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Chemical engineering as promoter of environmental engineering and disaster management

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Abstract: In the last decades, the number and severity of disasters throughout the world increased dramatically. The significant increase of human losses and damages requires a rational and efficient disaster management. Disaster management includes several fields of activities, such as risk and vulnerability assessment, Natech analysis, contaminated sites investigation, environmental education, population awareness, summing up an entire set of actions meant to ensure the society's sustainable development. The chemical industry in Romania developed very quickly after World War II, but the closing of numerous facilities after 1989 brought significant environmental issues. These issues required attention and an efficient management. This lead to the development of a new scientific field, that of environmental engineering, which combines the specifics of the chemical industry and of the environmental protection. Environmental engineering is a new discipline resulting from the basic chemical engineering, completed by competencies from geology, biology, ecology, sociology, economy, informatics etc.

Keywords. Chemical industry, environmental engineering, disaster management.

1. Chemical industry in Romania

The chemical industry in Romania developed rapidly after the Second World War. Before the war, the chemical industry manufactured especially soot, sulphuric and hydrochloric acid, caustic soda, fibers, paint and solvents and represented only 3% of the entire industrial production. Until the 80's, the chemical industry production increased by 10-20% of the entire industrial production, which represented more than 25% of the exports revenue [1].

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The petrochemical industry produced approximately 50% of the total chemical industry production. The largest petrochemical plants were built in Ploieşti and Piteşti, but there were other small plants in the country (Fig. 1).

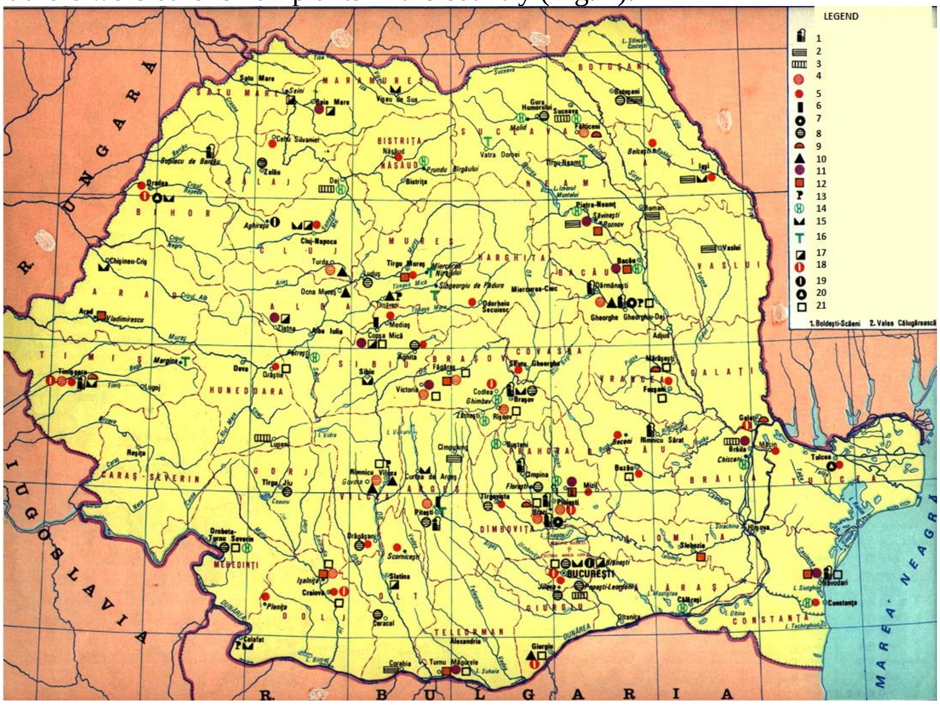

Fig. 1. Chemical industry in Romania in the '80s [2]
(1 – petrochemical facilities, including refineries; 2 – chemical fibers and fabrics; 3 – artificial fibers and fabrics; 4 - plastics and synthetic resins (manufacturing); 5 – plastics (processing); 6 – soot; 7 – synthetic rubber; 8 – rubber goods; 9 – detergents; 10 – chlorosodic goods; 11 – sulphuric acid; 12 – chemical fertilizers; 13 – pesticides, 14 – celluloses and paper; 15 – pharmaceutics and cosmetics; 16 – tanning agents and other wood products; 17 – electrochemical and abrasive products; 18 – paints; 19 – inks; 20 – alumina; 21 – other chemical products)

New industries for sulphuric acid were built in Victoria, Năvodari and Copşa Mică. Following the construction of the industries in Turda, Târnăveni, Govora and Ocna Mureş, Romania become the largest producer of sodium and chloride products in Comecon, after U.S.S.R. [1].

