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Occupational Risk Assessment in Landfills: Research Outcomes from Italy

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Abstract: Industrial production has brought increased wellbeing in the last years, but the amount of solid waste has undoubtedly increased. Thus, open dumpsites and landfills have been created throughout the world, with serious impacts on the environment and public health. In such a context, occupational health and safety (OHS) issues related to workers that have to deal with landfill characterization or management have not been considered sufficiently. To reduce such a research gap, in 2019 a research project started in Italy on OHS risk assessment in landfills. In fact, in such facilities, workers can be subjected to direct contact with the polluted environment and might not be completely aware of the entity and type of pollution (e.g., in open dumpsites). Starting with the analysis of INAIL data on accidents at work which occurred in Italy during the period 2008–2019, a specific risk analysis was carried out with the goal of defining risk determinants and profiles by means of K-means cluster analysis. Such an analysis allowed us to recognize the use of work equipment and the work environment as the main determinants of the accidents on the one hand, and the "driver of the excavator" as the most risky activity on the other. The achieved results take a step forward towards the characterization of occupational health and safety issues in landfills. Accordingly, the research outcomes represent a basis on which to address further research work in this field.

Keywords: occupational health and safety; risk assessment; safety management; landfilling operations; accident prevention; cluster analysis

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1. Introduction

Even though circular economy approaches have been promoted fostering the reduction of waste [1], in recent years the ever-increasing production of goods and services has caused a massive production of disposed goods and materials, which are still sent to landfills. According to World Bank Group data, global waste generation was estimated to reach 2.01 billion tons in 2016, and in most countries open dumpsites and landfills were found to be the main waste disposal methods [2].

In particular, one of the main issues related to waste disposal is represented by the management of illegal dumping, which refers to "Waste materials that have been dumped, tipped or otherwise deposited onto land where no licence or approval exists to accept such waste. Illegal dumping varies from small bags of rubbish in an urban environment to larger scale dumping of waste materials in isolated areas, such as bushland" [3]. As observed by Limoli et al. [4], landfills may cause the emission in the environment of hazardous gases, dust, and leachate, due to biochemical waste degradation, which can have serious impacts on the environment and public health [5–8].

To deal with this phenomenon, a consistent legislative framework has been implemented all over the world, as well as several research initiatives [9–11]. For instance, in

Europe, the Waste Shipment Regulation was the first act aimed at regulating the traffic of waste among European and Extra-European countries [4,12]. Directive 2008/99/EC provided the framework to promote the protection of the environment through criminal law provisions [13]. Then, in 2018 the European Commission also updated the legislative framework on waste landfills by means of the Directive 2018/850/EU [14].

Similarly, in Japan, a series of recent amendments has been added to the Waste Management and Public Cleansing Law, to include expanded criteria for operating waste treatments in landfills [15]. The Government of Singapore introduced severe provisions too, through the Environmental Public Health Act (EPHA) [16], while in New South Wales (Australia) the Protection of the Environment Operations (PEO) Act foresaw a tiered range of penalties for illegal dumping [17].

However, from the legislative point of view, only general provisions on occupational risk assessment and management can be found at the moment, while specific measures for this sector are missing. The lack of safety requirements for workers operating in landfills has been also outlined by Al-Khatib et al. [18], who investigated occupational health and safety among scavengers.

Such a situation can also be found in the literature, where numerous studies have investigated health and environmental problems related to illegal dumpsites and their management [19–21], while occupational health and safety issues concerning the operators involved in landfilling operations have not been considered sufficiently [22]. Indeed, besides guidelines providing instructions on how to carry out the cleanup of these sites (which are called "remediation activities") [23], there is a lack of studies and official documents addressing OHS for the workers involved in landfill remediation and management activities.

Based on the above considerations, in Italy, during the period 2019–2022, a joint research project on OHS risk assessment in landfills was carried out involving academia and the National Institute for Accidents at Work (INAIL) with the goal of developing specific occupational risk assessment models for activities carried out in landfills through the analysis of the official databases on work-related accidents. Thus, this study proposes the results achieved by such a project mainly focusing on the following aspects:

- definition of the accident causation model for workers involved in the characterization and management of landfills;
- definition of specific risk profiles for safety management in landfills.

In fact, on the one hand, the former represents a key aspect from the occupational safety point of view, since these activities in contaminated sites are of particular concern due to the lack of complete knowledge regarding the potential risks for the operators, as stressed by Burger and Gochfeld [24]. On the other hand, the latter issue can provide the definition of specific risk profiles which are capable of leading to the implementation of more precise and effective safety management procedures [25].

More in detail, the paper is organized as follows. In the next section, a background analysis is carried out to better explain the safety problems related to landfills. In Section 3, the research approach used to investigate risk profiles by means of cluster analysis tools is described. Section 4 illustrates the results achieved, while Section 5 discusses the study's outputs. Finally, Section 6 concludes the paper, addressing the direction for further research work.

2. Background Analysis

The background analysis is aimed at providing the "state of art" concerning the safety problems related to landfills, which includes both the effects on public health and the environment, as well as occupational risks. With this goal in mind, recent studies addressing these topics are considered, although a systematic literature review is not performed.

2.1. Effects of Landfills on Public Health and Environment

Inside any landfill, some biological and chemical reactions occur, converting a part of the waste into toxic substances released by landfill gas (LFG) and leachate. LFG includes hundreds of different gases: Nitrogen, Oxygen, Ammonia, Sulfides, Hydrogen, Carbon Monoxide, and non-Methane organic compounds. However, from 45% to 60% of LFG is covered by Methane (CH_4) and about 35% by Carbon Dioxide (CO_2) [7,26].

Analyzing epidemiologic studies, there is evidence that the continuous inhalation of CH_4 and CO_2 can cause nausea, vomiting, headache, loss of coordination, and increased blood pressure. At very high levels of exposure, methane may lead to coma and death due to asphyxia. Moreover, CH_4 is known to be extremely flammable and able to cause explosions when its concentration reaches 5% to 15% in the air [27,28].

With reference to acid gases, researchers have shown that Nitrogen Oxides (NOx) and Sulphur Oxides (SOx) can cause nose and throat irritations, respiratory diseases (especially in asthmatic people), and heart illnesses [29]. Additionally, neurological symptoms and deficits and vascular and respiratory diseases are reported to be related to the persistent inhalation of Hydrogen Sulphide (H_2S). H_2S is also a highly flammable gas, which contributes to the typical bad odors of landfill sites [30,31].

In the case of open dumping, dust and particulate matter can also be easily released into the atmosphere [4,32]. Accordingly, humans can be subjected to inhalation or accidental dermic contact or ingestion of heavy metals, absorbed by waste and soil particles floating in the air. The effects of heavy metals on human health are different according to each compound; they usually interfere with metabolic processes and can be carcinogenic [33].

Toxic substances for humans are also found in leachate: Aniline, Arsenic, Byphenil, Cyanide, Dichloromethane, Ethylbenzene, Fluoride, Nitrogen, Phosphorous, Toluene, etc., have been listed as chemicals discovered in more than 5% of leachate samples [34]. Additionally, leachate can contain many bacteria (e.g., *Escherichia coli*, total coliforms, etc.) [34].

Harmful effects of leachate on public health are generally reported as indirect, i.e., related to environmental pollution. In fact, the lack of efficient collection and treatment systems of leachate is likely to cause the contamination of soil, surface, and/or groundwater, and, accordingly, of food reservoirs (agricultural and farm products) [35,36].

Some studies on working conditions in open dumpsites can provide further information on the hazards on public health and the environment. Scavenging operators can be subjected to injuries from sharp surfaces (including potentially contaminated surfaces), as well as poisoning from chemicals [37,38]. A study carried out by Nyathi et al. [39] revealed that most injuries for pickers in the Onderstepoort waste dumpsite were cuts on the hands and legs. Moreover, bacterial infection and related pathogenic diseases are common consequences in such places [40].

Furthermore, some fatalities in uncontrolled dumps occurred due to waste slides, which have caused major disasters worldwide [21,41]. The main causes leading to landfill slope instability are heavy rainfall that infiltrates waste, waste heterogeneity, waste with poor geotechnical features (in terms of shear strength, cohesion, and compressibility), and the lack of a waste compaction process [42,43].

Finally, another threat is waste burning, both spontaneous (due to the lack of previous waste treatment) and intentional (to obtain more space in the dumpsite). A survey on recycling workers in the Gaza Strip (Palestine) showed that 175 out of 300 people (more than 58%) had suffered burns during the last twelve months [18].

An overview of landfill mismanagement effects on public health and environment is reported in Table 1.

