Ocean Journal of Chemical and Petroleum Engineering

Review Article

Comparative study of the Methods Used For the Risk Analysis of Emergency Water Pollution Accidents

Michail Chalaris[1*], Alexandros Giannopoulos[2], Georgia Koufioti[2], Nikolaos Stasinopoulos[1] Anastasia Tezari[1]

[1]Hephaestus Advanced research Laboratory, Department of Chemistry, School of Science, International Hellenic University, St Lucas 65404, Kavala, Greece

[2]MSc in Analysis and Management of Manmade and Natural Disasters, International Hellenic University – Hellenic Fire Academy, St Lucas 65404, Kavala, Greece

ABSTRACT

In this paper an attempt is made to compare several methods used for the purpose of risk analysis in cases of water pollution emergencies. The importance of the existence of quality assurance and quality control programs is highlighted. The risk management protocols frequently used for such purposes are thoroughly analyzed and discussed. Various methods aiming to the identification and evaluation of risks are demonstrated, such as the Bayesian formula, the Mort-method, the Geographic Information System, and the Fuzzy fault tree analysis (FFTA). Action recommendations in order to avoid as much as possible the catastrophic consequences of an accident in the aquatic environment are provided.

Keywords: Risk analysis; Accident; Risk management; Water pollution; Risk management protocols

---

Citation: *Chalaris M, Giannopoulos A, Koufioti G, Stasinopoulos N, Tezari A. Comparative study of the Methods Used For the Risk Analysis of Emergency Water Pollution Accidents. Oce Che Pet Eng Jour. 2021; 1(1):1-19.*

Received Date: 29 November, 2021; **Accepted Date:** December 3, 2021; **Published Date:** December 8, 2021

[*]Corresponding author: Michail Chalaris**,** Hephaestus Advanced research Laboratory, Department of Chemistry, School of Science, International Hellenic University, St Lucas 65404, Kavala, Greece

---

INTRODUCTION

Emergent water pollution accidents vary particularly on the basis of sources, levels, timeframe and location of pollution.[1] Due to the climate conditions, several human factors as well as technological flaws, a significant amount of environmental devastation, financial losses and deaths has taken place.[2, 3] This is enhanced by both spills and explosions in oil tankers and the chemical industry and improper chemical usage.

Emerging water pollution is an activity that creates water contamination and acts as a driver for potential damage to human health, financial and property loss, and socioeconomic detrimental effects. This is due to plenty socio economic activities, subsidiary factors and emerging natural disasters which frequently violate the regulations regarding water resource protection.[4-6] The specific conversations and already existing adaptation mechanisms in response to the unexpected water contamination event are quite ineffective and poor. At the moment, most water pollution research focuses on post-incident emergency evaluations, while studies on identification and assessment of risks are quite scarce. The methodologies utilized in these studies were largely referenced from other disciplines, such as preliminary risk analysis method, fault tree analysis method, and event tree analysis method, with the fault tree analysis method receiving the most widespread use.[7,8] Fault Tree Analysis is a well-known approach of unpredictable risk analysis that is widely used for anticipating the likelihood of emergencies and preparedness for decision making.[9-11]

The maritime risk is defined as the result of the probability of an accident occurring and its impact according to the International Maritime Organization (IMO). That is,

Accident Risk = (Accident Probability) x (Accident Impact)

The hazard study aimed to determine the relative risk of various geographical locations, types of accidents, and ship classifications. It did not consider existing controls, even though they were computed throughout the risk management process.

The impact of an accident may be determined if one examines the sensitivity parameters. Accident impact is determined by examining the sensitivity parameters. These include:[12]

- Special Natural Areas, such as protected areas, important habitat areas and bird marine mammal habitats, coastal nature gardens, sea grasses, and cultural areas.[13-14]

- Special Industrial Areas, such as fishing shelters, enclosed fishing areas and sea fishing areas, fishermen ports, factories and refineries, power plants, cargo and containers, shipyards, submarine power cables, recreational and touristic facilities).

The way ships and crews interact with technology is a major element in maritime accidents. The most effective way of technology integration is through training and data, which when used properly after proper training can improve shipping safety[15].

New technologies are increasingly invading shipping and especially maritime accidents. According to[16] the Automatic Identification System (AIS), which is installed on most of the ships today, is mainly in use for real-time tracking of ships.

