

What does 'risk' mean in municipal solid waste management?

¿Cuál es el significado de "riesgo" en el manejo de residuos sólidos municipales?

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Abstract. In the field of solid waste management, key concepts such as risk, impact and hazards have been used interchangeably and have had imprecise meanings and scopes; this can lead to a partial or biased vision, for example in relation to municipal solid waste management policies. This paper analyzes the use and diverse meanings of the concept of risk and its components in the scientific literature that addresses the issue of urban solid waste, from 1970 to 2020. It shows that the concept has been approached from various perspectives and interpretations. Economic and health crises can surprisingly increase risks and waste as in 2020. Waste composition has changed, since protective equipment against the coronavirus has been mixed with household waste. Of all risk components, vulnerability has

been the least addressed in the literature, because technical aspects such as hazard modelling predominate in this field. Most of the publications have studied the final disposal stage, given that open dumpsites and landfills are still the most common methods for disposing of solid waste. Finally, a reference framework is proposed.

Keywords: hazard, vulnerability, exposure, risk, final disposal.

Resumen. Dentro del tópico de los residuos sólidos urbanos (RSU), conceptos clave como riesgo, impacto y peligro se han utilizado indistintamente, con significados y alcances

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imprecisos, que ocasionan visiones parciales o sesgadas de las políticas municipales de gestión de esos residuos. Este artículo analiza el uso de diversos significados del concepto de riesgo y de sus componentes, a través del análisis de la literatura científica que aborda el tema de los RSU publicada entre 1970 y 2020. La literatura revisada se clasificó desde la perspectiva del manejo de los residuos en términos de enfoque, alcance temporal-espacial, tipo de receptor de los daños y otros. Se propuso también un marco de referencia para definir e integrar rigurosamente los componentes de riesgo asociados a esta categoría de residuos sólidos. Se encontró que no existe un lenguaje común para abordar el riesgo asociado con los residuos sólidos, ya que cada autor lo analiza desde una visión que depende de su área de interés. Se identificaron cinco enfoques del riesgo: i) ambiental y ecológico; ii) epidemiológico y sanitario; iii) ergonómico u ocupacional; iv) químico y tecnológico. También se identificó otro concepto como el impacto o seguridad ambiental, para referirse a las afectaciones sobre los ecosistemas en un contexto genérico. En términos de alcance espacial, la revisión de publicaciones científicas sobre riesgos relacionados con los RSU destaca que el número de artículos producidos ha crecido exponencialmente desde la década de los ochenta, con un marcado repunte a principios de la década de los noventa, lo cual, posiblemente se debe a que este período (1990-1999) fue designado por la Asamblea General de las Naciones Unidas como la Década Internacional para la Reducción de Desastres Naturales. Además, muchas de las políticas desarrolladas durante este período incidieron dentro de los riesgos antrópicos inherentes al manejo de los desechos sólidos. En cuanto a la distribución geográfica del origen de las publicaciones revisadas, el 69% consistió en estudios de caso (26% de Asia, 22% de América, 15% de Europa y 6% de África). Gran parte de las publicaciones abordan la etapa de disposición final, específicamente en tiraderos a cielo abierto o rellenos sanitarios, que son los métodos más comunes para disponer residuos en el mundo. Respecto al tipo de receptor del daño, 43% de las publicaciones analizadas identificó a los humanos como el receptor principal, con afectaciones que pueden ser causadas por contacto directo o indirecto, p.e. por inhalación, ingestión, contacto dérmico, y por exposición a vectores transmisores de

enfermedades. La atmósfera fue mencionada como receptora en 13%, al modelar la dispersión de un contaminante específico, como el metano o compuestos orgánicos volátiles. El agua fue considerada como receptora en 9% de los trabajos que abordaron principalmente la dispersión de los lixiviados y su efecto sobre las aguas subterráneas, dejando de lado la contaminación de las aguas superficiales. La vegetación fue considerada como receptora del daño en tan solo el 3%, con artículos que analizaron el daño a las especies vegetales, particularmente por la entrada de gases a los tejidos durante la fotosíntesis y la respiración. Desafortunadamente el suelo y la fauna no se han considerado como receptores primarios de daño, a pesar de que los desechos se depositan directamente sobre el suelo; en cambio, la fauna se ve más como un vector que causa malestar, enfermedad o daño. Al final del trabajo se propone un esquema conceptual del riesgo con relación a los RSU y se define el riesgo como el daño o la pérdida potencial de un componente propenso, que surge como resultado de la interacción de un elemento vulnerable (ser humano, flora, fauna o infraestructura) frente a una amenaza, que justamente son los residuos sólidos. Este riesgo puede ser amplificado o regulado por elementos como la tecnología, la normativa, la gestión y algunas variables ambientales.

Se concluye que, de los cinco principales enfoques identificados sobre el riesgo asociado a los RSU, no existe un lenguaje común en el manejo de los conceptos del riesgo, aunque sí hay un consenso en considerarlo desde el punto de vista antropogénico, particularmente dirigido a los efectos adversos al ser humano, por lo que también deben incluirse otros receptores como la vegetación, la fauna y el suelo. Dado que el análisis del riesgo es muy complejo, en la mayoría de las publicaciones, preferentemente se establecen modelos sobre la amenaza, muy poco para la vulnerabilidad y casi nunca se determina el riesgo de manera integral; por ello se propone un marco conceptual para aplicarlo en todas las etapas de manejo de los residuos y poder entenderlo de una manera más sencilla.

Palabras clave: peligro, vulnerabilidad, exposición, riesgo, disposición final.

