Causal relationship between environmental aspect and environmental risk

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Abstract. This study aims to determine the causal relationship between environmental aspects and environmental risks, and to develop a risk management model for various hazard consequences. The research utilizes a general project life cycle model based on ISO 21500, adapted to identify cause-and-effect relationships between environmental aspects and hazards. The relationship is defined as the critical accumulation of an organization's activities impacting the environment, which can trigger dangerous events under certain conditions. An algorithm for managing risks related to air, water, and soil pollution, stemming from this cause-and-effect relationship, is developed. The Bhopal tragedy is analyzed to illustrate the environmental consequences and economic losses from pollution. The study's originality lies in defining the interrelationship between environmental aspects, sources of danger, and adverse environmental events. Its practical value is in the development of a risk management algorithm to address hazards leading to pollution-related losses.

1 Introduction

It is important to identify the existence of environmental hazards from the influence of economic [1 – 3] and other activities [4]. This will make it possible to predict their impact on the environment, and therefore will make it possible to propose preventive measures [5 – 7]. However, due to financial and resource limitations, the organization cannot eliminate all threats at once [8, 9]. There is a need to rank them. It is convenient to apply the environmental risk assessment procedure [10, 11]. At the same time, environmental risk is defined as the

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product of the probability of the occurrence of a dangerous environmental event and the magnitude of the negative impact on the environment, which is determined taking into account the level of intensity, time and scale of the impact of the hazard [12]. The key in this process is the identification of hazards and the establishment of cause-and-effect relationships between the hazard and the dangerous event. At the same time, the ISO 14001 standard shows of the need to define and manage environmental aspects. At the same time, the environmental aspect means an element of the organization's activity or its products or services that interacts or can interact with the environment [13, 14]. A distinction is made between a significant environmental aspect, which causes or may cause a significant impact on the environment, and non-significant [15 – 17]. An urgent task arises in the combination of the ecological aspect and the assessment of environmental risk.

The analysis of scientific studies showed that all publications on environmental risk assessment, with certain assumptions, can be divided into two main directions. The first is aimed at improving the methods of environmental risk assessment. The second, focused on the optimization of models for environmental risk assessment .

For example, in the work [18] the authors proposed a model for evaluating the environmental security of cities based on sustainable infrastructure. At the same time, its advantages and disadvantages were described in detail. In another publication [19] the authors proposed a new method of entropy weight TOPSIS and ArcGIS for assessing the ecological state of forests. It is based on the detection of ecologically dangerous events from the influence of various dangerous factors characteristic of human activity.

An interesting solution was proposed in the article [20]. The authors proposed the concept and system of the stress index of the ecological footprint from anthropogenic impact on the ecosystem, taking into account the cost of services for their restoration. The shortcomings of the study include the inconsistency of various collected data, which leads to their incorrect classification.

A new model for assessing the level of environmental protection based on the stochastic impact of population health, wealth and technology was proposed in [21]. For evaluation, the authors chose four main indicators of flow, pressure, diversity and coordination based on the ecological safety assessment method. However, the characteristics of the indicators were the equivalence ratio, yield ratio and diversity ratio, while the scales for their determination were different, which has some influence on the final evaluation results [22 – 24].

Assessment of ecological safety is a key method of adaptation and mitigation of ecological degradation [25 – 28]. With its help, it is possible not only to investigate the state of the environment, but also to identify trends in ecological evolution and provide scientific proposals for preventing and controlling the deterioration of the ecological situation [29, 30]. This, in turn, will allow at least maintaining a certain balance between production [31] and disturbance of the ecosystem [32], offering appropriate solutions. Their important condition is flexibility [33], which will make it possible to provide timely proposals regarding changes in the environmental safety of organizations. At the same time, it requires an answer to questions about their budget in order to choose effective and efficient measures based on limited funding [34, 35].

The purpose of the article is determination of the cause-and-effect relationship between the environmental aspect and the environmental risk and to develop an environmental risk management model with different consequences of the hazard.

To achieve the purpose, the following tasks must be solved:

– Find out the connection between the ecological aspect and ecological danger.

– Establish a cause-and-effect relationship between ecological danger and ecological risk.

– To analyze the cause-and-effect relationship between the environmental aspect and environmental risk on the example of the Bhopal tragedy.

To conduct the research, a general model was used that describes the stages of the project life cycle according to the ISO 21500 standard, which was adapted to identify the cause-and-effect relationships between the environmental aspect and the hazard and hazardous event. The main advantages of the given model are the distribution of the external environment of the organization and the internal environment in which benefits, threats and operations are presented, which are aimed at obtaining the final result [36]. On its basis, the relationship between the environmental aspect – sources of danger (sources of opportunity) and dangerous environmental events (adverse environmental events) is determined, which will allow to ensure organizational management of environmental safety in accordance with the requirements of international standards for the formation of a strategy for reducing the environmental consequences of impact on the ecosystem. In addition, it is assumed that response to threats in accordance with the standard is provided by a comprehensive analysis of change management through the formation of an appropriate risk management algorithm, which includes formalization, planning and implementation of changes, management of the achievement of the organization's target state.

2 Determination of the connection between the ecological aspect and ecological danger

The environmental aspect is determined through the organization's activities, which can cause either a negative or a positive impact on the environment. For example, emissions of wood dust and gases during the papermaking process can pollute the ecosystem and contribute to the greenhouse effect. The key word is can. That is, there is a certain degree of activity of the organization that will lead to the emergence of danger. From this, there is a connection between the ecological aspect and ecological danger, which is characterized by the presence of actions and processes that can affect the state of the natural environment. Therefore, the ecological aspect, when reaching a certain limit, can act as a source of ecological danger, which is defined as a process or phenomenon that poses a threat to the environment. Thus, we identify a cause-and-effect relationship between the environmental aspect (activity of the organization that can change the environment) and danger (that is, when there is a critical accumulation of the results of the organization's activities on the environment), which can, under certain conditions, cause the occurrence of a dangerous event. And, on the other way around, the ecological aspect is also connected with a favorable environmental event through the creation of a source of opportunity – the presence of conditions for the emergence of favorable circumstances that help to improve the environment (Fig. 1).