This can be used in order to record accidents data and rates or be applied in parallel with other tools used generally in the transport industry. Such values are useful for the comparison of ship categories as well as for the monitoring of statistics regarding accidents over time. However, a full understanding of the types of ships and their activities is required-for the suitable activity measures selection. Also, through triangulation and by using different normalization forms, a combined analysis of the available results may provide a better understanding of the statistical causes of events.[16]

According to,[17] the Human Factors Analysis and Classification System (HFACS) method presents a simplified conceptual structure for the analysis and classification of the human error during a maritime accident, while the Analytical Network Process (ANP) technique provides a quantification of the accidents causes and providing a correlation between them. Thus, the most important causes of a maritime accident are investigated and analyzed numerically.[17]

In an emergency, the ultimate aim is to identify and implement suitable actions to decrease the possibility or impact, or both, to a level that the management team is ready to accept. There is also the potential that the impact will be minimal. So, in this instance, the management team's decision to do nothing and accept some risks may be quite fair. Whatever technique is used, the aim remains the same: the risk is taken via our behaviors.

According to,[18] inadvertent leaks of gasoline or lubricating oil into the engine room cause 31% of fires and explosions. Because ship fuels are very combustible, it is important to consider the safety features of alternate fuels. Locating combustible items and replacing them with less dangerous materials can help to lessen the risk of fire and explosion on board. It has been discovered that liquefied natural gas (LNG), cryogenic natural gas (CrNG), and methanol present characteristics that are more appropriate for fire risk mitigation than traditional fuels, and that effective risk management might may turn them into a safer alternative to traditionally used fuels.[18]

Inadequate maintenance, in addition to fuel, is one of the leading causes of fires and explosions; about 30-40% of all accidents and incidents are caused by maintenance-related issues. Explosion accounted for 44% of the 80 significant maintenance-related accidents, while fire accounted for 34%[19].

Ship-to-ship collision risk analysis has received increasing attention by the scientific community, as it provides accurate and quantitative insights and results for risk assessment and mitigation combined with impact assessment.[20] According to the research of[21] the ships General Cargo and Car Carrier show the greatest rates of ship losses from the collision. Reefer vessels, fishing vessels and bulk carriers, fishing vessels and Reefer vessels present a relatively low frequency of such losses, while other types of vessels have minor prices.[21]

The possibility of a collision of two ships consists of two cases:

(1) "geometric collision probability". This describes the collision probability of of ships or the frequency of a collision with another candidate within a specified timeframe, which is also known as “almost miss” (e.g.[22]) to academics and practitioners.

(2) Probability of cause. This describes the collision possibility due to unpredictable circumstances, such as mechanical failure, human reliability, human and organizational factors, etc.

Based on the results of a recent research on several methods and programs which are installed on most ships today, the probability of an accident remains high. They can be used to record accident data at accident rates or rates in parallel with those used in other transportation industries.[23]

AIM AND METHODOLOGICAL APPROACH OF THE STUDY

In a country where marine and tourist growth is a significant component of the economy, such as Greece, a study to prevent mishaps using chemical agents is required.[6] Because of its geographical position and rapid economic growth, Greek seas are vulnerable at any moment to a marine catastrophe that may result in an ecological disaster, causing harm to the country's various fragile ecosystems. As a result, accident risk analysis is a critical tool that may predict the likelihood of an accident, as well as its early treatment and mitigation of its consequences if one occurs.[12] When one considers the devastating repercussions of worldwide marine catastrophes, one realizes the need and usefulness of such a study.

Chemical agent risk analysis[24] entails risk assessment and risk management.[14] The first part is concerned with activities for identifying and assessing risk in order to take preventative action against an accident, while the second is concerned with dealing with it and restoring the environment to its former condition in the event of a genuine disaster.

THE SIGNIFICANCE OF QUALITY ASSURANCE AND QUALITY CONTROL PROGRAMS

Quality assurance and quality control programs require that every laboratory adhere to a set of well-defined rules in order to obtain high-accuracy analytical findings. The concept quality assurance refers to a set of standards that are established, recorded, and carefully followed in order therefore for accuracy of the findings of analysis to be declared with a high degree of confidence and to be legally defensible. The quality assurance strategy comprises record of sampling events, sample reception in the laboratory, and sample relinquishment to the appropriate personnel who execute the analysis. All of these occurrences are documented on chain-of-custody forms, which include dates and times, as well as the names and signatures of the person in control in accordance with the responsibilities. Quality control is also part of the strategy in a wider context.[25]

Many organizations will want to determine how likely it is that a risk event will occur. There are many ways for doing these quantitative assessments. The most frequently used are risk and function studies (HAZOP), and failure mode and effects analysis (FMEA).[26] Both of these strategies are methodical processes that guarantee no hazards are overlooked.