2.2. OHS Risk Assessment

Based on the above considerations, in landfill remediation and management activities, major risks for workers can derive from the fluxes of contaminants released by dumps; as observed by Limoli et al. [4], in such an environment, gases, leachate, and dust can be found. The presence of gases can lead operators to states of illness and even generate explosive climates. Moreover, toxic gases could be generated by waste burning, which is not unusual in landfills, as noted by Chavan et al. [44], who distinguished them into surface and sub-surface fires, where the latter burn old waste materials below the surface with disruptive effects on the biogas collection system and leachate liner.

Table 1. Effects of waste dumpsites on public health and environment.

Landfill Emissions	Main Hazards	Effects on Public Health and Environment
Landfill gas	CO_2 CH_4	nausea, vomiting, headache, loss of coordination, and high blood pressure; CH_4: coma and death due to asphyxia at very high levels
	NO_x SO_x	respiratory diseases and heart illnesses
	H_2S	neurological symptoms and deficits, vascular and respiratory diseases; extremely flammable; bad odors
Dust, particulate matter	heavy metals	Carcinogenic
Leachate	Chemicals (e.g., heavy metals, acids) and microorganisms	Contamination of soil, surface and/or groundwater, and, accordingly, of food reservoirs
Uncovered solid waste	Sharps; flammable waste; pathogens; geotechnical instability	Waste slides; open burning; illnesses; injuries; changes in biodiversity

Another aspect that should be taken into account is represented by the effects of both the anaerobic degradation of organic material and the infiltration of rain. The resulting leachate can have negative consequences for the workers both in case of direct exposure (e.g., contact with skin or ingestion) as well as in case of indirect exposure, such as the inhalation of gases and vapors [45].

Solid waste can also cause injuries due to the presence of sharp objects, while its surface can cause falls and could even collapse due to its poor geotechnical stability. Ismail et al. [42] reported that surface deformations are caused by the low level of cohesion of solid waste and its friction angles. Accordingly, risks for workers, such as falling from height and cuts, should be considered together with falling objects/materials and entrapment due to the presence of sinking areas.

Finally, it is worth noting that additional risks derive from the presence of bacteria and animals (e.g., rats and snakes) that can lead to both diseases and injuries [46,47].

Besides these specific risks, it must be noted that other hazardous situations can be found in construction sites, for example, those related to the use of machinery, hazardous substances (which are needed for field tests), and the presence of falling materials and electricity [25,48]. As previously remarked, only a few studies deal with OHS risks in these activities, underestimating the fact that landfill personnel work in direct proximity to numerous sources of danger [49].

To sum up the main risks for workers, a matrix sorted by activities and exposures is reported in Table 2: it should be noted that the indications provided are very general because a more detailed risk assessment can be carried out only when the specific working context and equipment are defined.

Table 2. Risk exposure per main activity carried out in landfills.

Activity	Hazards	OHS Risks
Topographic measures	solid waste, cutting objects, toxic gases, electricity, bacteria, and pathogens	biologic risk, fire risk, chemical risk, electric shock
Sampling	solid waste, cutting objects, toxic gases, geotechnical instability, leachate, flammable waste, machinery, bacteria, and pathogens	biologic risk, chemical risk, slipping and tripping, fire risk, risk of falling from height, risk of falling materials, risks related to machinery
Preliminary site visits	solid waste, cutting objects, toxic gases, leachate, bacteria, and pathogens, geotechnical instability	risk of falling materials, slipping and tripping, fire risk, biological risk, chemical risk
Working area set up	solid waste, cutting objects, machinery, contemporary presence of different contractors	risk of falling materials, slipping and tripping, machinery-related risks, interferential risks
Remediation activities	solid waste, cutting objects, toxic gases, leachate, bacteria and pathogens, machinery, geotechnical instability	risk of falling materials, biological risk, chemical risk, slipping and tripping, fire risk, machinery-related risks
Logistics/transportation	machinery, vehicles, contemporary presence of several workers	machinery-related risks, transportation-related risks

3. Materials and Methods

The research aimed to provide firstly a systematic analysis of accident causes in landfills and then a specific risk assessment for landfill management, based on the classifications of accidents through a data-driven approach carried out by means of cluster analysis. To achieve such a goal, national and European databases on occupational accidents were used. These tools are organized following a data mining approach: in fact, thanks to Regulation 2011/349/EU [50], data on occupational injuries have been organized at the European level through a specific model, which enables the comparison of statistics among European countries for research purposes [51,52]. As argued by Hola et al. [53], European databases report an analysis of accidents organized in a standardized manner, making the comparison of results of different investigations possible.

The use of occupational accident databases is very diffused in safety research in different sectors. To cite a few, with reference to the wood industry, Comberti et al. [52] carried out an application of self-organizing maps and K-means clustering for a sample of 1200 events. Accordingly, Lombardi et al. [25] showed the application of K-means clustering for a sample of 116 accidents to investigate electric shock in the construction sector. Molinero-Ruiz et al. [54] investigated the validity of the European Statistics on Accidents at Work (ESAW) variables' coding system to make specific risk profiling, while in the research by Jacinto and Soares [51], information on risks in the quarrying industry was derived through a data-driven approach. Similarly, Chokor et al. [55] developed a Natural Language Processing (NLP) methodology to evaluate risk profiles in the construction industry from OSHA safety inspection reports.

Actually, accident analysis is a very effective means to better understand the factors that lead to injuries, allowing engineers to bring to light recurring critical features [56]. Such an aspect was outlined by other studies, which demonstrated the benefits of investigating accidents based on databases to gain information on accidents′ causes and determinants, providing more specific protective and preventive measures [57,58]. In such a context, several studies have used cluster analysis to investigate accident reports and better categorize data emerging from statistics [59,60], pinpointing the usefulness of cluster analysis as a predictive tool in the management of safety information [25].

Consequently, this study is based on the use of the K-means cluster analysis to better categorize accidents that occurred in landfills, bringing to light the relevance of the most impactful accidents′ determinants (i.e., the accidents' variables), and their mutual relationships. More in detail, our research approach consists of two main phases:

1. The first phase concerned data collection, where information is gained from the accident databases of the Italian Workers Compensation Authority (INAIL) and organized;
2. In the second phase, a cluster analysis of a selected sample of accidents is carried out with the goal of identifying the main accident determinants and the related risks.

3.1. Data Collection

In this study the database called "Information Fluxes INAIL-Regions" was considered, as it was recognized as a valuable source of data in the scientific literature on risk assessment [52,61]. In this database, accidents are organized into vectors with alphanumeric coefficients, to avoid identifying people involved in the event (workers and employers), due to European privacy requirements. The data analyzed concerned the period 2009–2019, and the initial dataset included both moderate and serious accidents at work that occurred during this period. Previous accidents were not selected because the task classification, which was essential for identifying accidents in landfills, has only been made available by INAIL since 2008.

Hence, for each event, details are provided on accident dynamics, injured worker, employer, accident consequences, and complementary accident features, as illustrated in Table 3.

Table 3. Main features of the INAIL database.

Accident Factors	Accident Categories
Activity; contact; deviation; material agent of activity; material agent of contact; material agent of deviation; working process; workplace	Dynamics
Working task; age range; sex; nationality; level of working experience	Injured worker
INAIL compensation rate; ATECO code (i.e., the Italian classification of Economic Activities [62]); type of company; number of employees	Employer
Type of accident; type of injury; part of the body injured; lost days at work	Consequences
"In itinere" accident (yes/no); road accident; geographic accident location (region); year of the event; accident compensation	Other features

With reference to the first category (accident dynamics) it must be noted that: "Activity" stands for the working task performed by the injured worker when the event occurred; "Material Agent" of the activity is the object, material, etc., that was used by the worker while the accident occurred; "Deviation" is the accident determinant, i.e., the initial event that led to the injury. Based on this, the following definitions can be added:

- Material agent of the deviation, which represents the object, material, etc., that generated the source of injury;
- Contact, which stands for the way the injury occurred;
- Material agent of contact, which is the object, material etc. that inflicted the injury;
- Workplace is the working area where the accident occurred;
- Working process is the company process which the performed activity is part of.

For the purposes of this study, a unique Accident Code (AC) was assigned to each event, using the ESAW classification variables as data filters. Then, the Infor.MO database by INAIL [63] was considered in order to define the accidents' determinants. This database reports serious and fatal accidents only, providing detailed information on the energy exchange and descriptors of each event [64]. According to the Infor.MO model, accidents' determinants are defined as factors increasing the risk of incidents and can be related to:

- Activity of the injured (D1), i.e., the whole of the irregular actions performed by the injured person during the incident;
- Activities of third parties (D2), i.e., inappropriate actions performed by other workers or people present in the incident area;
- Working materials (D3);
- Work equipment (D4), i.e., equipment of any type (or part of it) which caused the accident due to some critical issues, such as presence of dangerous elements, removal of protections, tampering with protections, etc.;
- Working environment (D5): this category includes the absence of barriers, protections, parapets, armor, and inadequate signage; the absence of safe routes; the presence of bulky, dangerous elements; the presence of electrical wires and electrical line; the absence of suitable lighting; the presence of gases, vapors or liquids;
- Working clothes and personal protective equipment (PPE) (D6).
- It must be noted that for the study's purposes, the Infor.MO database was only used to define the accidents' determinants, while the analyzed sample of accidents was derived from another database, called "Information Fluxes INAIL-Regions".