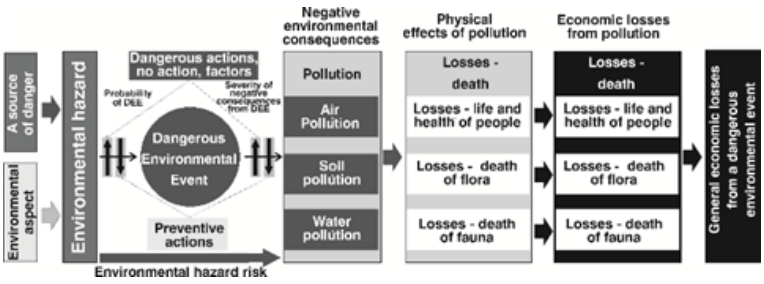

Fig. 1. The model of the relationship of the environmental aspect – sources of danger (sources of opportunity) and dangerous environmental event (adverse environmental event).

There are a significant number of methods for assessing environmental risks: impact on the natural environment, impact on public health, water, air, soil pollution, etc. For

example, only for the assessment of environmental risk associated with chemical pollution, there are three models: dose-response, threshold model, model of individual thresholds. This raises the question of how to choose a model that will best determine the magnitude of the risk to justify appropriate precautionary measures. In fact, the choice of the model depends on the conceptual system that determines the cause-and-effect relationships between the hazard and the dangerous event. Taking into account that each dangerous event can simultaneously lead to air, water and soil pollution, the bow tie model can be presented in the following form (Fig. 2). At the same time, the level of risk is determined taking into account the significance of each type of loss, including under the influence of various groups of dangerous factors [37, 38].

3 Determination of the cause-and-effect relationship between ecological danger and ecological risk

Each hazard – *j* leads to three environmental risks: air, water and soil pollution:

$$R_j^A = \sum_{i=1}^{n}(B_{ji} \cdot TH_{ji}^A);\ \ R_j^W = \sum_{i=1}^{n}(B_{ji} \cdot TH_{ji}^W);\ \ R_j^S = \sum_{i=1}^{n}(B_{ji} \cdot TH_{ji}^S),$$

where R_j^A, R_j^W, R_j^S are the level of the corresponding risk of air, water, and soil pollution from hazard *j*, taking into account the influence of hazardous factors *i*; B_{ji} is a probability the occurrence of a dangerous event from danger *j* under the influence of a dangerous factor; TH_{ji}^A, TH_{ji}^W, TH_{ji}^S are the degree of intensity of air, water, and soil pollution from the occurrence of a hazardous event that arose from hazard *j* under the influence of hazardous factor *i* appropriate scales are built, based on the recommendations of IS0 31073:2022, taking into account the level of intensity, time and scale of the impact of the hazard. Environmental risk is divided into two types:

– the risk of disruption of ecosystem stability as a result of real and potential pollution of the natural environment;

– public health risk, which is the probability of adverse health effects.

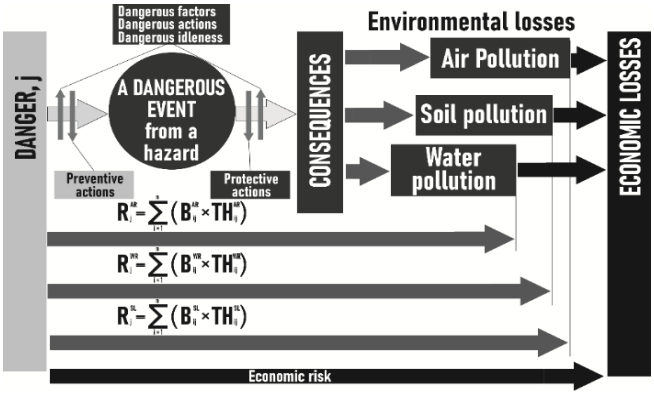

Fig. 2. Risk management model with different consequences of the hazard.

Every ecological risk of pollution: air, water and soil leads to loss of life and health of people, fauna and flora. From here it is possible to determine the general economic risk from loss of life and health of people, fauna and flora.

The given model provides for the development of an appropriate risk management algorithm with various types of consequences, the difference of which from the known ones is the need to identify the intensity of air, water and soil pollution from each identified hazard, taking into account the influence of various dangerous factors (Fig. 3).

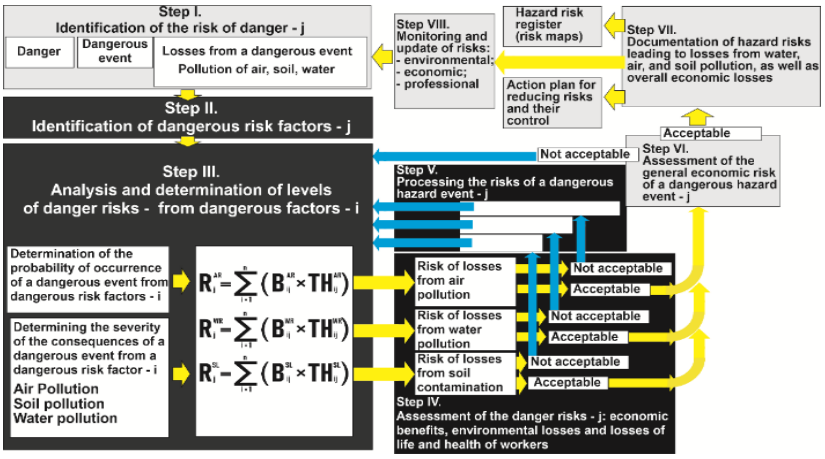

Fig. 3. Algorithm for managing risks from hazards that lead to losses from air, water, and soil pollution.

The given algorithm for managing risks from hazards that lead to losses from air, water, and soil pollution consists of eight steps.

The first involves the identification of components of the risk of danger, which requires the establishment of ecological aspects of the organization's activities, which will allow the detection of environmental hazards, dangerous events and losses for living and non-living nature.

