Types of Contamination in Landfills and Effects on The Environment: A Review Study

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Abstract. Waste disposal is one of the important problems in the world. In general, wastes are categorized into different groups, and there are some special landfills and methods for disposing of each of these waste materials. However, it should be noted that although there are some rules and regulations that try to reduce the impact of waste disposal, landfills have negative effects on soil, air, water, and natural life. One of the most important sources of pollution in landfills is the leachate that is generated by the decomposition of waste. Leachate can penetrate into the soil and water resources, contaminate them, and can affect human life. Leachate generation has five different phases and each of these phases contains some reactions that have a direct impact on the quality and quantity of leachate. Leachate has four main types of pollution and each of these pollutants can contaminate soil and water resources and be hazardous for aquatic and animals in the soil. In addition, some of these contaminations can enter the food chain and affect the ecosystem and human life. The negative impacts of landfills remain even years after the landfill is closed. Therefore, it is important to consider the short-term and long-term effects of landfills on their surroundings to protect the environment and human health.

1. Introduction

One of the side effects of human activities such as daily activities, industrial and commercial activities, scientific and laboratory researches and etc. is the production of unwanted substances. These waste materials can be municipal solid wastes, industrial wastes, or even wastes from construction and demolition activities. From time immemorial, these wastes were kept away from residential areas because waste has an unpleasant odor, it causes an increase in the rodent population, air pollution, aesthetic problems and is also dangerous for human health [1].

In recent decades, some methods have been developed to reduce waste production. For example, reducing the amount of non-recoverable waste, recycling some materials such as glass, steel, metal, aluminum, plastics, paper and etc. and reusing materials to decrease the use of raw materials and energy are ways that contribute to human society to reduce the amount of waste [2]. In addition, some wastes can be used to generate energy which reduces the amount of remaining waste [3-8]. But there are still some unwanted and unusable substances and they must be disposed of in a way that has the least impact on the environment and human health. In other words, the disposing of the wastes should be done in the safest way and this should be the last decision which is done only if there is no alternative method [9].

Before the 1950s, waste materials were disposed of in open dumpsites and the contaminations and impacts of wastes disposal in dumpsites on the environment and human health were not considered and
it was a general believed that leachate of the wastes is treated by soil and groundwater and it has no long-term or even short-term impact on the surrounding environment of dumpsites [2]. Therefore, one of the most problematic aspects of waste disposal in open dumpsite was leachate infiltration because there was no leachate collection system [10]. Although in the early 1930s, Europe raised concerns about the need to improve methods of waste disposal, by 1959 no significant action has been done to improve waste disposal [11].

In 1959, the American Society of Civil Engineers (ASCE) developed the first recognized definition of sanitary landfills. Wastes are generally divided into two groups which are hazardous and non-hazardous wastes. In this regulation, disposal sites of non-hazardous waste are called sanitary landfills and they require engineering operations to meet certain standards in design and operational stages [1,2].

In 1979, the United States Environmental Protection Agency (EPA) developed standards for solid waste disposal facilities that reduce the impact of the disposal sites on human health and the environment. Any landfill that fails to meet these standards is considered an open dump. On the other hand, Resource Conservation and Recovery Act (RCRA) prohibit the use of open dumping, therefore, open dumps must be closed or updated to meet the sanitary landfills standards [12]. Many other countries have developed rules and regulations to update their landfills but in some parts of the world, wastes are disposed of in open dumpsites, and rodents such as rats, odor, air pollution, scavenging birds such as crows, and insects in these dumpsites have serious impacts on the environment and human health [1].

Therefore, the design and development of a sanitary landfill are controlled operations that need planning and engineering design skills. Wastes are transported to the landfills and compacted with heavy types of machinery that have huge steel wheels and eventually covered by a layer of soil after each day of work [1,11]. In addition, some facilities such as leachate collection systems, liners such as impervious clay or synthetic materials, and capping have to prepared in sanitary landfills to prevent pollution infiltration to soil and groundwater [1,10]. In addition, waste usually contains organic matter, and anaerobic decomposition of organic matter produces some gases, such as methane and carbon dioxide. These gasses must be collected from sanitary landfills and they can be used for different purposes such as producing heat and electricity [1].