3.2. Cluster Analysis

Cluster analysis is a widespread statistical tool used for classification: it allows analysts to group together items whose patterns of scores on certain variables are similar [65]. In particular, the K-means cluster analysis was used to identify homogenous groups of accident cases in landfill activities, adopting the procedure proposed by Punj and Stewart [66]. The application procedure can be summarized as follows:

1. Extraction of data related to a specific type of accident (i.e., accidents which occurred during working activities in landfills) from the database.
2. Identification of the descriptive variables: the information available in the accident reports is codified into n variables and the related k descriptors according to the general model of cluster classification; in this case 4 descriptors were identified (i.e., the accidents' determinants D1, D2, D3, and D4).
3. Definition of the matrix of descriptors based on the accident determinants D1–D4: the n accident variables are converted into an algebraic vector through the Boolean coordinates. The Boolean values in the matrix are "1" if the accident is affected by a certain variable or "0" if the accident is not affected by that variable, in line with [25]. In other words, such categorical information is transformed into dichotomous variables allowing us to define a set of algebraic vectors.
4. Clustering: the set of vectors is partitioned into k ($\leq$ n) sets, which represent the clusters (accidents' aggregation cluster selected on the basis of the membership criterion—minimum Euclidean distance from the centroid): each vector is assigned to a certain cluster based on the criterion of "proximity" to the initial centroid. This is an iterative aggregation process that starts considering k = 4 (i.e., the number of variables). The significance of the results is performed through the Analysis of Variance (ANOVA) test [67] and if the results related to k = 4 are not significant, the aggregation is performed again for k = 3, and so on.

More in detail, the whole process consisted of the following activities:

1. Identification of the first accident data sample from INAIL database (period 2008–2019), using as data filters the following criteria:
    - INAIL compensation code related to "Cleaning up and urban waste cleaning" (code 0420);
    - ESAW variables "workplace" and "working process" related, respectively, to: "industrial sites" (group code 010) and other working places (group code 999); "other activities, complementary to groups 10, 20, 30, 40" (group code 050);
    - Economic sector of the company (i.e., by means of the ATECO codes) related to solid waste management or remediation activities.
2. Screening of data (pre-elaboration) through the selection of the following elements:
    - Accident occurred in the working place (not "in itinere");
    - INAIL compensation rate related to "Urban cleaning up, landfill and incinerators management" (code 0421);
    - ATECO codes related to solid waste treatment and disposal (see Table A1);
    - Working tasks, likely to be performed in landfills as indicated in the database (see Table A2).

Then, a further screening was carried out to exclude those accidents for which sufficient information related to the accident dynamics was not provided. This allowed us to carry out an analysis of the accident dynamics using the factors reported in Table 3. The output of this activity is represented by the definition of the so-called "matrix of descriptors": the complete matrix is available in Table S1, in the Supplementary Materials, while an extract is shown in Table 4. In this matrix the accidents' variables were transformed into algebraic vectors, which allow us to estimate the influence of the accident determinants on each event through Boolean coefficients [25]. More in detail, the elaboration of the "matrix of descriptors" took into account only the evaluation of the following determinants: Activity of the injured (D1), Materials (D3), Work equipment (D4), Environment (D5).

Table 4. Matrix of descriptors (excerpt).

Accident Code (AC)	Worker's Activity D1	Materials D3	Work Equipment D4	Environment D5
AC_01	1	1	0	0
AC_02	1	0	1	0
AC_03	1	0	1	0

Cluster analysis was carried out through the software IBM SPSS Statistics® vers. 28 [68]. Such a software has been used in different research works for data mining applications and, in particular, extracting data patterns [69,70]. In Table 5, the criteria used for the cluster analysis are listed, as suggested by [68].

Table 5. Cluster analysis criteria.

Hypotheses	Description
Algorithm	K-means, combined with ANOVA tests
Variables	Determinants: Activity of the injured (D1), Materials (D2), Working equipment (D3), Environment (D4). As suggested by IBM, determinants D1–D4 were considered "categorical variables" and, more in detail, "nominal variables"
Max number of clusters	Equal to the number of determinants (D = 4)
Criteria	Minimum Euclidean Distance from the centroids

4. Results

The selection of the first accident sample was carried out by an INAIL officer, due to privacy reasons. Accordingly, all data used respected privacy and ethics regulations: no sensitive or special category data were used in the analysis. Hence, all the study procedures are in line with the Declaration of Helsinki and the Sapienza University of Rome Ethical Code. The data filtering process is schematized in Figure 1.

Data were organized according to:

- The geographic location of accidents, through five classes stated by INAIL (northeast, northwest, middle, southern Italy, and islands);
- ESAW variables "working place" and "working process". However, the attention was focused only on files where the "working place" factor (i.e., landfill) was selected as the leading one to profile specific risks.

The output of this activity led to the selection of 636 accidents based on the geographical area, organized as follows:

- 56 accidents in central Italy (8.81%);
- 108 accidents in Italian islands (16.98%);
- 89 accidents in the northeast of Italy (13.99%);
- 333 accidents in the northwest of Italy (52.36%);
- 50 accidents in southern Italy (7.86%).

Finally, a sample of 78 accidents was selected: among them, only 8 accidents involved a person whose working task was related to landfill operations management (code 1132). Then, the analysis of the accident dynamics allowed us to identify 40 accident variables influencing the accident factors. In the following tables accident variables are reported: namely, Table 6 indicates the variables related to the material agent and physical activity; Table 7 those related to contact and deviations; and Table 8 those involving working process and workplace.

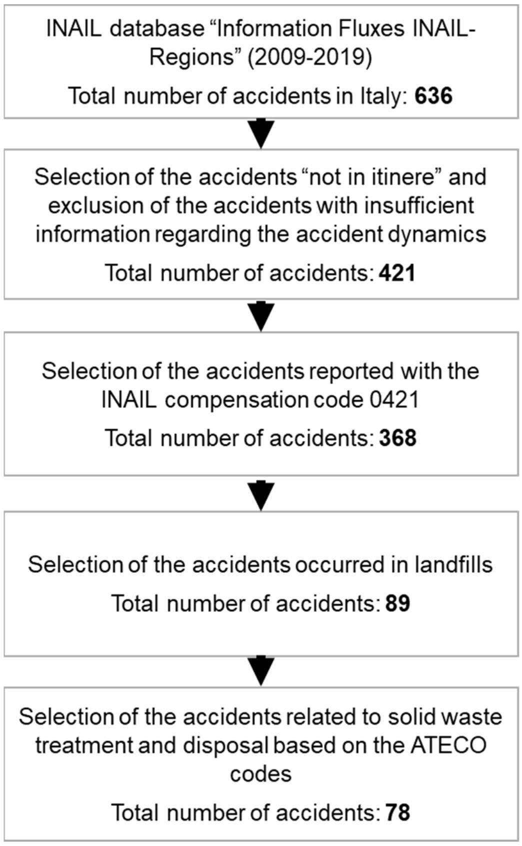

Figure 1. Scheme of the data filtering process.

Table 6. Variables related to "Material agent" factors and physical activity.

Material Agent		**Physical Activity**	
V_1	Piece of Construction (i.e., stairs, floor, etc.)	V_{10}	Operations on machinery
V_2	Materials	V_{11}	Objects manipulation
V_3	Utensils	V_{12}	Working with utensils
V_4	Machinery	V_{13}	Manual transport of items
V_5	Means of transport	V_{14}	Body movements
V_6	Waste	V_{15}	Other activities
V_7	No agent		
V_8	Surfaces		
V_9	Other material agent		

Table 7. Variables related to "Contact" and "Deviation" factors.

Contact		**Deviation**	
V_{16}	Contact with flame/thermic source	V_{22}	Material loss
V_{17}	Crushing	V_{23}	Breaking of material
V_{18}	Hit by an external item	V_{24}	Control loss
V_{19}	Contact with sharp or abrasive materials	V_{25}	Falling
V_{20}	Physical effort	V_{26}	Body movements
V_{21}	Other	V_{27}	Other

Table 8. Variables related to "Working Process" and "Workplace" factors.

