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Review

Human Health Impact of Municipal Solid Waste Mismanagement: A Review

Ernesto de Titto [1], Atilio Savino [2,*]

1. ISALUD University, Buenos Aires, Argentina; E-Mail: edetitto@isalud.edu.ar
2. Association for Solid Waste Studies (ARS), Buenos Aires, Argentina; E-Mail: asavino@ars.org.ar

* **Correspondence:** Atilio Savino; E-Mail: asavino@ars.org.ar

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Abstract

Management of municipal solid waste (MSW) is frequently not properly performed. Whenever this happens, those working in the different stages of the process, as well as residents close to the dumps, face health risks. Here, we revised the documented evidence of emissions liberated during MSW management and associated health problems to investigate if systematic and reproducible relationships can be established. Besides substances released during collection and transportation, various toxic substances, predominantly in small amounts, can be released in the leachate and the biogases liberated in the disposal of MSW. Activities in the dump produce fine and coarse particles that are dispersed through the air and can enter the respiratory system, causing a series of adverse health effects, as shown by an increase in the demand for health services and the presence of respiratory symptoms and exacerbations of chronic processes. On the contrary, all the studies on the risk of developing some form of cancer by populations living in the vicinity of a waste dump have not been able to conclusively identify a causal or even circumstantial relationship that such a risk exists. Besides, no systematic association between residence near a landfill and any adverse outcome of childbirth has been found. However, the assessment of potential health effects is uncertain because of their diversity, the varied means of exposure, the uncertainty associated with exposures to low amounts of toxins when they occur over long periods, the potential synergies of various pollutants, the difficulty in establishing direct relationships between the toxicants emitted and health problems, the necessary arbitrariness in the delimitation of the dispersion area of the toxics and the practical impossibility of identifying other sources of exposure that could have some share of responsibility in the emerging health, as well as the lack of control of confounding factors like social deprivation, the lack of data on migrations to or from the most critical areas that affect exposure times or considerations about latency periods in pathologies such as cancer that does not usually manifest until years after exposure.

Keywords
Controlled landfills; health risks; municipal solid waste disposal; occupational hazards; open dumps; sanitary landfills; waste management

1. Introduction

The proper management of Municipal Solid Waste (MSW) comes from activities that take place in the domestic, commercial, and service fields and encompasses a myriad of products like putrescible materials, such as food and food preparation surpluses, and other products such as paper and carton, glass, plastic and metals, is one of the most critical environmental challenges we face, since we all produce waste and do so on a daily basis.

The volume generated, as well as the composition of the MSW is determined by the lifestyle and behavioral habits of the generators, which are related not only to the technological potential, the availability of resources, and the commercial exchange but also to the idiosyncrasy and culture of the populations, their needs, conjunctural demands and the characteristics of the environment in which they reside, including seasonal climatic variations of the annual cycle and the impact of tourism.

The immediate consequence of unproperly managed MSW is pollution which opens the gate to a wide range of health and environmental problems. Although this has been studied in several opportunities, as it will be presented below, we still lack a clear picture of what can be expected in terms of human health when MSW are mismanaged. Therefore, in the present study, we aimed to characterize MSW emissions better and revise the reported evidence on the actual and/or potential impact that they may pose on human health.

2. Management as a Potential Source of Risk

The attribution of responsibility for managing MSW to municipalities faces the real and indisputable fact of their heterogeneous technical and economic capacity to adequately resolve the issue, resulting in a wide range of responses.

At one extreme, we find municipalities that lack an integral management of MSW, that is one that contemplates all stages of the waste cycle from its generation to its reinsertion into the market as inputs, generating inefficiencies throughout the management chain, wasting human and budgetary resources, and undermining opportunities that would allow a notable environmental improvement, social, public health, and local development. Open dumps (OD) as a method of final disposal are the main evidence of inadequate, inefficient, and insufficient management of MSW, since they constitute a huge source of environmental pollution, directly and negatively affecting resources such as air, water, and soils on the one hand, and society on the other as they have consequences on the health of the population and the quality of life in general.

At the other end of the quality of integrated management are the municipalities that have managed to intervene in the management chain and have a sanitary landfill (SL). In it, the waste is confined in an area of land previously prepared to avoid or minimize environmental impacts through engineering work that involves planning and design that considers the potential environmental and social impacts before its construction, commissioning and subsequent closure.

In the midst of this range of MSW disposal methods, we find controlled landfills (CLs), in which waste is accumulated in a space with perimeter protection and daily cover with earth but without an impermeable bottom or recovery of gaseous or liquid emissions.

The use of OD, CL, or SL, whose technical characterizations are presented in Table 1, is, in practice, an economic decision. It has been estimated that SL costs 3 to 8 times more than OD. At the same time, incineration, a capital, and energy-intensive option, is 5 to 10 times more costly than SL for developing countries while composting is 2 to 3 times more expensive [1]. Thus, incineration and SL predominate in the most developed countries and regions, and CLs and ODs are used in developing countries.

Table 1 Differences Between Open Dumps, Controlled Disposal and Sanitary Landfills.

	Open dumps	**Controlled landfills**	**Sanitary landfills**
Sitting of facility	Unplanned and often improperly sited	Hydro geologic conditions considered.	Site chosen is based on environmental, community and cost factors.
Capacity site	Capacity unknown	Planned capacity	Planned capacity
Cell planning	There is no cell planning. The waste is indiscriminately dumped. The working face/area is not controlled.	There is no cell planning, but the working face/area is minimized. Disposal is only at designated areas.	Designed cell by cell development. The working face/area is confirmed to the smallest area practical. Disposal is only at designated cells.
Site preparation	Little or no site preparation.	Grading of bottom of the disposal site. Drainage and surface water control along periphery of the site.	Extensive site preparation.
Leachate management	No leachate management.	Partial or no leachate management.	Full leachate management.
Gas management	No gas management.	Partial or no gas management.	Full gas management.

Application of soil cover	Occasional or no covering of waste.	Covering of waste implemented regularly but not necessarily daily.	Daily, intermediate and final soil cover applied.
Compaction of waste	No compaction of waste.	Compaction in some cases.	Waste compaction.
Access road maintenance	No proper maintenance of access road.	Limited maintenance of access road.	Full development and maintenance of access road.
Fencing	No fence	With fencing	Secure fencing with gate
Waste inputs	No control over quantity and/or composition of incoming waste.	Partial or no control of waste quantity, but waste accepted for disposal is limited to MSW.	Full control over quantity and composition of incoming waste. Special provisions of special types of wastes.
Record keeping	No record keeping.	Basic record keeping.	Complete record of waste volumes, types, sources and site activities/events.
Waste picking	No control on waste picking by scavengers.	Controlled waste picking and trading.	No site waste picking and trading.
Closure	No proper closure of site after cease of operations.	Closure activities limited to covering with loose or partially compacted soil and replanting of vegetation.	Full closure and post-closured management.
Cost	Low initial cost, high long-term cost.	Low to moderate initial cost, high long-term cost.	Increased initial, operational and maintenance costs, moderate long-term cost.
Environmental and health impacts	High potential for fires and adverse environmental and health impacts.	Lesser risk of adverse environmental and health impacts compared to an open dumpsite.	Minimum risk of adverse environmental and health impacts.

Source: Based on UNEP, 2005 [2].

According to the UNEP [3], 38% of the global MSW produced in 2020 was uncontrolled, that is not disposed by landfilling, recycling and/or sent to Waste-to-Energy plants. However, the degree to which MSW is managed varies significantly across regions. While in Western Europe and North America, management controls almost all of its waste in the other regions the situation is more heterogeneous, and frequently, data are uncertain.

Uncontrolled disposal of significant proportions of MSW has been estimated all over the planet (Eastern Europe 25%, West Asia and North Africa 34%, Sub-Saharan Africa 87%, and Central and

South Asia 79%). In Latin America and the Caribbean, as of 2018, on average, the MSW generated by 54% of the population was disposed of in SL; 19 percent in controlled landfills; and 27%, (approximately 145,000 t/day) in OD, flaring, or other inappropriate practices [4, 5]. Data from Asian countries are scarce, mainly from developed countries (Hong Kong, Japan, Singapore, South Korea and Taiwan). Moreover, in many Asian countries, there are no specific regulations for MSW (e.g., Indonesia and Thailand). In India, there were reported differences between states in volume per capita and composition but it has also been estimated that more than 90% of MSW collected is still landfilled or dumped on open lands [6, 7].

