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Research Article

Contribution to developing a new environmental risk management methodology for industrial sites

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Abstract
A fundamental requirement of any environmental management system for industrial sites is the identification and assessment of risk. To meet international standards in terms of environmental protection and preservation, industrial sites should ensure that a comprehensive environmental risk management process is in place by systematically identifying and managing risks arising from internal and external factors. The purpose of this study was to develop a new methodology to determine the significance of environmental hazardous situations associated with a process or activity. It uses qualitative or quantitative techniques to pinpoint weaknesses in design, operation, and lines of defense provided by engineering and administrative controls, which can lead to an environmentally hazardous event. It may also provide an assessment of risk resulting from the magnitude of the consequence and the probability of the environmental event occurring. The fundamental principle of this new risk-based hazard methodology is that whilst risk cannot be eliminated, it should be possible to reduce to ALARP (as low as reasonably practicable), and the environmental risk matrix could be a useful tool for establishing if an environmental risk rating is tolerable or not based on the likelihood and consequences. The outcome of this study is developing a new environmental risk matrix based on different consequences (health, environmental, reputation, and business interruption) with likelihood criteria. This matrix could be applied by industrial sites to identify and control their environmental risks.

Keywords: Environmental management, Industrial sites, Risk management, Risk matrix

INTRODUCTION

Heavy metals remain an important class of environmental pollutants due to their toxicity and persistence in the environment. Environmental degradation has captivated the world's attention and is one of the most widely debated topics locally, nationally, and worldwide (Bentivegna *et al.,* 2002). (Langston and Ding, 2001) argued that the world is on the verge of a major environmental disaster. Risk is defined in terms of qualitative approach interpretations as the likelihood of an awful situation; the possible future occurrence of adverse consequences resulting from an event; the collection of impacts arising from the activity and potential impacts; or, furthermore, the variance from a set point and the relating unpredictability indicators. (Nesticò *et al.,* 2018).

For the industry, the environment in which an organization functions, which includes air, water, land, natural resources, flora, fauna, and humans, as well as their interaction surroundings, extends from within an organization to the global system (ISO 14001:2015, 2021). Communication and consultation and monitoring and review are important risk management principles, but they are ongoing procedures that occur throughout the risk management framework. (Macciotta and Lefsrud, 2018). Environmental hazard identification risk assessment is a primary strategy for identifying and providing environmental dangers based on their probability, frequency, and severity and assessing negative repercussions such as possible loss, reputation, and business interruption. To promote the industry's effectiveness in terms of environmental protection, the work process in the industry must pay attention to environmental factors. Risk assessments were performed utilizing risk guidelines and standards. The industry must identify hazards, analyse the associated risks, and tolerate continuous levels (Tron and Than, 2021) (Falakh and Setiani, 2018).

An environmental risk assessment aims to determine which of the identified environmental risks are significant. In many circumstances, professional judgment will play an important role in determining how to address the significance, and this can be helped through consultation with appropriate stakeholders. Significance is determined by identifying the level of control on each environmental aspect and the severity of the environmental impact related to each aspect.(Aven, 2017). Throughout the development life cycle, industrial activities have an impact on the environment. These effects occur throughout the building process and into the operational phase. In fact, the impact of the industry's actions on human and environmental health is becoming increasingly alarming. Even if industry development has the potential to contribute to economic and social development and improve both the standard of living and the quality of life, it is also linked to environmental degradation (Ametepey and Ansah, 2014)

On the other hand, risk analysis is not widely acknowledged as a distinct discipline. Risk analysis approaches and methods are integrated with information from economics, sociology, engineering, industry, and various other disciplines and fields to tackle risk challenges (Aven, 2018). The main objective of this study was to create a new methodology using a risk matrix (Duijm, 2015) to determine the relevance of a process or activity's environmental danger condition. It employs qualitative and quantitative methods to identify flaws in the design, operation, and lines of defense provided by engineering and administrative controls, resulting in an environmental disaster (Zio and Aven, 2013). It also provides a risk assessment based on the degree of the consequence and the likelihood that the environmental event will occur. This new risk assessment methodology could help industrial sites suggest possible ways of minimizing the significant impacts.