Sanitary landfills have many different types but the schematic of a typical sanitary landfill is shown in Figure 1.

![Figure 1. A typical sanitary landfill [1]](image_url)

It should be noted that although sanitary landfills now have very strict rules and regulations to be able to work in a way that minimizes their environmental and health impacts as much as possible, these rules
and regulations are updated every few years by new researches to improve their efficiency and reduce their impacts [2,11].

In this paper, different types of landfills are discussed according to the type of material disposal, the effects of MSW landfills on different sources are described, and finally, soil and water pollution as a result of landfills leachate are explained.

2. Type of Landfills

There are many landfill features that can be used to classify landfills, but the most popular landfills classification system is mentioned in RCRA 2014. Each type of landfill is designed and operated for a specific type of waste material. According to RCRA, landfills are classified according to the type of waste accepted. It should be noted that in this classification system, solid wastes do not necessarily have a physical solid form and they can be in liquid and semisolid or gaseous form.

First of all, wastes are classified into two main groups, which are hazardous and non-hazardous solid wastes. Non-hazardous solid wastes are categorized into the following groups. The first group of non-hazardous solid wastes landfills accepts municipal solid wastes. These landfills are used specifically for the disposal of household wastes but due to the conditions, other non-hazardous wastes such as sludge, industrial solid waste, and construction and demolition wastes (C&DW) can be disposed of in municipal solid waste landfills [2].

The second group of non-hazardous landfills is industrial waste landfills. Industrial wastes are generated by manufacturing or industrial processes that include electric power generation, fertilizer or agricultural chemicals, food and related products or by-products, inorganic chemicals, iron and steel manufacturing, leather and leather products, mineral processing, organic chemicals, plastics and resins manufacturing, paper industry, stone, glass, clay, and concrete products, textile manufacturing, transportation equipment, and water treatment [12].

But it should be noted that these industrial wastes must not be hazardous. The investigation of hazardous wastes can be done according to different codes such as title 40 of the Code of Federal Regulations (CFR) in section 257.2 and in addition, industrial waste does not include mining waste or oil and gas production waste.

Industrial waste landfills have some subgroups, one of the main of which is Construction and Demolition Wastes (C&DW) landfills. Construction and demolition wastes are produced as a result of building new constructions, renovation, and demolition of old buildings, infrastructures, roads, bridges, runways, and site clearing. Construction and demolition wastes may contain a variety of building materials including concrete, ceramic, asphalt, wood, glass, gypsum, brick, metal, insulation, and plastics. Some parts of these materials can be recycled. The use of environmentally friendly materials provides an opportunity to reduce the use of raw materials. But some of these construction materials cannot be recycled and they are sent to the landfills. C&DW landfills only accept construction and demolition waste materials so, industrial solid wastes, MSW and hazardous wastes cannot be disposed of in these landfills [12].

As mentioned before, one of the main groups of landfills is related to the disposal of hazardous material. According to the definition of RCRA, hazardous waste is a waste that has dangerous impacts or capable to have harmful effects on human health or the environment. Hazardous waste may be present in the form of liquids, solids, gases, and sludge. these wastes are generated from different sources such as industrial manufacturing process such as batteries, fluorescent light bulbs or academic laboratories, Cathode Ray Tubes (CRTs), Mixed Radiological Wastes, and pharmaceutical hazardous materials.

Some systems have been developed to identify specific hazardous substances. But in general, hazardous wastes contain a specific concentration of some contaminants that have high toxicity or long half-life such as arsenic, barium, lead, benzene, cadmium, mercury, selenium and etc [12, 13].

As described earlier, the component of wastes is the most important parameter in the classification of landfills. There are different methods for disposing of different wastes and it should be noted that each of these types of material have different impacts on their surrounding environment when disposed of. In this paper, only the impacts of the municipal solid waste landfills are considered.
3. Landfills impacts

Landfills are potential sources of pollution in the environment that can cause water pollution, air pollution, soil pollution, and pollution of the natural environment [9]. Because the components of the environment have complex relationships with each other, pollution from any of the above sources can pollute other sources or worsen pollution and its effects.