The quality of MSW management plays a determining role in their potential impact on human health. Deficits in the collection, transport, and disposal stages inevitably result in greater exposure of operators, such as in informal settings and at dumpsites, when handling healthcare waste and dismantling e-waste, and residents to the polluting contents of garbage. So, negative human health impacts linked to MSW could be associated to two different but complementary reasons. First, the composition of MSW, and second, the way MSW have been managed.

Under this perspective, we consider it necessary to review the existing documentation to investigate whether it is possible to establish clear and systematic causal relationships between the modes of "mismanagement" and the identified human health emergencies.

3. Processes that Take Place during the Decomposition of Waste at Final Disposal Sites

The waste accumulated in a disposal site, be it an SL, a CL, or an OD, produces two types of effluents: leachate, which results from precipitation, uncontrolled runoff, and irrigation water that adds to the waters initially contained in the waste and those resulting from its decomposition, that drains towards the base of the accumulation, and gases, produced mainly by the anaerobic decomposition of the biodegradable organic fraction and released from the surface of the accumulation.

In all three ways of disposal, the composition of leachate and biogas is related to waste decomposition processes, which depend on various factors, such as:

a) The physicochemical properties of the waste, since its chemical composition, moisture content, decomposition capacity, and heat of reaction define the composition of leachate and biogas.

In this particular, it is worth highlighting the heterogeneity of the composition of MSW, both between different cities and in various sectors of the same city, largely related to the socioeconomic level of the generators and the relevance that separation practices have reached, as it has been shown in various countries [8-15].

b) Climatic and meteorological conditions at the disposal site; since the transformation processes are influenced by rainfall -which plays a dominant role in the generation of leachate-, ambient temperature -especially in the upper layers of the filling- and winds, which add their effect on the water balance of the waste.

The decomposition of waste results from a combination of aerobic and anaerobic processes. When oxygen is available - the air trapped in the landfill and the surface layers that receive aeration from the atmosphere - the microorganisms present in the waste participate in aerobic decomposition processes. This phenomenon also depends on humidity. MSW in developing countries usually has a moisture content of 35 to 55% of the total weight [16, 17], depending on the content in organic fraction, to which rainwater is added to favor the process since surface runoff and groundwater must be excluded from a landfill by definition. The decomposition products are mainly carbon dioxide, ammonia, and water, in an exothermic process that significantly raises the internal temperature of the filler and favors the evaporation of moisture.

The decomposition process is slower in the absence of oxygen, as in the lower layers of the filler, and when the trapped air is exhausted or isolated from atmospheric recharge. Here, the degradation begins in macromolecules, such as proteins, to generate organic acids, methane, and carbon dioxide, as well as denitrification and sulfate reduction processes.

Rainfall infiltrates the waste and dissolves and drags away various components of the waste and the products of the decomposition processes (a process called leaching). In CLs and ODs the product of this process (leachate) percolates to the soil and can become a contaminant of the groundwater table, while in a SL it accumulates at the bottom of the landfill and must be pumped or conducted by gravity to a tank or lagoon to receive further treatment.

c) The technology applied at the final disposal site affects the development of decomposition processes. Clearly, the dynamics of the evolution of waste decomposition in ODs will be different than in SLs whose design and operation (cell height, fill profile, compaction technology, type of cover, etc.) are aimed at facilitating decomposition. In addition, SLs employ practices such as recirculating leachate to the surface of the landfill to accelerate degradation processes in the body of waste and greater use of evaporation modify the dynamics of the degradation process and, therefore, the composition of leachate and biogas, and
d) The age of the landfill is an important factor because the composition of leachate and biogas also depends on the reaction capacity of the deposited materials, which decreases over time.

4. Emissions from a Sanitary Landfill

An SL made following the rules of the art of sanitary engineering is designed to carefully isolate the waste deposited there to prevent the contamination of the soil, water, and air. Insulation is usually achieved by combining the use of a bottom cover, gas ventilation, a drainage system, and daily coverage of deposited materials with a layer of soil, together with leachate treatment.

This technology significantly reduces the conditions necessary for the life and reproduction of animal vectors, which depend on the waste's organic fraction (OF), thus minimizing their potential effects on human health.

Aerobic (composting) and anaerobic (biogas production) processes are proven technologies for treating the OF. Additionally, the recovery and use of biogas to burn methane, whose heating capacity is 25 times more powerful than that of carbon dioxide [18], thus replacing conventional non-renewable fuel, reduces the release of greenhouse gases into the atmosphere.

4.1 Biogas Produced by a Sanitary Landfill

The waste decomposition process presents 5 phases [19] whose evolution, in terms of relative volumetric composition, is illustrated in Figure 1.

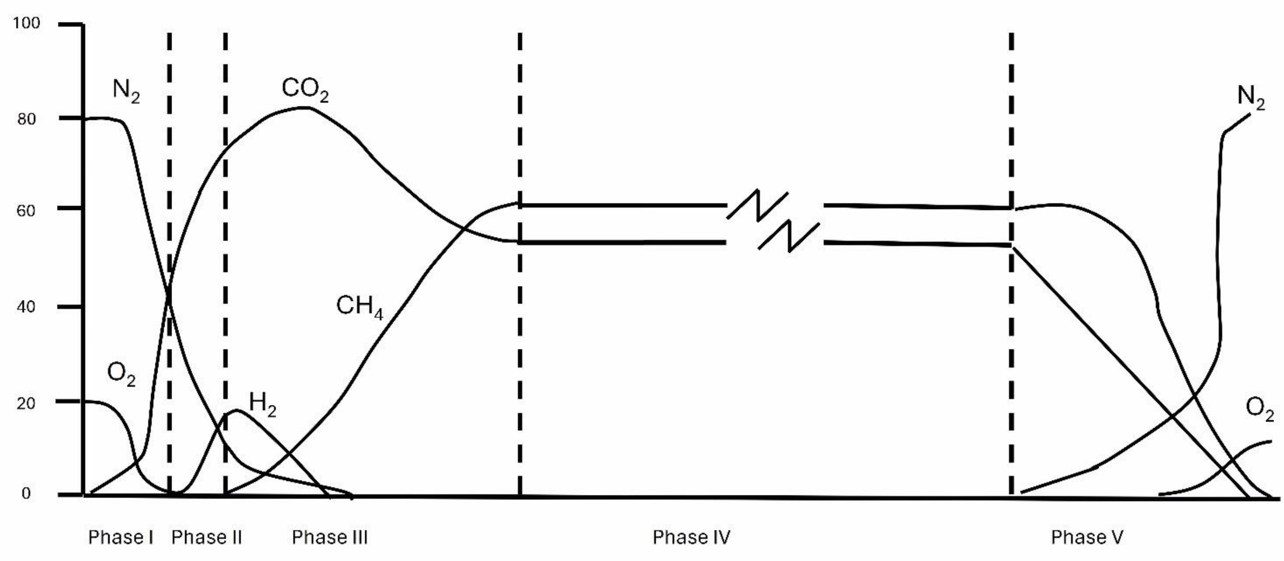

Figure 1 Diagram of biogas composition through decomposition phases. Modified from Johannessen 1999 [19].

In Phase I, called the aerobic stage, oxygen is consumed from the trapped air and nitrogen is subjected to nitrification processes. As a result, the temperature and production of carbon dioxide increase.

In Phase II, called the acid phase, the transition to anaerobic processes occurs, and leachate rich in organic acids begins to be generated, lowering the pH of the waste mass. Biogas is carbon dioxide and nitrogen that have not yet been consumed, with minor hydrogen fractions.

Phase III is a methanogenic stage in which anaerobic conditions predominate, and the release of carbon dioxide decreases. At the same time, volatile fatty acids are incorporated into the biogas, reducing the leachate and increasing pH.

Phase IV, or the stable methanogenic stage, is when methane production becomes maximum, accounting for more than 50% of total biogas, and carbon dioxide is the rest; the pH remains high in the leachate, and the organic load is reduced. Typical composition of biogas in this phase is presented in Table 2.

Table 2 Typical Composition of Biogas Produced in a Sanitary Landfill in Stable Phase.

Component	% In Volume
Methane (CH_4)	45-55
Carbon dioxide (CO_2)	40-50
Nitrogen (N_2)	2-3
Hydrogen sulfide (SH_2)	1-2
Hydrogen (H_2)/Oxygen (O_2)	<1
Carbon monoxide (CO), Ammonia (NH_3), Aromatic hydrocarbons, Volatile organic compounds (VOC)	traces

Source: Modified from Kiss Köfalusi & Aguilar, 2006 [8].