This study discusses the risk management concepts, identification and assessment using the ALARP (As Low As Reasonably Practical) Approach, and ultimately the new environmental risk matrix.

MATERIALS AND METHODS

Risk management principles

Risk management aims to protect people, the environment, and resources from harmful outcomes caused by human actions or natural disasters. In other words, risk management allows industry to devise strategies for containing or reducing the potential damage from an activity's hazards/threats(Aven and Renn, 2009). As a result, managing different risks is a set of techniques for identifying and analysing those risks; this process can also involve risk mitigation related to the performance of each industry (Aven, 2016)

The risk management process model comprises the seven basic steps listed below (Fig. 1) (Standards Australia (Organization) and International Organization for Standardization, 2009).

The risk management process steps are the following:

1. **Communication and consultation:** All stages of the risk management process should include communication and interaction with external and internal stakeholders. Throughout the risk management process, it should make it easier to exchange necessary information and coordinate stakeholders' perspectives.
2. **Establishing the context**: The objectives, scope, and criteria for the remaining risk management process are determined by creating the context. This covers both external and internal elements affecting the organization and the role of the risk management process within the company and the basic criteria used to evaluate risks. The scope of risk causes and implications is the most important contribution to the risk identification process.
3. **Risk identification:** This step entails identifying risk sources, impact locations, and events, as well as their causes and consequences. This stage aims to compile a complete list of risks based on events that have a substantial impact on achieving the goals.
4. **Risk analysis:** The investigation of the previously identified threats leads to a better knowledge of these dangers. It generates the essential data for a proper risk assessment (both in terms of the right method for assessment and the required data) and the creation of successful therapies. Both the evaluation process and the data gathered are considered inputs.
5. **Risk evaluation:** During risk evaluation, choices are made on which risks require treatment and the priority of risk treatments based on the information acquired during risk analysis. It takes advantage of the criteria that were established throughout the context's creation. The risk treatment step is subsequently transferred to the prioritized list of risks.
6. **Risk treatment:** One or more treatment options are chosen and applied for each risk that requires treatment. It entails evaluating various treatments, determining the residual risk as a result, and determining whether additional risk treatments are required to accomplish the desired risk reduction. The monitoring and evaluation procedure receives the chosen

therapies, their predicted benefits, and the assessed hazards.

7. **Monitoring and review:** The identified risks are monitored and assessed, including the detection of developing risks, so that modifications in their assessment and treatment can be made as needed. To allow for process control and improvement, the risk management process is also monitored and reviewed. As a result, the monitoring and review process interacts with all other processes in terms of process design, execution, and risk management.

Environment risk process map

Environmental risk management could be presented by a process map, as shown in Fig. 2:

Environment risk identification process

Environmental hazard registers must be able to properly identify the list of dangers to the environment. The goal of this process, which is presented in Table 1, is to identify the environmental risks connected with each industry's operations. When employing this strategy, the emphasis should be on the effects rather than the possibility.

Risk assessment process

The aim of this process (Table 2) is to ensure that there is a methodology in place to evaluate the risk associated with all environmental hazards related to the site's intrinsic design or operating intent, as well as dangers related to normal and nonroutine activities.

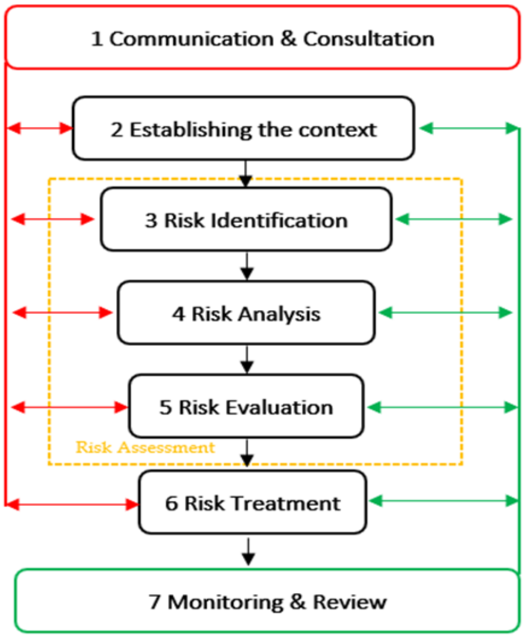

Fig. 1. *Risk management process (following iso 31000) (Standards Australia (Organization) and International Organization for Standardization, 2009)*