However, in order to conduct an appropriate quantitative study, a diverse group of specialists must be included.[5]

In repair operations, HAZOP and FMEA procedures are more easily used. HAZOP investigations are frequently performed in hazardous chemical facilities and complicated transportation infrastructure like as railroads. HAZOP analyses of complicated installations, like as nuclear power plants, are also conducted on a regular basis. They can also be used to assess the safety of a product. In all cases, they are highly comprehensive and time-consuming techniques, but they will be required in a variety of situations.[27]

Risk assessment seems to be a decision-making tool. An adequate risk analysis provides information important to successful decision making and will frequently elucidate the decision to be addressed. Risk assessment information is frequently shared to the business to assist impacted parties in understanding the elements affecting the decision.

Risk assessment must be carried out in a methodical manner. These steps include the hazard identification, the frequency assessment, the consequence assessment, and finally the risk assessment. The amount of required information to make a choice may vary significantly.[28]

In reality, eleven procedures may be used in the chemical industry in order to perform hazard assessment. These are the following: checklists, relative ranking, safety review, human-error analysis, “what if” analysis, preliminary hazard analysis, failure modes, effects, and criticality analysis (FMEA), hazard and operability studies (HAZOP), cause-consequence analysis, fault tree analysis and event tree analysis.

RISK MANAGEMENT PROTOCOLS

A variety of risk management procedures or recommendations must be developed, and a typical protocols selection is shown in Figure. The risk protocols go into further detail on how they should be provided and interpreted. Risk management protocols may be thought of as standing guidelines for risk management.[29] They will frequently necessitate the keeping of records, such as the risk register. The risk assessment methods, together with the risk control goals, the risk resourcing arrangements, the reaction planning needs and the risk assurance systems will be described in the risk management protocols or guidelines.[5]

Figure 1: Risk management protocols

As an example, it may be presented the following (Table 1) of the study of Shi et al, referring to the risk analysis indesystem for river chemical spills.[30]

Table 1: The risk assessment index system of emergency disposal projects.[30]

The period of making emergency disposal plan	The reliability of emergency monitoring and early warning	The reliability of the emergency monitoring network can be expressed by the reliability index (100%, 80%, 60% and the following)
	The possibility of surrounding factors effect on the project	The water periods, the location of the project, and the reliability of tall module support and scaffolding system
	The possibility of a pollution loads greater than the engineering load	The pollutants' type, the pollutant exceeding multiple, the pollutant toxicity level, and the pollutant hazard properties
	The risk of failure when choosing emergency disposal technology	The emergency disposal technology timeliness, the implementation difficulty, and the emergency supplies reserves
The period of constructing emergency disposal project	The possibility of natural environment alterations	Earthquake, landslide, typhoon, flood, fires, subsidence, fires and poor geological conditions
	The risk of failure for con-	The coordination of contractors, designers and owners,

	struction organization	internal organization and coordination, and logistic support
	The risk of failure for construction technology	The construction technological uncertainty, equipment mismatch, installation error, problems with use, material loss and supply, and construction delays
The period of operating emergency disposal project	The failure risk of engineering operation	The maaterial characteristics, the equipment reliability and the defect detection.
	The subsequent environmental impact risks	The water economic activity with a long-term negative impact on human health and the environment.
	The harmless process risk	The treatment of materials and equipment in a harmless manner, as well as the river sediment treatment

The subjective calculation is based on subjective expert judgments of the risk factors and is used when there is a dearth of historical data or when quantifying the risk is usually difficult. In these instances, to avoid the problem of a lack of data, specialists' know-how (both theoretical and practical knowledge) is employed, which, when combined with the evaluation of external environmental variables, results in risk assessments. Quantitative Risk Assessment is the most often used statistical approach for statistically processing data from incidents involving hazardous goods vehicles and calculating the occurrence of similar events in the future. The risk is considered to be equal to the product of the chance of occurrence and the consequences in this technique. Although this approach is simple to use, its main disadvantage, which impacts its accuracy and dependability, is a lack of precise data (historical data) on traffic accidents involving dangerous products. This lack is primarily due to the nature of these accidents being rare (it takes a large number of years to record these accidents in order to obtain a significant statistical sample for analysis) as well as a lack of details regarding these accidents (exact location of the accident, traffic and weather conditions, type of goods, mode of transport), resulting in the collected data being incomplete.