Finally, after the closure of the SL, phase V is reached for the stabilization of the waste when the production of carbon dioxide and methane decreases and nitrogen and oxygen emissions reappear.

In short, due to its composition, the biogas emitted by an SL is not a dangerous product. It should be noted, however, that it has a significant environmental impact because its main components (methane and carbon dioxide) are pollutants of the atmosphere and have a greenhouse effect, so their release contributes to global warming.

4.2 Leachate Produced by a Sanitary Landfill

It is important to note that the leachate of an SL does not have a dangerous nature since it is not corrosive, reactive, explosive, toxic, flammable, or infectious, characteristics that we require to consider a product unsafe.

The variation in their composition due to the biodegradation of MSW is not easy to observe since the overlapping of residues carries the mixture of leachates generated by residues of different ages. This makes it challenging to establish the relationship between the waste's biodegradation phases, the leachate's composition, and the time required for the stabilization of the deposit, for example, to reach the methanogenic phase.

The composition of the leachate and its variation over time has been the subject of several studies, also considering that the composition of MSW and climatic conditions are different in different places and over time. Among the organic compounds present in leachates, we can mention organic acids, aromatic compounds, aliphatic and halogenated aromatic compounds, pesticides, volatile fatty acids, benzene, toluene, ethylbenzene, and xylene [20]. Pathogenic microorganisms of fecal origin are also found. Several studies, such as those carried out in Almoloya del Río-Mexico [21], Mekelle-Ethiopia [22], Sri Lanka [23], and Hanoi-Vietnam [24], have highlighted the need to treat leachate to reduce emerging environmental pollution. The composition of the leachate stabilizes after the landfill stops receiving waste, which has taken less than a year in Hong Kong [25] and Campiñas-Brazil [26], a year and a half in Taiwan [27], and about two years in Poland [28].

More than 20 years ago, WHO concluded that exposure to emissions from an SL could be suspected of posing a risk to neighbouring populations but that data were judged insufficient for a reliable risk assessment, as quantitative information on exposure was scarce and the methods used to assess exposure were weak [29]. WHO then recommended the need of more and better targeted scientific data to help governments and the waste management industry optimize their practices, prevent health impacts and improve risk communication.

This does not remove the need to assess exposure near an SL since it is necessary to ensure compliance with regulations and preserve the health of workers at the waste disposal site.

A vital incentive to assess exposure understood as an umbrella term that includes both the measurement of actual exposures or concentrations of pollutants, and the calculation, estimation, and modeling of exposures based on existing data, is the need to provide clear communication of potential risks to the general public since it is possible that the community neighboring one SL expresses concerns when in reality there is no exposure or risk to health.

5. Emissions from an Open Dump

The leachate of an OD or a CL is much more dangerous than that of an SL since there is no guarantee that hazardous waste, waste produced in health care and/or electrical and electronic equipment waste have not been illegally disposed of in it, and in the absence of proper waterproofing of the base that leachate can contaminate the groundwater and nearby areas.

The leachate of an OD or a VC contains several types of organic compounds, such as non-biodegradable carbons, humic and fulvic acids; inorganic compounds such as colloids; heavy metals; inorganic salts such as sodium and calcium sulfates, and ammonia; as well as other toxic and dangerous substances due to the lack of separation of the waste discharged [30, 31].

A recent review [32] presented the results of studies of the concentration of chemical contaminants in soil, leachate and/or groundwater in the environment of different ODs in Brazil, Cuba, Malaysia, Mexico, Nigeria, Thailand, and Tanzania, showing that they are frequently higher than acceptable international standards for soil and drinking water. Similar results were found in numerous landfills studied in India [33, 34], in the vicinity of an OD in Oyo-Nigeria [35], and another one in Kumasi-Ghana [36].

ODs can also receive construction waste and end-of-life tires, two sources of health risk because they can facilitate the development of animal vectors of different pathologies and/or release potentially hazardous particulate materials and gases such as CO, SO_2, NO_2, volatile organic compounds, and polyaromatic hydrocarbons into the atmosphere.

The combustion of waste accumulated in a landfill may also generate other pollutants dangerous to human health: the presence of dioxins (PCDDs), furans (PCDFs), and polychlorinated biphenyls (PCBs) have been demonstrated in the environment of ODs in Cambodia, the Philippines, India, Indonesia, and Vietnam [37, 38].

Finally, from the perspective of the polluting potential of a waste landfill, the lack of leachate and gas control systems is more relevant than the nature of the waste.

6. Risks Associated with Inadequate Management of MSW

The potential health risks caused by the inadequate disposal of waste through its accumulation or burial, a definition that integrates sites with controlled and uncontrolled disposal, is an issue of permanent public concern.

Among the environmental effects, we find those that are related to the affectation to the flora and fauna of the place as well as the deterioration of the landscape and those that result from the contamination of the soil and the air -by gases and open burnings- and of the water -by leachate that debase the underground and superficial groundwater-, risk that is increased if those waters are then used for the supply of the population.

Those most exposed to health risks are those who make direct contact with MSW by injuries or diseases of microbiological origin. Likewise, these people become vectors and potential generators of health problems among the people with whom they live and are in contact.

Likewise, activities in a landfill produce fine and coarse particles dispersed through the air, whose conformation will depend on the activities carried out on the site and the types of waste that are handled. Dust produced at a waste disposal site includes particles with a diameter of less than 10 µm (PM_{10}) and particles with a diameter of less than 2.5 µm ($PM_{2.5}$). Exposure to particles that can enter the respiratory system is associated with several adverse health effects. PM_{10} particles may not enter beyond the nose or larynx, but the chance of them passing through to the lungs and depositing in the airways increases as the diameter decreases. $PM_{2.5}$ particles, also known as black carbon (BC) particles or "fine" particles, are deposited relatively effectively in the deeper parts of the lung, for example, in the alveolar spaces. BC is formed from the incomplete combustion of biocomponents in landfills. WHO has reviewed studies [39] ensuring that there is an association between daily variations in BC concentrations and short-term health impacts (all-cause mortality and cardiovascular risks, in addition to cardiopulmonary and hospital admissions) and that there are sufficient data on associations of mortality of all types and for cardiopulmonary causes with long-term average BC exposure. On the other hand, BC, like methane, tropospheric ozone and hydrofluorocarbons, are part of the climate pollutants grouped as "short-lived" since they remain in the atmosphere significantly shorter times than the most classically studied greenhouse gases such as CO_2. According to the Climate & Clean Air Coalition “short lived climate pollutants” are responsible for up to 45 percent of global warming. Various contaminants can increase the adverse respiratory impact of these particles adsorbed on their surface, making air pollution associated with 7 million premature deaths annually [40].

Other gaseous emissions in high concentrations impact the health of exposed people. Hydrogen sulfide (H_2S) is a throat irritant and mediator of respiratory distress as it inhibits cytochrome oxidase, causing tissue anoxia and metabolic acidosis. Sulphur dioxide (SO_2) is a colorless, pungent gas that can produce, even at great distances from the source of the emitter, adverse health effects (such as irritation and inflammation of the respiratory system, lung conditions and insufficiencies, alteration of protein metabolism, headache or anxiety). Inhalation of ozone (O_3), even in small amounts, can irritate the eyes, throat, and lungs, produce a significant and reversible reduction in lung function, increase the risk of respiratory infections, and aggravate bronchial asthma by making people more sensitive to allergens (breathable fine dust, pollen, dust mites, pet hair, etc.) that are the most common generators of asthma attacks. Formaldehyde (CH_2O) is carcinogenic, but it is also irritating.

The dominant emissions differ depending on the waste composition and the different stages of waste decomposition. Among them, and in very low proportions, sulphur, and oxygenated compounds predominate in the early stages, and hydrogen sulfide and aliphatic and aromatic hydrocarbons during the methanogenic phase. However, the composition of emissions depends on the composition of the waste and is therefore different in different landfills. Gaseous emissions include odors, another key driver of waste deposits, typically associated with the decomposition of biodegradable waste, waste management practices, and/or the presence of trace components in the gas or leachate.

In Europe and the USA, trace gas emissions were contained at the end of the 1990s by establishing restrictions on waste to be deposited in landfills by regulations (Landfill Directive 1999/31/EC and EPA Air Pollutant Emission Factors 42, respectively). In developing countries, in general, the problem persists [41].