Risk management process

Within ALARP, all identified risks will be addressed in accordance with local legal and statutory standards. If the initial risk is deemed unbearable, more controls must be imposed until the risk is lowered to ALARP or the job must be discontinued, whichever comes first. The principle of the risk management process is presented in Table 3.

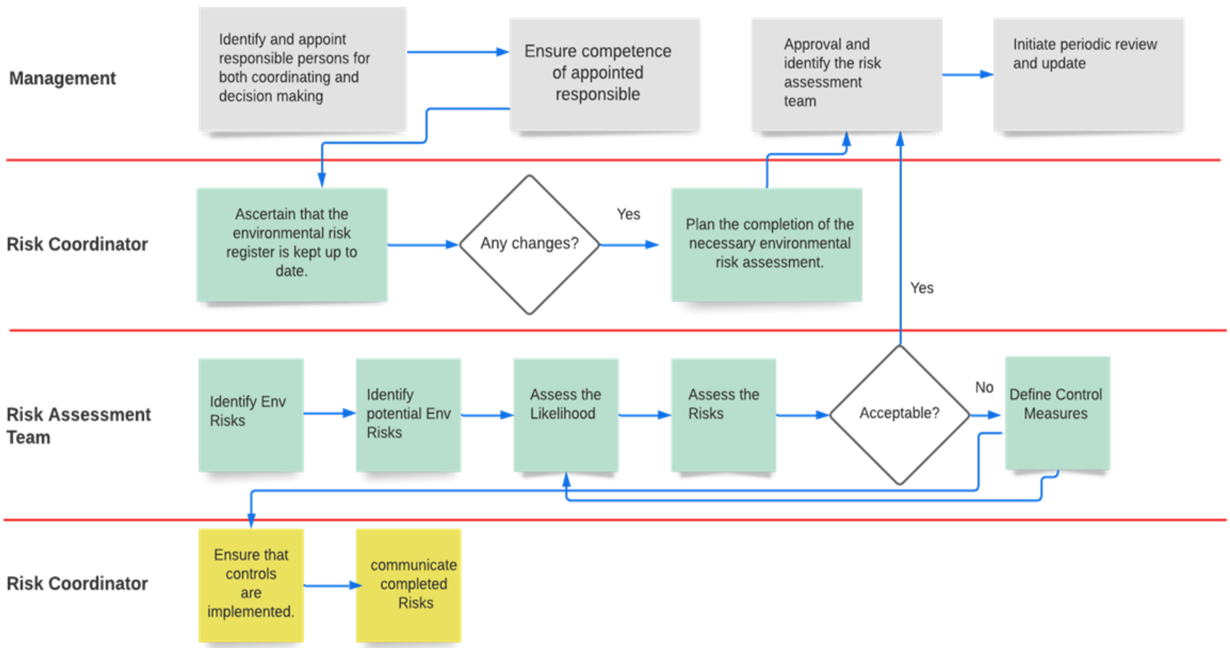

Fig. 2. *Environment risk process map*

Table 1. Environmental Risk Identification process actions

Process Actions	Deliverable
Provide a method that systematically identifies environmental hazards and assesses the implications utilizing the risk matrix's outcomes. The environmental hazard identification process must be completed to guarantee that all inherent dangers are identified, regardless of their likelihood or controls.	List of Major Environmental threats Should be updated as required
To analyse each significant environmental treaty, the following activities will be carried out. Air emissions compliance, soil contamination, water contamination, biodiversity, and other important issues are examples of major issues. a) For each environmental concern, identify the most important occurrence. b) Each conceivable cause or beginning event must be investigated for the top event. c) The top event will be examined independently for repercussions such as business disruption, image, and legislation.	List of major environmental hazards and the controls that are in place to address them.