In the second step, we find out the presence of dangerous factors that increase the probability of the occurrence of a dangerous event and the severity of the consequences. The following groups of factors can be attributed to them: human, technical, organizational, climatic and others.

In the third step, we analyze and determine the level of environmental risks danger as a product of the probability of the occurrence of a dangerous event and the ty of the safety consequences. To establish the probability of occurrence of a dangerous event.

It is important to form a logical structure and to systematize and classify the evaluation indicators of the general approach to identifying a conceptual system that requires clarification of the terminology, what is an ecological hazard, what is an ecologically dangerous event, what are the risks (carcinogenic, potential, cumulative, population, for health). Thus, the following legislative documents are in force in our country: Laws of Ukraine “On Environmental Protection”, “On Environmental Impact Assessment”, “On Ratification of the Convention on Access to Information, Public Participation in the Decision-Making Process and Access to Justice on Matters, relating to the environment” and DBN A.2.2-1-95 “Composition and content of environmental impact assessment materials during the design and construction of enterprises, buildings and structures”. To achieve the effectiveness of environmental risk assessment, it is necessary to take into account that the fields of application require a combination of interdisciplinary areas. For example, it is important to consider the social, cultural, political, economic and legal consequences of a hazardous event. The ERA should include a methodology that identifies and allows priorities, assesses the consequences of possible impacts, the way in which

impacts on ecosystems could be avoided, isolated or reduced, taking into account the history of accidents, as well as the effectiveness of emergency plans, conducting verification tests, etc.

In the fourth step, the level of risk from the hazard is assessed, taking into account the influence of all dangerous factors. You can use different methods for this. We suggest using a five-point scale for the probability of the occurrence of a dangerous event, where 1 point - a dangerous event does not occur or can happen more than once every 20 – 50 years, 2 points – a dangerous event is unlikely and can happen once every 1-20 years) ; 3 points – a dangerous event is likely and occurs once a month-year); 4 points – a dangerous event will definitely occur, i.e. once a day-week); 5 points – a dangerous event occurs continuously 1 time per work shift; and for the severity of the consequences, where 1 point means no consequences, the ecological system has not been violated; 2 points – the consequences are not significant, the ecological system is violated; the period of self-recovery is less than a year); 3 points – the consequences are noticeable, the ecological system is disturbed; self-recovery period from one to three years); 4 points – significant consequences of the ecological system being violated; self-recovery period from three to ten years); 5 points – catastrophic consequences, the ecological system is irreversibly disturbed; there is no recovery period).

In the fifth step, we justify the precautionary measures in case of unacceptable level of risk for one or all components. Precautionary measures include the strengthening of industrial transformation and modernization, the promotion of ecosystem protection, as well as the development of nature reserves, the formation of important wetlands, the reduction of buildings, the creation of zones with an original vegetation system that forms an ecological barrier between industrial zone and living environment [39, 40].

At the sixth step, the total economic loss from environmental pollution is assessed. This is a rather complex task that requires the analysis of various data on the damage caused by pollution, the funds needed for restoration, as well as financial losses from indirect economic losses, etc. In general, the economic assessment of environmental costs (E) is calculated according to the formula [41, 42]:

$$E = E_c + E_d,$$

where E_c is the expenses for the creation of special measures; E_d is the environmental damage is the actual damage caused to the economy and the population after the implementation or because of the non-implementation of environmental protection measures in terms of value.

In the seventh step, risks are documented in the appropriate developed forms that allow monitoring the effectiveness of preventive measures, as well as the level of residual risk after preventive measures have been implemented [43].

At the eighth step, appropriate monitoring of the impact of the hazard on the environment is ensured, which should take place based on four main directions of action (systems, management, diversity, sustainability), three areas (the principle of environmental precautions, the principle of socio-cultural precautions, the principle of economic precautionary measures), ways of their application and working instructions [44].

4 Analysis of the cause-and-effect relationship between the environmental aspect and environmental risk on the example of the Bhopal tragedy

Let’s analyze the overall environmental risk from the Bhopal tragedy, which occurred in 1984 at the UCIL pesticide plant of the Union Carbide chemical corporation due to the

release of 42 tons of the toxic substance methyl isocyanate (MIC). This led to the death of more than 3.500 people and the pollution of an area of more than 70 km^2. The results of the above analysis are shown in Table 1 and Fig. 4. Data for analysis were taken from the following works (reference list below).

Table 1. Analysis of ecological and total economic consequences of the Bhopal tragedy.

Environ-mental aspect	Environmental hazard	Environmentally dangerous event	Physical effects of pollution	Economic consequences of pollution	General economic losses
To make a pest control insecticide called Sevin, the UCC company used the toxic gas methyl isocyanate, which was stored in special tanks dug into the ground	Methylisocyanate is highly toxiccolorless liquid with a sharp smell. Getting into the air, it turns into a vapor phase. Getting into the soil and water, it is hydrolyzed, and the hydrolysis products may include N-carboxymethylamine, methylamine, carbon dioxide, N′–dimethylurea	Release of 42 tons of methyl isocyanate (MIC) gas into the environment	*Air Pollution.* 42 tons of MIC got into the air, which in reaction with oxygen led to the release of hydrocyanic acid, carbon monoxide and carbon dioxide	470 million dollars. compensation awarded by UCC to victims of MIC poisoning	Economic damages from the accident included loss of employment, loss of earning capacity of victims, business disruption, compensa-tion and rehabilitation costs, and legal costs. The total value of all compensa-tion was 1.2 billion US dollars
			Soil pollution 12 chemical compounds were found – naphthol, naphthalene, sevin, tar residue, mercury, chromium, copper, nickel, lead, hexachloroethane, hexachlorobutadiene	It is reported that the company Eveready Industries India Limited spent 2 million dollars. for the construction of a safe landfill and evaporation ponds	
			Water pollution. Naphthol, naphthalene, sevin, resin residues, alpha-naphthol, mercury, chromium, copper, nickel, lead, hexachloroethane were found	3 million dollars was allocated by the Government of India for the incineration of waste that will remain at the site of the tragedy	
			Impact on wildlife. 3787 people died. About half a million people were poisoned	470 million dollars. compensation allocated by the company UCC for victims of MIC poisoning	