The Bayesian Formula

The Bayesian Network technique is founded on the Bayesian formula. It displays the interrelationship of the prior and posterior probability respectively and may utilize the current prior probability to calculate the particular likelihood of accident[31]. This method is commonly used in uncertainty analysis. BBNs enable the modification of a formal risk description. This concept has been widely utilized in the marine industry for risk assessment and management.[32,33] These probabilistic techniques provide a full reflection of the existing knowledge about the phenomenon under consideration, as well as its comprehension. The probability of event A under the condition of event B is stated as follow (Figure 2)[34, 35]:

$$P\left(\frac{A}{B}\right) = \frac{P(\frac{B}{A}) \times P(A)}{P(B)}$$

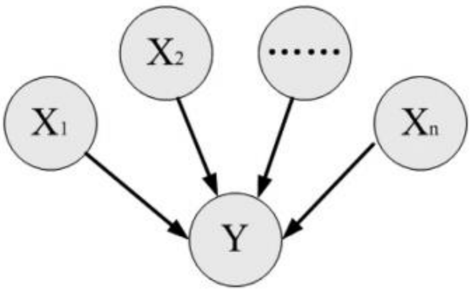

Figure 2: Bayesian Network[36]

Mort Method

The Management Oversight and Risk Tree (MORT) is an approach for analyzing the causation and all the contributing variables.[37] Accidents are described as “unplanned events that cause hurt or damage, i.e. losses" in MORT. [37] When a hazardous substance gets into interaction with a person or an asset, an effect arises. This connection can take place as a result of a failure to prevent or as an adverse but acceptable result of a risk that has been appropriately identified and addressed (an ‘‘assumed risk"). Before examining the ‘‘assumed risk" hypothesis, MORT analysis without exception examines the ‘‘failure" path. The majority of the effort in MORT analysis is aimed on finding issues in the management of a process and shortcomings in the preventive barriers connected to that as well. These issues are then investigated to see where they originated in terms of planning, design, policy, and so on. To utilize MORT, first identify important episodes in the chain of events; each incident may be defined as: a vulnerable target subjected to a harmful agent in the absence of appropriate barriers. [38]

MORT analysis may be used to all the recognized episodes; the decision held upon the circumstances of the research. Users will have to conduct an ‘‘Energy Trace and Barrier Analysis" to pinpoint these critical occurrences (Figure 3). MORT analysis may be focused thanks to barrier analysis; without it, even a cursory use of MORT is difficult.[37]

The Geographic Information System

The GIS is a spatial data managing system, taking into account all the characteristics associated with it. It is, in its most basic form, a digital system aimed at integrating, storing, adapting, analyzing, manipulating, and displaying spatially linked data. In a broader sense, a GSP is a "smart map" tool that enables the capture of an overview of the world as it actually is, creates interactive spatial or descriptive user-generated queries, analyzes spatial data, and adapts and renders them in analog media, such as printing maps and diagrams, or digital media, such as spatial data files and interactive maps. [39]

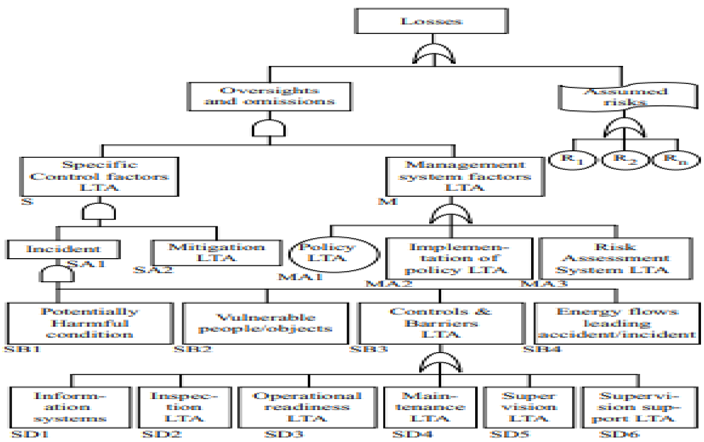

Figure 3: Basic MORT structure[38]

GIS and CAD systems both collect spatial data in various coordinate systems(geographic, cartographic, Cartesian). A major characteristic of GSPs is that geographic data can be linked to a descriptive set of data (Figure 4). For example, a set of points indicating different locations in a city is directly linked to a table in which each item, besides the location, provides information such as the name, the population, etc.[40, 8]

The linking of geographical and descriptive information is a distinguishing feature given by GIS (which does not have a spatial substance in itself). This function is powered by the following technology (Figure 5):

- In the relational data architecture, descriptive data is tabulated independently and then connected with geographical data via certain unique values shared by both data classes.
- Either in the object-oriented data model, where both geographical and descriptive data are integrated into objects that can describe some physical objects, or in the relational data model.

The object-oriented paradigm is becoming more popular in GIS applications due to its superior capabilities over the relational model, which allows for the straightforward and simplified modeling of complex natural processes and objects with spatial dimensions.