Table 2. Environmental risk assessment process actions

Process Actions	Deliverable
The risk assessment method is a step-by-step procedure for determining the impact and possibility of all conceivable environmental threats. The procedure is used for the following purposes: Activities that are both routine and nonroutine. Third-party services; Working conditions and schedules; Previous environmental occurrences, especially emergency situations, and their causes;	Specific Environmental Risk Assessment Process
Identify environmental hazards; determine potential effects; assess likelihood; assess risk; and determine risk tolerance.	Risk Assessment Records
Competent professionals are required to conduct risk assessments.	Risk Assessment Training and Competence Matrix

Table 3. Environmental risk management process actions

Process Actions	Deliverable
Elimination, prevention, control, and mitigation are the four levels of control that are implemented. The most critical step is to keep risk within a bearable zone or ALARP (as low as reasonably practicable). Additional controls must be applied to any evaluated risk that falls outside of the ALARP or acceptable zone.	ALARP demonstration and control measures
All recommendations for additional controls or lowering the risk to ALARP must be documented with a deadline for execution.	Recommendations list

ALARP approach

Risk assessment is frequently used in the safety and environmental fields, where it is required to protect human life and the environment from the consequences of harmful activity performance. Risk management in this industry has traditionally been based on a prescriptive regulatory regime in which the requirements for plant design and operation were detailed (Maselli *et al.,* 2021).

Over time, there has been a progressive trend toward goal-oriented regimes that focus more on the goal to be attained than the tools to achieve it. As a result, more integrated risk governance systems have emerged, resulting in improved levels of productivity and risk reduction (Anguenot and Borysiewicz, 1998) (Health and Consumer Protection Directorate-General, 2000)

Quantitative risk assessment (QRA) is increasingly used in these techniques, to the point where many regulatory authorities apply quantitative procedures that can increase the economic efficiency of risk management decision-making (Bérenguer *et al.,* 2012) (Macciotta and Lefsrud, 2018)

Reducing risk to a reasonable level is considered a statutory requirement for safety and environment-related systems and provides guidance that addresses both the implementation of best practices and arguments for ALARP (Menon *et al.,* 2013)

To control the inherent hazard of industrial processes, the British Health and Safety Executive (HSE) outlined some broad risk acceptance guidelines in 1992.

The ALARP principle is a set of guidelines developed by the American Library Association. Risks must be minimized to the extent that they are as low as reasonably practicable. In other words, all mitigation measures must be implemented until the costs appear to be disproportionate to the benefits that can be achieved. Threshold values for "acceptable" and "tolerable" hazards are defined in the ALARP context. (Health and Safety Executive, 1992) (Office for Nuclear Regulation, 2020).

Risks that are below the tolerance threshold must be decreased since they are unacceptable, according to the ALARP principle. The ALARP area includes risks that fall between the tolerance and acceptability levels; thus, they must be mitigated until they are reasonably practicable. Finally, risks that exceed the threshold of acceptance are "widely acceptable"; thus, they do not need to be mitigated.

The ALARP guidelines, which are commonly used in high-risk areas of industrial engineering, demand that individuals in charge of the activity decrease risks to "as low as reasonably practicable" levels (Pike *et al.,* 2020). An illustration of the ALARP approach is presented in Fig. 3.

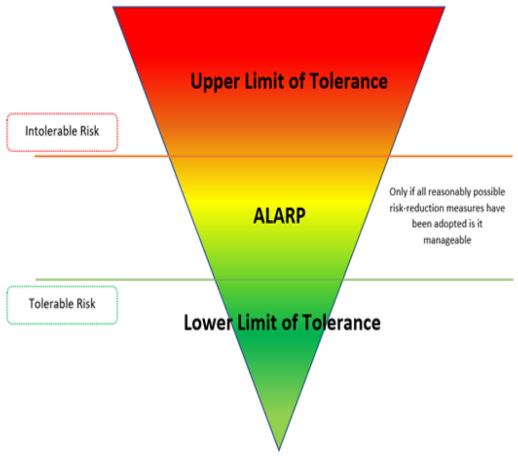

Fig. 3. *Illustration of ALARP principle*

RESULTS AND DISCUSSION

Explanation and risk matrix

The methodology described earlier was implemented to estimate the expected likelihood and consequences according to each industry activity.