INTRODUCTION

Municipal Solid Wastes (MSW) are those discarded materials that come from various activities performed daily by human being in household or outside it, including those generated in public spaces and streets (Diario Oficial de la Federación-DOF, 2015). If these wastes are handled incorrectly, they can cause serious damage to the environment, for example, air, soil and water pollution (surface and underground), even causing the death of some flora and fauna species (Butt, Lockley, and Oduyemi, 2008; Burkowska, Swiontek, and Kalwasińska,

2011; Alam and Ahmade, 2013; Vaverková *et al.*, 2018; Ferronato and Torretta, 2019; Feng, Tat-Dat, Ming-Lang, Kuo-Jui, 2020). MSW can also cause several problems within urban settlements, for example, floods due to obstruction of wastewater drainage systems, bad odours and adverse effects to human health (Sakurai, 1980; Sakawi, Mastura, Jaafar, and Mahmud, 2011; Martínez, Rico, Hernández, Romero, and Maldonado, 2013). All these effects can be considered as the consequences of risk by poor MSW management.

Unfortunately, this type of risk, called anthropic, has been addressed by multiple disciplines,

that use the concept of risk and its components in different ways, leading to confusion (Cardona, 1993; Chávez-López, 2018). For example, in the manuscripts of Sankoh, Yan and Tran (2013) and Zhang and Klenosky (2016), the concepts of environmental impact and environmental risk are sometimes used interchangeably to refer to the damage to ecosystems, the former referring to the actual damage suffered by ecosystems (disaster), while the second referring sometimes to a potential damage. Another example is the use of the terms hazard, danger, threat and even risk, which are often used as synonyms, especially in non-English speaking countries (Luhmann, 1996; Marcano and Cartaya, 2010).

Moreover, there are also frequent inconsistencies in the scope of risk assessments. This can be seen in the manuscripts of Chen and Kao (2008) and Colomer and Gallardo (2009), where risk assessments are carried out with a single component of risk (hazard or exposure); limiting risk analysis to a simple hazard or exposure assessment, although the concept of risk is eminently a function that involves several components simultaneously.

This ambiguity in terminology impedes the correct design of public policies focused on improving the management of MSW; this causes that many of these policies used in several countries, are an adaptation of those used in other disciplines such as waste and hazardous materials, rather than being a policy or management plan entirely originated in the field of MSW.

This paper analyses risk with regard to MSW management, to determine how this term and several related categories are conceptualized and used in an extensive range of researches applied to MSW. Additionally, a reference framework is proposed to rigorously define and integrate the components of risk associated with MSW. This framework can be potentially useful for interpreting how the components of risk interact with each other and for fostering further precision regarding how this anthropogenic risk is produced and managed. It should be noted that this manuscript differs from others that exist in the literature, since the proposed reference framework is constructed totally within the field of MSW, while other manuscripts

design their reference framework as an adaptation of already existing approaches.

MATERIALS AND METHODS

A database was prepared with more than 100 indexed papers, several of them from specialized journals on the topic of MSW with an impact factor. The attributes included were: title, abstract, year of publication, waste management stage, country of investigation and primary receptor of damage. The number of papers reviewed is considered adequate to provide insight on how the concept of risk is addressed within MSW.

Relevant papers were identified using English and Spanish keywords. The most common risk-related keywords within the literature concerning waste were integrated into the search for papers (Table 1). Most of the articles reviewed were obtained from the Science Direct search engine, and those are in English. Google Scholar was also used to obtain papers in Spanish and within the Latin American context of risk associated with MSW; other technical documents, such as the regulations of some countries, were also obtained.

Table 1. Keywords used in the search for papers via the Internet

Main words	Secondary words
Municipal solid waste	Collection, final disposal, incineration, infrastructure, landfill, landfill gas, leachate, storage, transfer, transportation.
Risk	Assessment, damage, environment, exposure, fragility, hazard, impact, public health, sensitivity, threat, vulnerability.
Residuos sólidos municipales/urbanos	Almacenamiento, disposición final, gases de relleno, recolección, incineración, infraestructura, lixiviado, relleno sanitario, transporte, transferencia.
Riesgo	Amenaza, ambiente, daño, exposición, evaluación, fragilidad, impacto, peligro, salud pública, sensibilidad, vulnerabilidad.

Source: own elaboration.

Within each journal, the search focused on papers published between 1970 and 2020. The literature was classified from the perspective of MSW management in terms of focus, temporal and spatial scope, and type of receptor of damage.

RESULTS AND DISCUSSION

Approaches in the risk literature

Paper analysis shows that there is no common language to address the risk associated with MSW, since each author sees it from a perspective that depends on their area of interest. This can cause confusion for decision-makers, since methods of assessment may not be comparable due to the variety of concepts used, potentially leading to public policies and management plans that do not share a common goal.

This paper classifies the reviewed publications into five MSW risk approaches. It also includes another item that considers only one component of risk. Each of them has its own specific characteristics.

Environmental and ecological risk: papers using this approach address the adverse effects on human beings, flora and fauna caused by toxic agents in a contaminated site. The methods of risk assessment in contaminated sites have had an influence on them; a series of stages have also been developed for their execution, such as: I) hazard identification, II) dose-response evaluation, III) exposure assessment and IV) risk characterization. The characteristics of the toxic agent and the receptor of damage are very important. The works carried out by Butt and Oduyemi (2003), Butt Clark, Coulon, and Oduyemi, (2009), Durmusoglu, Taspinar and Karademir (2010), Butt, Javadi, Nunns, and Beal (2016) are related to this risk classification, because they all incorporate some of the above mentioned assessment stages.