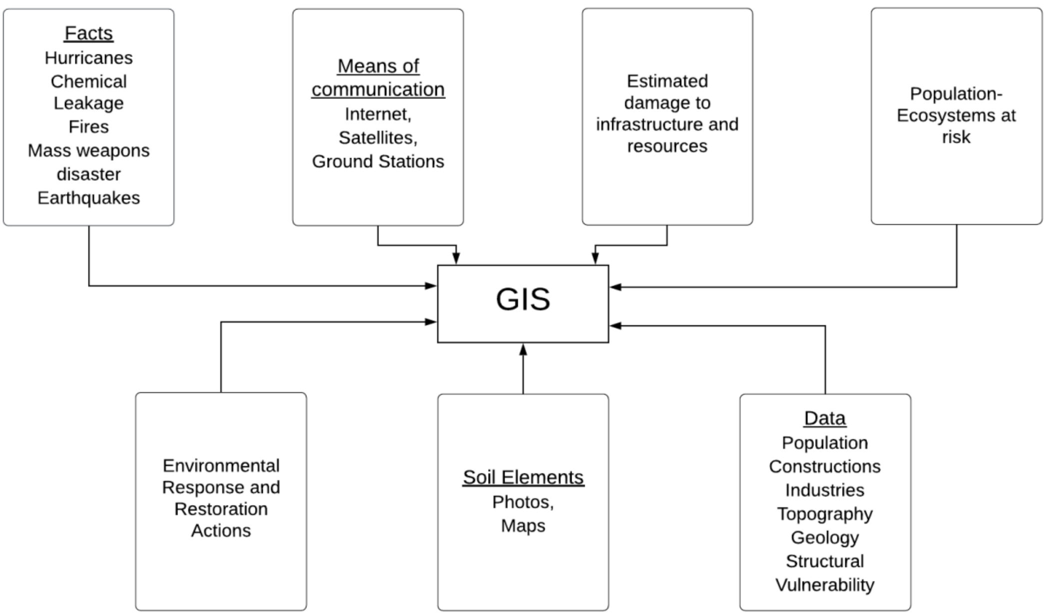

Figure 4: The parameters of the GIS.

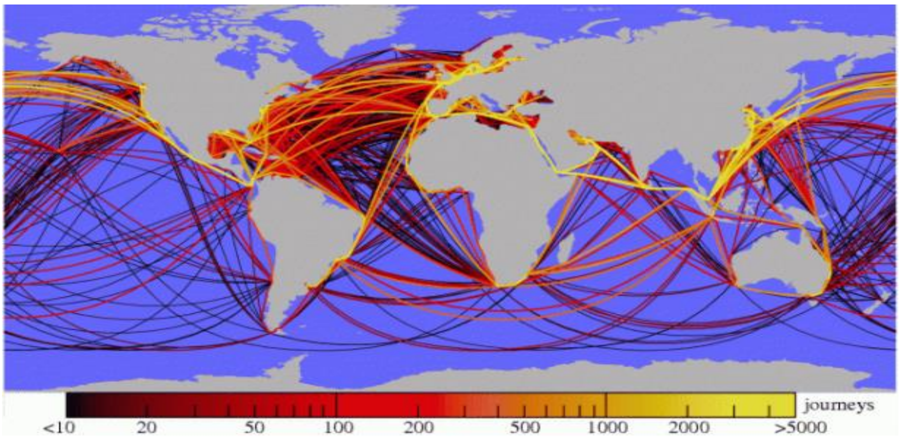

Figure 5: Number of transits for various routes of global shipping in one year, as mapped with GPS.[41]

Fuzzy fault tree analysis (FFTA) assessment process

Fuzzy fault tree analysis (FFTA) is a methodical procedure for identifying possible reasons of system failure.[42, 43] A fault tree depicts the interconnections between various events using logical gates and the possible ways these interactions might lead to a failure of the system.[44, 45] Experts with differing perspectives on the occurrences may reach differing conclusions based on their knowledge and expertise. Seven qualitative words have been established to rank the likelihoods of fundamental event failures from least likely to most probable.[46] According to Miller (1956), the typical estimation of the human brain is seven plus-minus chunks, which means that the amount of linguistic terms in need to be established is five tonineín order to make proper estimations as well as assessment of every expert subjective of basic event failure potentials, based on the current seven qualitative linguistic terms.[47, 30] This is also a fuzzy number given by

M~ = ¼ R~L~ (*Risk Analysis of Water Pollution Second, Revised and Expanded Edition*, n.d.)

