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Disposal of expired empty containers and waste from pesticides

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Abstract

Global pesticide use increased from less than 2.5 million tonnes (2,303,814 tonnes) of active ingredients (a.i.) in 1990 to more than 4 million tonnes (4,168,778 tonnes) of active ingredients in 2019, with an absolute change of +1,864. 964 tons and a relative change of +81%. In Africa, total use of pesticides was 65,943 tons in 1999 and increased to 107,864 tons in 2019. Insecticide use in Africa is greater than relative changes globally (+29% in Africa vs. +20% globally). . However, the total use of pesticides in Egypt's agricultural sector was 13,214 tons in 1999 and decreased to 13,178 tons in 2019. After application, there are gradually a lot of containers and pesticide waste. There are various types of pesticide waste: empty containers, surplus pesticide solution mixtures, surplus pesticide products, active ingredients, expired raw materials, ready-to-use formulations, rinse water from containers, application equipment, spill clean-up materials and obsolete pesticides. All developed and developing countries face the problem of pesticide waste; however, the problem is different in developed industrialized countries and in poor developing countries. The share of pesticide packaging collected in 2005 was 17.3% worldwide. Therefore, in 2019, CMPT will offer 56 container management programs worldwide. On the other hand, the innovative treatment technologies for the disposal of pesticide waste include various processes, i.e. H. chemical dechlorination, photocatalytic oxidation, thermal desorption, biodegradation, solidification and stabilization technologies. There are many difficulties with meter development, including a lack of national regulations, laws and awareness of pesticide waste and container disposal. In addition, there is insufficient control and regulation of pesticide imports, the lack of good storage facilities, and political and social problems that impede the development process.

Keywords: pesticides; wastes; containers; disposal; obsolete; recycle; agriculture.

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1. Abbreviations

FAO	; Food and Agriculture Organization of the United Nations
OECD	; Organization for Economic Cooperation and Development
IPM	; Integrated Pest Management
WHO	; World Health Organization
FRAC	; Fungicide Resistance Action Committee
HRAC	; Herbicide Resistance Action Committee
IRAC	; Insecticide Resistance Action Committee
GRM	; Global Resistance Management
IBC's	; Intermediate Bulk Containers
EPC	; Empty pesticide containers
EPPC	; Empty plastic pesticide containers
EWC	; European Waste Catalogue
IGNAM	; International Group of National Associations of Manufacturers
WPPC	; Wasted Plastic Pesticide Containers
GIFAP	; Group of National Associations of Manufacturers of Agrochemical Products (GIFAP)
PGR	; Plant growth regulators
IGR	; Insect growth regulators
SVR's	; Small volume returnable
HDPE	; High-density polyethylene
EPPC	; Empty plastic pesticide containers
IGNAM	; International Group of National Associations of Manufacturers
WPPC	; Wasted Plastic Pesticide Containers
PMPWF	; Pest Management Principles for the Wisconsin Farmer
CMPT	; Container Management Project Team
PCBs	; Polychlorinated biphenyls
GC-MS	; Gas Chromatograph- Mass Spectrometer
HPLC	; High-Pressure Liquid Chromatograph
4,4-DDE	; 4,4'-dichlorodiphenyldichloroethylene (DDE)
DDT	; Dichlorodiphenyltrichloroethane
FAO	: Food and Agriculture Organization

2. Introduction

Worldwide, all developed and developing countries face the problems of pesticide waste, although the problem is different in developed industrial countries and poor developing countries. It has been note that the consideration of the industrialized countries focuses on pesticide waste management, container disposal and recycling, wastewater treatment, and treatment of contaminated soil [1]–[4]. Whereas, poor developing countries were the disposal of unused, unwanted, obsolete, and expired pesticides, pesticide containers and the problem of soil contaminated with pesticides among the main problems of pesticide waste management [5], [6].

Over a period of four decades, Africa has accumulated an estimated 50 000 tonnes of obsolete pesticide stocks [7], [8]. African countries like Botswana, Mali, Morocco, Ethiopia, South Africa, and Tanzania were each estimated to have more than 1000 tonnes of obsolete pesticide stockpiles, according to the Food and Agriculture Organization (FAO's) obsolete pesticide inventory study [9]. Pesticides that can no longer be utilized and must thus be disposed of are referred to as obsolete by the FAO. These include contaminated soil buried in shallow open or closed pits or designed landfills as well as banned, out-of-date, unlabeled, and/or unidentified pesticides in all forms, including liquids, powders, granules, emulsions, and/or gases [10]. Additionally, empty pesticide containers pose a serious risk to human health and the environment. For instance, a research in Greece [11] discovered that farmers typically dispose of empty pesticide containers by dumping them by the field (30.2%), tossing them near or into irrigation canals and streams (33.3%), and burning them over an open fire (17.9%). The storage of fuel, food, and water, as well as other residential needs, are also done with empty pesticide containers [12], [13].

In fact, the issues revolving around the management of pesticide waste and containers in developing countries are significantly different from those in major industrialized countries [6]. The most severe effects are seen in developing countries, primarily because of a lack of knowledge about the inherent risks of pesticides and the methods to protect people [8], [14]–[18]. Although, all developing countries have access to the factors, problems, and strategies for the safe disposal of pesticide waste and containers; however, the issue of containers and pesticide wastes is significant and requires more attention [3]–[6], [19], [20].

Innovative technologies for disposing of pesticide wastes include a variety of processes, such as chemical dechlorination, photocatalytic oxidation process, thermal desorption, biodegradation, solidification and stabilization technologies [21], [22]. By transforming polluted soils into a durable, rigid, glassy product as it cools, vitrification technology treats contaminated soils on-site. 4,4-DDT and dieldrin pretreatment concentrations of 13,00 ppm and 4,600 ppm, respectively, were both lowered to less than 16 ppm when the test was over. Molten technologies trap pollutants in a matrix, much like vitrification. However, molten methods incorporate trash into a molten bath of salts or metals rather than melting the contaminated matrix [21], [22].

According to the European Waste Catalog (EWC), empty pesticide waste containers, which still contain pesticide residues, are considered hazardous waste (EWC). The residual pesticide must be classed as "dangerous" or "non-hazardous" waste in accordance with EU Regulation N. 1272/2008 because its active substance content must be assessed and compared to ecotoxicity standards [23].

There are still many regions that need attention in order to stop the buildup of pesticides, despite several regulatory actions and the application of Integrated Pest Management (IPM). These include teaching pesticide importers, distributors, and retailers how to manage pesticides in accordance with approved worldwide procedures; teaching pesticide storekeepers across the nation how to manage their stores; and teaching pesticide consumers how to use pesticides properly. Additionally, the public needs to be made aware of the advantages and risks of pesticides, as well as their unintended buildup; organic farming application in various agricultural settings [8]. To the best of our knowledge, countries and manufacturers combine to play a crucial role in the disposal of pesticide waste and empty containers without paying any costs on the part of farmers, in addition to increasing awareness, educating people, and transferring knowledge.