In addition, another health risk comes from the proliferation of animals (flies, mosquitoes, rats, and cockroaches to begin with) carriers, and therefore vectors, of microorganisms capable of transmitting diseases to the entire population, which find in the MSW, in addition to food, a favorable environment for their reproduction, transmitters of no less than fifty diseases, from uncomplicated diarrhea to severe pictures (see below) [42, 43]. Thus, for example, insects of the orders Diptera and Hymenoptera, whose radius of displacement can reach 10 km and carriers of pathogenic Enterobacteriaceae (*Escherichia coli, Enterobacter agglomerans and Klebsiella ozoenae*), were collected in the SL of the municipality of Ponta Grossa in the State of Paraná-Brazil [44].

7. Potential Routes of Exposure

In general terms we can recognize four potential main routes [45] (Figure 2):

a) direct contact, due to the limited practice of separating waste at source that results in the presence of organic remains and hazardous inorganic materials such as broken glass, metals, razor blades, syringes from household use, and possibly infectious or industrial waste. These conditions can reach collection personnel - when it is not mechanized as in large cities - and informal segregators, who can operate in the presence of gaseous and particulate emissions in addition to the mechanical risk.
b) indirect contact, due to the interaction of gaseous, particulate or liquid effluents, poorly or unprocessed, with the population neighboring a disposal site, either by wind dragging or soil infiltration.
c) through mechanical vectors that carry on their legs, wings or any part of the body etiological agents of various diseases, for example, houseflies, cockroaches, rats, etc., and
d) by biological vectors that, at some stage of their life cycle, are carriers of some microorganism that is an etiological agent of human diseases, for example, the Anopheles mosquito, the *Aedes aegypti*, lice, fleas, ticks, etc.

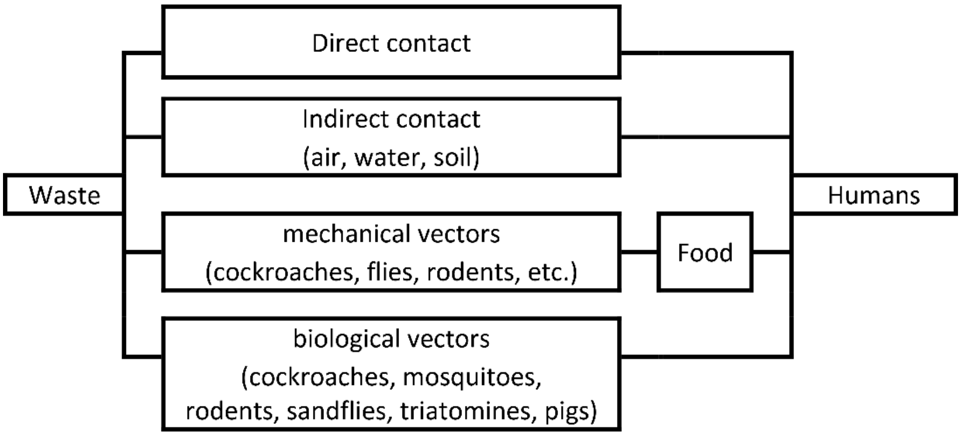

Figure 2 Potential contact routes between people and waste Modified from Heller, 1997 [45].

So, from the health point of view, insects, arachnids, and arthropods are of interest, which, in addition to acting as mechanical or biological vectors, can affect human health, constituting themselves the cause of the disease -scabies and myiasis, for example-, producing poisoning, irritations, and allergies. Examples of animal vectors that can be present in MSW and vectorial diseases that can be transmitted by them are presented in Table 3 and Table 4. In the case of biological vectors, an additional factor to consider is the climate of the area, which can favor their reproduction, degree of activity, movements, dispersion, and potential for infection.

Table 3 Vectorial Diseases and Responsible Microorganisms Survival Time in MSW.

Vectors	Diseases	Responsible Microorganisms	Survival time in MSW (days)
Bacteria			
Cockroaches and Flies	Cholera	*Vibrio cholerae*	1-13
	Gastroenteritis	*Escherichia coli* and other fecal coliforms	35

	Typhoid fever	*Salmonella typhi*	29-70
Cockroaches	Paratyphoid fever Salmonellosis Bacillary dysentery	*Salmonella paratyphi* *Salmonella* sp. *Shigella*	29-70 29-70 02-07
Rats and Fleas	Leptospirosis	*Leptospira*	15-43
?	Tuberculosis	*Mycobacterium tuberculosis*	150-180
Helminths			
Human and animal feces	Ascariasis Trichiuriasis Ancylostomiasis	*Ascaris lumbricoides* *Trichuris trichiura* Ancyclostoma larvae Other worms larvae	2000-2500 1800 35 25-40
Protozoa			
Cockroaches and Flies		*Entamoeba histolytica*	08-12
Virus			
Contaminated water	Poliomyelitis (Poliovirus)	Enterovirus	20-70

Source: Modified from Lima 2001 [46].

Table 4 Main Vectorial Transmitted Diseases Potentially Present in MSW.

Vectors	**Way of transmission**	**Main diseases**
Birds	Feces	Histoplasmosis Toxoplasmosis
Cockroaches	Mechanical (wings, legs and bodies) Feces	Cholera Giardiasis Salmonellosis Typhoid fever
Dogs	Biting	Rabies Toxoplasmosis
Flies	Mechanical (wings, legs and bodies)	Amebiasis Bacillary Dysentery Cholera Giardiasis Salmonellosis Typhoid fever
Mosquitoes	Female mosquito bite	Chikungunya Dengue Filariasis Malaria West Nile Virus Yellow fever Zika
Pigs	Ingestion of contaminated meat	Cysticercosis Taeniasis Toxoplasmosis

		Trichinosis
Rodents	Biting, urine, and feces Fleas	Bubonic plague Hantavirus Leptospirosis Murine typhus
Sandflies	Biting	Leishmaniasis
Triatomines	Biting	Chagas disease

Thus, 56 species of arthropods were identified, including various species of fleas in rodents, ticks and synanthropic flies in two ODs (Mokattam y Ezbet el Nakhl) in Cairo-Egypt [47]. In comparison, in an OD in Urmia-Iran 33 species of arthropods were identified, including some of high health relevance, such as species of the genus *Blattodea* [48].

8. People at Risk and Potential Hazards

8.1 People in Direct Contact

- Inhalation of gases or particles adhering to dust emitted at the site
- Mechanical accidents with sharp elements or material carrying microorganisms

8.2 Close Neighbors

- Inhalation of gases or particles adhering to dust emitted from the site
- Ingestion of domestically grown food contaminated by air, water and/or soil
- Ingestion of water obtained from private wells contaminated by leachate
- Bathing and washing with contaminated water by establishing skin contact or inhalation of evaporated volatile organic compounds
- Inhalation of polluted indoor air through soil, leachate, and gas migration
- Skin contact with contaminated soil or inhalation of soil evaporation
- Recreational use of areas near landfills or contaminated land

8.3 General Population

- Ingestion of contaminated agricultural products
- Water consumption from contaminated municipal supplies
- People do not have regular waste collection at home since the waste they generate is disposed of in their immediate environment, which deteriorates the environment with the presence of vectors, fumes, bad odors, and animals that feed on the waste.

In all these circumstances, the risks are more significant for children and pregnant women, as they are the most vulnerable populations.

9. Documented Evidence of Health Impact around Waste Landfills

As noted above, solid waste disposal can release various toxic substances, predominantly in small quantities. Given their diversity, the varied means of exposure, the uncertainty associated with exposures to low amounts of toxicants when they occur over long periods, the potential synergies of various pollutants, the difficulty in establishing direct relationships between the toxins emitted and health problems, the necessary arbitrariness in the delimitation of the area of dispersion of the toxicants and the practical impossibility of identifying other sources of exposure that could be having some share of responsibility in the emerging health impact means that concern about the potential health effects is tinged by the lack of certainty for its evaluation.

At this point, it should be noted that although we understand health as "a state of physical, mental and social well-being and not merely the absence of disease" [49], a condition resulting from multiple environmental and social determinants [50, 51], in practice when assessing the potential impact on health of a situation, such as the existence of waste disposal sites, more emphasis has been placed on mortality and morbidity than on other emerging impacts such as well-being and quality of life, a condition that includes other determinants of health such as accessibility to health systems or their employment, or the quality of housing [52].