Epidemiological and health risk: the risk generally refers to human diseases caused by MSW and their subsequent spread. Damage caused to other living beings is not considered. Damage usually occurs through indirect contact with the MSW. For example, the proliferation of vectors such as flies, rodents and mosquitoes due to inadequate

storage of MSW can favour dengue, typhoid fever, salmonellosis and dysentery (Radin, Al-Gheethi, Noman and Abdullah, 2016).

Derived from the economic and health crisis caused by the COVID 19 pandemic, the year 2020 has brought about a change in habits, which directly influences the production of waste and its composition. In most cases, an important part of the generated waste, such as masks, empty gel bottles, alcohol, cleaning products and other containers related to the pandemic, are being disposed of together with municipal solid waste without any control. Together with the above, an undetermined amount of hospital waste is added (Ouh sine *et al.*, 2020; You, Sonne and Ok, 2020).

Populations living close to MSW management infrastructures such as incinerators, compost plants, landfills or open dumpsites can suffer from respiratory damage and, in severe cases, cancer (Nabavi-Pelesaraei, Bayat, Hosseinzadeh-Bandbafha, Afrasyabi, and Chau, 2017; Malinauskaite *et al.* 2017; Ma *et al.*, 2018; Ferronato and Torretta, 2019).

A study has shown that the level of pollutants around the areas where solid waste has been composted, is low and that, therefore, it does not represent a serious risk (Nguyen and Fogarassy, 2020; Vaverková *et al.*, 2018) However, if composting is not properly done, it can cause various environmental problems including the formation of toxic smelly gases, dust and bio-aerosols, resulting in health or sanitation problems for nearby residents (Nguyen and Fogarassy, 2020; Hoang and Fogarassy, 2020).

The papers by Giusti (2009), Pheby Grey, Giusti, and Saffron (2002) and Porta, Milani, Lazzarino, Perucci, and Forastiere (2009) are related to this risk classification, because they carry out exhaustive researches on various diseases that are caused by MSW. All damages are analyzed within the framework of epidemiology, i.e., identifying how a disease is distributed according to time, place and people's characteristics.

Ergonomic and occupational risk: this approach is related to damage to humans by direct contact during collection, transport and final disposal of MSW. It includes back, leg, shoulder and arm pain, lacerations and cuts in the hands, as well as

the appearance of skin ulcers and respiratory tract irritation (see studies by Cimino, 1975; Jayakrishnan, Cherumanalil and Bhaskar, 2013; Rendleman and Feldstein, 1997).

Chemical and technological risk: it is considered that the risk occurs when the liquid, solid or gaseous emissions that affect humans and ecosystems are emitted in the MSW management infrastructure, such as final disposal sites, separation plants and incinerators. Damage occurs through indirect contact. The characteristics of the MSW management infrastructure and the toxic agent are important (see studies by Bosque, Díaz and Díaz, 2002; Bosque *et al.*, 2004; González, 2006).

Environmental impact or safety: this approach addresses the adverse effects on ecosystems but in a generic context. This occurs because the terms such as impact and risk are mixed without any distinction. It is important to clarify that "impact" refers to damage that has already occurred and the management will be corrective, whereas "risk" refers to potential damage and the management can be preventive. Sometimes in considering manipulation of substances with corrosive, reactive, explosive, toxic or biologically infectious characteristics, these publications refer to risk instead of impact. The papers by Daskalopoulos, Badr, and Probert (1997), El-Fadel, Findikakis, and Leckie (1997), Hamer (2003), Kiss and Encarnación (2006) and Rabl, Spadaro, and Zoughaib (2008), are related to this category, because they interchangeably use the terms impact or risk. It should be noted that there are also other papers that carry out research entirely within the field of environmental impact, for example, Salas and Quesada (2006) and Mosquera, Canchingre, and Morales (2014); however, these papers use specific terminology of environmental impact, such as "beneficial, adverse, reversible, irreversible, synergistic impacts, etc; therefore, there is no misunderstanding as regards the terms used.

Other approaches use a single component of risk: some publications do not deal with the concept of risk in an integrated way, but rather focus on some of its components, such as vulnerability or exposure. Several papers address

some component in terms of the social aspects of waste management, such as inequity in the provision of services, environmental education, or the integration of the informal sector. Table 2 shows the description of the papers according to this type of risk approach.

One of the factors that allow the existence of these approaches, is the fact that the concept of risk and its components are still evolving from the theoretical bases established in the past. For example, the investigations of Burton and Kates (1964), and White (1973), established the conceptual bases of what is today risk and hazard; whereas thanks to the contributions of United Nations Disaster Relief Organization-UNDRO (1979), Quarantelli (1987, 1995, 1998) and Maskrey (1989), new concepts such as vulnerability were generated, as well as new ways of approaching risk. However, even today these approaches and others are still being discussed.

The legislation of each country is another factor that significantly influences the formulation of the concept of risk associated with MSW. Many countries consider environmental and ecological risks, an approach expressed in their laws and regulations, for example in Mexico (General Law for the Prevention and Integral Management of Residues in Mexico (DOF, 2015) and the US Conservation and Recovery Act in the United States of America (United States Environmental Protection Agency-USEPA, 1976). This may be related to the rise and development of methods of risk assessment in contaminated sites, such as those developed by the US Environment Agency (2003, 2004), Ireland Environmental Protection Agency-IEEPA (2007), USEPA (1989, 1992, 1993) and Pan-american Health Organization-OPS (1999). These methods have been well accepted in the country of origin, and their conceptual bases have permeated the laws and regulations of other countries.