The objective of this review is to provide current knowledge on the optimum methods for disposal of expired empty containers and wastes of pesticides.

3. Common types of pesticide active ingredients

The pesticides consist of active ingredients and other additive materials to formulate their commercial pesticide products. Pesticide active ingredients are described and classified according to the type of pest they are controlling or how they work. Persons regularly use the word "pesticide" to mention only insecticides, but it essentially applies to all active ingredients used for pest control [24]. Therefore, pesticides are classified based on the pests that control into insecticides, molluscicides herbicides, acaricides, nematicides, rodenticides, and fungicides. In addition to plant growth regulators (PGR), Insect growth regulators (IGR), algicides, disinfectants, plant defoliants, attractants and swimming pool treatments (SPT), and others, that are less well-known pesticides but they are important for protection or control important pests. Moreover, the other important pesticides classification is classified based on the mechanism of action according to Insecticide Resistance Action Committee (IRAC) (https://irac-online.org/international/introduction/). The chemical structure and classification of insecticides based on the mode of action can be browsed on phone using the phone app [25]. The fungicide classification based on the mode of action is classified by the Fungicide Resistance Action Committee (FRAC) (https://www.frac.info/) also with mobile app [26] and herbicides by the Herbicide Resistance Action Committee (HRAC) (https://www.frac.info/) [27] and also, with mobile app. In this year, the Resistance Action Committees (IRAC, HRAC FRAC) released the Global Resistance Management (GRM) Mode of Action App as one application for ease of access by the user. This app includes the three app committees that include all data and information of IRAC, FRAC, and HRAC. The individual IRAC, FRAC and HRAC Mode of Action Apps are still available and all applications can be downloaded from the Apple App and Google Play stores.

4. Worldwide consumption of pesticide active ingredients

The food and Agriculture Organization of the United Nations published the total pesticides used in the agricultural sector worldwide annually from 1999 to 2019 and is available at this link http://www.fao.org/faostat/en/#data (Retrieved 17-05-2022) [28]. Pesticide use increased from less than 2.5 million tonnes of active ingredients of the year 1990 to more than 4 million tonnes of active ingredients in 2019. These pesticides include major pesticide groups used in the agricultural sector for crops and seed treatments. These groups included insecticides, herbicides, fungicides, IGR, and rodenticides. The same trend in increasing uses of total pesticides is found in the uses of insecticides in most of the country worldwide. The total pesticides used in agriculture (tonnes) in the world account for 2,303,814 tonnes in 1999 and increased to 4,168,778 tonnes in 2019 with an absolute change of +1,864,964 tonnes and the relative change account +81%. In Africa, the total use of pesticides account for 65,943 tonnes in 1999 and increased to 107,864 tonnes in 2019 with absolute change of +41,921 t and the relative change account +64% [28], [29].

The total insecticides used in agriculture (tonnes) in the world accounted for 583,406.00 tonnes in 1999 and increased to 698,169.00 tonnes in 2019 with an absolute change of +114,763.00 tonnes and the relative change account +20%. In Africa also, the same trend of increased use of insecticides in agriculture was reported which account for 2,345.00 tonnes in 1999 and increased to 28,905.00 tonnes in 2019 with an absolute change of +6,560.00 tonnes and the relative change account +29%. The use of insecticides in Africa is greater that the relative changes worldwide (+29% of Africa vs +20% worldwide) [28], [29].

Pesticide breakdown by type in 1999 of world account for 11601, 49196, 115460, 698169, 969061 and 2222273 tonnes of rodenticides, plant growth regulators, other pesticides, insecticides, fungicides and bactericides, and herbicides, respectively. While, Africa account for 1740, 2545, 2246, 22345, 21233, 13763 tonnes of rodenticides, plant growth regulators, other pesticides, insecticides, fungicides and bactericides, and herbicides, respectively [28], [29].

5. Egypt consumption of pesticide active ingredients

According to the Food and Agriculture Organization data, the total pesticides used in the agricultural sector in Egypt account for 13,214 tonnes in 1999 and decreased to 13,178 tonnes in 2019 with an absolute change of -36 tonnes and the relative change account -0% (Table 1). In the contrast, the insecticides used were account 4,233.00 tonnes in

1999 and increased to 5,242.00 tonnes in 2019 with an absolute change of +1,009.00 tonnes and the relative change account +24% [28], [29]. In Africa also, the same trend of increased use of insecticides in agriculture was reported which account for 2,345.00 tonnes in 1999 and increased to 28,905.00 tonnes in 2019 with an absolute change of +6,560.00 tonnes and the relative change account +29%. The use of insecticides in Africa is greater that the relative changes worldwide (+29% of Africa vs +20% worldwide)[28], [29].

However, the use of pesticides in agriculture in Africa is highly variable and depends on a number of factors, including the country in question, the type of pesticide used, and the type of agricultural sector in which it is used. It is reported that in 2016, 788000 tonnes of pesticides were applied in the African continent, accounting for 7.8% of the world total. Pesticide use disproportionately targeted countries in East and North Africa, accounting for over 46% of the Africa-wide use. The two most used were insecticides (66%) and herbicides (32%), with fungicides accounting for only 2%. The most commonly used insecticides were organophosphates, carbamates, and pyrethroids [30].

Table 1. Total pesticides in Agricultural Use in Africa and Egypt from 1999 to 2019.

Year	Total pesticides use (tonnes)	
	Africa	Egypt
1990	65943	13214
1991	62720	8255
1992	54424	6156
1993	49613	4175
1994	51088	4283
1995	56930	4391
1996	58553	4499
1997	59460	4607
1998	60754	4715
1999	63010	4823
2000	63873	4931
2001	64503	5039
2002	67492	5147
2003	69668	5255
2004	73236	5363
2005	71280	5471
2006	77360	9781
2007	75614	9105
2008	79227	9527
2009	79611	9013
2010	84706	11590
2011	92543	12945
2012	98119	13991
2013	99987	13653
2014	98734	11363
2015	97584	8044
2016	97450	8414
2017	102100	9988
2018	107023	11352
2019	107864	13178

Source: Food and Agriculture Organization of the United Nations.