Working Process		Workplace	
V_{28}	Treatment/transformation	V_{37}	Industrial site
V_{29}	Storage	V_{38}	Maintenance/production area
V_{30}	Building works	V_{39}	Storage area
V_{31}	Services	V_{40}	Other site
V_{32}	Maintenance		
V_{33}	Cleaning up		
V_{34}	Waste management		
V_{35}	Circulation (with/without means of transport)		
V_{36}	Other process		

Based on this, the relationships among these variables and accident factors were defined, as illustrated in Figure 2. It has to be underlined that these relationships were determined through the analysis of the accidents' reports, which are codified based on the ESAW rules.

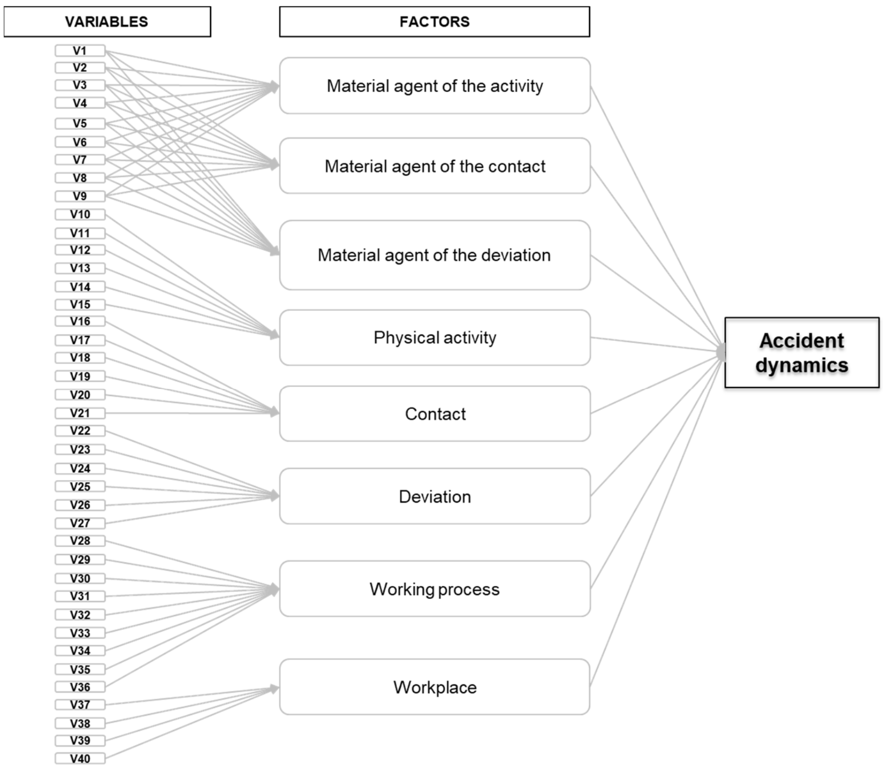

Figure 2. Relationship among accident variables and factors.

Filtering the sample extracted by the INAIL database, it emerged that most accidents are related to the use of work equipment in landfill management activities and the following hazardous situations could be specifically depicted for operators in MSW landfills:

- AC_23 and AC_24: damages to the musculoskeletal system due to picking up a heavy piece of equipment up (such as a garbage can, a large container, etc.);
- AC_35: slipping due to the physical effort related to picking up a heavy piece of equipment;
- AC_66: contact with an abrasive/sharp tool due to the loss of its control.

Similarly, the following risks were identified for operators at municipal solid waste (MSW) landfills: slipping, manual handling, and contact with sharp or abrasive items. To sum up, 36 accidents related to equipment misuse were analyzed, as reported in Table 9. The determination of these risks was carried out in collaboration with a group of experts through the analysis of the accident scenarios described in the accident reports.

Table 9. Main risks due to the work equipment misuse.

Working Tasks [INAIL Classification]	Number of Accidents	Main Risks
Driver of the excavator	22	Slipping, handling of loads, falling from heights, falling materials, road crushes, being run over
Maintenance operator	6	Falling, crushing, contact with sharp or abrasive surfaces
Electrician for vehicles	2	Contact with sharp or abrasive surfaces
Operations management worker	1	Contact with sharp or abrasive surfaces
Driver of waste compactors	1	Physical effort
Operator at MSW landfills	4	Slipping, manual handling of loads, and contact with sharp or abrasive surfaces

Then, a K-means cluster analysis was carried out considering the selected 78 accidents by means of the IBM SPSS Statistics software [68], and several iterations were carried out and verified by means of ANOVA tests [67]. In Table 10, the four-cluster solution with centroids is reported, where values in red indicate the most relevant variables for each cluster.

Table 10. Results of the four-cluster solution.

Variables (Determinants)	Cluster			
	1	2	3	4
Worker Activity	0.56	0.81	0.00	1.00
Materials	0.67	0.00	0.07	0.00
Work equipment misuse	0.00	0.72	0.14	0.00
Environment	0.00	0.00	1.00	1.00
Clustering validity value				
cluster 1: 9	cluster 2: 47	cluster 3: 14	cluster 4: 8	
Valid values: 78	Missing values: 0			

The results of this analysis revealed that all four clusters are partially disjointed since they are polarized on different variables: as in Table 8, the centroids of the four clusters show a different level of correlation among the determinants. More in detail, Cluster 1 is polarized on "worker activity" and "materials", Cluster 2 is polarized on "worker activity" and "work equipment misuse", Cluster 3 is polarized on "environment", and Cluster 4 on "worker activity" and "environment". Thus, with regard to the accident determinants, the "worker activity" and "environment" are the most important variables, as illustrated in Figure 3. This elaboration of the results is in line with Schreiber and Pekarik [71], who fostered the use of graphic representations to show the relevance of the cluster determinants.

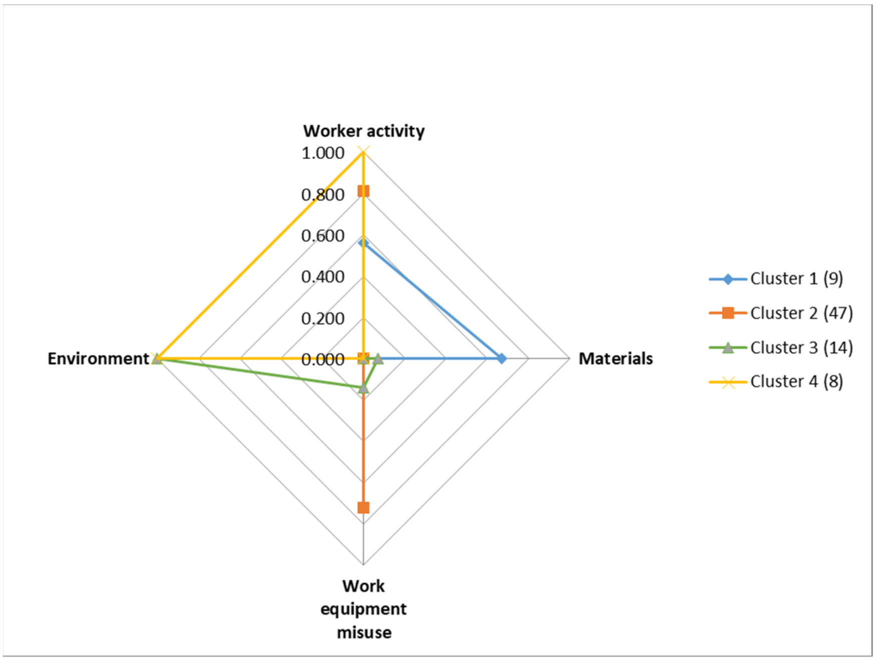

Figure 3. Result of the four-cluster solution.

Then, further elaborations were carried out analyzing both three-cluster and two-cluster solutions to better screen the relevance of the determinants. As shown in Figure 4, which reports the three-cluster solution, the importance of the misuse of work equipment emerged, along with worker activity.

