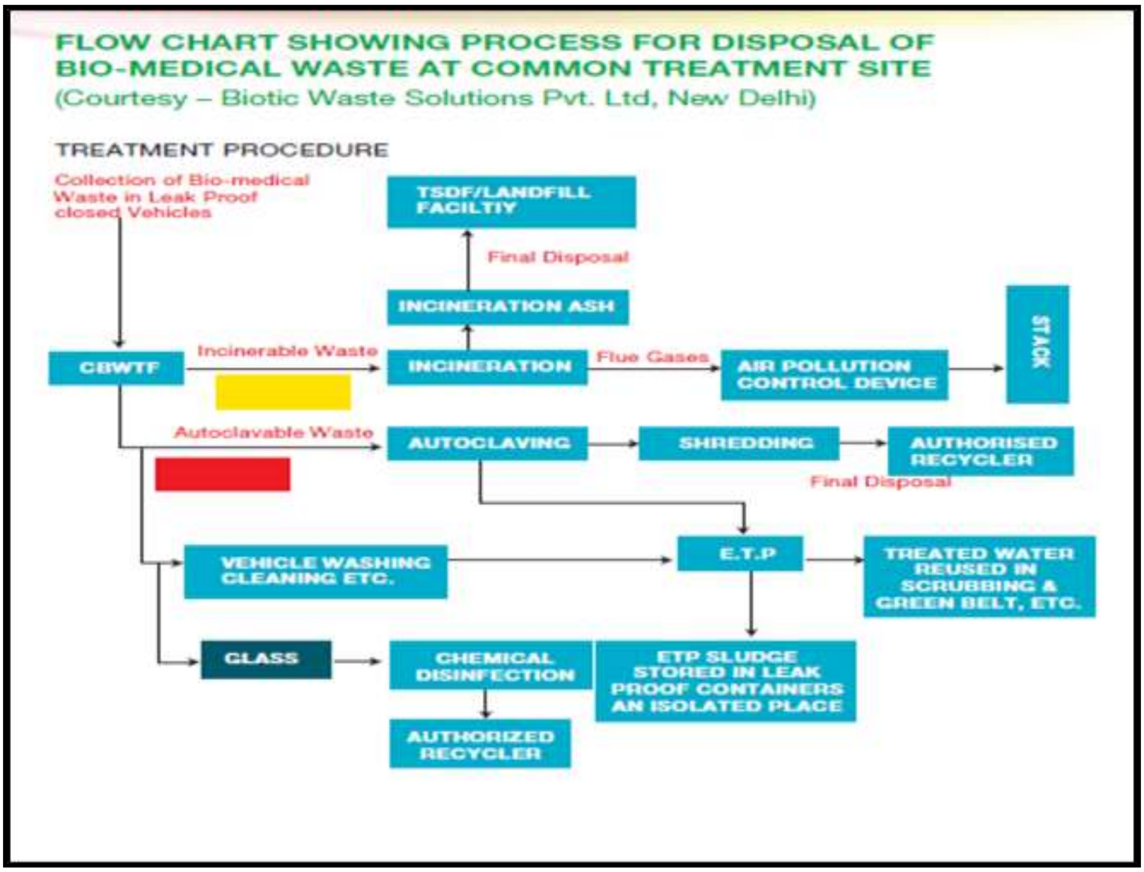

Figure 6: Flow chart - Disposal of BMW at common treatment site.

Figure 7: CBWTF - Common biomedical waste treatment facility (Incinerable Waste-Yellow bin waste treatment)

Figure 8: CBWTF - Common biomedical waste treatment facility (Autoclavable Waste-Red bin waste treatment)

Figure 9: Chemical liquid waste: Separate collection system to STP-AIIMS

Heidari *et al.* developed a new multi-objective mathematical programming model considering new employment opportunities as the social side of sustainability [45]. Furthermore, due to ineffective public participation in the waste management processes in the developing countries, incorporating waste separation after collection in the waste management practices is the suggestion of this study to contribute to the social sustainability. Another aspect of the developed model was uncertainty that is inevitable and should be acknowledged to guarantee reliability in the decision-making process. To handle the uncertain model coefficients and stipulations, the robust possibilistic programming approach was utilized. The application of the proposed model is demonstrated in a real case study associated with the Tehran MSW system. The obtained results indicated that composting is the worst waste final disposal alternative, while anaerobic digestion and incineration have better performance in terms of the sustainability indicators.

Conclusion

Governing the educational institution environment has presented the administration and government with many difficulties over the years. The development of alternative technology to completely stop the production of chemical wastes is challenging. In developing nations, the emphasis on economic growth frequently places a higher value on manufacturing expenses than the finest possible technology, which increases the output of waste. Such waste treatment and disposal costs constitute a social obligation. Prior to choosing a landfill, consideration should be given to other possibilities such as resource recovery through reuse and recycling of such wastes. Everywhere in the country, secured landfill sites are chosen using environmental impact assessments (EIAs) to ensure that the facility has as minimal of an adverse effect on natural and social systems as possible.

This review concentrates on waste categorization and highlights the significance of a number of elements, such as waste diagnosis, the requirement for open dumping regulatory requirements, the transformation of open dumping sites to hygienic landfills, and the formation of waste management, resource and power recovery modules. This review also covers different types of chemical waste and comparison studies of chemical waste management in different educational institutions in India. The characterization investigation indicates that organic waste, which makes up 76% of all trash, is the most prevalent waste constituent. This discovery led to the discovery of anaerobic digestion as a practical therapeutic possibility. Additionally, it has been demonstrated that segregating waste at the origin enhances the efficiency of anaerobic digestion facilities. In order for source-segregated waste to be gathered independently and transferred to waste management units, academic institutions must invest in waste collecting facilities.

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