Among the main causes of the environmental disaster in Bhopal, experts attribute a number of reasons that are related to both inappropriate organizational culture and technical deficiencies in the production process. Unfortunately, at that time, a full assessment of the environmental aspects of UCC's activities was not carried out. At the same time, various organizations that had the opportunity to conduct audits of production process management

systems pointed out a number of shortcomings, the elimination of which would prevent the tragedy. For example, specialists from the University of California paid attention [45], that due to the reduction of financial costs, pipelines made of carbon steel were installed at the plant, instead of stainless steel, which would lead to corrosion processes more quickly. Also, a reduction in the number of protective devices was noted (one flare tower for the disposal of excess methyl isocyanate and one gas scrubber for air purification were installed, while at similar plants with a similar volume of insecticide production there were three such devices), which made it possible to save up to 6 million $ [45]. In addition, the safety devices installed in similar plants were controlled by automatic systems, including early detection of threats and non-conformities, whereas in Bhopal they were not installed [46, 47]. The given analysis shows that the owners of the UCC company acted in accordance with the requirements of the national legislation and had no desire to establish additional safety measures that would make such a disaster impossible. It can be assumed that no one foresaw the possibility of such an accident and such serious environmental consequences. At the very least, the lack of contingency planning supports the conclusion reached. It is interesting that the harbingers of the accident were a significant reduction of competent specialists and the lack of financial income for the renewal of production facilities in the last two years before the tragedy. Moreover, the management of the plant made a decision to continue operating the equipment beyond the design operating parameters [47 – 51].

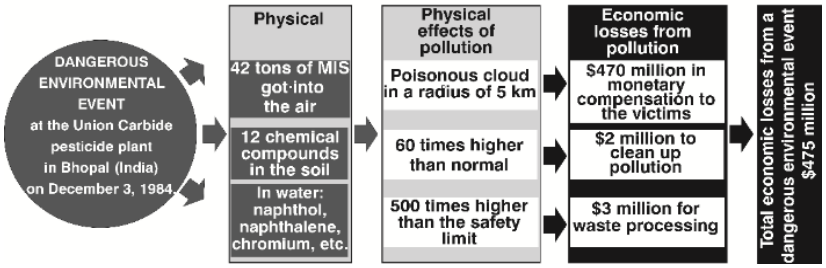

Fig. 4. Analysis of the ecological consequences of the Bhopal tragedy.

The results of the assessment of the chemical risk from hazards in the production of methyl isocyanate, taking into account the effect of the hazardous factor on the probability of occurrence of a hazardous event and/or on the safety of the consequences of a hazardous event, are shown in the Table 2.

The conducted surface analysis of the production of methyl isocyanate shows the presence of an unacceptable level of risk, which requires the introduction and constant support of preventive and protective measures. As shown by the preliminary analysis of environmental consequences (see Table 1), the amount of total economic losses suffered by the company, based on various lawsuits, amounted to a smaller amount than the costs of updating and maintaining in working order all safety systems of production equipment and technology. Of course, no one at that time considered the possible environmental damage, which was partially paid by the Indian government. Moreover, the consequences of the Bhopal tragedy are felt even now, although forty years have passed. In particular, experts note the presence of residual levels of pollution that exceed the norms and do not allow living in the territory near the plant within a radius of 5 – 7 km. Although, the new owners of the UCIL company indicate that this is because the Indian government has allowed a landfill of various industrial wastes that constantly pollute the ecosystem. Feedback from the accident is now noted on the increase in the number of diseases in the population.

Table 2. Identification of hazards, dangerous factors, analysis and assessment of the risk of danger from the production of methyl isocyanate.

Hazard No	Identification			Identification of dangerous factors	Analysis – determination of the level of negative risk for each dangerous factor and the overall negative risk of the hazard			
	Danger	Dangerous event	Negative consequences	Influence on the probability of occurrence of a dangerous event and/or on the severity of the consequences of a dangerous event from a dangerous factor	The probability of occurrence of a dangerous event from a dangerous factor	The degree of severity from the occurrence of a dangerous event from a dangerous factor	Level n of risk from a dangerous factor	Assessment of the negative risk of danger for each dangerous factor
1	methyl isocyanate	Release of methyl isocyanate (MIC) into the environment	Air, soil and water pollution by decay products methyl isocyanate	*Human factor:* staff incompetence due to layoffs, low pay, and cost savings	4	5	20	unacceptable
				The human factor: lack of equipment maintenance schedule and timely elimination of defects	4	5	20	unacceptable
				Technological factor: inadequate service tanks (errors in pressure gauge readings, lack of fuses, malfunction of indicators)	4	5	20	unacceptable
				Technological factor: failure of gas scrubber and flare tower due to untimely maintenance	4	5	20	unacceptable
				Technical factor: lack of tightness in the system due to valve aging, corrosion, malfunction	4	5	20	unacceptable
				Technical factor: failure of the cooling and ventilation system due to operation outside the established norms	3	5	15	unacceptable
				Organizational factor: lack of computerized monitoring systems for early detection of failures	3	5	15	unacceptable
				Organizational factor: lack of emergency planning procedures	3	5	15	unacceptable
				Climatic factor: high ambient temperature, which led to the need for additional cooling of the tanks	4	5	20	unacceptable
				General primary negative environmental risk – *Rj* of danger *j* from all *n* factors	*Bj*1 *Tj*1 + …. + *Bji Tji* + …+ *Bjn Tjn*		165	unacceptable

The main conclusion to be drawn from such disasters is, first of all, the development and improvement of national man-made and environmental safety requirements for its citizens. At the same time, each of the projects related to the construction of similar factories or the renewal of existing installations must undergo expert evaluation based on international standards.

5 Discussion

Adaptation of organizations to environmental risks includes the formation of their response to the actual or expected consequences of the implementation of environmental aspects that can form environmental hazards. For this, it is necessary to establish cause-and-effect relationships between environmental aspects and danger, which will allow to develop strategies to reduce their impact on the environment [52, 53].