A group of exposure assessment experts convened by WHO suggested that priority pollutants should be defined on the basis of toxicity, persistence, environmental mobility, bioaccumulation, and other hazards such as explosiveness. In addition, they proposed that landfill investigations should consider metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorinated hydrocarbons, pesticides, dioxins, asbestos, pharmaceuticals, and pathogens [29]. However, much of the health literature on the toxicity of the individual substances highlighted above refers to occupational or accidental exposure and, therefore generally higher-than-expected exposure levels from waste disposal processes. Many of the substances, such as cadmium, arsenic, chromium, nickel, dioxins, and PAHs are considered carcinogenic based on animal studies or studies of people exposed to high levels. However, the evidence that these substances cause cancer at environmental levels is often unknown or misleading.

There have been many studies of populations living near landfills, which are often conducted near a specific site in response to public concern. These studies have varied in design and include cross-sectional, case-control, retrospective, and ecological (geographically comparative) studies.

In this paper we have reviewed the published studies on the health problems found in populations near MSW landfills and in those who work with MSW, although the intensity and duration of exposure between both groups is not the same. We include studies carried out in ODs, CLs, and SLs without ignoring that SLs are a lower potential source of health hazards than ODs but considering that their findings suggest a risk floor that in CLs and ODs can only be equal or more significant. We excluded from the analysis studies explicitly conducted in relation to hazardous waste deposits, except in those cases that were included but not discriminated from a sample of landfills. The review was limited to English, French, Italian, Portuguese and Spanish papers.

A significant limitation arises from lacking a consensual definition of the different waste streams. Thus, over time and in other countries, hazardous, special, industrial, urban, and household waste categories do not always refer to the same products. Added to this is the uncertainty resulting from the fact that the materials discarded in some landfills have changed over time.

The results were grouped into broad categories of emerging health problems: injuries and other occupational impacts, impacts on the respiratory system, congenital anomalies and reproductive disorders, cancer, infectious diseases, and other health impacts.

9.1 Emergent Impact: Injuries and Other Occupational Impacts

MSW disposal tasks require activities that combine mechanized processes and processes dependent on the physical activity of the operators, the relative importance of which is greater the lower the relative degree of development of the locality. In addition to the regular operators, the population at risk is also the waste pickers, often informal, who work in much more precarious conditions than the former.

Table 5 presents the potential occupational hazards to which formal and informal workers are exposed in an OD.

Table 5 Potential Occupational Hazards in an Open Dump.

Potential Hazard	Description
Physical	• Injuries due to surface subsidence, underground fires, and landslides • Musculoskeletal injuries to the back and joints from lifting weights • Puncture wounds can lead to various infections (tetanus, hepatitis, etc.) • Genitourinary problems due to difficulty of free access to drinking water and sanitary facilities • Eye problems due to exposure to dusts, fumes and volatile compounds
Chemical/Biological	• Dermatological diseases due to contact with irritating substances • Bacterial, viral, fungal and/or parasitic infections from direct contact with contaminated material or from eating food from animals fed on waste and/or vegetables produced in contaminated areas • Infectious diseases transmitted by animal vectors • Food poisoning from eating contaminated food in the workplace • Headaches and nausea from anoxic conditions due to high methane, carbon dioxide, and carbon monoxide content at the disposal site • Respiratory diseases due to the ingestion of particles, bioaerosols and volatile organic compounds when working in the presence of fumes and dusts • Lead poisoning, from burning materials with batteries, paints and solder that contain lead, and with other heavy metals
Psychosocial	• Concern about living conditions • Problems of personal hygiene, insecurity, social marginalization

Some or more of these conditions have been documented, among other countries, in Brazil [53, 54], Denmark [55], Egypt [56], Ethiopia [57-59], Ghana [60, 61], Germany [62], India [63-65], Italy [66, 67], Malaysia [68], Nepal [69], Nigeria [70, 71], Norway [72], Philippines [73], Romania [74], Spain [75], Switzerland [76], Taiwan [77], Thailand [78, 79], the USA [80] and Zimbabwe [81], as well as systematically reviewed [82].

In particular, exposure to bioaerosols (aerosols carrying volatile organic compounds, bacteria, fungi and/or endotoxins) [83], capable of inducing inflammation in the airways, has been documented, among other countries, in Canada [84], Denmark [85, 86], Finland [87], France [88], Germany [89], Greece [90], Italy [91], Korea [92], the Netherlands [93], Norway [72, 94, 95], Poland

[96], Switzerland [97], Turkey [98], the United Kingdom [99] and the USA [80]. In Denmark, it was shown that in waste collectors, there is a dose-response relationship between exposure to endotoxins and the occurrence of nausea and between exposure to endotoxins and viable fungi and diarrhea [100]. A very comprehensive review on the subject has recently been published [101].

The mismanagement of activities in ODs adds to the aforementioned hazards the occurrence of landslides that collapse the accumulation of waste, such as those that took place in Bandung-Indonesia in February 2005, which caused the death of 143 operators [102], and in Shenzhen-China in December 2015 that had 77 fatalities [103].

All these studies show that the manual tasks carried out in the management of MSW lead to exposure to various situations hazardous to the health of operators. However, given the diversity of formal and informal activities, it is risky to generalize the potential health impacts [104] since the category "MSW management" encompasses a broad spectrum of activities, from the formal urban collector to the informal worker who recovers materials in an OD, with varying levels of exposure and personal vulnerability that vary from city to city.

9.2 Emerging Impacts on the Respiratory System

The impact of environmental pollution on the respiratory system has been extensively studied. An increase in perceived symptoms, the demand for health services, and the presence of respiratory symptoms and exacerbations of chronic processes, such as chronic obstructive pulmonary disease (COPD) and asthma, have been reported [105, 106]. In addition, exposure to pollutants generated in waste has been associated with a reduction in lung function parameters, such as forced expiratory volume in one second (FEV) and peak expiratory flow [88, 107, 108].

Workers at a landfill and nearby residents are exposed to inhaling volatile compounds (hydrogen sulfide, aldehydes, ammonia, mercaptans, benzene, toluene, ethylbenzene, xylene, styrene may be present in the landfill air) [109, 110]. Long-term exposure to these volatile compounds has been associated with health problems such as respiratory irritation, cancer, damage to the central nervous system [111-113], and other somatic symptoms (anxiety, headaches, eye irritation, vomiting) so they should be considered a risk factor for the health and well-being of exposed populations [114-117].

More dangerous to health is the open burning of MSW that releases smoke into the environment since this visible mixture of gases (carbon monoxide and dioxide, nitrogen dioxide and volatile organic compounds) and fine particles is carried by the wind and can reach populations far from the landfill or carried out at the domestic level as an alternative "solution" to the limitations of organized collection.

The highest prevalence of respiratory problems among those working in ODs has been demonstrated in Delhi [118], Kolkata and Mumbai [119] in India, Manila-Philippines [1], Colombo-Sri Lanka [120], Johannesburg-South Africa [121], Bangkok-Thailand [78], Istanbul-Turkey [98], in those which have lived and worked for more than 10 years near the Olusosum OD in Ojota, Lagos-Nigeria [122], and around four ODs in Malaysia, here using the accumulation of heavy metals in the nails as an indicator [123].

In studies carried out in Colombia in the population neighboring (radius considered at risk = 3 km) to an OD in Cali, it was reported child physical growth retardation accompanied by an increase in the presence of respiratory symptoms in children under five years of age [124] and a more excellent perception of the risk of respiratory diseases [115]. In addition, the results of a prospective study with a six-month follow-up of a fixed cohort of adults over 50 years of age living in the landfill's area of influence to assess the monthly presentation of respiratory symptoms and alterations in lung function, compared to a fixed cohort of adults in a non-exposed area, revealed more prevalence of severe respiratory symptoms in those exposed, although the difference was not statistically significant [107]. The study included the characterization of air pollutants (PM_{10}), sulfur dioxide (SO_2), methane (CH_4), xylene, and benzene through controls in the two zones [125], exploring the likely relationship of respiratory diseases with air pollution [126].

In Lazio-Italy, a cohort study carried out in the vicinity (5 km) of nine waste landfills that have been used for more than 20 years showed an association between exposure to hydrogen sulfide, taken as a marker of air pollutants, and hospitalizations due to respiratory causes (hazard ratio = 1.02, 95% CI: 1.00-1.03), especially acute respiratory infections in children (0-14 years) (hazard ratio = 1.06, 95% CI: 1.02-1.11) [127].