A fault tree is a flowchart that represents the logical sequence of those events (key events) that are capable and necessary to trigger a specific event (top event). The peak event is usually the critical event in a possible accident scenario such as e.g. explosion or spillage of toxic material. A complete error tree consists of key events that are linked through intermediate events (Figure 6). To calculate the probability of a peak event, the basic principles of probability are used.

Let A and B be two events of a sample space. Then the relation P (A∪ B) = P (A) + P (B) - P (A∩ B) is valid. The aim in designing industrial units is for A and B to be independent events (ie the appearance of one does not affect the appearance of the other), in which case P (A∩ B) = P (A) P (B). In fact, if the probabilities P (A) and P (B) are low, then the product P (A) P (B) can be completely omitted, finally taking a good approximation of the probability P (A∪ B).

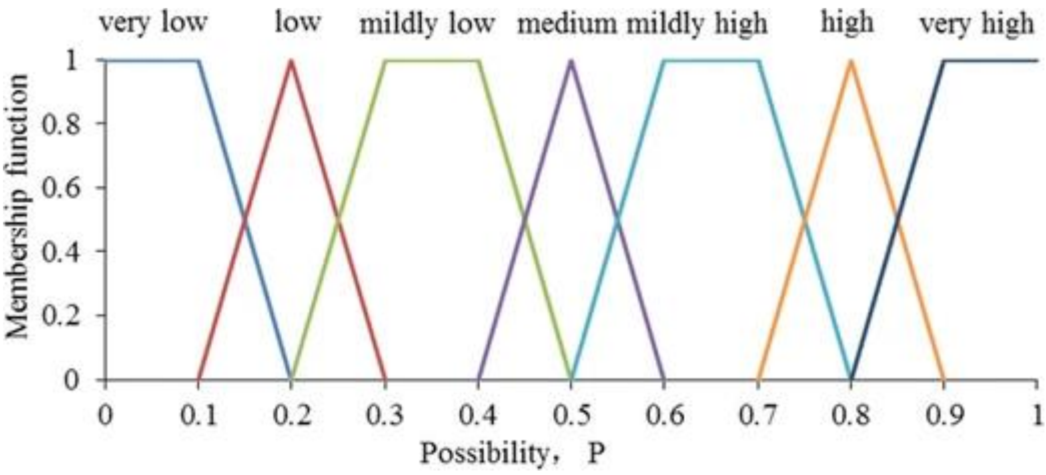

Figure 6: Fuzzy numbers representing linguistic values.[30]

CONCLUSION

The relevance and usefulness of the risk assessment process and the availability of a contingency plan are considerable because they can help avoid and discourage risk, and if it does occur, they may reduce its consequences and provide proper treatment, saving time and money and perhaps saving lives. It is required not just in situations of environmental risk assessment and catastrophe prevention, but also in every business, area of health, government agencies, and, in general, in every agency and organization of the contemporary economy.

In this work we compare several methods used for the purpose of risk analysis in cases of water pollution emergencies. The risk management protocols frequently used for such purposes are thoroughly analyzed and discussed. Various methods aiming to the identification and evaluation of risks are demonstrated, such as the Bayesian formula, the Mort method, the Geographic Information System, and the Fuzzy fault tree analysis (FFTA). Action recommendations to avoid as much as possible the catastrophic consequences of an accident in the aquatic environment are provided. Aside from the disastrous effects that a chemical agent accident may have on the environment of the specific region or on its value as a social and / or a touristic area, it is a reality, as demonstrated above, that decontamination is highly costly. Effective activities need meticulous preparation, regular monitoring and assessment, a great number of skilled personnel, as well as functional and effective equipment. In numerous situations, the expenses are even larger than the disasters caused by the implementation of inadequate cleaning operations in sensitive regions. The key to cost control and reduction is to minimize environmental and property damage. The only way for an efficient decontamination operation execution is to take action quickly, which may be only feasible if studies on the risk of accidents have been conducted. As a result, the advantages of such a study are apparent.

The notion of sustainability serves as the fundamental guiding principle for current environmental management practice, with three dimensions: environmental preservation, economic development, and social development. For a management policy to be deemed effective, all three aspects must coexist. Of course, this is far from simple and straightforward. Environmental management is a rather complex undertaking, with the following key components: social consensus and partnership, education, environmental awareness, political will, legislation, financial resources, interdisciplinarity, scientific recognition of the existing state of technology, evolution, and constraints.