Dangerous events from hazards that can occur under the influence of various dangerous factors will lead to financial costs for organizations or to strengthen environmental sustainability, that is, the ability to prevent a man-made accident or to adapt and eliminate

the consequences of an emergency [54, 55]. This raises an urgent question regarding the choice of the most effective direction. At first glance, of course, this is an increase in stability. At the same time, each type of financial assets can provide a different level of stability, which requires careful analysis to predict probable disasters [56 – 58]. Otherwise, the money spent will not allow you to get the appropriate tools to avoid dangerous events. For example, work [59, 60] shows that organizations affected by a natural disaster increase their investments in intangible research and development, reducing the costs of tangible capital. This will allow such organizations to avoid financial losses in the short term. However, whether this approach will work in the long term – as the climate is changing and new threats may arise, which also require appropriate research [61, 62]. On the other hand, by developing the sphere of adaptation, responding to emergency situations, organizations provide better flexibility in life support.

Based on the existing literature, we have identified two contrasting predictions regarding the impact of environmental risk on firms' investment decisions. The first prediction is the “disincentive to investment” effect, which suggests that environmental risks have a negative influence on investment activities. According to this perspective, the presence of environmental threats discourages firms from committing resources due to the heightened uncertainty and potential for loss. On the other hand, the second prediction, known as the “investment readiness” effect, posits that environmental risk might actually encourage investment. This view argues that the probability of facing a natural disaster could prompt firms to increase their investments as a precautionary measure. By investing, firms aim to better equip themselves to handle potential disruptions and maintain operational resilience. Therefore, these two perspectives offer competing views on how environmental risks might shape investment behavior among firms [63, 6].

Our first contribution to the study was to provide a thorough empirical assessment aimed at determining which of the two competing hypotheses holds greater validity. To achieve this, we conducted an analysis focused on how the environmental risks associated with the geographical regions where firms are located influence their investment costs [65]. Specifically, we explored whether these risks have a negative or positive impact on the investment decisions of firms operating within those areas. By examining this relationship, we sought to shed light on the extent to which environmental factors directly affect the financial decisions of businesses [64].

In addition to this, we also tested the hypothesis concerning the “environmental sustainability of green technologies”. This involved analyzing whether the relationship between investment and environmental risk differs based on how environmentally friendly a firm's sector is. Furthermore, we investigated the green awareness hypothesis by assessing whether the influence of technological ecology on firms' investment sensitivity to environmental risks has strengthened since the adoption of the Paris Agreement in 2015. This part of our study aimed to determine whether increased global awareness and commitment to environmental sustainability have had a tangible effect on the way firms respond to environmental risks in their investment strategies [64, 66].

As a result of the proposed risk management process, better coordination of actions within the organization is ensured, strengthening the synergistic effect, which consists in the fact that the overall result of coordinated actions is higher than the sum of individual results, this allows:

1) increase the competitiveness of the enterprise by increasing the level of its business reputation and the quality of management of the organization;

2) minimize the functional disconnection of personnel in the organization, which arises during the development of autonomous management systems;

3) ensure the functioning of integrated management systems with much less effort than the creation of several parallel systems;

4) ensure a balance of interests of the external parties of the organization than several systems that function in parallel;

5) to achieve greater "transparency" and manageability of the organization, because the number of internal and external connections in the integrated system is less than the total number of these connections in several systems;

6) reduce the total volume of documents in several parallel systems;

7) reduce conflict and the likelihood of possible contradictions between issues related to the economy, ecology and security, a more holistic approach to increasing profitability, more efficient use of resources, increasing the coherence of the process of information exchange, and preventing duplication of processes.

6 Conclusions

The cause-and-effect relationship between the environmental aspect and the environmental risk was determined, which occurs due to the critical accumulation of the results of the organization's activities on the environment, which can, under certain conditions, cause the occurrence of a dangerous event.

Developed a risk management algorithm from hazards that lead to losses from air, water, and soil pollution on the basis of the causal relationship between environmental hazard and environmental risk.

The cause-and-effect relationship between the environmental aspect and environmental risk was analyzed using the example of the Bhopal tragedy, which made it possible to establish environmental consequences of air, water and soil pollution, as well as general economic losses from the organization's activities.

References

1. Mamaikin, O., Sotskov, V., Demchenko, Y., & Prykhorchuk, O. (2018). Productive flows control in coal mines under the condition of diversification of production. *E3S Web of Conferences*, (60), 00008. https://doi.org/10.1051/e3sconf/20186000008
2. Dychkovskyi, R.O., Avdiushchenko, A.S., Falshtynskyi, V.S., & Saik, P.B. (2013). On the issue of estimation of the coal mine extraction area economic efficiency. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (4), 107-114.
3. Bazaluk, O., Ashcheulova, O., Mamaikin, O., Khorolskyi, A., Lozynskyi, V., & Saik, P. (2022). Innovative activities in the sphere of mining process management. *Frontiers in Environmental Science*, (10), 878977. https://doi.org/10.3389/fenvs.2022.878977
4. Mäkká, K., Kampová, K., Loveček, T., & Petrlová, K. (2021). An environmental risk assessment of filling stations using the principles of security management. A case study in the Slovak Republic. *Sustainability*, *13*(22), 12452. https://doi.org/10.3390/su132212452
5. Cao, S., Li, S., Duan, X., Zhang, Y., Gong, J., Guo, Q., Xu, X., Peng, L., & Meng, X. (2023). Environmental and behavioral factors in association with lung function impairment in children living in Wuhan, China. *International Journal of Environmental Research and Public Health*, *20*(2), 1134. https://doi.org/10.3390/ijerph20021134
6. Fomychov, V., Mamaikin, O., Demchenko, Y., Prykhorchuk, O., & Jarosz, J. (2018). Analysis of the efficiency of geomechanical model of mine working based on computational and field studies. *Mining of Mineral Deposits*, *12*(4), 46-55. https://doi.org/10.15407/mining12.04.046
7. Tulu, M.M., Mkiramweni, M.E., Hou, R., Feisso, S., & Younas, T. (2020). Influential nodes selection to enhance data dissemination in mobile social networks: A survey. *Journal of Network and Computer Applications*, (169), 102768. https://doi.org/10.1016/j.jnca.2020.102768