A study conducted 6 years after the closure of a landfill in the municipality of Várzea, in São Paulo-Brazil, found that children under 13 were at greater risk of acute respiratory symptoms than their counterparts in other areas of the city [108]. A study in China also showed that children living in a landfill environment had reduced immunity and lung capacity [113], while a study conducted in Finland found a higher prevalence of asthma among residents of dwellings built on areas previously used as waste disposal sites than among residents living near them [128].

A special chapter deserves the subject of odor perception [129], which can indicate the degree of air pollution by gases, some of which (whether odorous or not) may be toxic. In China, it has been shown that sulfides and aromatic compounds are the most contributing to odorous emissions from a landfill [130]. In recent years, there has been a significant improvement in the technological resources for assessing the composition of gaseous emissions, bearing in mind that problematic substances constitute a fraction of less than 1% (by volume) of the total emitted by a landfill [131].

It should be borne in mind that gaseous emissions, including odor emissions, are not stable or homogeneous in the landfill environment as they depend on the composition of the waste, the orography of the area, and the climatic conditions (temperature, intensity, and direction of the winds, for example).

Residents of an OD in Nigeria have identified odors as their most significant cause for concern [132], while in South Africa (OD of Thohoyandou in the province of Limpopo), neighbors consider the perception of odors as an indicator of pollution and concern for their health [133].

In summary, the evidence consistently suggests that working in and/or living near an MSW landfill increases the risk of contracting diseases linked to air pollution.

9.3 Emerging Impact: Congenital Anomalies and Reproductive Disorders

We can distinguish two types of studies: those conducted at a single site and those performed at a group of sites. The former has the advantage of referring to a single source of pollution with the disadvantage that the population involved is small and therefore makes it challenging to detect infrequent problems. At the same time, the latter, on the contrary, reaches larger populations but is exposed to emissions from heterogeneous waste deposits.

Most of the studies that have shown possible relationships between final waste disposal sites and the emergence of low birth weight and/or preterm births have been conducted in the environment of hazardous waste landfills, so we cannot consider them for our purposes.

A study conducted in the setting of an OD in Montreal, Quebec-Canada, found high risks of low birth weight (OR = 1.20, 95% CI: 1.04-1.39) and smaller size for gestational age (third quartile, OR = 1.01, 95% CI: 0.96-1.24) [134]. Still, the lack of association for both variables and the impossibility of ruling out confounding factors prevented a transparent relationship with landfill emissions.

Two extensive multi-site case-control studies conducted in the 1990s in the USA used place of residence to measure exposure and found no association with low birth weight [135, 136]. These same studies investigated the relationship with the presence of congenital malformations, finding in one case a slight increase (1.5-fold) in the number of cardiac and circulatory malformations and no change in the remaining malformations. In contrast, the other study found no association. However, one review author found the results unconvincing because of flaws in the questionnaire and little clarity in the definition of congenital malformations [137].

In Wales, a study compared several variables before and after the establishment of an OD (Nant-y-Gwyddon, recipient of domestic, commercial, and industrial waste), finding no differences in annual all-cause mortality, the presence of respiratory diseases and cancer, but showed an increase in the rates of congenital malformations [138]. The result is limited because the rates were already high before the start of operations compared to the rest of England and Wales, making it difficult to link it to the landfill establishment.

A study conducted in the United Kingdom investigated the risk of problem births in populations living within 2 km of 9,565 landfills in Great Britain operating at some points between 1982 and 1997, compared to those occurring in populations living farther away (reference population) [139]. The sites included 774 sites for hazardous waste, 7 803 for non-special waste, and 988 for unknown waste. Among the 8.2 million live births and 43,471 stillbirths, 124,597 congenital anomalies (including miscarriage) were examined, including, among other pathologies, neural tube defects, cardiovascular defects, abdominal wall defects, hypospadias and epispadias, low birth weight (<2500 g) and meager birth weight (<1500 g). The main analysis, conducted for all landfills during their operation and after closure, found a small but statistically significant increased risk of total and specific anomalies (OR = 1.01, 95% CI: 1.01-1.02) in populations living within 2 km, and also an increased risk of low (OR = 1.05, 95% CI: 1.05-1.06) and meager (OR = 1.04, 95% CI: 1.03-1.05) birth weight. Additional analyses were conducted separately for sites handling special and non-special waste and in the pre- and post-opening periods for the 5,260 landfills with available data. After adjusting for deprivation and other possible confounding variables (sex, year of birth, administrative region), they found a slight increase in the relative risks of birth with low and very low birth weight and for all congenital anomalies except cardiovascular abnormalities. The risks of all congenital anomalies were higher for people living near special waste landfills (OR = 1.07; 95% CI: 1.04-1.09) than non-special waste landfills (OR = 1.02, 95% CI: 1.01-1.03). No excess risk of stillbirth was found.

In Denmark, they investigated the finding of congenital disabilities using maternal residence as an indicator of exposure to the location of 48 landfills [140]. The authors found no association between landfill location and all congenital or nervous system anomalies and a small excess risk of congenital anomalies of the cardiovascular system. The main limitation of this study is the lack of consideration of the socioeconomic level of the families [51].

A study in São Paulo-Brazil did not find higher rates of congenital malformations in children born in an environment of 2 km from 15 landfills compared to the rest of the municipality [141].

In a study conducted in three ODs in India, 38% of women working there had lost one pregnancy, and 10% had lost 3 or more [1], while in Nigeria, with a small sample of participants who were required at least 10 years of exposure to OD emissions, preterm births, miscarriages, and births with congenital malformations in the most exposed group doubled or tripled that of the control group [122].

In the Guadeloupe archipelago, a French enclave in the Caribbean, they studied preterm births near three BCAs since the local rate was three times that of mainland France (15.8% vs 5.5%). Using a focused cluster test specifically designed to detect spatial clustering around point sources, they found high values of preterm birth in the surroundings (2 km) of one of the landfills (Saint-François, RR = 4.82 - p = 0.04) but not in the other two (La Gabarre, RR = 2.01 - p = 0.26 and Bailif, RR = 1.06 - p = 0.64). Potential socio-demographic confounding factors, as well as other nearby sources of pollution, were excluded [142].

In England and Wales, they studied the risk of birth with Down syndrome in the population living in the vicinity of 6,289 landfills (processing waste of all kinds). People were considered exposed if they lived in a 2 km area around each site, while people beyond this area were the reference group. A two-year delay was taken between the possible exposure of the mother and her delivery to a child with Down syndrome. The analysis was adjusted for maternal age, urban-rural status, and deprivation index. No statistically significant excess risk was found in exposed populations, regardless of the type of waste dumped [143].

On this basis, two reviews [52, 144] concluded that while most of the studies that reported positive associations are of good quality, more than half of the studies report that there is no association with any adverse birth outcome, and most of the latter are also well conducted, so the evidence for an association of adverse birth outcomes with residence near a landfill should be considered to be unconvincing.

In summary, the analysis of the emergence of impacts on pregnancy has the virtue of exploring effects that manifest during or immediately after exposure, without prolonged latency as in the development of tumors. The fact is that while some studies conducted on multiple waste disposal sites, which always include some hazardous waste recipients, showed an increased risk of births to children with congenital anomalies, no analysis of the impact of a disposal site, even of hazardous waste, could unequivocally demonstrate a relationship with the induction of congenital anomalies or identify the route of exposure. The same result was obtained by a review of 41 studies on this relationship in the proximity of contaminated sites, including waste dumps [145]. The increase in low birth weight is more convincing, but the evidence associated with ODs is very limited.

9.4 Emerging Impact: Cancer

The various types of cancer result from the combination of three factors: random errors in the DNA replication process, heredity, and environment. Among the environmental factors we can mention numerous compounds that can be released from waste into the air, water and even the food chain, such as volatile organic compounds (alcohols, aldehydes, ketones, esters, dioxins, furans, etc.), or heavy metals (cadmium, chromium, nickel, lead, etc.). While there is no defined rule of thumb, the latency between exposure and manifestation is estimated to be 10 years for solid cancers and 5 years for hemopoietic and lymphatic cancers.

In Great Britain, the risk of developing some form of cancer was studied in populations living within 2 km of 9,565 out of 19,196 landfills that were operational from 1982 to 1997. They found no excess risk of bladder, brain, hepatobiliary or leukemia cancer after adjusting for age, sex, calendar year and socioeconomic conditions [146]. The study was very large and is very powerful; however, the difficulty in assessing individual exposure might have decreased the chance of detecting an effect [147].