Landfills can contaminate surface water and groundwater resources. Solid waste landfills produce leachate that contains various components. Contaminants, concentration, and amount of leaching mainly depend on the type of waste disposed of in landfills. Landfills leachate usually contains toxic elements and heavy metals, biodegradable and persistent organic compounds, dissolved methane, fatty acids, sulfate, nitrate, nitrite, phosphates, and calcium [14, 15]. Leachate can pass through soil and enter the surface water or groundwater [9]. In addition, when leachate enters groundwater, it may leak into adjacent rivers and pollute rivers [18]. It should be noted that rainfall and soil moisture play an important role in the production of leachate. Precipitation passes through the wastes and chemical and physical reactions occur and carry dissolved constituents that can enter the soil [9].

Landfills can cause air pollution by emitting dust and gases such as methane, carbon dioxide, and etc. These gasses are produced as a result of the decay of organic wastes by microorganisms [15]. These gases can be collected by some facilities and separate methane and used for various purposes such as generating electricity or heat. But if these gasses are released into the air, they cause air pollution [15, 16]. It should be noted that landfill gases contain different components according to municipal solid waste sources and operating conditions of the landfill [16]. In addition, there is always the potential for fires due to the production of flammable gases in landfills because of the activity of microorganisms in landfills [17]. The smoke of the landfill fire contains gases such as CO, H₂S, CH₄, and etc. which depend on the type of burning wastes. The amount of landfill gases is highly dependent on the composition of the waste, moisture content, temperature, landfill age, and etc. [9].

Plants, animals, and ecosystems may be affected by landfills. First of all, it should be noted that heavy vehicles movement for the construction phase and the operational phase of landfills can prepare excessive compaction of topsoil and subsoil and cause destruction of vegetation of the area, which has a direct effect on the animal life. On the other hand, gas pollution can pass through surrounding landfill soil and replace by available soil oxygen, which reduces the population of animals in the soil and damage the roots of the plants [20].

Acid rain may be caused by gases released from landfills, which can affect the acidification of soils and ecosystems. Acidic rain can cause a loss of stomatal control, a reduction in photosynthesis, enzyme inhibition, and changes in synthetic pathways on plants [14].

Soil contamination around landfills can occur as a result of the penetration of leachate to the soil. In addition, landfills have some effects on the biological, erosional, hydrological, and geochemical properties of the soil and water resources [18].

Thus, it shows that landfills can have a very wide range of impacts on their surrounding environment and damage various resources on the earth. However, the impacts of landfills on their surroundings have not ended after the landfill was closed. Because the natural decomposition of waste continues for several years and groundwater, surface water, and soil resources can become contaminated decades after the waste is disposed of and landfills closed [19]. Landfill gas generation can be continued for 15-25 years after closing the landfills [9].

In the next section, the characteristics of the leachate and its components are fully described.

4. Soil and water Contamination and Effects on the Environment

In the previous part, the general impacts of nonhazardous wastes landfills on soil, water sources, air, and natural environment were described. In this section, the components of the leachate, the contamination of the soil and groundwater, and environmental problems caused by penetrating leachate from MSW landfills to the soil and water resources are discussed in more detail.

When wastes are moved to a landfill and buried, various series of biological and chemical reactions take place for the decomposition of the wastes. These reactions can be categorized into four different phases,
which are initial aerobic phase, anaerobic acid phase, initial methanogenic phase, and stable methanogenic phase. The overall condition of the landfill has an effect on the process of decomposition reactions. In addition, there is a direct relationship between the decomposition stage and the characteristics of the leachate. Because the wastes are buried in landfills over the years, therefore, in each period of time different parts of the landfill are subjected to different decomposition reactions and generate leachate with different characteristics [20].