6. Pesticide formulations

Pesticide formulations are a combination of pesticide active ingredients, adjuvants, and other carriers such as water, oils, or other solvents. Formulating these ingredients into a pesticide product is an important process since it affects how the active ingredient acts, how long it remains on a surface, how it disperses in the environment, and how well plants and pests absorb it. Pesticide formulations, such as liquid sprays, dust, granules, baits, and aerosols, vary in appearance and application methods. Each formulation type requires a specific amount of active ingredient (AI) to be effective and therefore has different active ingredient concentrations. Common pesticide formulations include Emulsifiable Concentrates (EC), Water Dispersible Granules (WDG), Wettable Powders (WP), Soluble Powders (SP), Aerosol or Fogger, and Bait. In fact, pesticide's active ingredients are formulated in different forms for easy application and use. Therefore, the good design of the pesticide container is very important and it must consider the interactions between the pesticide active ingredients and the materials of the container to protect the pesticide container during the transport and storage process. Pesticide formulations may be either in liquid or dry form. They contain a wide-ranging of solutions, emulsions, powders, dust, granules, pellets, and aerosols. Pesticides are found in the commercial form in different formulations with different concentrations of active ingredients, which ranged from high or low percentages of the active ingredients, depending on the percentage of inert materials. In addition, some commercial pesticide formulations may be ready to

use or must be diluted before use and application [31]–[36].

7. Empty containers and pesticides wastes

Empty containers and pesticide wastes should be handled and disposed of properly to prevent contamination of the environment and potential harm to human health. This can include proper cleaning and rinsing containers before disposal, and disposing of pesticides in accordance with local regulations. Some communities may have special disposal programs or designated collection sites for pesticides and pesticide containers. It is important to consult with local authorities to determine the proper disposal method for each area. Additionally, it is a good practice to reduce the use of pesticides and consider alternative methods of pest management.

7.1. Pesticide containers

Pesticide containers are containers that are used to hold and transport pesticides. They are typically made of plastic or metal, and are designed to protect the contents from leakage and to prevent contamination of the surrounding environment. Pesticide containers must meet certain regulations to ensure that they are safe for use and disposal. These regulations may include requirements for labeling, packaging, and transportation. Pesticides are found in different formulation forms most of them are in the liquid and solid states. Therefore, the most common and used agriculture pesticide containers are made from plastic. Plastic drums are the most common agricultural pesticide containers, as well as portable refillable containers with large-sized that can be packaged and reused, which are usually larger than drums and are used to transport large quantities and sizes of pesticides. In addition to small hand-held containers, which are small ranging from 2.5 gallons and less. Refillable portable containers are not required to be rinsed by the applicators. It is the supplier's responsibility to rinse and clean the containers before refilling them [19].

Pesticide containers are divided into two main categories of ***non-refillable containers*** and ***refillable containers*** (Fig. 1). The first one, non-refillable containers are generally mentioned as containers that have one use only and are available for one-way or disposable packages. Non-refillable containers can be of different sizes such as 2.5,5 and 10 gallons or less size and big sizes such as drums 30 and 55 gallons. There are many examples of these containers such as bag-ln-a-box designs, bags, cans, aerosol cans, and water-soluble bags. In these types of pesticide containers, different materials, openings and closures, and designs can be used for making a wide variety of containers [19]. The second one, refillable containers are prepared and made for multi uses and they have been specially designed and constructed to make them refilled with pesticides for sale or distribution such as bulk storage tanks, mini-bulks, refillable bags, and small volume returnable (SVR's). However, some requirements for pesticide containers are needed to ensure their protection during shipping, handling, and storage. For example, bags that contain no more than 10 kg must be made of one or more layers of paper sheets or aluminum foil. Bottles containing not more than 1 kg or one lite must be provided with protective caps of no more than a diameter in the case of liquids about 63 mm. Polyethylene bottles or other plastic bottles must be made of resins that have a high level of resistance to environmental factors. Metal containers containing no more than 20 liters must be made of steel and lined with tin or other metals to ensure compatibility with the rest of the contents of the packaging and to provide external protection. Metal containers for liquids must be made of a special composition that prevents pressure and volatilization of vapors, and the packaging must be sealed if this is done without welding. Large containers must be made of reinforced materials such as metal or polycarbonate Polyethylene, synthetic fiber, or cardboard boxes. Packages containing no more than 250 kg or 200 liters of steel must be made of steel, which is lined internally with protective material against rust or corrosion. Polyethylene or plastic containers must be made of high-quality resins high level of resistance to environmental factors.

7.1.1 Advantages of good design of pesticide containers

According to the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO), one of the important areas is the design of a pesticide container that can help to reduce the risks of pesticide leakage through transport and storage [20]. Reducing the

contact between workers, users, and releases to the environment after using the containers. Poorly designed containers are therefore very hazardous and countries are setting requirements for the design of pesticide packs (Fig. 2). The requirements include the quality of the package, containing the pesticide, preventing it from escaping during storage and transportation, protecting the pesticide from damage during the storage period, preserving the health of users, and not leaking the product and endangering the health of users or the environment [19], [20], [37], [38].

7.1.2 Disadvantages of poor design of pesticide containers

Similarly, a poorly designed container is unsafe. Therefore, pesticide containers and formulations are important and all country apply their regulation when registering a pesticide product. The principal criteria for a well-designed container are to protect the pesticide product from damage due to the different conditions of storage and transport and to protect users or the environment and reduce the problem on the environment [20].

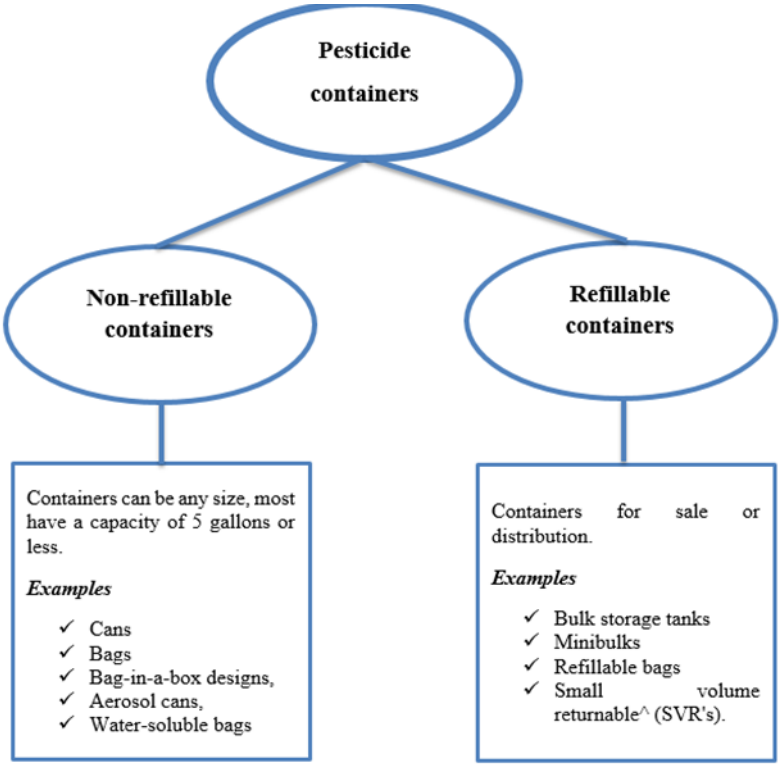

Figure 1. Non-refillable and refillable pesticide containers and some examples of containers.