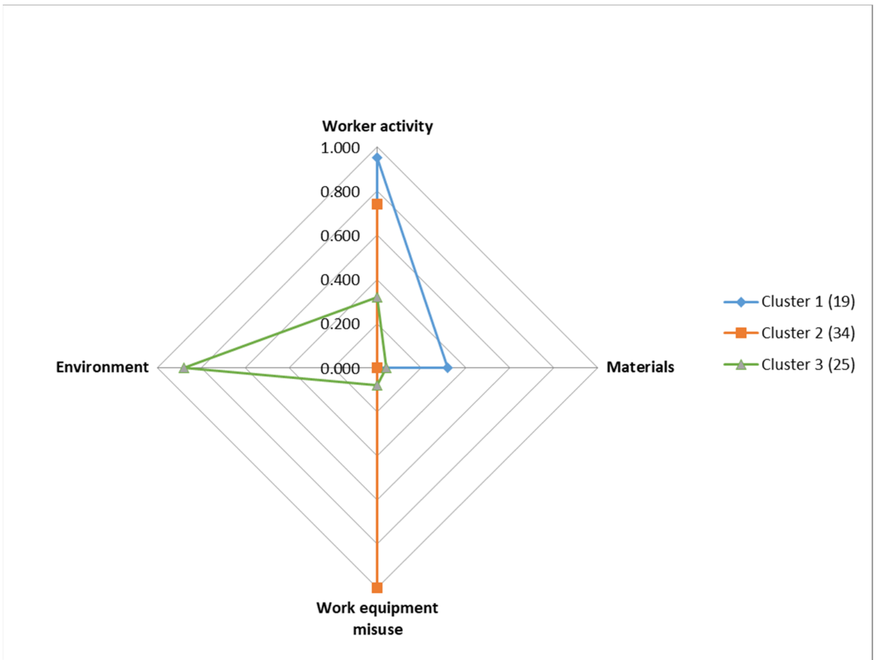

Figure 4. Result of the three-cluster solution.

5. Discussion

Overall, the results achieved provide a holistic solution to risk analysis in landfills, according to the dimensions of safety climate (work environment, organization, and individual behavior) [72]. In fact, the proposed analysis can support engineers in considering the multidimensional nature of safety. In the landfill working context, safety managers are required to evaluate several factors, such as the presence of toxic substances (e.g., solid waste, leachate, gases, etc.), the lack of complete knowledge of the entity and type of pollution, the presence of different types of work equipment and their misuse, etc. Accordingly, at the general level, an overview of risk management in landfills was elaborated, bringing to light the relationships among main injury causes and these different factors. Indeed, to provide a systematic accident assessment tool for safety professionals, a checklist (Failure Matrix) was implemented (Table 11). Such a tool can allow engineers to analyze the causes of an accident, distinguishing omissions and deviations in the work procedure, where a deviation involves an incorrect execution of the work activity that can lead to an accident, while an omission directly leads to an operational error.

Table 11. Checklist of the main injury causes and factors in landfill activities.

Ambit	Injury/Disease Factors	Deviation	Omission
System management	Lack of training (provided)	☐	☐
	Lack of barriers	☐	☐
	Lack of planning of the machinery circulations	☐	☐
	Lack of a system for collecting rainwater	☐	☐
	Lack of a system for collecting leachate	☐	☐
	Lack of a system for collecting gases	☐	☐
	Lack of capping	☐	☐
Machinery	Crush/hit	☐	☐
	Vibrations	☐	☐
	Noise	☐	☐
	Hot parts	☐	☐
	Electricity	☐	☐
	Lack of machinery protection systems (ROPS, seatbelts)	☐	☐
	Lack of filters against dust, gases, and vapors	☐	☐
Worker	Misuse of personal protective equipment (PPE)	☐	☐
	Lack of training (copy)	☐	☐
	Errors	☐	☐
	Stress, fatigue	☐	☐
Materials (waste)	Dust	☐	☐
	Sharp surfaces, edges	☐	☐
	Explosive materials	☐	☐
	Flammable materials	☐	☐
	Lack of stability	☐	☐
	Vapors, gases	☐	☐
	Toxic materials (e.g., asbestos)	☐	☐
Environment	Toxic gases and vapors	☐	☐
	Floods and hydro-geo risks	☐	☐
	Lack of stability	☐	☐
	Extreme temperatures (hot, cold)	☐	☐

In such a scheme, it must be noted that when referring to the operator, "errors" stands for those improper behaviors that are usually counted as human errors, such as action, checking, planning, and selection errors [73,74]. On the one hand, this aspect is certainly related to the lack of information on the landfill features, justifying the workers' inappropriate behavior to some extent. On the other, it must be stressed that the great variability of the work environment affects the safety conditions of landfill activities greatly, as demonstrated by the cluster analysis output. Hence, additional effort should be made in both workers' training and safety planning. This finding is consistent with the research of Khanal et al. [75], who investigated the awareness and proper usage of PPE (personal protective equipment) among waste workers at the Sisdol landfill site.

When referring to machinery, the work equipment used in landfills is primarily an excavator and/or a compactor. Most hazardous situations are related to the lack of machinery protective systems, such as dust filters and roll-over protective structures (ROPS). However, the lack of an established viability as well as the poor training of the equipment users must also be underlined. These results are very similar to those emerging from the safety research on both agriculture and construction machinery drivers (e.g., [48,76,77]), since the features of work equipment are very similar, and the uncertainties related to the work environment can be considered comparable. Nevertheless, unlike the latter sectors, in landfill work, the materials (i.e., the waste) have to be added as a cause of accidents and diseases: in particular, the presence of very hazardous materials represents one of the most dangerous issues that must be considered [78].

As far as the output of the analysis of accident dynamics is concerned, a similar situation can be found, where the majority of accidents are those related to the excavators' drivers, which account for more than 61% of the relevance when compared with other activities carried out in the landfill, as shown in Figure 5.

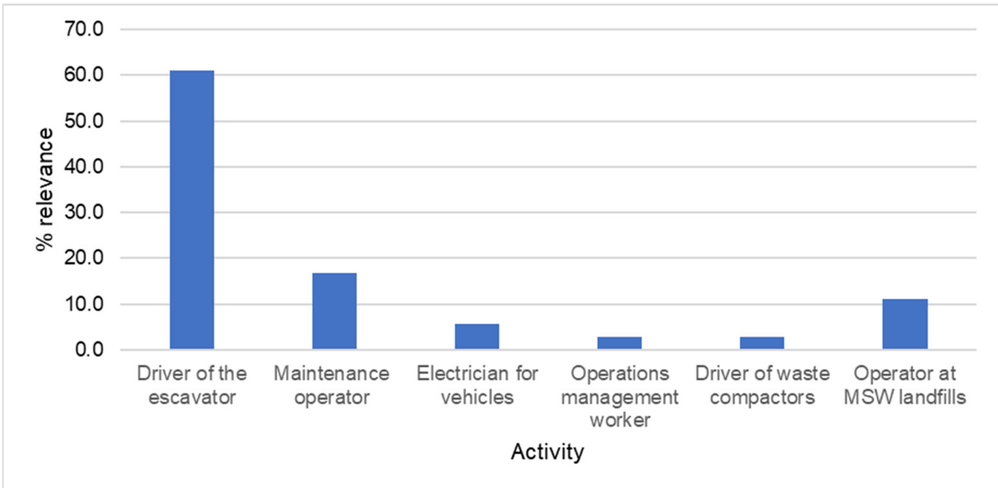

Figure 5. Relevance of work activities in landfill accidents (in percentage).

The relevance of all the activities related to the machinery use and management in the occurrence of accidents is marked by the fact that the vehicle's maintenance activities are also relevant. Such a finding is line with the research output by Rudakov et al. [79], who developed a risk chart for excavator operators in the mining industry in which the hazardousness of maintenance activities is stressed. These results are confirmed by the outcomes of the cluster analysis, according to which "environment", "work activity", and "work equipment misuse" are shown to cause most accidents.

At a more general level, it should be noted that the proposed approach allowed us to translate qualitative information on accidents into quantitative data (a set of Boolean vectors), synthesizing information from the accident databases and bringing to light aspects that affected the occurrence of the accident. Currently, accident reports contain qualitative information, which was transformed into Boolean vectors allowing the analyst to better gain information on the accident even when the report is not filled properly. In detail, each accident corresponds to a vector where (as specified earlier) "1" means that the accident is affected by a certain variable, while "0" means that the accident is not affected by a certain variable. This transformation was carried out by the authors through several meetings that led us to fill in the matrix of descriptors (MoD), which represents the input for the cluster analysis. Accordingly, detailed information on occupational risks related to landfill management activities are provided, shedding light on the main factors that can lead to an accident and thus defining specific risk profiles for the workers. This can be beneficial especially at the organizational level, where remediation or management activities are planned and risk assessment models are needed [80,81].

In summary, the output of this analysis can be considered an attempt to provide first practical addresses to improve the safety management of landfill work activities, in the context of safety management of both industrial and municipal dumpsites, where the lack of information increases the risk levels, as outlined by [82,83]. This aspect, consistent with research in the construction sector [84,85], brings forward the need for implementing a safety management approach to improve the safety level of landfill activities.

Besides these positive outcomes, the study's limitations must also be pointed out, which mostly comprise the limited number of the cases analyzed. We selected the period 2008–2019 because INAIL introduced the working task classification in 2008. Hence, only accidents which occurred during the period 2009–2019 were included. Moreover, in this sample, the differentiation among minor injuries and serious or fatal accidents was not considered. This aspect limited the granularity of the analysis.