8. Mesquita, A.F., Gonçalves, F.J.M., Rocha, C.P., Marques, J.C., & Gonçalves, A.M.M. (2021). Biochemical effects of two pesticides in three different temperature scenarios on the diatom Thalassiosira weissflogii. *Processes*, *9*(7), 1247. https://doi.org/10.3390/pr9071247
9. Keizer, M.C.O., Flapper, S.D.P., & Teunter, R.H. (2017). Condition-based maintenance policies for systems with multiple dependent components: A review. *European Journal of Operational Research*, *261*(2), 405-420. https://doi.org/10.1016/j.ejor.2017.02.044
10. Ranke, J., & Meinecke, S. (2019). Error Models for the Kinetic Evaluation of Chemical Degradation Data. *Environments*, *6*(12), 124. https://doi.org/10.3390/environments6120124
11. Kemajl, Z., Stojance, M., Gzim, I., & Ledi, M.L. (2024). Comprehensive analysis of the mining accident forecasting and risk assessment methodologies: Case study – Stanterg Mine. *Mining of Mineral Deposits*, *18*(2), 11-17. https://doi.org/10.33271/mining18.02.011
12. Pylypenko, H.M., Pylypenko, Yu.I., Dubiei, Yu.V., Solianyk, L.G., Pazynich, Yu.M., Buketov, V., Smoliński, A., & Magdziarczyk, M. (2023). Social capital as a factor of innovative development. *Journal of Open Innovation: Technology, Market, and Complexity*, *9*(3), 100118. https://doi.org/10.1016/j.joitmc.2023.100118
13. Qu, M., Tian, Y., Liu, B., & Xu, D. (2023). Ecological risk assessment and impact factor analysis of ecological spatial patterns in coastal counties: Taking Dalian Pulandian district as an example. *Sustainability*, *15*(15), 11805. https://doi.org/10.3390/su151511805
14. Salli, S., Pochepov, V., & Mamaykin, O. (2014). Theoretical aspects of the potential technological schemes evaluation and their susceptibility to innovations. *Progressive Technologies of Coal, Coalbed Methane, and Ores Mining*, 491-496. https://doi.org/10.1201/b17547-81
15. Radosz, Ł., Chmura, D., Dyczko, A., & Woźniak, G. (2024). The abiotic habitat factors and soil carbon dioxide release under spontaneous vegetation in coal mine heaps. *Journal of Ecological Engineering*, *25*(6), 239-257. https://doi.org/10.12911/22998993/187382
16. Gao, L., Tao, F., Liu, R., Wang, Z., Leng, H., & Zhou, T. (2022). Multi-scenario simulation and ecological risk analysis of land use based on the PLUS model: A case study of Nanjing. *Sustainable Cities and Society*, (85), 104055. https://doi.org/10.1016/j.scs.2022.104055
17. Zhang, W., Chang, W. J., Zhu, Z. C., & Hui, Z. (2020). Landscape ecological risk assessment of Chinese coastal cities based on land use change. *Applied Geography*, (117), 102174. https://doi.org/10.1016/j.apgeog.2020.102174
18. Chmura, D., Jagodziński, A. M., Hutniczak, A., Dyczko, A., & Woźniak, G. (2022). Novel ecosystems in the urban-industrial landscape – interesting aspects of environmental knowledge requiring broadening: A review. *Sustainability*, *14*(17), 10829. https://doi.org/10.3390/su141710829
19. Guo, Y., Ma, X., Zhu, Y., Chen, D., & Zhang, H. (2023). Assessment of forest ecological security in China based on DPSIRM model: Taking 11 provincial administrative regions along the Yangtze river basin as examples. *ISPRS International Journal of Geo-Information*, *12*(7), 272. https://doi.org/10.3390/ijgi12070272
20. Błońska, A., Chmura, D., Hutniczak, A., Bakr, J., Wilczek, Z., Dyczko, A., Plewa, F., Sotek, Z., Popczyk, M., & Woźniak, G. (2024). Wetland vegetation of novel ecosystems as the biodiversity hotspots of the urban-industrial landscape. *Journal of Ecological Engineering*, *25*(7), 317-331. https://doi.org/10.12911/22998993/188902
21. Ryś, K., Chmura, D., Dyczko, A., & Woźniak, G. (2024). The Biomass Amount of Spontaneous Vegetation Concerning the Abiotic Habitat Conditions in Coal Mine Heaps as Novel Ecosystems. *Journal of Ecological Engineering*, *25*(5), 79-100. https://doi.org/10.12911/22998993/185586
22. Falshtynskyi, V., Dychkovskyi, R., Khomenko, O., & Kononenko, M. (2020). On the formation of a mine-based energy resource complex. *E3S Web of Conferences*, (201), 01020. https://doi.org/10.1051/e3sconf/202020101020
23. Magdziarczyk, M., Chmiela, A., Dychkovskyi, R., & Smoliński, A. (2024). The Cost Reduction Analysis of Green Hydrogen Production from Coal Mine Underground Water for Circular Economy. *Energies*, *17*(10), 2289. https://doi.org/10.3390/en17102289