In Italy, they investigated mortality risk in a small area (Malagrotta, Rome) with multiple sources of air pollution (a very large waste landfill serving the entire city of Rome, a waste incineration plant and an oil refinery). Standardized mortality rates (SMR) were calculated in bands of increasing distance from plants to a radius of 10 km. No association was found between proximity to sites and multi-organ cancer mortality, particularly hematopoietic liver, lung, and lymphatic cancer. Conversely, mortality from laryngeal cancer decreased with distance from pollution sources, and the statistically significant trend was maintained after adjusting for socioeconomic status [148]. The main uncertainty of the study is related to the assessment of exposure since only distance was considered [147] and to the relative contribution of each air pollutant source.

Another study that surveyed the surroundings of 9 landfills in the Lazio region of Italy found an increased risk of lung cancer associated with exposure to airborne pollutants, using the concentration of hydrogen sulfide as an indicator, with no clear clues of causality [127].

In Finland, they studied whether exposure to landfills caused cancer or other chronic diseases in the inhabitants of houses built in former industrial and household waste dumping area. After adjusting for age and sex, an excessive number of male cancer cases (RR = 1.6, 95% CI: 1.1-2.2) was observed, especially for pancreatic (RR = 5.0, 95% CI: 1.4-12.9) and skin (RR = 4.0, 95% CI: 1.3-9.4) cancers. The relative risk increased slightly with the number of years lived in the area [109]. However, the results include some uncertainties regarding assessing exposure and outcomes [147] and the weakness of not considering confounding factors such as tobacco and alcohol use. A subsequent study of the same group of residents revealed that at 13 years of follow-up, the standardized incidence of cancer (SIR) for all combined locations in the group (RR = 1.32, 95% CI: 0.9-1.8 in males and RR = 0.53; 95% CI: 0.3-0.8 in females) was indistinguishable from that of the Helsinki population [149]. The relevance of these studies is that they were carried out in a population that had lived for many years on an OD covered with a layer of several meters of earth before the construction of the houses and that they studied a large population and a critical control group.

Two studies investigated whether the incidence of cancer among people living near the local landfill (Miron Quarry, recipient of municipal and industrial waste for many years) was different than expected in Montreal, Quebec-Canada. The first study was carried out by geographical comparison with the incidence in the city of Montreal, and the second was conducted using a case-control protocol (n = 2,928), always using the appropriate geographic and sociodemographic controls. In the first study, higher values were found in the study area, but there was no evidence of a dose-response effect. The results of the second showed that the relative risk (RR) among men was elevated for stomach cancer (RR = 1.3, 95% CI: 1.0-1.5); liver and intrahepatic bile ducts (RR = 1.3, 95% CI: 0.9-1.8); trachea, bronchus and lung (RR = 1.1, 95% CI: 1.0-1.2) and prostate (RR = 1.2, 95% CI: 1.0-1.4), while among women the relative risks for stomach (RR = 1.2; 95% CI: 0.9-1.5) and uterine (RR = 1.2, 95% CI: 1.0-1.5) cancer [150, 151]. Although both studies are robust, they are limited by comparing with a small control group, not considering the time of exposure, using distance to landfill to estimate exposure, and the short period between the onset of exposure (1968) and the assessment of the presence of cancer (1979-1985).

A study in Brazil found that in the vicinity (2 km) of the 15 landfills in the city of São Paulo, standardized mortality rates from bladder cancer, liver cancer, or leukemia were similar to those in the rest of the municipality [141].

In summary, all the studies reviewed, as well as the reviews of them by other authors [104, 147, 152, 153] on the risk of developing some form of cancer by populations living in the vicinity of a waste landfill in operation or already closed, even those in which hazardous waste was discarded, have failed to conclusively identify a causal or even circumstantial relationship that this risk exists.

9.5 Emerging Impact: Infectious Diseases

Residents of the urban area closest to an OD in Manzini-Swaziland most frequently had malaria, cholera, diarrhea, and chest pain [154], while residents of an OD in Dili-East Timor, in the Indonesian archipelago north of Australia, had acute respiratory infections, intestinal parasitosis, diarrhea, dengue and malaria [155]. Similar results were reported in Bahawalpur-Pakistan [156].

Studies carried out in Olinda-Brazil, Manila-Philippines, Calcutta-India, and Bangkok-Thailand have shown a high frequency of parasitic infections (due to protozoa such as Giardia or helminths such as Ancyclostoma or Ascaris) among waste collectors, frequencies that were at least twice as high as those of populations of the same socioeconomic level with other work activities [1].

The development of some of several insect vectors of microorganisms pathogenic to humans (Aedes mosquitoes transmitting dengue, Zika and Chikungunya and Anopheles mosquitoes transmitting malaria; sandflies transmitting leishmaniasis, triatomines transmitting American trypanosomiasis), as well as the transmission of urban zoonoses (mediated by rats -typhus, bubonic plague- and dogs -rabies, leptospirosis-) has been reported in at least one landfill in several countries of Africa (Eswatini, Ethiopia, Kenya, Madagascar, Reunion Island, Swaziland), America (Argentina, Brazil, Chile, Ecuador, El Salvador, Mexico, Peru, Puerto Rico, Trinidad, USA, Venezuela), Asia (China, Philippines, India, Indonesia, Iran, Fiji Islands, Kuala Lumpur, Laos, Malaysia, Myanmar, Pakistan, Sri Lanka, Thailand, Taiwan, Timor-Leste) and Europe (Spain, France) [42, 43, 154]. Obviously, this listing only includes findings in landfills that have been investigated and does not exclude the possibility of similar developments in other landfills.

9.6 Other Emerging Impacts

Symptoms and illnesses reported by residents of municipal waste landfills in Wales include stress, fatigue, headaches, eye irritation and infections, cough, dry throat and nausea, sarcoidosis, asthma, and gastroschisis [138].

Similar results have been reported by the residents of the Los Laureles canyon, on the border between Mexico and the United States, which developed inorganically at the rate of growth of the maquiladora industries and in which more than 50 ODs have been registered [157].

In Malaysia, neighbors living up to 1 km far from the OD in Sabak reported significantly higher reports of sore throat (RR = 1.88, 95% CI: 1.05-3.38), diabetes mellitus (RR = 2.84; 95% CI: 1.10-7.30) and hypertension (RR = 2.56; 95% CI: 1.27-5.13) compared to an unexposed population [158].

In South Africa, in addition to documenting a significant increase in the number of landfills between 2008 and 2015, such that the median distance from a national sample of 400 households to a landfill was reduced from 68.3 to 8.5 km, it was found that residing within 5 km was significantly associated with the presence of asthma (RR = 1.41, 95% CI 1.20-1.64), tuberculosis (RR = 1.18, 95% CI 1.02-1.36), diabetes (RR = 1.25, 95% CI 1.05-1.49) and depression (RR = 1.08, 95% CI 1.03-1.14) [159].

A telephone survey of New York City Department of Sanitation employees working in the Fresh Kills SL and a similar number of employees working in other sections of the Department as controls found a significantly higher prevalence of respiratory, dermatological, neurological, and hearing impairment problems in the former, allegedly linked to their work activity [160].

In Ontario-Canada, a study showed that the distance between the home and the place where waste was processed significantly influences environmental stress, defined as "a process by which environmental events threaten, impair or challenge the well-being or existence of an organism and by which the organism responds to this threat" [161].

Another interesting result, although challenging to generalize, was obtained in California-USA, where it was found that in the population near a landfill, the most concerned neighbors reported more significant symptoms of health problems than the least concerned [162]. This correlation between concern about danger and manifestation of symptoms has been found on more than one occasion [163].

In summary, it is difficult to generalize the results of the numerous studies investigating the health impact of the final disposal of household waste. There are several reasons for this: 1) the differences in the composition of MSW and in the possible mixing with hazardous waste, 2) the practical impossibility of assessing individual exposure, 3) the assessment of the health impact with self-reports by residents or with epidemiological surveys that do not consider confounding factors such as work activity or social situation, and 4) the fact that many studies have been carried out in a single landfill site, which would help establish causal relationships, are limited because the exposed population is low, which reduces the statistical power to establish associations, while conversely studies conducted at multiple sites gain statistical power but cannot ensure homogeneity in emerging chemical contamination.