Furthermore, the results are essentially limited by the use of the ESAW model to filter data. In fact, on the one hand, such a classification system solved privacy issues in data analysis, providing comparable statistics at the European level; on the other hand, this model limits risk profiling related to specific workplaces. Similarly, the INAIL classification system also provides insufficient details on accidents, reducing the possibility to carry out a thorough analysis.

Additionally, risk profiling and management proposed in such research work do not take into account those hazards requiring specific procedures and mitigation measures. For this reason, risks related to asbestos or radiation were excluded from any analysis, even though workers could face them during their activities [86,87]. Hence, further research is needed to include these issues in the risk assessment of landfill activities.

Finally, it must be noted that the study is focused on the analysis of occupational injuries only. In the official databases that take into account occupational illnesses, it was not possible to select those related to workers specifically involved in landfill activities.

6. Conclusions

Waste landfills represent a significant concern worldwide due to the extensive environmental pollution and the related risks to human health and environment. However, while the extant literature largely investigates these issues, occupational risks to which the personnel working in these sites is exposed to are scarcely addressed. The current study is based on the first outcomes of a research project promoted by the Italian Compensation Authority (INAIL), which is focused on the analysis of the official accident databases to provide a risk assessment framework capable of defining specific risk profiles. The analysis carried out has shown that the main risks are related to the work environment and the misuse of work equipment, underlining the need to provide workers with specific information and training on these aspects. Additionally, the lack of specific occupational risk assessment when planning remediation activities also emerged. However, these findings can be considered only preliminary outcomes, as further research is needed to better address the risk profiles that emerged, combining them with specific preventive and protective measures. Hence, this article should be considered the result of an initial stage of implementation, and researchers and practitioners are invited to contribute to its further development.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/safety9010003/s1, Table S1: matrix of descriptors.

Author Contributions: Conceptualization, M.L., M.F., S.B. and Q.N.; methodology, M.L., M.F. and F.M.; software, M.L., F.M. and D.B.; writing—review and editing, M.L., D.B., M.F. and F.M.; validation, M.L., M.F., D.B., F.M. and S.B. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The article concerned an analysis of occupational accident data provided by the Italian Compensation Authority (INAIL) with respect to all privacy and ethics regulations. Accordingly, no sensitive or special category data were used in the manuscript. Hence, the study is exempt from requiring ethics approval. All the study procedures are in line with the Declaration of Helsinki and the Sapienza University of Rome Ethical Code (Code no. D.R._1636_CodiceEticoAteneo_23-05-2012).

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Appendix A

Tables A1 and A2 report the codes used in the INAIL accident dataset.

Table A1. ESAW, ATECO, and INAIL compensation codes used as data filters.

INAIL Compensation Codes	ESAW Codes	ATECO Codes
0420: Cleaning up and urban waste cleaning 0421: Urban cleaning up, landfill and incinerators management	Workplace 010: industrial sites 999: other workplaces not mentioned in ESAW classification Working process 050: Other activities, complementary to groups 10, 20, 30, 40	E 38.21.09 urban solid waste treatment and disposal E 38.22.00 hazardous solid waste treatment and disposal E 39.00.09 remediation and other solid waste management activities

Table A2. INAIL working tasks in landfills.

INAIL Working Tasks Code	Description
1132	Operator at urban solid waste landfills
133	Driver
381	Electrician for vehicles
384	Excavator operator
595	Warehouseman
602	Maintenance operator
702	Guardian
741	Light-wheel mechanic
797	Operator at press brakes
1094	Driver of waste compactors
1230	Operator at pump area
1321	Operations management worker

References

1. European Commission (EC). Circular Economy Action Plan. Available online: https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en (accessed on 2 September 2022).
2. Kaza, S.; Yao, L.; Bhada-Tata, P.; Van Woerden, F. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*; World Bank Publications: Washington, DC, USA, 2018; ISBN 9781464813290.
3. NSW—Environmental Protection Authority (EPA). Illegal Dumping Research Report. 2015. Available online: https://www.epa.nsw.gov.au/~{}/media/EPA/Corporate%20Site/resources/illegaldumping/150481-illegal-dumping-report.ashx (accessed on 2 September 2022).
4. Limoli, A.; Garzia, E.; De Pretto, A.; De Muri, C. Illegal landfill in Italy (EU)—A multidisciplinary approach. *Environ. Forensics* **2019**, *20*, 26–38. [CrossRef]
5. Mazza, A.; Piscitelli, P.; Neglia, C.; Rosa, G.D.; Iannuzzi, L. Illegal dumping of toxic waste and its effect on human health in Campania, Italy. *Int. J. Environ. Res. Public Health* **2015**, *12*, 6818–6831. [CrossRef] [PubMed]
6. Triassi, M.; Alfano, R.; Illario, M.; Nardone, A.; Caporale, O.; Montuori, P. Environmental pollution from illegal waste disposal and health effects: A review on the "triangle of death". *Int. J. Environ. Res. Public Health* **2015**, *12*, 1216–1236. [CrossRef] [PubMed]
7. Njoku, P.O.; Edokpayi, J.N.; Odiyo, J.O. Health and environmental risks of residents living close to a landfill: A case study of thohoyandou landfill, Limpopo province, South Africa. *Int. J. Environ. Res. Public Health* **2019**, *16*, 2125. [CrossRef]
8. Fazzo, L.; De Santis, M.; Beccaloni, E.; Scaini, F.; Iavarone, I.; Comba, P.; Airoma, D. A Geographic Information System-Based Indicator of Waste Risk to Investigate the Health Impact of Landfills and Uncontrolled Dumping Sites. *Int. J. Environ. Res. Public Health* **2020**, *17*, 5789. [CrossRef] [PubMed]
9. Visvanathan, C.; Tränkler, J.; Kuruparan, P.; Basnayake, B.F.A.; Chiemchaisri, C.; Kurian, J.; Gonming, Z. Asian Regional Research Programme on Sustainable Solid Waste Landfill Management in Asia. In Proceedings of the Sardinia 2005, Tenth International Waste Management and Landfill Symposium, Cagliari, Italy, 3–7 October 2005.
10. Hidalgo, D.; López, F.; Corona, F.; Martín-Marroquín, J.M. A novel initiative to counteract illegal dumping in rural areas of Valladolid Province (Spain). *Environ. Sci. Pollut. Res.* **2019**, *26*, 35317–35324. [CrossRef] [PubMed]
11. Extraordinary Commissioner for the Remediation of Illegal Italian Landfills. Available online: http://www.commissariobonificadiscariche.governo.it/it/ (accessed on 28 October 2022).
12. EUR-Lex. European Parliament and Council Regulation 1013/2006. *Off. J. Eur. Union* **2006**, *190*, 1–98. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32006R1013 (accessed on 28 October 2022).
13. EUR-Lex. European Parliament and Council Directive 2008/99/EC. *Off. J. Eur. Union* **2008**, *328*, 28–37. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0099 (accessed on 28 October 2022).
14. EUR-Lex. European Parliament and Council Directive 2018/850/EU Amending Directive 1999/31/EC on the Landfill of Waste. *Off. J. Eur. Union* **2018**. Available online: https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=celex:32018L0850 (accessed on 28 October 2022).
15. Fujikura, M. Japan's Efforts Against the Illegal Dumping of Industrial Waste. *Environ. Policy Gov.* **2011**, *21*, 325–337. [CrossRef]
16. Heng, L.L. The judiciary and and environmental governance in Singapore. *J. Court Innov.* **2010**, *3*, 133–155.
17. NSW—Environmental Protection Authority (EPA). Illegal Dumping Prevention and Clean Up. 2011. Available online: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/illegaldumping/110002-prevention-cleanup.pdf (accessed on 28 October 2022).
18. Al-Khatib, I.A.; Al-Sari, M.I.; Kontogianni, S. Assessment of Occupational Health and Safety among Scavengers in Gaza Strip, Palestine. *J. Environ. Public Health* **2020**, *2020*, 3780431. [CrossRef] [PubMed]
19. Vaverková, M.D. Landfill impacts on the environment—Review. *Geosciences* **2019**, *9*, 431. [CrossRef]
20. Senior, K.; Mazza, A. Italian "Triangle of death" linked to waste crisis. *Lancet Oncol.* **2004**, *5*, 525–527. [CrossRef]
21. Zhan, L.T.; Zhang, Z.; Chen, Y.M.; Chen, R.; Zhang, S.; Liu, J.; Li, A.G. The 2015 Shenzhen catastrophic landslide in a construction waste dump: Reconstitution of dump structure and failure mechanisms via geotechnical investigations. *Eng. Geol.* **2018**, *238*, 15–26. [CrossRef]
22. Lombardi, M.; Napoleoni, Q.; Mauro, F.; Fargnoli, M.; Berardi, S. Safety Management of the Characterization Activities of Illegal Dumpsites. In Proceedings of the 4th European International Conference on Industrial Engineering and Operations Management, IEOM 2021, Rome, Italy, 2–5 August 2021; IEOM Society: Southfield, MI, USA, 2021; pp. 126–137.
23. United Nations Environmental Programme (UNEP). Closing of an Open Dumpsite and Shifting from Open Dumping to Controlled Dumping and to Sanitary Landfilling. Training Modules. 2005. Available online: https://www.unep.org/resources/report/close-open-dumpsite-and-shifting-open-dumping-controlled-dumping-and-sanitary-land (accessed on 28 October 2022).
24. Burger, J.; Gochfeld, M. Health Risks to Ecological Workers on Contaminated Sites-the Department of Energy as a Case Study. *J. Community Med. Health Educ.* **2016**, *6*, 427. [CrossRef]
25. Lombardi, M.; Fargnoli, M.; Parise, G. Risk Profiling from the European Statistics on Accidents at Work (ESAW) Accidents′ Databases: A Case Study in Construction Sites. *Int. J. Environ. Res. Public Health* **2019**, *16*, 4748. [CrossRef]
26. Agency for Toxic Substances and Disease Registry (ATSDR). Landfill Gas Basics (Chapter 2). In *Landfill Gas Primer: An Overview for Environmental Health Professionals*; ATSDR: Washington, DC, USA, 2008. Available online: https://www.atsdr.cdc.gov/hac/landfill/html/ch2.html (accessed on 28 October 2022).