Finally, other factors also influence the use of the concept of risk. For example, the stage of waste management is related to the place where the damage occurs, such as collection truck, treatment plant or final disposal site. In addition, the receptor of damage (human or ecosystem) and the characteristics of the MSW can condition the use of

Table 2. Papers that use a simple component of risk

Papers	Description	Papers	Description
Al-Khatib, Kontogianni, Abu, Alshami, and Al-Sari (2015)	This paper assesses citizens' knowledge of household waste, particularly the identification and handling of hazardous materials within the total stream of MSW. This document only addresses the hazard component, especially its perception.	Ma and Hipel (2016)	In this paper, the literature on the social dimension of MSW management was reviewed, in terms of public participation, attitude and behavior, environmental education, and policy. Two components of risk are frequently used in this literature review (vulnerability and exposure).
Cross (2013)	The objective of this paper is to analyze the type of social insertion offered by social programs, especially those aimed at creating jobs for vulnerable populations. This document addresses the vulnerability component, although it is seen as its inverse, i.e., resilience.	Sembaring and Nitivattananon (2010); Paul, Arce, Rayena and Villamor (2012); Wilson, Velis and Cheeseman (2006)	These papers discuss the integration of the informal sector into MSW management, particularly in the stages of collection and final disposal. Different components of risk are addressed; however, the emphasis is on the vulnerability of waste pickers. Sometimes the context of vulnerability can be seen as its inverse, i.e., resilience.
Durand and Metzger (2009)	This document addresses the concept of vulnerability and how it is transferred from one place to another or from one group of people to another, through the management of MSW.		The main objective of this paper is to provide a literature review of the perception and attitude of settlements located near waste management facilities. Throughout this document, the terms impact and risk are used interchangeably to refer to general damage. However, due to the context of the work carried out, we can infer that the exposure component is really addressed, since the perception that people have of MSW management (external aspects) is described, instead of addressing the internal characteristics of MSW.
Elliott <i>et al.</i> (1993)	In this paper, psychosocial effects are investigated in populations exposed to solid waste management facilities. The exposure and vulnerability components are addressed. These components of risk are observed through various characteristics of the human being, such as age, sex and others.	Zhang and Klenosky (2016)	

Source: own elaboration.

certain techniques or methodologies to assess the risk or a specific component of it. This last point can be seen in the papers of Chen, Tu, Chen and Chen (2016) and Araiza and Rojas (2019), where mathematical dispersion models and characteristics of a toxic agent present in waste are used. In other cases, when analysing the human being as a damage receptor, mathematical indexes are used that consider factors such as variability among individuals, for example, age, sex, race and lifestyles, and so on (Ilizaliturri *et al.*, 2009).

Temporal and geographical distribution of publications

The review of scientific publications on risk related to MSW suggests that the number of papers produced has grown exponentially since the 1980s, with a marked upswing in the early 1990s. This is possibly because this period (1990-1999) was designated by the United Nations General Assembly as the international decade for natural disaster reduction. In addition, many of the policies developed during this period influenced the

anthropic risks inherent in the management of MSW. In these years, various ecological initiatives were undertaken, such as the declaration of Rio de Janeiro in 1992 and the Kyoto Protocol in 1997, which were very important because they introduced concepts such as environmental impact and sustainable development within the studies and risk assessments (Chávez-Lopez, 2018).

Regarding the geographical distribution of the papers reviewed, 69% were case studies: 26% from Asia, 22% from the Americas, 15% from Europe, and 6% from Africa. No publications were found for the Oceania region (Figure 1). These values are biased, because the search for scientific publications used the platforms Science Direct or Google Scholar, in which most of the publications retrieved are in English, and non-indexed journals or journals in other languages are not found.

Steps of waste management

Well-known references in the topic of waste such as Tchobanoglous, Theisen, and Vigil (1993) and Worrell and Vesilind (2002), establish that MSW are a consequence of life and they emphasize that, in order to improve the quality of life of urban areas, it is essential to use an integrated management of MSW. This management includes actions to manipulate waste from its generation until its

final disposal, including intermediate operations such as transfer and treatment, as well as the implementation of regulations.

However, deficiencies in integrated waste management are very frequent, due to economic or technological issues or due to the incorrect execution of regulations. All these deficiencies will have adverse effects on environmental quality and human health. For this reason, it is very important to know at which MSW management stage these damages occur.

About 61% of the reviewed publications reported research regarding risk at the final disposal stage. This is because open dumps or landfills are still the most common methods for waste disposal in most part of the world (Aljaradin and Persson, 2012; Espinosa *et al.*, 2010; Medina, 2005; Velasco, de la Rosa, Rosas, Solórzano, and Volke, 2004). Waste treatment was studied in 14% of the articles; the main technologies are thermal such as incineration (Cordier *et al.*, 2004; Johnson, 2016; Pan *et al.*, 2013; Rovira, Vilavert, Nadal, Schuhmacher, and Domingo, 2015; Zhou *et al.*, 2015), followed by biological methods (e.g., composting) (Domingo and Nadal, 2009; Sharifi, Hossaini, and Renella, 2016). Collection-separation of the waste was studied in 13% of the articles, and waste transfer in 2%. The remaining 10% were