The nature of the wastes is heterogeneous and landfill operating characteristics are varied, thus, the ecosystem of the landfills is various in different parts. Although the ecosystem is affected by environmental conditions such as temperature, pH, the presence of toxins, moisture content, and the oxidation-reduction potential, the diversity of the landfill ecosystem is stable. The waste stabilization occurs in five separate and distinct phases and the amount and components of the leachate produced during each of these phases are the same [1].

Vesilind & Worrell (2012) described these five phases as below:

• **Initial Adjustment Phase**

In this phase, the wastes are buried and moisture accumulates in the landfill. A period of time is required to sufficient moisture develops for supporting an active microbial community. Some initial environmental changes occur to provide suitable conditions for biochemical degradation.

• **Transition Phase**

In this phase, the transfer from aerobic to anaerobic environment occurs in the landfill and the oxygen in the landfill is discharged. After completion of this phase, chemical oxygen demand (COD) and volatile organic acids (VOAs) are found in measurable concentrations in leachate components.

• **Acid Formation Phase**

In this phase, the process of continuous hydrolysis of waste and microbial conversion of biodegradable organic content causes the production of high concentrations of intermediate volatile organic acids. The pH value decreases in phase.

• **Methane Fermentation Phase**

In this phase, intermediate acids are converted to methane and carbon dioxide due to consumption by methane-forming consortia. The pH increases and causes growth of methanogenic bacteria.

• **Maturation Phase**

In this phase, the available nutrients and substrate are limited and the biological activity and gas production are reduced. The strength of leachate remains constant at lower concentrations.

It should be considered that the most problematic challenge of landfills is leachate. The quality and quantity of leachate in different landfills depend on various parameters such as the amount of waste, waste composition, solubility, and moisture content of solid waste. In addition, some local factors such as hydrogeological conditions, climate, height, and type of landfill can have an effect on the quality and quantity of leachate. The leachate components vary across a landfill due to waste characteristics, composition, degradation stage, and landfills technology [21]. But in general, the composition of leachate generated at landfills is divided into four different groups: [20, 22]

• Dissolved organics (Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), and Biochemical Oxygen Demand (BOD))

• Inorganic Macro components (calcium, magnesium, sodium, potassium, ammonium, iron, chloride, sulfate, and hydrogen carbonate)

• Heavy metals (cadmium, chromium, copper, lead, nickel and zinc)

• Xenobiotic organic compounds (benzene, toluene, ethylbenzene, xylenes, tetrachloroethylene and trichloroethylene.)
4.1 Dissolved organics matter

Dissolved organic matter (DOM) is one of the matters that contains in MSW landfills leachate. DOM contains several major parameters such as TOC (Total Organic Carbon), COD (Chemical Oxygen Demand), and BOD (Biological Oxygen Demand). DOM has a significant biochemical and geochemical effect on landfills. DOM can interact with organic and inorganic contaminants therefore, some functional groups such as carboxylic, phenolic, and carbonyl in DOM cause interaction between DOM and other substances in the environment [23].

Natural soil usually has some amount of DOM and it depends on vegetation, soil type, clay mineralogy, metal oxides, and environmental factors such as temperature and rainfall. But penetrating leachate to the soil increases soil DOM and cause imbalances in the soil ecosystem [29]. DOM is transported to water sources through the soil and affect water photochemistry, biological activity, pH of the water [21,24]. One of the important parameters of water quality is related to dissolved oxygen, which plays an important role in protecting fish and aquatic organisms. But dissolved oxygen in the water is affected by the entry of DOM because the decomposers decompose the organic matter by using oxygen. Therefore, increasing the amount of DOM penetrating into water sources reduces the amount of dissolved oxygen. This indicates that some materials that do not have specific pollutants, can have a detrimental effect on the environment according to the condition [25].