REFERENCES

1. del Moral L, van der Werff P, Bakker K, Handmer J. Global Trends and Water Policy in Spain. Water International. 2003; 28(3): 358-366.
2. Duan W, Chen G, Ye Q, Chen Q. The Situation of Hazardous Chemical Accidents in China between 2000 and 2006. Journal of Hazardous Materials. 2011;186(2–3): 1489–1494.
3. Posthuma L, Wahlstrom E, Nijenhuis R, Dijkens C, de Zwart D, van de Meent D, et al. The Flash Environmental Assessment Tool: Worldwide First Aid for Chemical Accidents Response, Pro action, Prevention and Preparedness. Environment International. 2014;72:140–156.
4. Boykoff MT. Flogging a dead norm? Newspaper Coverage of Anthropogenic Climate Change in the United States and United Kingdom from 2003 to 2006. Area. 2007;39(4): 470-481.

5. Goerlandt F, Montewka J. Maritime Transportation Risk Analysis: Review and Analysis in Light of Some Foundational Issues. Reliability Engineering and System Safety. 2015;138:115-134.

6. Soares CG, Teixeira AP. Risk Assessment in Maritime Transportation. Reliability Engineering and System Safety. 2001;74(3):299-309.

7. Hu J, Chu J, Liu J, Qin D. Risk Identification of Sudden Water Pollution on Fuzzy Fault Tree in Beibu-Gulf Economic Zone. Procedia Environmental Sciences. 2011;10(PART C): 2413–2419.

8. Liu, Yinge, Zhang, Y, Long Y, Wang L. (2020). Risk Assessment of Sudden Water Pollution Accidents Based on the One-Dimensional Hydrodynamic Model for Weihe River Basin, China. IOP Conference Series: Earth and Environmental Science, 2020;555(1).

9. Liu, Yang, Fan ZP, Yuan Y, Li H. A FTA-Based Method for Risk Decision-Making in Emergency Response. Computers and Operations Research. 2014;42: 49-57.

10. Osorio JC, Manotas DF, García JL. Operational Risk Assessment in 3PL for Maritime Transportation. Research in Computing Science. 2017;132(1): 63-69.

11. Rebelo A, Ferra I, Gonçalves I, Marques AM. (2014). A Risk Assessment Model for Water Resources: Releases of Dangerous And Hazardous Substances. Journal of Environmental Management. 2014;140:51-59.

12. Gyenes Z, Wood MH, Struckl M. Handbook of Scenarios for Assessing Major Chemical Accident Risks, EUR 2017;28518.

13. Chang CH, Xu J, Song DP. (2015). Risk Analysis for Container Shipping: From A Logistics Perspective. The International Journal of Logistics Management. 2015;26:147-171.

14. Wolf FG. Operationalizing and Testing Normal Accident Theory in Petrochemical Plants and Refineries. Production and Operations Management. 2001;10(3): 292-305.

15. Allianz Global. Allianz Global Corporate & Specialty Safety And Shipping Review 2020 An annual review of trends and developments in shipping losses and safety. In AGCS. 2020.

16. Bye RJ, Almklov PG. Normalization of Maritime Accident Data Using AIS. Marine Policy. 2019;109:103675.

17. Akyuz E. A Marine Accident Analysing Model to Evaluate Potential Operational Causes in Cargo Ships. Safety Science. 2017;92:17-25.

18. Baalisampang T, Abbassi R, Garaniya V, Khan F, Dadashzadeh M. Review and Analysis of Fire and Explosion Accidents in Maritime Transportation. Ocean Engineering. 2018;158:350-366.

19. Okoh P, Haugen S. A Study of Maintenance-Related Major Accident Cases in the 21st Century. Process Safety and Environmental Protection. 2014; 92(4): 346-356.

20. Chen P, Huang Y, Mou J, van Gelder PHAJM. Probabilistic Risk Analysis for Ship-Ship Collision: State-of-the-art. Safety Science. 2019;117:108-122.

21. Eleftheria E, Apostolos P, Markos V. Statistical Analysis of Ship Accidents and Review of Safety Level. Safety Science. 2016;85: 282-292.

22. Zhang W, Goerlandt F, Kujala P, Wang Y. An Advanced Method for Detecting Possible Near Miss Ship Collisions from AIS data. Ocean Engineering. 2016;124:141-156.

23. Mazaheri A, Montewka J, Kujala P. Correlation Between the Ship Grounding Accident and the Ship Traffic – A Case Study Based on the Statistics of the Gulf of Finland. TransNav The International Journal on Marine Navigation and Safety of Sea Transportation. 2013;7(2):119-124.

24. Risk Analysis of Water Pollution Second, Revised and Expanded Edition.

25. Patnaik P. Handbook of environmental analysis: Chemical pollutants in air, water, soil, and solid wastes, third edition. In Handbook of Environmental Analysis: Chemical Pollutants in Air, Water, Soil, and Solid Wastes, Third Edition. 2017.