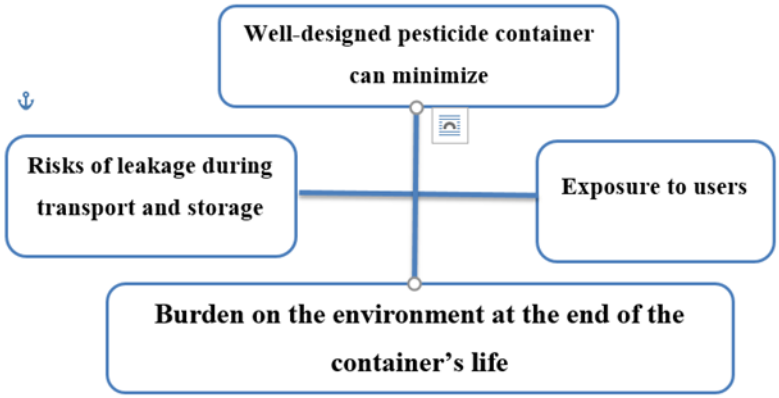

Figure 2. Benefits of the good design of pesticide containers.

7.1.3 Safe disposal of empty pesticide containers

Poor management of pesticide containers constitutes a major health and environmental problem due to the lack of safe use and proper disposal. Pesticides are manufactured, distributed, and used according to a specific system, which includes the collection, reuse, or recycling of empty pesticide containers. Pesticide package management programs are among the important topics that include a group of stages and different methods [23], [39]–[47]. The main objective of these programs is to reduce the adverse health effects of pesticide exposure and to protect humans and the environment. These programs include collecting pesticide containers safely from the farm, preventing the reuse of pesticide containers, and packaging them for use in other purposes, which pose risks to humans and the ecosystem. In addition to recycling containers and reusing them as a source of raw materials in the manufacture of other products or using them as an energy source are the main targets [39], [42], [44], [45], [47].

Pesticide containers consisted of many different types according to size, material, as well as a packaging design.

- Hard-to-rinse containers are containers that are difficult to rinse and the rinsing process cannot be done properly, such as some seed treatment containers or other pesticide formulations that adhere to the inner surfaces of the containers. The following guidance should be taken when collecting packages, Separation from the source of containers that are difficult to rinse or contaminated. These containers are not placed in recyclable containers. Dispose of these containers by incineration in waste incinerators or energy recovery areas.

- End-of-Life Collection & Recycling of Drums, Intermediate Bulk Containers (IBC's) this a result of using a large volume of pesticides in agriculture to control pests in bag farms at a large scale. These containers are refilled and reused a number of times over a period of years such as drums, and IBC's. However, some of these larger containers are sometimes designed as one-way trip containers. In plastic container at recycling, the non-plastic components must be removed before recycling and the plastic can be recycled for the recovery of heat energy at cement plants, or at waste-to-energy facilities. Steel drums and steel components from plastic containers, once thoroughly rinsed and cleaned, can be recycled at a steel recycling facility.

- Caps packaging will be separately collected because it is made from high-density polyethylene (HDPE). This is different plastic than that typically used for the containers.

- Some small size packaging is hard to rinse and/or consists of different materials making recycling difficult to achieve. Caps packaging is made from high-density polyethylene (HDPE). This is different plastic than that typically used for the containers.

- Small size packaging is hard to rinse and/or consists of different materials making recycling difficult to achieve. The type of small packages and the different methods of their disposal.

However, empty pesticide containers should be triple rinsed with water, and then punctured or crushed to prevent reuse. They should then be disposed of in accordance with local regulations. It is important to check with local authorities to determine the appropriate disposal method in your area, as regulations can vary depending on location. In some cases, it may be necessary to take the containers to a designated hazardous waste disposal facility.

Many researchers have studied the safe disposal of pesticide containers. In these works, different methods were used to dispose of pesticide congeners. It seems that disposal through incineration is the fastest method to dispose of these materials. A design of a pilot plant and a full-scale plant for the incineration and disposal of containers was performed [44]. Empty containers of pesticides are one of the important hazardous wastes, which pose a possible risk to humans and the environment. Containers can be reused by farmers to store water or foodstuffs without good clear or injuring the containers on the farm with the potential of releasing toxic from pesticides and plastic [45]. It has established 36 'mature' programs throughout the world for the management of pesticide containers. Most of these programs focus on recycling of High-Density Polyethylene (HDPE) one-way disposable containers, which represent the majority of containers entering the market [45].

7.1.4 Important of design for reducing the environmental load of the recycling or disposal of the empty pesticide containers

As discussed before, the good design of pesticide containers is an important criterion for protecting

humans and the environment. it will reduce exposure during pesticide storage, transport, and use as well as minimize the problem of recycling or disposal of the empty container in the environment [19], [20], [35]–[38]. One-way pesticide containers are the most common containers used for pesticide packaging. These containers need programs to manage, recycle and dispose of them after use. Alternative containers have been designed to avoid damage caused by recycling, disposal of containers from these new designs are reusable or refillable containers, and water-soluble containers that offer alternatives that are less hazardous to humans and the environment.

7.1.5 Water Soluble Packs

Pesticide water-soluble packaging is a new pack that uses for pesticide formulation that will be diluted in water and added directly into the tank before pesticide application such as the package used in insecticide methomyl. This container provides two advantages including reducing direct worker exposure and no empty containers for recycled or disposal. The important requirement of pesticide water-soluble containers is to protect them through cover this packaging using waterproof secondary packaging that prevents damage during storage and transport [20], [31].

7.1.6 Management of empty plastic pesticide containers (MEPPC)

Waste plastic pesticide containers make up the majority of waste from pesticide containers of various package sizes worldwide. According to the European Waste Catalogue (EWC), plastic pesticide packaging is considered hazardous waste, which contains residues of hazardous substances from pesticides. The rinsing and cleaning process of empty pesticide containers is considered an important source of wastewater pollution by pesticides. Therefore, appropriate treatment methods are very important and requested use to protect water from contamination by pesticide residues. In developing countries, the reuse of pesticide packaging for domestic purposes poses a risk to farmers' health [48]. Moreover, due to a shortage of knowledge, farmers are regularly unwilling to clean and destroy empty pesticide containers [30]. In order to properly manage empty plastic pesticide containers, they should be triple-rinsed with water to ensure all remaining pesticide residue is removed. The container should then either be punctured or crushed to prevent reuse and disposed of at an approved waste management site, according to environmental regulations applicable to the area. It is important to never reuse, re-fill, or burn empty plastic pesticide containers. Farmers can empty pesticide countries or package through one of the following possible disposal methods according to the International Group of National Associations of Manufacturers (IGNAM) [30], [48].