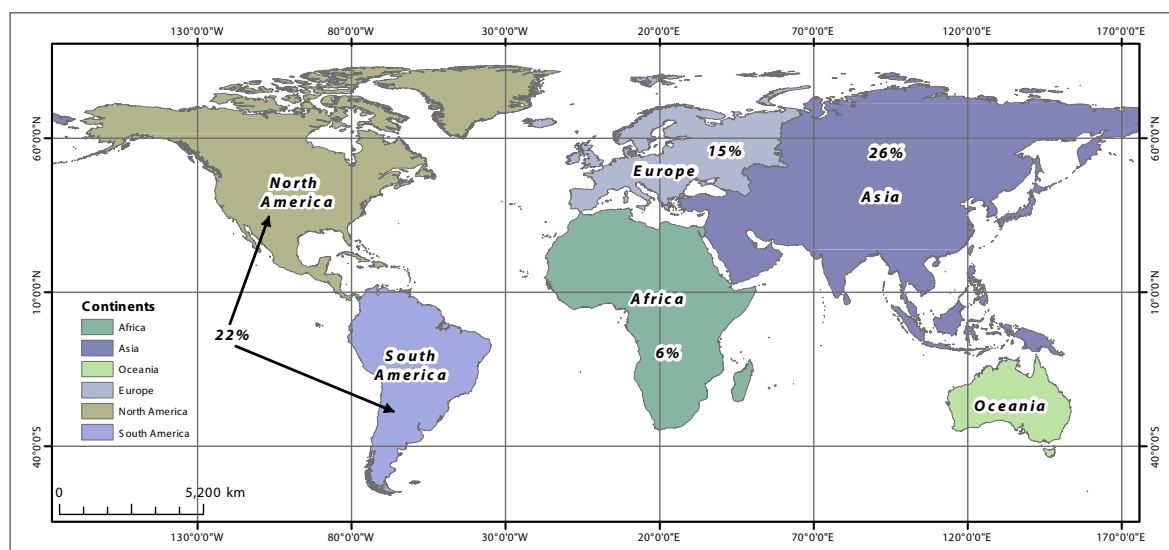


Figure 1. Geographical distribution of papers (1970-2020) related to risk and MSW. Source: Own elaboration.

not case studies and covered several stages of the process (Figure 2).

Hazardous elements of MSW

MSW are different from hazardous waste, since the latter have corrosive, reactive, explosive, toxic or biological infectious characteristics (USEPA, 2005). MSW theoretically do not have these properties, but some materials that are thrown away in urban areas do have them, such as batteries, aerosols or expired drugs. Note that these sub-products are becoming more noticeable, because in several studies of MSW generation, their percentages of appearance range between 0.2 and 5% by weight (Apaza, 2006; Favela, Ojeda, and Lozano, 2009; Saldaña, Hernández, Messina, and Pérez, 2013; Castillo and De Medina, 2014; Otorala, 2016; Araiza, Chávez, and Moreno, 2017).

On the other hand, it should be noted that MSW can become hazardous for other causes, for example, due to failures in integrated management for economic, technological or regulatory reasons. This can be seen in several studies that have reported deficient waste management in urban settlements and in their final disposal sites (Turan, Çoruh, Akdemir, and Nuri, 2009; Ogwueleka, 2009; Araiza, Chávez, Moreno, and Rojas, 2017).

Additionally, the compounds generated by the MSW, such as leachates and gaseous emissions, are other causes of hazards. In 50% of the publications analyzed, the gases emitted by the organic fraction of MSW, such as volatile organic compounds or greenhouse gases, are identified as hazardous;

leachates are also frequently addressed (36%), specifically for their high toxicity due to metals and high organic loads. Fewer publications (14%) analyze MSW materials that can be hazardous such as expired drugs, aerosols, paints, sharp objects, and metals (Slack, Gronow, and Voulvoulis, 2004; Slack, Gronow, and Voulvoulis, 2005).

Receptors of damage (elements at risk)

Of all the papers, 43% identified humans as the main receptor (Figure 3); damage can be inflicted by direct contact with MSW, such as by inhalation, ingestion or dermal contact (Binion and Gutberlet, 2012; Bleck and Wettberg, 2012; Gutberlet and Baeder, 2008; Hafizhin and Abdul, 2015; Ivens *et al.*, 1997; Ivens, Breum, Ebbehøj, Nielsen, Poulsen, and Würtz, 1999; Paulsen *et al.*, 1995; Ray, Roychoudhury, Mukherjee, Roy, and Lahiri, 2005). Damage may also arise through indirect contact, by exposure to vectors that transmit diseases such as dengue and typhoid fever, since waste management facilities favour the reproduction of these transmitters such as mosquitoes (De and Debnath, 2016; Gouveia and Prado, 2010; Omar, Karuppanan, and Ayuni, 2012; Palmiotto, Fattore, Paiano, Celeste, Colombo, and Davoli, 2014; Vrijheid, 2000).

The atmosphere was mentioned as receptor in 13% of publications, in modeling the dispersion of a specific pollutant, such as methane or volatile organic compounds (Castillo, Gandini, and Laín, 2012; de la Rosa, Volke, and Solórzano, 2006; Saral, Demir, and Yildiz, 2009; Úbeda, Ferrer, Sanchis, Nicolas, and López, 2010; Zhao, Lu,

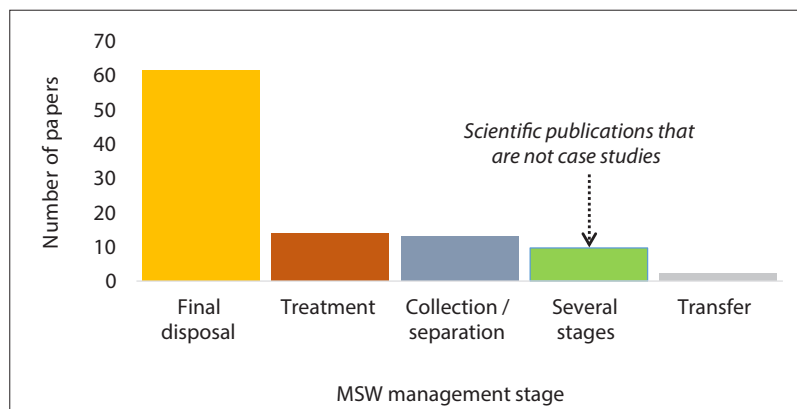


Figure 2. Distribution of publications by stage of waste management (1970-2020). Source: Own elaboration.