4.2 Inorganic macrocomponents

Inorganic macrocomponents contain various ions such as calcium, magnesium, sodium, potassium, ammonium, iron, chloride, sulfate, nitrate, hydrogen carbonate and etc. [25]. The concentration of Inorganic macrocomponents in the leachate depends on the phases of the landfill stabilization. During methanogenic reactions, the pH is high and the concentration of calcium, magnesium, iron, and manganese decrease. Sulfate concentration reduces during methanogenic reactions due to microbial reduction of sulfate to sulfide. Ammonia is the most important component of the leachate. The source of ammonia in landfills is the decomposition of proteins, but there is no mechanism in landfills that can reduce the concentration of ammonia, and its concentration decreases only if it is discharged from the landfill through the leachate, otherwise, according to researches, the concentration of ammonia remains stable even 30 years after the closure of the landfill, that has very low inorganic content [20].

When the concentration of these ions in leachate and soil increases, it becomes harder for the roots of plants to get water from the soil because of osmotic pressure and cause reduce plant growth and damage vegetation. In addition, the presents of some ions such as sodium can significantly reduce the permeability of the soil. On the other hand, the high concentration of some specific ions can cause plant toxicity and contamination of groundwater [25].

4.3 Heavy metals

Heavy metal leachate is one of the most important contaminants of leachate. Heavy metals can pollute soil, groundwater, surface water, and also affect human health through mobility, solubility, and the ability to transfer in water or plants [26]. The main heavy metals in waste disposal leachate are cadmium, chromium, mercury, copper, zinc, lead, and arsenic [27]. These heavy metals can be produced by disposing of various materials such as batteries, consumer electronics, ceramics, light bulbs, and glass in landfills. The use of heavy metals has increased over the years. Heavy metal concentration is usually high in the earlier phases of leachate production because more heavy metals dissolve in low pH as a result of organic acids [26].

Food industry wastes are one of the most important materials disposed of in MSW landfills. Food wastes contain a variety of heavy materials in low concentrations, but some heavy metals are hazardous and seriously toxic even in low concentrations. For example, plastics used for food packing or other purposes mainly contain cadmium, chromium, and lead. These heavy metals cause serious toxicity on water and its impact on the aquatic ecosystem, food chain, and human health [27].
4.4 Xenobiotic organic compounds
Xenobiotic organic compounds contain monoaromatic hydrocarbons such as benzene, toluene, ethylbenzene, xylenes, and halogenated hydrocarbons such as tetrachloroethylene and trichloroethylene [20]. These components are usually part of the household and industrial chemical wastes such as personal care products, pharmaceuticals, industrial, pesticides, and medicines wastes [21, 22]. In addition, food additives such as stabilizers, antioxidants, pigments, as well as food packaging materials are another source of xenobiotic organic compounds in landfills [24].

Xenobiotic organic compounds have complex chemical structures and remain in the environment for a long time, therefore they have long-term effects on the environment, such as toxicity and biological accumulation in the cells of organisms. Xenobiotic organic compounds can enter the groundwater, surface water, or even agricultural soils. They affect aquatic life even in a short time. In addition, these compounds can reach the human food chain and cause various health problems. As their chemical structure is so stable in the environment, low concentrations of these compounds can be hazardous because they can accumulate and reach higher concentration and affect the environment [28-30].

These four groups of leachate contaminations that are generated in landfills show that the leachate has a wide range of components, each of which can have a negative impact on soil, groundwater, surface water, and the life of aquatic and animals. In some cases, they can enter the food chain and be hazardous for human health.

5. Conclusion
To summarize, in open dumpsites, there is no barrier between wastes and soil. Therefore, leachate directly penetrates the surrounding environment. In addition, there is no cover for the wastes to prevent odors, flies, birds, and animals. In contrast, sanitary landfills have engineered facilities and collecting leachate systems and they are covered by a soil layer after each day of operation, all of these improvements minimize the negative impact of the landfills on their surrounding environment.

However, sanitary landfills can have an impact on the surrounding environment, and one of the most important ones is related to leachates. The components of the leachate are different in each part of the landfill according to the dispose of materials and the phase of decomposition. However, it should be noted that the entry of leachate into soil and water resources has a negative impact on the environment and ecosystem, and also the generating of leachates continues even 30 years after landfills closure and as a result, these negative impacts continue for several years.

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