24. Vladyko, O., Maltsev, D., Cabana, E.C., Shavarskyi, I., & Dychkovskyi, R. (2022). Formation of the models of mining enterprise management. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (3), 30-36. https://doi.org/10.33271/nvngu/2022-3/030
25. Nguyen, T.T., Grote, U., Neubacher, F., Rahut, D.B., Do, M.H., & Gokul, P.P. (2023). Security risks from climate change and environmental degradation: implications for sustainable land use transformation in the Global South. *Current Opinion in Environmental Sustainability*, (63), 101322. https://doi.org/10.1016/j.cosust.2023.101322
26. Salli, S., & Mamajkin, O. (2012). Ecological aspects of the quantitative assessment of productive streams of coal mines. *Geomechanical Processes During Underground Mining – Proceedings of the School of Underground Mining*, 115-118. https://doi.org/10.1201/b13157-21
27. Tsopa, V., Cheberiachko, S., Yavorska, O., Deryugin, O., & Bas, I. (2022). Increasing the safety of the transport process by minimizing the professional risk of a dump truck driver. *Mining of Mineral Deposits*, *16*(3), 101-108. https://doi.org/10.33271/mining16.03.101
28. Castanier, B., Grall, A., & Bérenguer, C. (2005). A condition-based maintenance policy with non-periodic inspections for a two-unit series system. *Reliability Engineering & System Safety*, *87*(1), 109-120. https://doi.org/10.1016/j.ress.2004.04.013
29. Polyanska, A., Pazynich, Y., Mykhailyshyn, K., Babets, D., & Toś, P. (2024). Aspects of energy efficiency management for rational energy resource utilization. *Rudarsko-Geološko-Naftni Zbornik*, *39*(3), 13-26. https://doi.org/10.17794/rgn.2024.3.2
30. Sári, D., Ferroudj, A., Semsey, D., El-Ramady, H., Brevik, E.C., & Prokisch, J. (2024). Tellurium and Nano-Tellurium: Medicine or Poison? *Nanomaterials*, *14*(8), 670. https://doi.org/10.3390/nano14080670
31. Salli, S., Mamaykin, O., & Smolanov, S. (2013). Inner potential of technological networks of coal mines. *Annual Scientific-Technical Collection – Mining of Mineral Deposits 2013*, 243-246. https://doi.org/10.1201/b16354-45
32. Thrippleton, T., Temperli, C., Krumm, F., Mey, R., Zell, J., Stroheker, S., Gossner, MM, Bebi, P., Thürig, E., & Schweier, J. (2023). Balancing disturbance risk and ecosystem service provisioning in Swiss mountain forests: an increasing challenge under climate change. *Regional Environmental Change*, (23), 29. https://doi.org/10.1007/s10113-022-02015-w
33. Yi, C., & Jackson, N. (2021). A review of measuring ecosystem resilience to disturbance. *Environmental Research Letters*, (16), 053008. https://doi.org/10.1088/1748-9326/abdf09
34. Gaiser, E.E., Bell, D.M., Castorani, M.C.N., Childers, D.L., Groffman, P.M., Jackson, C.R., Kominoski, J.S., Peters, D.P.C., Pickett, S.T.A., Ripplinger, J., & Zinnert, J.C. (2020). Long-term ecological research and evolving frameworks of disturbance ecology. *BioScience*, *70*(2), 141-156. https://doi.org/10.1093/biosci/biz162
35. Tsopa, V.A., Cheberiachko, S.I., Yavorska, O.O., Deryugin, O.V., & Aleksieiev, A.A. (2022). Improvement of the safe work system. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 104-111. https://doi.org/10.33271/nvngu/2022-6/104
36. Simonaitis, A., Daukšys, M., & Mockienė, J. (2023). A Comparison of the project management methodologies PRINCE2 and PMBOK in managing repetitive construction projects. *Buildings*, *13*(7), 1796. https://doi.org/10.3390/buildings13071796
37. Bazaluk, O., Tsopa, V., Cheberiachko, S., Deryugin, O., Radchuk, D., Borovytskyi, O., & Lozynskyi, V. (2023). Ergonomic risk management process for safety and health at work. *Frontiers in Public Health*, (11), 1253141. https://doi.org/10.3389/fpubh.2023.1253141
38. Bazaluk, O., Tsopa, V., Okrasa, M., Pavlychenko, A., Cheberiachko, S., Yavorska, O., Deryugin, O., & Lozynskyi, V. (2024). Improvement of the occupational risk management process in the work safety system of the enterprise. *Frontiers in Public Health*, (11), 1330430. https://doi.org/10.3389/fpubh.2023.1330430
39. Lu, Y., Li, Y., Fang, G., Deng, M., & Sun, C. (2023). Ecological risk assessment and management for riverfront development along the Yangtze River in Jiangsu Province, China. *Ecological Indicators*, (155), 111075. https://doi.org/10.1016/j.ecolind.2023.111075