10. Conclusions

MSW landfills have been, are, and will continue to be in the immediate future an inevitable response to the permanent increase in the amount of waste, since even when alternative treatments (compost, recycling, controlled incineration, recovery as an energy source, etc.) grow there will always be a leftover that will require a final disposal site. It is therefore important to have an in-depth knowledge of their possible impacts on the environmental health of their surroundings.

A recent study estimated that 24% (500 million tons) of all MSW generated on the planet is not collected, and another 27% is mismanaged after collection [164].

Figure 3 schematically represents the diverse municipal waste management practices, the possible environmental pathways of transmission by which the exposed population segments can get to contaminants, the potential routes of exposure and possible adverse health outcomes documented in some locations. As can be seen, there is no linear relationship between the different MSW management practices and potential health problems for at-risk populations.

<table>
<tr><th colspan="8">Municipal Solid Waste management practices</th></tr>
<tr><td rowspan="2">Generation
Segregation at source or not</td><td rowspan="2">Collection</td><td rowspan="2">Transportation</td><td rowspan="2">Recycling
Composting
Anaerobic Digestion</td><td colspan="4">Final Disposal</td></tr>
<tr><td>Incineration</td><td>Sanitary landfill</td><td>Controlled landfill</td><td>Open dumping</td></tr>
<tr><th colspan="8">Possible environmental transport pathways for pollution</th></tr>
<tr><td></td><td>Air</td><td>Soil</td><td>Water</td><td>Fauna</td><td colspan="2">Flora</td><td></td></tr>
<tr><th colspan="8">Potential routes of exposure to health risks</th></tr>
<tr><td></td><td colspan="2">Direct contact</td><td>Indirect contact</td><td colspan="2">Mechanical vectors</td><td>Biological vectors</td><td></td></tr>
<tr><th colspan="8">Population at risk because of mismanagement</th></tr>
<tr><td></td><td colspan="2">MSW operators</td><td>Waste pickers</td><td colspan="2">Neighbours to disposal sites</td><td>General population</td><td></td></tr>
<tr><th colspan="8">Possible adverse health outcomes</th></tr>
<tr><td>Injuries and other occupational impacts</td><td>Impacts on the respiratory system</td><td>Congenital anomalies and reproductive disorders ?</td><td>Cancer ?</td><td>Infectious diseases</td><td colspan="3">Other outcomes</td></tr>
</table>

Figure 3 Schematic representation of municipal solid waste management practices and possible outcomes.

However, there are essential differences between landfill emissions in developed and developing countries, among other reasons, due to the different incorporation of waste separation at source, sanitary landfill development and controlled incineration practices [119, 165]. While prosperous countries have developed waste management to a point where new research and potential improvements are aimed at resource recovery and the development of a circular economy, in other parts of the world the disposal of manufactured materials and products once they become 'waste' at the end of its helpful life still is a dangerous and disruptive business for those involved in the process.

There is no doubt that, given the diversity of materials that fall into the waste category, their management carries considerable potential for hazardous exposure. High air, soil, and water pollution levels in some well-publicized situations have led to widespread concern about the potential health effects of waste management processes, particularly within communities near landfills.

At the same time, while the possibility of installing MSW landfills near urban centers is less and less socially acceptable, the population living in the vicinity of a waste disposal site, in a scenario in which they face a broad spectrum of risks, does not always perceive the danger that it poses to their physical well-being, which prevents them from reacting to it [166, 167].

Most epidemiological studies have been carried out in populations living near sites of uncontrolled disposal of hazardous waste, evaluating the association between residences and some specific diseases [168, 169], with the additional limitation of the lack of international consensus on the definition of hazardous waste and its variation over time, which prevents the homogeneous consideration of landfills in different countries. And even in various locations in some countries. The most consistent results suggest that the risks of congenital anomalies in newborns and hospitalization for respiratory diseases are relevant when the poorly controlled final disposal site contains hazardous waste [153].

A vast body of literature dispels these concerns when it comes to controlled final disposal sites for a number of reasons. On the one hand, it is reasonable to expect emissions from waste management processes to be a mixture of substances, including many for which a toxicological profile is unknown. On the other hand, there is a lack of evidence to precisely indicate the substance(s) whose presence may be associated with emerging health impacts. It is also reasonable to expect that the levels of most potentially hazardous substances would be extremely low, even if all sources of exposure were considered.

The methods used to estimate the population exposed to pollutants emitted by these sites represent a crucial issue in epidemiological investigations. Most studies used exposure indicators based on residence, a proxy that can lead to misclassification of exposure, including failure to record population migration to and from relevant areas. The main difficulties in assessing exposure are caused by the heterogeneity of the contaminants present at the often-unknown waste sites and the diversity of exposure routes. Due to informal and uncontrolled activities, the lack of this information makes the use of models particularly complex [154]. Lack of specificity can also occur in the definition of health outcomes, particularly if they are self-reported.

From the above, it is clear why the studies on the potential effects of MSW disposal sites on the health of the surrounding population have been inconclusive. Many studies have documented health effects potentially linked to residues in populations in their area of influence. Still, these tend to have methodological limitations and do not give consistent results. There is very little data on direct human exposure, and most studies used surrogates such as distance from residence, while more recent studies include data on potential routes of exposure (e.g., concentration of pollutants in soil, modeled atmospheric exposure). In many studies, confounding factors have not been adequately controlled, especially poverty and exposure to sources other than the one investigated. There is no data on migrations to or from the most critical areas that affect exposure times, nor considerations on latency periods in pathologies such as cancer, which usually does not manifest until years after exposure [104, 170-173].

These assessments are consistent with the conclusions of two workshops organized by the WHO on the health impact of landfills (in 2000) [52] and on landfills and waste incinerators (in 2007) [174], which agreed that the relationships between landfills and health impacts investigated (especially with cancer, reproductive problems, and mortality) are inadequate or insufficient. Similar conclusions were presented more recently by the International Solid Waste Association (ISWA) [175].

Finally, the presumption of a health hazard differs depending on the nature of the waste disposed. The impact is practically nil if the discarded materials result from a differentiated collection that is preceded by a virtuous separation at source and the disposal follows the rules of the art of sanitary engineering, while at the other extreme, the result of an undifferentiated collection that includes what is known as hazardous waste and that completes its life cycle in an OD. In all circumstances, even the best from a waste management perspective, the risks will be more significant for those who make direct contact with waste: workers in the sector must have the necessary personal protective equipment, and picking must be avoided.

Open burning is particularly widespread in low- and middle-income countries, where collection and disposal systems are often poor or non-existent. There is little precise data or empirical evidence on what, how much, and where solid waste is currently burned, what is released during burning, and what impact burning has on people and the environment locally or on a larger scale. Waste is burned near homes, inside industrial or commercial premises, and in large, uncontrolled landfills. The dangerous cocktail of emissions released into the atmosphere and land threatens the environment and the health of those who live and/or work nearby. It is clear that simply banning open burning without proper oversight will not solve the current safety problems, and a larger-scale response is needed.

In summary, in the last 30 years, in more than 20 countries spread across the 5 continents, more than 100 studies have been carried out on the impact of the final disposal of MSW on human health. Although these results are limited because the practice of publication tends to concentrate on studies that show some "positive" results, ignoring studies that do not identify "correlations" [50], they suggest that: a) in this period, the development of Sanitary Landfills has gained relative space and no relevant health impact has been demonstrated as a result of its operation; b) the practice of disposing of MSW in open landfills is a cause of contamination of the soil and surrounding airspace and, therefore, a source of varied hazards for the population surrounding them, although given the diversity of the composition of the waste and the possible mixing with hazardous waste facilitated by the fact that this modality goes hand in hand with the least controlled spaces, makes it very difficult to establish causal and systematic relationships; c) when this type of disposal adds the burning of waste, the health impact is more significant; and d) the direct contact of workers, formal and informal, with waste is the most significant potential hazard.

Abbreviation/Acronym List

BC	black carbon
CL	controlled landfills
MSW	municipal solid waste
OD	open dump
OF	organic fraction
PM_{10}	particles with a diameter of less than 10 µm
$PM_{2.5}$	particles with a diameter of less than 2.5 µm
SL	sanitary landfill
WHO	World Health Organization

Author Contributions

Both authors contributed equally to conceptualization, writing and visualization of the article.

Competing Interests

The authors declare that no competing financial interest or personal relationships that could have appeared to influence the work exist.

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