27. Nwachukwu, A.N.; Ephraim, B.E. Temperature Influence on the Variability and Emission of CH_4 and CO_2 from a Former Manchester Landfill. *Pak. J. Anal. Environ. Chem.* **2022**, *23*, 109–117. [CrossRef]
28. Duncan, I.J. Does methane pose significant health and public safety hazards?—A review. Methane: Health and Public Safety Hazards. *Environ. Geosci.* **2015**, *22*, 85–96. [CrossRef]
29. Boningari, T.; Smirniotis, P.G. Impact of nitrogen oxides on the environment and human health: Mn-based materials for the NOx abatement. *Curr. Opin. Chem. Eng.* **2016**, *13*, 133–141. [CrossRef]
30. Li, L.; Moore, P.K. Putative biological roles of hydrogen sulfide in health and disease: A breath of not so fresh air? *Trends Pharmacol. Sci.* **2008**, *29*, 84–90. [CrossRef] [PubMed]
31. Lewis, R.J.; Copley, G.B. Chronic low-level hydrogen sulfide exposure and potential effects on human health: A review of the epidemiological evidence. *Crit. Rev. Toxicol.* **2015**, *45*, 93–123. [CrossRef] [PubMed]
32. United Nations Environment Programme (UNEP). Training Module: Closing an Open Dumpsite and Shifting from Open Dumping to Controlled Dumping and to Sanitary Land Filling. 2005. Available online: https://wedocs.unep.org/handle/20.500.11822/8444;jsessionid=E25B8C02034587C1988C23AEAE7784B4 (accessed on 28 October 2022).
33. Jaishankar, M.; Tseten, T.; Anbalagan, N.; Mathew, B.B.; Beeregowda, K.N. Toxicity, mechanism and health effects of some heavy metals. *Interdiscip. Toxicol.* **2014**, *7*, 60–72. [CrossRef] [PubMed]
34. Grisey, E.; Belle, E.; Dat, J.; Mudry, J.; Aleya, L. Survival of pathogenic and indicator organisms in groundwater and landfill leachate through coupling bacterial enumeration with tracer tests. *Desalination* **2010**, *261*, 162–168. [CrossRef]
35. Davoli, E.; Fattore, E.; Paiano, V.; Colombo, A.; Palmiotto, M.; Rossi, A.N.; Il Grande, M.; Fanelli, R. Waste management health risk assessment: A case study of a solid waste landfill in South Italy. *Waste Manag.* **2010**, *30*, 1608–1613. [CrossRef]
36. Vaccari, M.; Vinti, G.; Tudor, T. An analysis of the risk posed by leachate from dumpsites in developing countries. *Environments* **2018**, *5*, 99. [CrossRef]
37. Patwary, M.A.; O'Hare, W.T.; Sarker, M.H. An illicit economy: Scavenging and recycling of medical waste. *J. Environ. Manag.* **2011**, *92*, 2900–2906. [CrossRef]
38. Thirarattanasunthon, P.; Siriwong, W.; Robson, M.G.; Borjan, M.M. Health risk reduction behaviors model for scavengers exposed to solid waste in municipal dump sites in Nakhon Ratchasima Province, Thailand. *Risk Manag. Healthc. Policy* **2012**, *5*, 97–104. [CrossRef]
39. Nyathi, S.; Olowoyo, J.O.; Oludare, A. Perception of Scavengers and Occupational Health Hazards Associated with Scavenging from a Waste Dumpsite in Pretoria, South Africa. *J. Environ. Public Health* **2018**, *2018*, 9458156. [CrossRef]
40. Wachukwu, C.K.; Mbata, C.A.; Nyenke, C.U. The health profile and impact assessment of waste scavangers (Rag pickers) in Port Harcourt, Nigeria. *J. Appl. Sci.* **2010**, *10*, 1968–1972. [CrossRef]
41. Lavigne, F.; Wassmer, P.; Gomez, C.; Davies, T.A.; Sri Hadmoko, D.; Iskandarsyah, T.Y.W.M.; Gaillard, J.; Fort, M.; Texier, P.; Boun Heng, M.; et al. The 21 February 2005, catastrophic waste avalanche at Leuwigajah dumpsite, Bandung, Indonesia. *Geoenviron. Disasters* **2014**, *1*, 10. [CrossRef]
42. Ismail, S.; Taib, A.M.; Rahman, N.A.; Hasbollah, D.Z.A.; Ramli, A.B. Slope stability of landfill with waste degradation. mboxemphInt. J. Innov. Technol. Explor. Eng. **2019**, *9*, 393–398. [CrossRef]
43. Reddy, K.R.; Hettiarachchi, H.; Gangathulasi, J.; Bogner, J.E.; Lagier, T. Geotechnical properties of synthetic municipal solid waste. *Int. J. Geotech. Eng.* **2009**, *3*, 429–438. [CrossRef]
44. Chavan, D.; Lakshmikanthan, P.; Mondal, P.; Kumar, S.; Kumar, R. Determination of ignition temperature of municipal solid waste for understanding surface and sub-surface landfill fire. *Waste Manag.* **2019**, *97*, 123–130. [CrossRef] [PubMed]
45. Polvara, E.; Essna ashari, B.; Capelli, L.; Sironi, S. Evaluation of Occupational Exposure Risk for Employees Working in Dynamic Olfactometry: Focus On Non-Carcinogenic Effects Correlated with Exposure to Landfill Emissions. *Atmosphere* **2021**, *12*, 1325. [CrossRef]
46. Krystosik, A.; Njoroge, G.; Odhiambo, L.; Forsyth, J.E.; Mutuku, F.; LaBeaud, A.D. Solid wastes provide breeding sites, burrows, and food for biological disease vectors, and urban zoonotic reservoirs: A call to action for solutions-based research. mboxemphFront. Public Health **2020**, *7*, 405. [CrossRef]
47. Vinti, G.; Bauza, V.; Clasen, T.; Tudor, T.; Zurbrügg, C.; Vaccari, M. Health risks of solid waste management practices in rural Ghana: A semi-quantitative approach toward a solid waste safety plan. *Environ. Res.* **2023**, *216 Pt 3*, 114728. [CrossRef]
48. Haber, N.; Fargnoli, M.; Lombardi, M. A fuzzy-QFD approach for the enhancement of work equipment safety: A case study in the agriculture sector. *Int. J. Reliab. Saf.* **2018**, *12*, 306. [CrossRef]
49. Wilhelm, V. Occupational Safety at Landfills. In *Contaminated Soil'90*; Arendt, F., Hinsenveld, M., Van Den Brink, W.J., Eds.; Springer: Dordrecht, The Netherlands, 1990.
50. European Parliament and Council Regulation n. 349/2011/UE. *Off. J. Eur. Union* **2011**, *97*, 3–8. Available online: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32011R0349 (accessed on 28 October 2022).
51. Jacinto, C.; Soares, C.G. The added value of the new ESAW/Eurostat variables in accident analysis in the mining and quarrying industry. *J. Saf. Res.* **2008**, *39*, 631–644. [CrossRef]
52. Comberti, L.; Demichela, M.; Baldissone, G.; Fois, G.; Luzzi, R. Large occupational accidents data analysis with a coupled unsupervised algorithm: The S.O.M. k-means method. An application to the wood industry. *Safety* **2018**, *4*, 51. [CrossRef]
53. Hoła, A.; Sawicki, M.; Szóstak, M. Methodology of classifying the causes of occupational accidents involving construction scaffolding using Pareto-Lorenz analysis. *Appl. Sci.* **2018**, *8*, 48. [CrossRef]