40. Fu, M., Liu, S., Jia, H., & He, D. (2020). Experimental study of an orientation and resin-lifting device for improving the performance of resin-anchored roof bolts. *Rock Mechanics and Rock Engineering*, *53*(1), 211-231. https://doi.org/10.1007/s00603-019-01906-5
41. Hernández-Pérez, L.G., Villicaña-García, E., Cansino-Loeza, B., Alsuhaibani, AS, El-Halwagi, M.M., & Ponce-Ortega, J.M. (2022). Incorporating the occupational health in the optimization for the methanol process. *Journal of Loss Prevention in the Process Industries*, (74), 104660. https://doi.org/10.1016/j.jlp.2021.104660
42. Zhai, Y., Jiang, Y., Cao, X., Leng, S., & Wang, J. (2022). Valuation of ecosystem damage induced by soil-groundwater pollution in an arid climate area: Framework, method and case study. *Environmental Research*, (211), 113013. https://doi.org/10.1016/j.envres.2022.113013
43. Petrović, M.D., Milovanović, I., Gajić, T., Kholina, V.N., Vujičić, M., Blešić, I., Đoković, F., Radovanović, M.M., Ćurčić, N.B., Rahmat, A.F., Muzdybayeva, K., Kubesova, G., Koshkimbayeva, U., & Dávid, L.D. (2023). The Degree of Environmental Risk and Attractiveness as a Criterion for Visiting a Tourist Destination. *Sustainability*, *15*(19), 14215. https://doi.org/10.3390/su151914215
44. Cheberiachko, S., Yavorska, O., Deryugin, O., Lantukh, D., Bas, I., Kruzhilko, O., & Melnyk, V. (2023). Improving safety of passenger road transportation. *Transactions on Transport Sciences*, *14*(2), 11-20. https://doi.org/10.5507/tots.2023.003
45. Labib, A.W., & Champaneri, R. (2012). The Bhopal Disaster – learning from failures and evaluating risk. *Maintenance & Asset Management*, *27*(3), 41-47. https://doi.org/10.1016/B978-0-12-416727-8.00004-7
46. Dudek, M. (2012). Utilisation of simulation modelling to coordinate of distributed logistic resources. *Congress Proceedings – CLC 2012: Carpathian Logistics Congress*, 151-159.
47. Bazaluk, O., Pavlychenko, A., Yavorska, O., Nesterova, O., Cheberiachko, S., Deryugin, O., & Lozynskyi, V. (2024). Improving the risk management process in quality management systems of higher education. *Scientific Reports*, (14), 3977. https://doi.org/10.1038/s41598-024-53455-9
48. Polyanska, A., Cichoń, D., Verbovska, L., Dudek, M., Sala, D., & Martynets, V. (2022). Waste management skills formation in modern conditions: the example of Ukraine. *Financial and Credit Activity: Problems of Theory and Practice*, *4*(45), 322-334. https://doi.org/10.55643/fcaptp.4.45.2022.3814
49. Feria-Domínguez, J.M., Jiménez-Rodríguez, E., & Merino Fdez-Galiano, I. (2016). Financial perceptions on oil spill disasters: isolating corporate reputational risk. *Sustainability*, *8*(11), 1090. https://doi.org/10.3390/su8111090
50. Garver, G. (2013). The rule of ecological law: the legal complement to degrowth economics. *Sustainability*, *5*(1), 316-337. https://doi.org/10.3390/su5010316
51. Hellweg, S., & Milà i Canals, L. (2014). Emerging approaches, challenges and opportunities in life cycle assessment. *Science*, *344*(6188), 1109-1113. https://doi.org/10.1126/science.1248361
52. Khorolskyi, A., Hrinov, V., Mamaikin, O., & Demchenko, Y. (2019). Models and methods to make decisions while mining production scheduling. *Mining of Mineral Deposits*, *13*(4), 53-62. https://doi.org/10.33271/mining13.04.053
53. Shogelova, N., & Sartin, S. (2023). Earth remote sensing application for forest fire size, burn state and fire recovery. *Engineering Journal of Satbayev University*, *145*(3), 31-39. https://doi.org/10.51301/ejsu.2023.i3.05
54. Portnov, V.S., Yurov, V.M., Maussymbayeva, A.D., Kassymov, S.S., & Zholmagambetov, N.R. (2017). Assessment of radiation risk at the population from pits, dumps and tailing dams of uranium mines. *International Journal of Mining, Reclamation and Environment*, *31*(3), 205-211. https://doi.org/10.1080/17480930.2016.1268801
55. Cherniaiev, O., Anisimov, O., Dreshpak, O., & Borodina, N. (2024). Substantiation the safety open pit wall parameters in the conditions of a reduced protective zone near State critical infrastructure. *E3S Web of Conferences*, (526), 01014. https://doi.org/10.1051/e3sconf/202452601014

56. Cheberyachko, S., Deryugin, O., Tretyak, O., & Dusmatova, O. (2020). Assessment of the risks of occupational diseases of the passenger bus drivers. *Safety and Health at Work*, *11*(4), 543-549. https://doi.org/10.1016/j.shaw.2020.07.005
57. Sarybayev, O., Nurpeisova, M., Kyrgizbayeva, G., & Toleyov, B. (2015). Rock mass assessment for man-made disaster risk management. *New Developments in Mining Engineering 2015: Theoretical and Practical Solutions of Mineral Resources Mining*, 403-409. https://doi.org/10.1201/b19901-69
58. Bochkovskyi, A.P., & Sapozhnikova, N.Yu. (2021). Development of system of automated occupational health and safety management in enterprises. *Journal of Achievements in Materials and Manufacturing Engineering*, *107*(1), 28-41. https://doi.org/10.5604/01.3001.0015.2454
59. Bochkovskyi, A., & Sapozhnikova, N. (2019). Minimization of the "human factor" influence in occupational health and safety. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 95-106. https://doi.org/10.29202/nvngu/2019-6/14
60. Lewicka, D., Zarębska, J., Batko, R., Tarczydło, B., Woźniak, M., Cichoń, D., & Pec, M. (2023). *Circular Economy in the European Union.* Circular Economy in the European Union: Organisational Practice and Future Directions in Germany, Poland and Spain, 21-267 https://doi.org/10.4324/9781003411239
61. Yang, D., Zhao, J., Suhail, S.A., Ahmad, W., Kamiński, P., Dyczko, A., Salmi, A., & Mohamed, A. (2022). Investigating the ultrasonic pulse velocity of concrete containing waste marble dust and its estimation using artificial intelligence. *Materials*, *15*(12), 4311. https://doi.org/10.3390/ma15124311
62. Bieda, B., Skalna, I., Gaweł, B., Grzesik, K., Henclik, A., & Sala, D. (2018). Life cycle inventory processes of the integrated steel plant (ISP) in Krakow, Poland-continuous casting of steel (CCS): a case study. *The International Journal of Life Cycle Assessment*, *23*(6), 1274-1285. https://doi.org/10.1007/s11367-017-1365-0
63. Mignan, A., & Wang, Z. (2020). Exploring the space of possibilities in cascading disasters with catastrophe dynamics. *International Journal of Environmental Research and Public Health*, *17*(19), 7317. https://doi.org/10.3390/ijerph17197317
64. Oliviero, T., Rondinella, S., & Zazzaro, A. (2024). Green firms, environmental hazards, and investment. *Sustainability*, *16*(2), 542. https://doi.org/10.3390/su16020542
65. Tabachenko, M., Saik, P., Lozynskyi, V., Falshtynskyi, V., & Dychkovskyi, R. (2016). Features of setting up a complex, combined and zero-waste gasifier plant. *Mining of Mineral Deposits*, *10*(3), 37-45. https://doi.org/10.15407/mining10.03.037
66. Noy, I., & Strobl, E. (2023). Creatively destructive hurricanes: do disasters spark innovation? *Environmental and Resource Economics*, (84), 1-17. https://doi.org/10.1007/s10640-022-00706-w