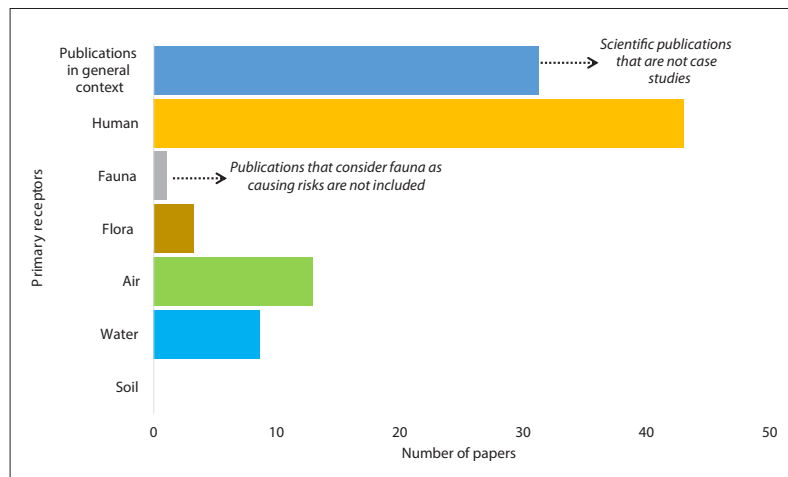


Figure 3. Distribution of publications by affected receptor in the period 1970-2020. Source: Own elaboration.

and Wang, 2015). These publications related the modeling only indirectly to the adverse effects on humans, marking exposure areas. In recent years, investigations have been carried out at the final disposal sites, linking the atmosphere as a primary receptor and the human as a secondary receptor. These investigations have quantified greenhouse gas emissions (methane and carbon dioxide) and related them to climate change and damage to humans (Couth, Trois, and Vaughan, 2011; Lou and Nair, 2009; Mattos, Gomes, and Ribeiro, 2016; Solórzano, 2003; Weitz, Thorneloe, Nishtala, Yarkosky, and Zannes, 2002).

Water was considered as a receptor in 9% of the papers that addressed mainly the dispersion of leachates and their effect on groundwater (Akinbile and Yusoff, 2011; Gómez, Reyes, López, and Belmonte, 2012; Gómez, Morales, Macedo, and Pavón, 2013; Pérez, Vicencio, Alarcón, and Vaca, 2002; Rapti, Sdao, and Masi, 2006; Mouhoun-Chouaki, Arezki, Tazdaït, Salah-Tazdaït, 2019) and left the contamination of surface waters aside. Vegetation was considered as a receptor of damage in only 3% of the publications; these papers analyzed the damage to plant species, particularly by the ingress of gases into the tissues during photosynthesis and respiration (Flower, Gilman, and Leone, 1981; Márquez and Sánchez, 2014; Sánchez, Trejo, and Márquez, 2012; Banerjee, Aditya, and Saha, 2013). Soil and fauna have not been seen as primary receptors of damage, even

though MSW is deposited directly on the soil which is also the habitat of a myriad of organisms that can be affected. Fauna is seen more as a vector causing discomfort, disease or damage (Banerjee *et al.*, 2013; Dutta, Khan, Khan, Sharma, Doloi, and Mahanta, 1999; Gabrey, 1997; Garmendia, López, Muñoz, and Martínez, 2011).

A reference framework for interpreting risk in MSW management

Most of the published articles focus on technical aspects, specifically on the modelling of the hazard rather than vulnerability, which implies that a complete risk assessment is not carried out. It is necessary to begin to consider the social and environmental dimension, seen as part of the vulnerability, to complement the risk language associated with MSW.

The analysis of published researches shows that there is no unified conceptual framework to understand the risk associated with MSW. For this reason, this final section presents a proposal on how to define and integrate the components of this risk. Note that this proposed conceptual framework is constructed totally within the field of MSW, based on the origin of the word risk and all its components involved.

Risk concept: risk is the interaction of a damage-prone component and a damage-producing component (Gelman, 1996). The first component is the place or subject where the damage occurs, i.e.,

the vulnerable elements. The second component corresponds to the elements that cause the damage, called hazards, capable of adversely affecting the dynamics of the damage-prone component.

The risk stemming from MSW is difficult to understand and analyze because it is a long-term process and, except for a few occasions, it is not catastrophic or sudden, and for this reason several authors call it a chronic risk (Alexander, 2014; UNISDR, 2016). Moreover, the hazard frequently becomes a factor of vulnerability and the components of risk can act as cause and/or effect, so the risk must be analyzed holistically. This means that the risk would not exist if some of its components were not included in the assessment, because otherwise, possibly only a hazard, exposure or vulnerability assessment would be performed.