1. Return WPPC to chemical companies for reuse,
2. High-temperature incineration,
3. Chemical treatment,
4. Landfilling “is an engineered method for land disposal of solid and hazardous”.

An important awareness of fires empties pesticide containers in open area, safe incineration techniques, and safe landfilling must be compelling with a standard protocol [11]. However, farmers in Pakistan, Papua New Guinea, Costa Rica, and Uganda developing countries lack knowledge and dispose of containers after pesticide application in water canals, streams, or nearby vegetation [49], [50]. The farmers in Papua New Guinea dispose of Wasted Plastic Pesticide Containers (WPPC) by different methods based on the knowledge as flow, in fields (44%), buried in the ground (12%), discard into streams (9%), and burn in open fires (9%), reuse for home purposes (6%) and reuse for other purposes (14%). In the study performed in Pakistan similar trend was found. About 53% of farmers disposed of WPPC into the environment and households reused it (18%). Farmers in Costa Rica (14%) and in Uganda (19%) discard pesticide residues into rivers. They reuse the WPPC for domestic purposes poses such as even store water, carrying vegetables and washing clothes [49]. Previous studies reported the different unsafe uses of pesticide containers by farmers due to the lack of knowledge [11], [30], [44], [49], [50].

7.1.7 Hierarchy of the disposal of empty pesticide containers management

The hierarchy of managing empty pesticide containers includes a set of waste management methods. It is based on the most preferred choices that have little negative impact on humans and the environment and the least preferred choices come at the end of the hierarchy [19], [31], [51]. Less preferred container disposal methods have a relatively

significant negative impact on the environment and humans. These methods include avoiding or reduce using the pesticide containers packages, reusing, recycling, resource recovery, incineration and landfilling (Fig. 3).

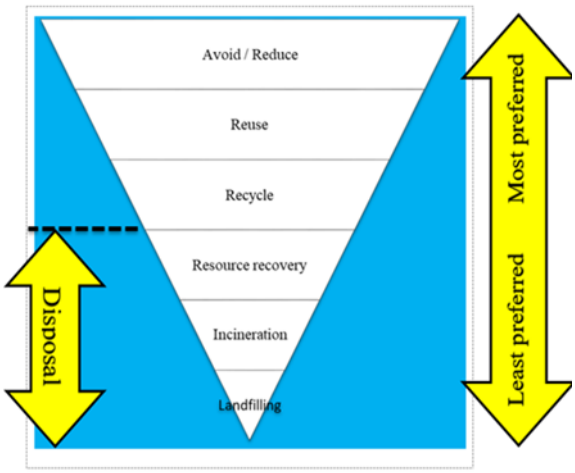

Figure 3. Hierarchy of disposal of empty pesticide containers management.

It is important to note that proper handling and disposal of empty pesticide containers is crucial to protect human health and the environment. It is essential to follow the regulations and guidelines set by the government and follow the manufacturer's instructions. In addition, to reduce the use of pesticides, the hierarchy of the disposal of empty pesticide container management is as follows: 1. Reuse: Empty pesticide containers can be cleaned and reused if they are in good condition. 2. Recycling: Empty pesticide containers can be recycled if they are made of materials that can be recycled, such as plastic or metal. 3. Incineration: Empty pesticide containers can be incinerated, which is a process of burning the containers in order to reduce their volume. 4. Landfill: As a last resort, empty pesticide containers can be disposed of in a landfill, but this is not a preferred option as it can lead to contamination of soil and groundwater.

7.1.8 Advantages of cleaning empty pesticide containers

Cleaning empty pesticide containers have many environmental and economic advantages. The economic benefits of cleaning pesticide containers including saves money (rinsing and adding about 2% of pesticide to the tank throughout cleaning the containers at the preparation of the pesticide solution), and reducing the pesticide wastes of recycling or disposal containers which leads to lower pesticide residues contamination. The environmental benefits of cleaning pesticide containers include minimizing the risks of contamination of soil and water, reducing users' exposure and animals, and can recycling containers for new products without requiring destruction as hazardous waste [19], [51].

7.1.9 Cleaning methods of empty pesticide containers

There are several methods for cleaning empty pesticide containers, including the following:

1. Triple rinse method: This involves rinsing the container three times with water, with the rinse water being added to the spray tank each time.
2. Power washing: Using high-pressure water to forcefully remove any remaining pesticide residue from the container.
3. Steam cleaning: Using high-temperature steam to break down and remove pesticide residue from the container.
4. Chemical cleaning: Using a cleaning solution specifically designed for cleaning pesticide containers to dissolve and remove residue.
5. Crushing or puncturing: Puncturing or crushing the container to ensure it cannot be reused and can no longer hold any pesticide.

It is important to follow the manufacturer's instructions and any local regulations when cleaning pesticide containers to ensure they are safe for disposal or reuse. The cleaning methodologies of empty pesticide containers are on the chemical and physical properties of pesticide formulation (Table 2). The instructions pesticide label and material safety data sheet (MSDS) should include the methods of cleaning the pesticide containers. Pesticide containers should be Rinse and immediately cleaned after the containers are emptied and the washing solution should be reinstated to the spray tank for use in the application as part of the pesticide solution.

Table 2. Cleaning methodologies of empty pesticide containers.

Formulation type	Method of Cleaning			
	Triple rinsing	Pressure rinsing	Integrated pressure rinsing	Rinsing with solvent
Emulsifiable concentrates (EC)	√	√	√	x
Water soluble products (WSP)	√	√	√	x
Water soluble solids (WSS)	√	√	√	x
Oil and solvent based products	x	x	x	√

Recommended method (√), un-recommended method (x).

The study by Doersch [52] of Pest Management Principles for the Wisconsin Farmer (PMPWF), found that triple rinsing is effective in reducing pesticide-active ingredients remaining in a container to greater than 99.999% with good cleaning. This conclusion was based on data collected from tests on 1 oz (28g) of liquid remaining in 22.5-liter containers (5 gallons) (Table 3).

Table 3. Effect of the number of rinsings (1st, 2nd and 3rd rinse) on the remaining pesticide in the containers.

Topic	Rinsing stage (after draining, 1st, 2nd and 3rd rinse)			
	After draining	1st rinse	2nd rinse	3rd rinse
Pesticide residue (g)	14.2	0.2	0.003	0.00005
Remaining (%)	100.0	1.4	0.021	0.00035
Removing (%)	0.00	98.60	99.79	99.99965

7.1.10 . Pesticide containers management systems around the world

Pesticide container management systems are systems and procedures used to properly handle, transport, and dispose of empty pesticide containers. This can include cleaning and triple rinsing containers before disposal, properly labeling and storing containers, and following regulations for transport and disposal. The goal is to minimize the potential for contamination and ensure the safety of the environment and human health.