Consequences

The following consequences criteria (Table 4) could be applied to give an adequate score of the risk assessment:

Table 4. Environmental risk assessment consequences

Score	Environmental	Business interruption	Health and safety
U	Minor leak or spill automatically controlled (using technology) No reputation impact	Interruption of business lasting less than 04 hours	Temporary Unhealthy Working Conditions
V	Spill/Leak of toxic and hazardous substances in a contained environment. A minor short-term impact on the reputation of the local community.	Interruption of business lasting less than a day	First aid case
W	Spill/Leak of a hazardous substance that may be controlled locally and does not require external notification A short-term impact on the reputation of the regional community	Interruption of business lasting between 02 and 04 days.	Slight health Impact Medical treatment
X	Spills/Leak of hazardous substances that necessitate external reporting but can be managed by internal resources A short-term impact on the reputation of the country community	Interruption of business lasting between 04 and 06 days.	Has a short-term impact on human health Lost Time injury (LTI)
Y	External reporting and mobilization of external services are required in the event of a hazardous substance spill or leak. Significant national damage to one's reputation	Interruption of business lasting between 06 and 11 days.	Has a long-term impact on human health Permanent Disability
Z	A significant leak or spill of a hazardous material may necessitate the involvement of environmental agencies. Significant international damage to one's reputation	Interruption of business lasting more than 11 days.	Fatal to human (fatality)

Likelihood criteria

The likelihood criteria are presented in Table 5.

Risk matrix (6x6)

This matrix (Table 6) can provide a clear understanding of the risk priority and the adequate controls for each score category, as presented in Table 7:

Based on this new risk matrix, the ALARP illustration is presented in Fig. 4.

Risk assessment review

Environmental risk assessments should be examined, approved, and accepted by certain levels of management based on the severity of the hazards, and choices should be well documented. An annual evaluation of environmental risk management is required, or whenever any of the following events occur:

Adding a new activity to the mix

Laws and regulations that have changed

Changes that occur because of any environmental incidents or emergencies

Risk assessment communication

The risk assessment process and outcomes should be communicated to all stakeholders (Table 8).

Training and competence

To carry out the above requirements, the following competency requirements must be met:

Knowledge and understanding of the environmental risk matrix.

Relevant industrial expertise

The ability to assess the likelihood, consequence, and demonstrate ALARP criteria.

Risk treatment

To change the risk ratings, risk treatment involves mitigation steps and controls.

The following therapeutic options are suggested:

Avoiding the risk (not starting or stopping an activity)

Increasing the risk to seek an opportunity

Removing the risk source

Changing the likelihood

Changing the consequences

Retaining the risk through informed decision

One or more mitigation strategies may be used in conjunction with the requisite treatment alternatives.

Controls must be put in place to ensure that the adjusted level of risk rating is maintained and controlled.

Risk owners will be in charge of putting mitigation

Table 5. Environmental risk assessment likelihood criteria

Likelihood	Score	Criteria
Not Possible	01	Never happened not at all.
Extremely Unlikely	02	Not Has happened in a similar industry but has happened in other different process industry
Unlikely	03	Has happened once every ten years in a similar industry;
Possible	04	Has happened once every five years in a similar industry;
Likely	05	Has happened once every one year in a similar industry;
Extremely likely	06	It happens multiple times a year.