54. Molinero-Ruiz, E.; Pitarque, S.; Fondevila-McDonald, Y.; Martin-Bustamante, M. How reliable and valid is the coding of the variables of the European Statistics on Accidents at Work (ESAW)? A need to improve preventive public policies. *Saf. Sci.* **2015**, *79*, 72–79. [CrossRef]
55. Chokor, A.; Naganathan, H.; Chong, W.K.; Asmar, M. El Analyzing Arizona OSHA Injury Reports Using Unsupervised Machine Learning. *Procedia Eng.* **2016**, *145*, 1588–1593. [CrossRef]
56. Raviv, G.; Shapira, A.; Fishbain, B. AHP-based analysis of the risk potential of safety incidents: Case study of cranes in the construction industry. *Saf. Sci.* **2017**, *91*, 298–309. [CrossRef]
57. Ayhan, B.U.; Tokdemir, O.B. Predicting the outcome of construction incidents. *Saf. Sci.* **2019**, *113*, 91–104. [CrossRef]
58. Ale, B.J.; Bellamy, L.J.; Baksteen, H.; Damen, M.; Goossens, L.H.; Hale, A.R.; Mud, M.; Oh, J.; Papazoglou, I.A.; Whiston, J.Y. Accidents in the construction industry in the Netherlands: An analysis of accident reports using Storybuilder. *Reliab. Eng. Syst. Saf.* **2008**, *93*, 1523–1533. [CrossRef]
59. Alper, S.J.; Karsh, B. A systematic review of safety violations in industry. *Accid. Anal. Prev.* **2009**, *41*, 739–754. [CrossRef]
60. Raviv, G.; Fishbain, B.; Shapira, A. Analyzing risk factors in crane-related near-miss and accident reports. *Saf. Sci.* **2017**, *91*, 192–205. [CrossRef]
61. Palamara, F.; Piglione, F.; Piccinini, N. Self-Organizing Map and clustering algorithms for the analysis of occupational accident databases. *Saf. Sci.* **2011**, *49*, 1215–1230. [CrossRef]
62. European Parliament and Council Regulation (EC) N. 1893/2006 Establishing the Statistical Classification of Economic Activities NACE Revision 2. *Off. J. Eur. Union* **2006**, *393*, 1–39. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32006R1893 (accessed on 28 October 2022).
63. INAIL Database Infor.Mo. Available online: https://www.inail.it/cs/internet/attivita/ricerca-e-tecnologia/area-salute-sul-lavoro/sistemi-di-sorveglianza-e-supporto-al-servizio-sanitario-naziona/informo.html (accessed on 28 October 2022).
64. Campo, G.; Cegolon, L.; De Merich, D.; Fedeli, U.; Pellicci, M.; Heymann, W.C.; Pavanello, S.; Guglielmi, A.; Mastrangelo, G. The italian national surveillance system for occupational injuries: Conceptual framework and fatal outcomes, 2002–2016. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7631. [CrossRef]
65. Goyal, K.; Kumar, S. Financial literacy: A systematic review and bibliometric analysis. *Int. J. Consum. Stud.* **2021**, *45*, 80–105. [CrossRef]
66. Punj, G.; Stewart, D.W. Cluster analysis in marketing research: Review and suggestions for application. *J. Mark. Res.* **1983**, *20*, 134–148. [CrossRef]
67. Harb, H.; Makhoul, A.; Couturier, R. An enhanced K-means and ANOVA-based clustering approach for similarity aggregation in underwater wireless sensor networks. *IEEE Sens. J.* **2015**, *15*, 5483–5493. [CrossRef]
68. IBM SPSS Statistics 28 Documentation. Available online: https://www.ibm.com/support/pages/ibm-spss-statistics-28-documentation#en (accessed on 31 October 2022).
69. Coelho, C.; Mojtahedi, M.; Kabirifar, K.; Yazdani, M. Influence of Organisational Culture on Total Quality Management Implementation in the Australian Construction Industry. *Buildings* **2022**, *12*, 496. [CrossRef]
70. Sen, S.; Yildirim, I. A Tutorial on How to Conduct Meta-Analysis with IBM SPSS Statistics. *Psych* **2022**, *4*, 640–667. [CrossRef]
71. Schreiber, J.B.; Pekarik, A.J. Using Latent Class Analysis versus K-means or Hierarchical Clustering to understand museum visitors. *Curator Mus. J.* **2014**, *57*, 45–59. [CrossRef]
72. Dien, Y.; Dechy, N.; Guillaume, E. Accident investigation: From searching direct causes to finding in-depth causes—Problem of analysis or/and of analyst? *Saf. Sci.* **2012**, *50*, 1398–1407. [CrossRef]
73. Lane, R.; Stanton, N.A.; Harrison, D. Applying hierarchical task analysis to medication administration errors. *Appl. Ergon.* **2006**, *37*, 669–679. [CrossRef]
74. Fargnoli, M.; Lombardi, M.; Puri, D. Applying Hierarchical Task Analysis to Depict Human Safety Errors during Pesticide Use in Vineyard Cultivation. *Agriculture* **2019**, *9*, 158. [CrossRef]
75. Khanal, A.; Sondhi, D.A.; Giri, S. Use of personal protective equipment among waste workers of Sisdol landfill site of Nepal 1. *Int. J. Occup. Saf. Health* **2021**, *11*, 158–164. [CrossRef]
76. Vigoroso, L.; Caffaro, F.; Cavallo, E. Warning against Critical Slopes in Agriculture: Comprehension of Targeted Safety Signs in a Group of Machinery Operators in Italy. *Int. J. Environ. Res. Public Health* **2019**, *16*, 611. [CrossRef] [PubMed]
77. Bohm, J.; Harris, D. Risk Perception and Risk-Taking Behavior of Construction Site Dumper Drivers Risk Perception and Risk-Taking Behavior of Construction Site Dumper Drivers. *Int. J. Occup. Saf. Ergon.* **2010**, *16*, 55–67. [CrossRef] [PubMed]
78. Mukherjee, S.; Mukhopadhyay, S.; Hashim, M.A.; Gupta, B.S. Contemporary Environmental Issues of Landfill Leachate: Assessment and Remedies. *Crit. Rev. Environ. Sci. Technol.* **2015**, *45*, 472–590. [CrossRef]
79. Rudakov, M.; Gridina, E. Risk-Based Thinking as a Basis for Efficient Occupational Safety Management in the Mining Industry. *Sustainability* **2021**, *13*, 470. [CrossRef]
80. Hoła, B.; Szóstak, M. Modeling of the Accidentality Phenomenon in the Construction Industry. *Appl. Sci.* **2019**, *9*, 1878. [CrossRef]
81. Ning, X.; Qi, J.; Wu, C. A quantitative safety risk assessment model for construction site layout planning. *Saf. Sci.* **2018**, *104*, 246–259. [CrossRef]
82. Mishra, H.; Karmakar, S.; Kumar, R.; Singh, J. A Framework for Assessing Uncertainty Associated with Human Health Risks from MSW Landfill Leachate Contamination. *Risk Anal.* **2017**, *37*, 1237–1255. [CrossRef]

83. Gotvajn, A.Z.; Tisler, T.; Koncan, J.Z. Comparison of different treatment strategies for industrial landfill leachate. *J. Hazard. Mater.* **2009**, *162*, 1446–1456. [CrossRef]
84. Fargnoli, M.; De Minicis, M.; Di Gravio, G. Knowledge Management integration in Occupational Health and Safety systems in the construction industry. *Int. J. Prod. Dev.* **2011**, *14*, 165–185. [CrossRef]
85. Gunduz, M.; Laitinen, H. A 10-step safety management framework for construction small and medium-sized enterprises. *Int. J. Occup. Saf. Ergon.* **2017**, *23*, 353–359. [CrossRef] [PubMed]
86. Li, J.; Dong, Q.; Yu, K.; Liu, L. Asbestos and asbestos waste management in the Asian-Pacific region: Trends, challenges and solutions. *J. Clean. Prod.* **2014**, *81*, 218–226. [CrossRef]
87. Jibiri, N.N.; Isinkaye, M.O.; Momoh, H.A. Assessment of radiation exposure levels at Alaba e-waste dumpsite in comparison with municipal waste dumpsites in southwest Nigeria. *J. Radiat. Res. Appl. Sci.* **2014**, *7*, 536–541. [CrossRef]