CropLife International Container Management Project Team (CMPT) offers management and guidance to managers of container recycling programs in individual countries [53]. As of 2019, around 56 programs for container management were working in countries worldwide. Country have container management programs include Argentina, Australia, Belgium, Austria, Brazil, Canada, Bolivia, Chile, Costa Rica, Colombia, Croatia, Ecuador, Dominican Republic, El Salvador, Germany, France, Honduras, Guatemala, Luxembourg, Hungary, New Zealand, Mexico, Netherlands, Panama, Nicaragua, Peru, Paraguay, Portugal, Poland, Slovenia, South Africa, Romania, Spain, United States, and Uruguay.

In the years 2004 and 2005, the weight of pesticide packaging shipped into the market in kilogram accounted for 20 778 300 and 20 960 264 for North America, 29 144 283 and 37 154 000 for Latin America, 2 744 666 and 2 049 021 for Australia–New Zealand, 24 341 000 and 24 141 000 for Europe, and the total accounted for 77 008 249 and 84 304 285, respectively. On the other hand, the weight of pesticide packaging collected in the same years accounts for 5 550 480 and 5 539 616, 11 034 797 and 16 322 283, 1 070 420 and 1106 471, 9 199 950 and 9 961 900 kg of North America, Latin America, Australia–New Zealand, and Europe and the total accounted for 26

855 647 and 32 930 270 kg. The percentage of collected pesticide packaging in 2005 accounted for 17.3 % worldwide [51].

7.1.11 Empty pesticide containers management programs (EPCMP)

EPCMP have been created all throughout the world and are generally used by nonprofit organizations with governmental control. Information about some of these projects, which are recognized national programmes with quantifiable results, as well as information on the country of application (Table 4). Information specific documents provide in-depth guidance on setting up an EPC management system [54]–[57].

Managing obsolete or abandoned pesticide containers for a long period is one of the two programs included in the management of empty pesticide containers. The second program is the management of pesticide containers for pesticides currently in use following the use of pesticides and emptying those containers. The second program consists of a series of procedures for the successful handling of empty containers, as well as the removal of pesticide residues from packages through appropriate washing. To obtain the program's goals, it is necessary to recognize the numerous roles and responsibilities as well as to be knowledgeable of the laws and regulations that regulate work and supervisory [58].

Table 4. Example of worldwide empty pesticide containers management programs (EPCMP).

No.	Programs or project	Country	Organization	Reference
1	EPC recycling	Australia	DrumMUSTER	[57]
		U.S.A	Ag Container Recycling Council ACRC	[55]
		Spain	Sigfito Agroenvases SL	[56]
		Canada	CleanFARMS	[57]
		Netherlands	STORL	[54]
		Germany	PAMIRA	[54], [55]
		Cyprus	Green Dot Cyprus Public Co. Ltd	[23]
2	Campo Limpo	Brazil	InPeV	[55], [59]
3	Agrolimpio	Argentina	CASAFE	[60]
4	EPC collection	France	ADIVALOR	[61]
5	AgriRecover	Belgium	Phytofar	[23]
6	Fee-per-bag collection service	Ireland	Irish Farm Film Producers Group's (IFFPG) and Farm Plastics Recycling Ltd	[23]
7	Disposal to a waste or recycling contractor	United Kingdom	The Voluntary Initiative	[23]

Adopted from Marnasidis *et al*., [23].

7.2. Types of pesticide waste

Expired Pesticide waste poses significant environmental and health risks, especially in developing and poor countries in the Third World, which do not have the funds and technology to help them safely dispose of pesticide waste. Pesticide waste includes all expired pesticide products, active ingredients, empty containers, containers, dilute pesticides, expired raw materials, ready-to-use formulations, and other pesticide waste, materials, packages, supplies, and devices used in the application (Fig. 4) [30]. Therefore, there are different types of pesticide waste that are empty containers, excess pesticide solution mixture, excess pesticide products, rinse water from containers, application equipment, and materials resulting from cleaning spills and leaks. Moreover, obsolete pesticides which defined by the Food and Agriculture Organization of the United Nations (FAO) as all currently unused pesticides, which have been excluded, deteriorated, damaged, expired, and will be not used in the future [62]–[65]

7.2.1. Managing and disposing of pesticide wastes.

Pesticide waste poses a real hazard to the environment and human health. Therefore, there is growing interested in the good management and safe disposal of pesticide wastes. They pose a major

problem in the agricultural sector and have significant environmental and health impacts. Unsuitable disposal of pesticide wastes and containers is one of the most important problems of environmental pollution, especially in developing and poor countries. They pose a hazard to the environment, workers' safety, and health. Inappropriate disposal of pesticide wastes and containers leads to contamination of surface and groundwater. These risks can be reduced using suitable integrated management techniques for the safe management and disposal of pesticide wastes and containers [11], [20], [66], [67].

In fact, the generation of pesticide waste and containers is a continuous process during each agricultural process of a crop from the beginning of obtaining and taking pesticides until the use, cleaning, and disposable of spraying equipment and pesticide packs. Major pesticide manufacturers and producers can withstand advanced recovery, treatment, and cleaning technologies for expired containers, packages, and pesticides. Farmers and small farms have problems with the disposal of pesticide waste and empty packaging despite small-scale pesticide use. These include the disposal of pesticide waste, contaminated soil, treatment of water from the equipment laundering process, empty pesticide containers, spills, and the problem of wastewater treatment and pesticide residues, especially in developing countries [5], [11], [30], [66]–[68]. The issues revolving around the management of pesticide waste and containers in developing countries are significantly different from those in major industrialized countries. These are due to some factors in developing countries that aggravate the problem of pesticide waste, empty containers, soil, and environmental pollution. For example, regulations, laws, and awareness, pesticide importation, lack of technology and funds, storage facilities, reuse of empty containers, and political and social issues [3]–[6], [19], [20].

7.2.2. Selection of disposal options

As has been previously discussed, there are many sources of pesticide waste, including all expired pesticide products, active ingredients, empty containers, containers, dilute pesticides, expired raw materials, ready-to-use formulations, and other pesticide waste, materials, packages, supplies, devices used in the application and obsolete pesticides [30], [62]–[65]. Obsolete pesticides are very important and unused pesticides, that have been excluded, damaged, expired, and will not use in the future. The selection of disposal action is dependent on the status of pesticide wastes. For example, product stile use and can recycling, went to stock destruction and disposal using different methods such as incineration by high-temperature hazardous waste incinerators (small and mobile incinerators). Disposal using special techniques as performed for disposal of pressurised gases such as methyl bromide, crushed steel drums or using the other technology such as plasma technology and chemical decomposition. The International Group of National Associations of Manufacturers of Agrochemical Products (GIFAP) outlined a strategic plan for selecting the most practical waste remediation method [69]. Once the item has been located, a decision can be made regarding whether to use it or recycle it. If the pesticides meant for a particular crop and pest are kept apart from one another and there is enough storage, even wastewater streams can be recycled [70]. When recycling and use are not practical options, methods of treatment or destruction must be employed. The strategic analysis now deals with the technical feasibility, the logistical questions, the need for monitoring, and the local availability of disposal technologies, the infrastructure and material requirements and the long-term disposal needs.