The present work defines risk as a quantitative and/or qualitative estimate of the potential chronic damage that may be generated by MSW (hazardous agent) to human and the environment (vulnerable systems) in a specific geographical space and time. In practical terms, the risk, associated with MSW is the damage to, or potential loss of, a damage-prone component as a result of interaction with (exposure to) a hazardous agent.

Hazard concept: "hazard" can be conceived from different viewpoints depending on the area of scientific research, and therefore this concept has no single definition. Sometimes it is also used as a synonym for the terms danger or threat (Marcano and Cartaya, 2010). Within the topic of MSW, the term is often applied to the sub-products genera-

ted by MSW, such as leachates or gases, or to the poorly operated MSW management infrastructure, or sometimes to the waste management itself. This proposed framework is based on an anthropic view of risk, where the adverse effects on humans and ecosystems are caused by human errors, so that solid waste per se must be considered a hazard (MSW = Hazard). Regarding leachates and landfill gas, they should be considered as hazardous agents, produced by various chemical reactions within the MSW.

Note that both the risk and its components may be reduced or amplified by other elements such as technology, regulation, management and certain environmental variables such as soil type, slopes, wind and others (Figure 4). All these elements should be called "factors" (hazard factors and vulnerability factors).

With regard to hazard and its hazardous agents, internal factors such as the quantities of MSW, leachates or landfill gas generated, as well as their composition (organic and inorganic materials) and their inherent characteristics must be taken into account. External factors such as coverage and frequency of collection, methods of final disposal and any other aspect related to waste management are also relevant.

This conceptual framework proposes that the hazard can be defined as the probability or possibility, that the MSW by themselves or through the materials present in their composition or the compounds they generate, may cause adverse effects to the human being and ecosystems.

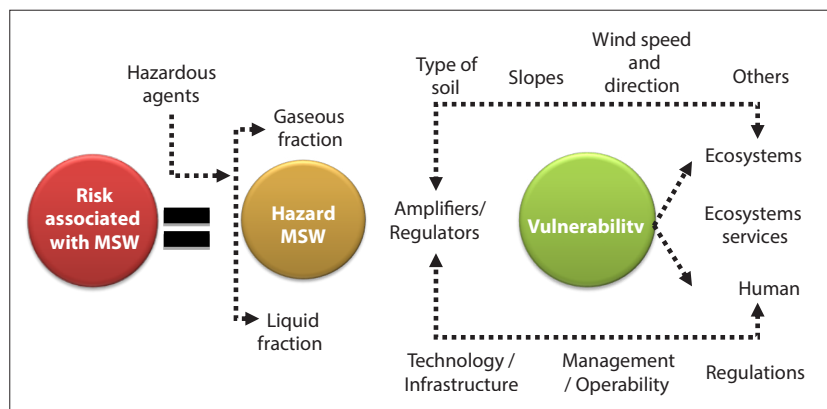


Figure 4. Components of Risk in MSW Management. Source: Own elaboration.

Vulnerability concept: another component of risk is “vulnerability”, also called sensitivity or fragility in other areas of scientific research (see studies by Cereda and Röhm, 2014; Jensen, Halls and Michel, 1998). There are two kinds of vulnerability, intrinsic and extrinsic (Figure 5). Intrinsic vulnerability refers to the inherent characteristics of the damage-prone component. With regard to MSW, the vulnerable elements may be human beings, ecosystems or even infrastructure; but it should be noted that this last element is the least addressed, since there are few contributions in the literature (see, for example, Laner, Fellner and Brunner, 2009).

On the other hand, extrinsic vulnerability, also called “exposure”, is not governed by the receptor characteristics; it rather refers to the intensity (dose or quantity) of the hazard to which a territory and the organisms are exposed (Díaz and Díaz, 2002). This component of risk will exist as long as the damage-prone component interacts with the damage-producing component.

Note that internal and external factors also regulate both types of vulnerability. The intrinsic vulnerability factors are the easiest to identify through socio-demographic, economic, cultural and biophysical variables of (Bayo, Chicharro, and Galve, 1995). On the other hand, the extrinsic vulnerability (exposure) factors are more difficult to define, since many of them can act as cause and/

or as effect, i.e., they can be part of the hazard or the vulnerability (intrinsic).

This conceptual framework proposes the following concepts of intrinsic vulnerability, considering that there may be two highly vulnerable elements, human beings or ecosystems. Additionally, a simple concept is also proposed to define exposition to MSW.

Environmental vulnerability (ecological systems) must be understood as the susceptibility or predisposition of the damage-prone component (air, water, soil, flora and fauna) to suffer damage or losses, due to the presence of the hazard. Within the topic of MSW, it refers to the response of a living organism (some species of flora or fauna) to the presence of waste, but also to the response of more complex systems such as aquifers or water bodies, soil and air.

Human vulnerability (social systems) refers to the conditions and degree of organization of people or communities, which limit their ability to respond to a hazardous situation related to MSW, including human health.

Exposure is a situation in which a damage-prone component and a damage-producing component interact. This situation occurs in a specific geographical space and time. For MSW, the exposure may be the situation caused by the mismanagement of MSW, the incorrect operation in a specific management stage or the lack of regulations.