26. Mousavi M, Ghazi I, Omaraee B. Risk Assessment in the Maritime Industry. Engineering, Technology & Ap-

plied Science Research. 2017;7(1):1377-1381.

27. Berle Ø, Norstad I, Asbjørnslett BE. Optimization, Risk Assessment and Resilience in LNG transportation Systems. Supply Chain Management. 2013;18(3):253-264.

28. Lim GJ, Cho J, Bora S, Biobaku T, Parsaei H. Models and Computational Algorithms for Maritime Risk Analysis: A Review. Annals of Operations Research. 2018;271(2):765-786.

29. Deng Y, Zhang W, Feng X. An Advanced Method of Collision Risk Assessment in terms of Encountering Ships. IOP Conference Series: Materials Science and Engineering. 2021;1043(5).

30. Shi B, Jiang J, Liu R, Khan AU, Wang P. Engineering Risk Assessment for Emergency Disposal Projects of Sudden Water Pollution Incidents. Environmental Science and Pollution Research. 2017; 24(17):14819-14833.

31. Ma X, Xing Y, Lu J. Causation Analysis of Hazardous Material Road Transportation Accidents by Bayesian Network Using Genie. Journal of Advanced Transportation. 2018.

32. Darwiche A. Modeling and Reasoning with Bayesian Networks. In Modeling and Reasoning with Bayesian Networks. 2009;9780521884.

33. Madsen AL, Lang M, Kjærulff UB, Jensen F. The Hugin Tool for Learning Bayesian Networks. Lecture Notes in Artificial Intelligence (Subseries of Lecture Notes in Computer Science). 2003;2711:594-605.

34. Hänninen M, Valdez Banda OA, Kujala P. Bayesian Network Model of Maritime Safety Management. Expert Systems with Applications. 2014;41(17):7837-7846.

35. Nadkarni S, Shenoy PP. A Causal Mapping Approach to Constructing Bayesian networks. Decision Support Systems. 2004;38(2): 259-281.

36. Tang C, Yi Y, Yang Z, Sun, J. Risk Analysis of Emergent Water Pollution Accidents Based on a Bayesian Net-Work. Journal of Environmental Management. 2016;165:199-205.

37. Risk Initiative Foundation, N. (n.d.). NRI-1 (2009) NRI MORT User's Manual For use with the Management

Oversight & Risk Tree analytical logic diagram Second Edition Produced by In Partnership with The Noordwijk Risk Initiative Foundation Royal Dutch Navy Koninklijke Marine. Retrieved July 19, 2021.

38. Safety, Reliability and Risk Analysis. In Safety, Reliability and Risk Analysis. CRC Press. 2008.

39. Zhou F, Guo H, Hao Z. Spatial Distribution of Heavy Metals in Hong Kong's Marine Sediments and Their Human Impacts: A GIS-based Chemometric Approach. Marine Pollution Bulletin. 2007;54(9):1372-1384.

40. Jiang J, Wang P, Lung W. seng, Guo L, Li, M. A GIS-based Generic Real-Time Risk Assessment Framework and Decision Tools for Chemical Spills in The River Basin. Journal of Hazardous Materials, 2012;227-228:280-291.

41. DNV. Technical Data Report, Marine Shipping Quantitative Risk Analysis, Enbridge Northern Gateway Project. 2010

42. Anoop MB, Rao KB, Gopala krishnan S. Conversion of Probabilistic Information into Fuzzy Sets for Engineering Decision Analysis. Computers and Structures. 2006;84(3-4):141-155.

43. Balmat JF, Lafont F, Maifret R, Pessel N. Maritime RISk Assessment (MARISA), A Fuzzy Approach to Define an Individual Ship Risk Factor. Ocean Engineering. 2009;36:1278-1286.

44. Akyuz E, Celik E. (2018). The Role of Human Factor in Maritime Environment Risk Assessment: A Practical Application on Ballast Water Treatment (BWT) System in Ship. Human and Ecological Risk Assessment. 2018;24(3):653-666.

45. Shankar R. Application of Fuzzy Logic to Matrix FMECA. AIP Conference Proceedings. 2003;557(1), 1987-1994.

46. Purba JH, Lu J, Zhang G, Pedrycz W. A Fuzzy Reliability Assessment of Basic Events of Fault Trees Through Qualitative Data Processing. Fuzzy Sets and Systems. 2014;243:50-69.

47. Azizi A, Fathi K. Selection of Optimum Maintenance Strategies Based on a Fuzzy Analytic Hierarchy Process. Management Science Letters. 2014;4(5):893-898.