7.2.3. Innovative treatment technologies of disposing for pesticide wastes

There are several treatment technologies for disposing of pesticide wastes, including:

1. Incineration: Pesticide waste is burned at high temperatures, reducing it to ash and gaseous by-products
2. Landfilling: Pesticide waste is buried in a specially designed-landfill to prevent contamination of soil and groundwater
3. Biodegradation: Pesticide wastes is broken down by microorganisms into a non-toxic compound
4. Chemical treatment: Pesticide waste is treated with chemicals to neutralize or transform it into less toxic compounds
5. Physical treatment: Pesticide waste is physically separated into different fractions (e.g. liquids, solids) for further treatment or disposal .
6. Phytoremediation: Pesticide waste is treated using plants that can absorb and degrade the chemical.

The most appropriate treatment method depends on the specific pesticide and the amount and type of waste generated. It is important to follow the regulations and guidelines of the local government for the disposal of pesticide waste. However, many scientists have examined the technology of disposal of concentrated chemicals at an industrial level such as unwanted pesticide stockpiles, pesticide waste, and expired pesticides. The technology used to dispose of pesticide stocks or remove pesticides from a polluted environment is divided into three groups. The first relief is where the pesticide is destroyed through some chemical reactions such as chemical dechlorination, photocatalytic oxidation, and bioremediation by using microorganisms. The second category is where pollutants are extracted from specific environmental media such as thermal adsorption. As for the third category, the movement of pollution in a niche is topped, including the techniques of hardening, stabilization, glaze, and fusion [21], [22], [71].

The innovative treatment technologies of disposing for pesticide wastes include different process i.e., chemical dechlorination process for removing the chlorine atom from the compound via the destruction or detoxification such as the removal of organochlorine pesticides, polychlorinated biphenyls (PCBs) and dioxins from contaminated soils and wastewater. The photocatalytic oxidation process for reducing contaminated water using a UV source from sunlight or UV lamps and another catalyst such as titanium dioxide (TiO2). The other process such as thermal desorption by heating the soil at low temperatures (300° - 1 000° Fahrenheit). Biodegradation process for organochlorines and dioxin that have some limitation due to slow rate of biodegradation [21]. The main goal of solidification and stabilization technologies is to reduce the solubility or mobility of pollutants, typically through physical rather than chemical means. Waste stabilization technologies convert pollutants into lower answerable, mobile, or poisonous forms by adding a binder to the waste, similar to cement kiln dust or fly ash [21], [22]. By transforming polluted soils into a durable, rigid, glassy product as it cools, vitrification technology treats contaminated soils on-site. 4,4-DDT and dieldrin pretreatment concentrations of 13,00 ppm and 4,600 ppm, respectively, were both lowered to less than 16 ppm when the test was over. Molten technologies trap pollutants in a matrix, much like vitrification. However, molten methods incorporate trash into a molten bath of salts or metals rather than melting the contaminated matrix [21], [22] (Fig. 5).

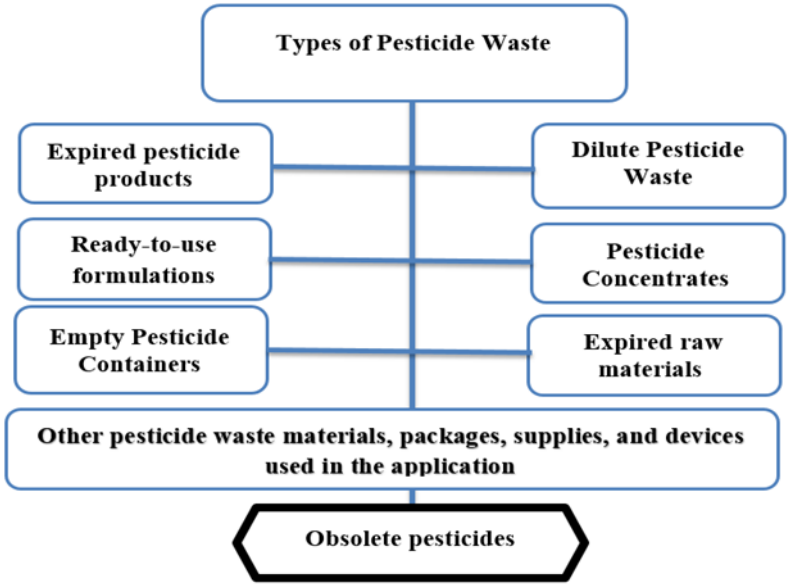

Figure 4. Simple diagram shows some types of pesticide waste

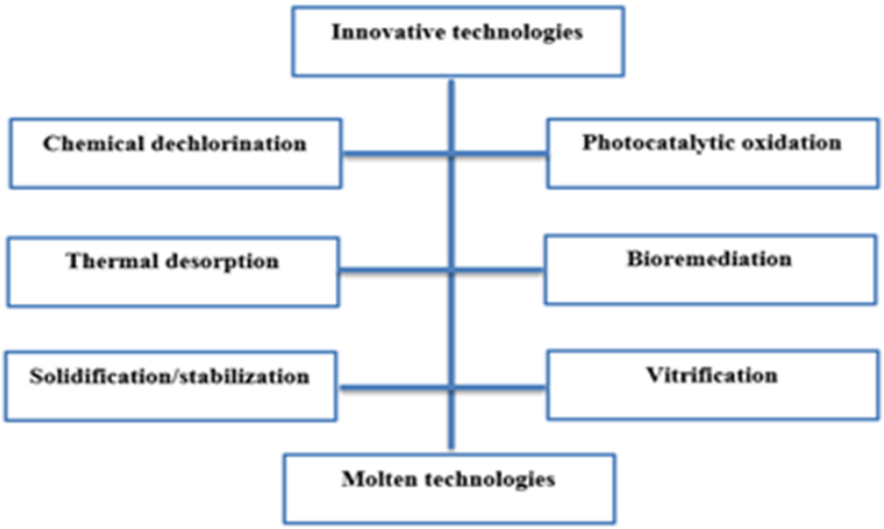

Figure 5. Different innovative of disposing for pesticide wastes.

7.2.4. A Strategy for disposal of pesticide wastes

Clearly, any waste management strategy should place the highest importance on actions that prevent or at the very least reduce waste generation and support material recycling. The Australian Waste Management Hierarchy classification is a good illustration of such a strategy. FAO [14], [22], [72] and the International Group of National Associations of Manufacturers of Agrochemical Products (GIFAP) have developed other helpful strategies for managing wastes as well as pesticide stocks [69].