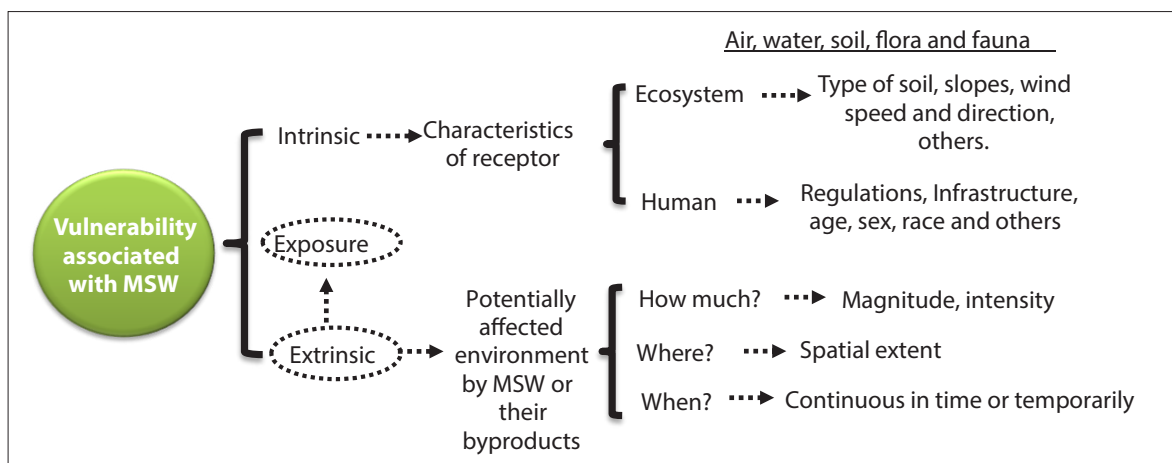


Figure 5. Structure of vulnerability associated with Risk in MSW Management. Source: Own elaboration.

The assessment of the risk associated with MSW is difficult because no tool integrates all stages of waste management at the same time. An assessment of this risk necessarily involves separately analyzing each stage of waste management, and these then need to be combined to obtain the global risk. Unless there is an integrated approach with several risk components, such efforts should not be classified as risk assessment.

With regard to hazard, it is necessary to know the kinds of adverse effects that occur at each management stage, considering quantity, composition and transformation of the waste across time to be able to identify the magnitude and intensity of the exposure. Regarding intrinsic vulnerability, it is necessary to know the characteristics of the damage-prone component that make it vulnerable when they are exposed to the waste; these can regulate or magnify the risk.

Each stage of waste management requires a reference framework that includes all the components of the risk, to allow for changes in the characteristics of the hazard and the vulnerable elements, the amplifiers and regulators.

An example of an application to obtain the global risk involves analyzing the waste collection stage with techniques that allow to determine conventional risks in workers (lacerations, cuts, etc.). Then the resulting information must be standardized and weighted.

Furthermore, in other stages of waste management, techniques must be applied to determine risks in different receptors. Subsequently, the resulting values of each applied technique must also be standardized, weighted and added to those previously obtained in other stages of waste management.

It is important to note that some situations play key roles in a risk assessment study, for example, the scale of preparation of that study and the sources of information. In regional studies, it is common to obtain information from databases compiled by government agencies. In local studies, the information is obtained through interviews at the household or urban settlement level. Finally, in site studies covering small areas, the experience of the researcher, field and laboratory work, as well as mathematical models of dispersion are usually used, among other sources of information.

CONCLUSIONS

This paper reviews the scientific literature from 1970–2020 that addresses the concept of risk associated with MSW management. It proposes a framework to classify this risk and its components that can be useful to assess risk in an integrated manner. The major conclusions from the analyses are summarized as follows:

The several approaches to the concept of risk in the literature of MSW have been (i) environmental and ecological risk; (ii) epidemiological and health risk; (iii) ergonomic and occupational risk; (iv) chemical and technological risk; and (v) environmental impact or safety. There is no common language to address the risk associated with MSW.

61% of the scientific publications regarding risk related to MSW have studied the final disposal stage, specifically in open dump sites or landfills, because they are the most common methods of final disposal.

The concept of risk is considered anthropocentrically, with most publications focusing on the adverse effects on humans. However, the way to approach risk must change, since other receptors such as vegetation, fauna, and soil are also important. In addition, often the human is not the primary receptor of damage, but rather the secondary receptor.

Published papers suggest that MSW becomes hazardous through failures in its integrated management, and because of its composition or the generated compounds, such as leachates or landfill gas.

Most of the published articles focus on technical aspects, specifically on the modelling of the hazard rather than the vulnerability, which implies that a complete risk analysis is not carried out. It is necessary to begin to consider the social and environmental dimension, seen as part of the vulnerability, to complement the risk language associated with MSW.

The published risk assessment methods have usually considered a single component of risk (hazard, exposure or vulnerability), because of the complexity of integrating them into a single tool. To generate complete risk assessments, it is

necessary to analyze each MSW management stage separately.

The risk associated with MSW has two components, hazard and vulnerability (intrinsic and extrinsic). This risk can be amplified or regulated by elements such as technology, regulations, management and certain environmental variables.

A consensus as regards the concepts of risk and its components would permit to compare the various assessment methods, and would give public policies and waste management plans a common framework.

This paper defines the risk associated with MSW as the damage to, or potential loss of, a damage-prone component, which arises as a result of the interaction of the vulnerable element with (exposition to) a hazard.

Finally, by way of recommendations, it is important to highlight that technological developments will always be essential to reduce risks from MSW, but they must be in accordance with the technological and economic level of each country. In developed countries, it is common to use thermal technologies that can sometimes be risky because of mismanagement, not poor technology. In developing countries, open dumps or landfills must be improved with the implementation of mechanical separation or biological treatments, which are often inexpensive.

Moreover, consistent policies must be applied to reduce risks, especially in developing countries, which have large socioeconomic inequalities. Programs for the separation, prevention and reuse of some materials at the source are examples of policies that can be implemented regardless of the socioeconomic level of the population.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

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