Table 6. Environmental risk matrix (6x6)

Consequence/Severity						
Z	Z1 (6)	Z2 (12)	Z3 (18)	Z4 (24)	Z5 (30)	Z6 (36)
Y	Y1 (5)	Y2 (10)	Y3 (15)	Y4 (20)	Y5 (25)	Y6 (30)
X	X1 (4)	X2 (8)	X3 (12)	X4 (16)	X5 (20)	X6 (24)
W	W1 (3)	W2 (6)	W3 (9)	W4 (12)	W5 (15)	W6 (18)
V	V1 (2)	V2 (4)	V3 (6)	V4 (8)	V5 (10)	V6 (12)
U	U1 (1)	U2 (2)	U3 (3)	U4 (4)	U5 (5)	U6 (6)
	1	2	3	4	5	6
	Not Possible	Extremely Unlikely	Unlikely	Possible	Likely	Extremely likely

Table 7. Environmental risk priority and controls

Score color	Matrix score	Risk Priority	Controls
Green Color	U1,2,3,4 V1,2,3,4 W1,2,X1,2	Low Priority and Tolerable Risk	Review Periodically by competent persons
Blue Color	Z1, Y1	Medium Priority and Tolerable Risk	Contingency Procedures should be required
Orange	U5, U6	Medium Priority + Intolerable Risk	Procedural and administrative coverage should be required.
Yellow color	V5,6; W3,4,5,6; X3,4; Y2,3; Z2,3	Medium to high Priority + Intolerable Risk	The risk should be managed
Red color	X5,6; Y4,5,6 Z4,5,6	High Priority + Intolerable Risk	The risk should be eliminated

Table 8. Risk assessment communication

Action	Deliverable	Frequency
Completed environmental risk assessments should be communicated to all stakeholders by email, bulletins, and printed copy. To promote effective communication, relevant stakeholders might sign a document acknowledging that they have read and understood the risk.	Necessary personnel aware of the environmental risk assessment and awareness of required control measures	When and if necessary (to take into consideration the legal requirements.

activities and controls in place as soon as possible.

Monitoring and review

After completing a first detailed assessment, delta changes should be noted at regular intervals to track progress.

Controls necessitate periodic testing. Throughout the process, continuous improvement in approach, tactics, and risk management will be implemented.

It is suggested that all high-rated risks be reviewed at least once a quarter.

It is suggested that all medium-rated risks be reviewed quarterly or at least biannually.

For low-rated risks, some selected risks will be subjected to periodic audits to ensure that controls are effective and that they are maintained. Audits should be performed at least once a year, if not twice a year.

Effectiveness of the risk matrix for taking decisions

All risk matrix limits must be recognized to appreciate the nature of environmental risk, assess its degree, and constraints, as they may have a negative impact on its effectiveness, particularly for the outcome provided. Unwary risk matrix managers may fall into traps. (Baybutt, 2015) Assessing the environmental risk after it has been evaluated using the matrix is unreliable if the matrix is not filled out properly (Bao et al., 2017).

Despite its widespread use, many researchers have already evaluated the limits and inconsistencies of the risk matrix approach, focusing on the design, use, and effectiveness of decision-making.

Conclusion

This study aims to develop a model that can help industrial operators manage environmental risk and develop a novel methodology for estimating risk acceptability and tolerance thresholds that combine the ALARP criteria with other factors. The environmental risk matrix becomes an effective tool for assessing the likelihood in conjunction with the consequences and determining whether the environmental risk rating is tolerable. It also aids the industry in determining which risks should be handled first. The notions of the environmental risk tolerability threshold, or the limit below or above which the environmental risks are universally tolerable or not to the analyst, are parts of the ALARP reasoning.

Understanding the external and internal context of each industry is essential to managing environmental risk. Each industry should ensure that comprehensive environmental risk identification and management processes are in place by systematically identifying and managing risks arising from internal and external factors. This new risk assessment methodology, which is based on a matrix (6x6), will assist industrial organizations in developing accurate suggestions to decrease the risk associated with all types of hazardous environmental events. These methods aim to lower either the event's consequences or the likelihood of it occurring. Only those potentially hazardous environmental events for which the assessed risk is intolerable are subjected to environmental risk control.

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Conflict of interest

The authors declare that they have no conflict of interest.

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