According to the recommended of GIFAP [69], in small farm or industry, a small-scale waste are producers that cannot be expected to do in-depth strategic analysis and planning. Nevertheless, agricultural or environmental regulatory agencies can conduct the assessments and then present an array of feasible choices to the waste generator. To split the cost of disposal, smaller generators could form cooperatives. Users of pesticides can adhere to the Australian Waste Management Hierarchy in addition to the GIFAP strategy (Table 5).

Table 5. Queensland Farmers of pesticide waste management hierarchy strategy

Australian Waste Management Hierarchy strategy (Queensland Farmers)					
Classification	Least preferred	Good	Better	Even better	Most preferred
Practice	Waste disposal	Waste treatment	Waste recycling	Waste reduction	Waste avoidance
Objective	The final waste management choice should only be made after all other realistic options have been explored. Waste should be controlled and kept within a specific region to prevent damage to the environment or to people's health.	Using a process that turns waste into a form that may be used, disposed of, or recycled more easily or safely (e.g., adsorption by activated carbon, chemical or biological detoxification).	Strategies for recovering, reusing, or processing a product (e.g., using returnable chemical containers; accessing programmes that use crushed chemical drums for industrial fuel; spraying rinse water on crop edges).	Reducing the amount of garbage produced by employing all available methods (i.e., changing practices; e.g., ultra-low volume applications; use of low-rate compounds).	Avoiding generation of waste at the source by looking at the situation and changing practices or by choosing the least hazardous products.

7.2.5. Characterization of disposal pesticide waste constituents

The best disposal method may depend on the specific components of the pesticide waste. Old pesticide stocks, for example, that include lead arsenate or mercury, should not be burned. Solvents and surfactants, which are inert substances, may have an impact on the possibility of bioremediation. In order to develop a disposal alternative, qualitative and quantitative studies are the first steps. Although industrialized nations are likely to have equipment like gas and high-pressure liquid chromatographs (HPLC, GC/MS) readily available and fitted with selective detectors or coupled with mass spectrometers, developing nations might have trouble locating reliable, reasonably priced facilities nearby (FAO, 2007; GIFAP, 1991) [69], [72]. However, for any type of tiny waste generation, affordability is a major barrier to acquiring accurate waste categorization.

7.2.6. Disposal of obsolete pesticide or unused Pesticide Stocks

Ironically, unused or outdated pesticide stockpiles were donated by rich nations with the goal of helping underdeveloped nations with their waste problems. Despite the United States ban on exporting outdated pesticides to poor nations [73], excessive prior gifts from wealthy nations have left thousands of metric tonnes of outdated stocks dispersed throughout a number of nations, particularly in Africa [74]. Twenty-eight African countries participated in an inventory of outmoded pesticides in 1996, and it was projected that 15,000 tonnes needed management [14], [22], [72]. Over 100,000 tonnes worth of obsolete stocks are thought to exist in non-OECD (Organization for Cooperation and Economic Development) countries. Obsolete stocks frequently have labels with severe deterioration and are improperly stored in rusted and leaky containers, leading to contaminated soils and tainted goods.

7.2.7. Acceptable methods for disposal of bulk quantities of obsolete pesticides

After securing a storage location, disposal possibilities might be explored. Fig. 6 lists the disposal techniques that the FAO deems acceptable and unsatisfactory. High-temperature incineration would be the most effective way, however it is frequently not viable due to cost and accessibility issues with the correct kind of incinerator.

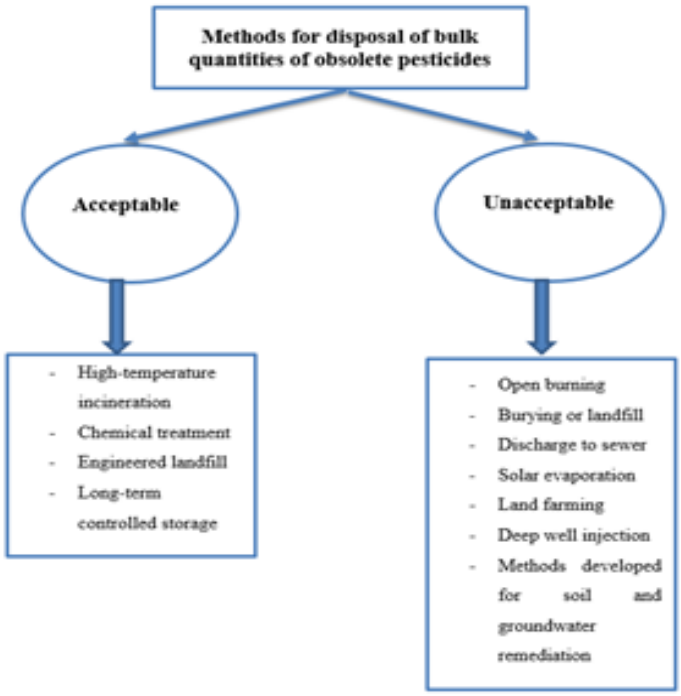

Figure 6. Acceptable and unsuitable techniques for getting rid of large amounts of outdated pesticides in developing countries [14].

8. Summary

Worldwide, pesticide use increased from less than 2.5 million tonnes (2,303,814 tonnes) of active ingredients (a.i.) in the year 1990 to more than 4 million tonnes (4,168,778 tonnes) of active ingredients in 2019 with an absolute change of +1,864,964 tonnes and the relative change account +81%. In Africa, the total use of pesticides account for 65,943 tonnes in 1999 and increased to 107,864 tonnes in 2019. The use of insecticides in Africa is greater that the relative changes worldwide (+29% of Africa vs +20% worldwide). However, the total pesticides used in the agricultural sector in Egypt accounted for 13,214 tonnes in 1999 and decreased to 13,178 tonnes in 2019. Sequentially, a lot of containers and pesticide waste are generated after application. There are different pesticide wastes that are empty containers, excess pesticide solution mixture, excess pesticide products, active ingredients, expired raw materials, ready-to-use formulations, rinse water from containers, application equipment, materials resulting from cleaning spills, and obsolete pesticides. All developed and developing countries face on the problems of pesticide waste; however, the problem is different in developed industrial countries and poor developing countries. The percentage of collected pesticide packaging in 2005 accounted for 17.3 % worldwide. Therefore, CMPT offers 56 programs for container management worldwide in 2019. On the other hand, the innovative treatment technologies of disposing for pesticide wastes include different process i.e., chemical dechlorination, photocatalytic oxidation, thermal desorption, biodegradation, solidification and stabilization technologies were reported for uses. There are many difficulties in developing counters including lack of national regulations, laws and awareness for management of pesticide wastes and containers. In addition, insufficient control over pesticide importation and regulation control absence of good storage facilities, and political and social problems that hinder the development process.

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