After 1985, Romania focused on the production of complex chemical products, such as: special plastics, synthetic rubber, fibers, electrodes, medicines, detergent etc. Furthermore, the industry of artificial fertilizers was also developed, through the construction of plants in Valea Călugărească, Făgăraş, Târnăveni, Năvodari, Turnu Măgurele, Piatra Neamţ, Victoria etc. All this was done with the aim of doubling the fertilizers and agriculture products in Romania by 1989 [1].

Significant changes were brought by the year 1989, when many industrial sites closed, following the socio-politic necessities which were based on the development of the services sector. The unsustainable economic units were also characterized by several environmental issues, which required specific attention and which had to be managed in an adequate and efficient manner. This led to the development of a new scientific field, that of environmental engineering, which combines the specifics of the chemical engineering and of the environmental protection.

The recent situation reveals a decrease in the number of chemical plants: at the end of 2011, there were 4,598 active industrial facilities, while in 2013, 22% of these firms were closed [3]. In 2015, the chemical production totaled 44,386 million lei, which is almost 11 times smaller than in 1990. This increase in production meant also that several sub-fields disappeared in Romania: synthetic chemical fibers, plastics and synthetic rubber [4].

Regarding Seveso sites (chemical units where dangerous substances are used or stored in large quantities) in Romania, in 2002 there were identified 333 industrial establishments, 245 of which were upper-tier (high risk) and 88 low-tier sites (low risk). It must be mentioned that most upper-tier establishments are chemical and petrochemical facilities (144 upper-tier sites) [5]. The inventory in 2006 identified 287 industrial sites, 128 upper-tier and 159 lower-tier. In Romania, according to GD no. 79/2009, at national level there are 277 establishments under the Seveso Directive, of which 115 upper-tier and 162 lower-tier. In 2016, there were identified 299 Seveso sites, of which 120 are upper-tier and 179 are lower-tier.

In the Ro-Risk Project [6] a hazard and risk analysis for Seveso sites was elaborated, taking into consideration the results of the Safety Reports, Safety Management Systems and expert judgment. Based on these results a hazard map was developed considering 5 levels of magnitude, where 1 represents the area without any serious health effects on population, 2 – reversible injuries, 3 – irreversible injuries, 4 – beginning of lethality, 5 – high lethality area (Fig. 2). In the analysis four types of hazards were considered: toxic dispersions, fires, explosions with overpressure, BLEVE phenomena (Boiling Liquid Expanding Vapor Explosion). The hazard map summarizes all these four types of hazards using the above mentioned magnitude scale.

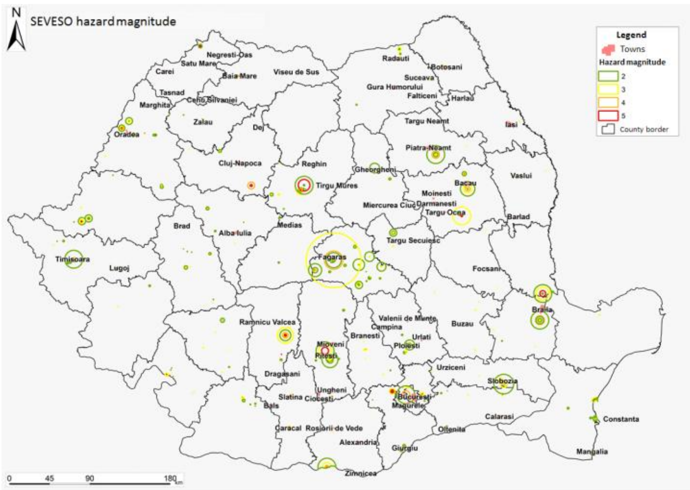

Fig. 2. Seveso hazard magnitude map in 2016 [6].

Transport of all dangerous materials is a major threat due to the potential impact of an accident on human health, the environment and the infrastructure. According to the statistics at national level, most accidents occur on national roads and within localities, where the traffic is heavier [6]. Also, most accidents involve flammable liquids and gases, these being the most transported type of goods. Transportation hazard maps were developed within the Ro-Risk Project [6], considering the same types of hazards and magnitude scale, as described above, for road, rail and naval transportation on the main routes (Fig. 3).
In both cases, Seveso chemical units and dangerous materials transportation, the hazard maps present the possibly affected areas in case of an accident.

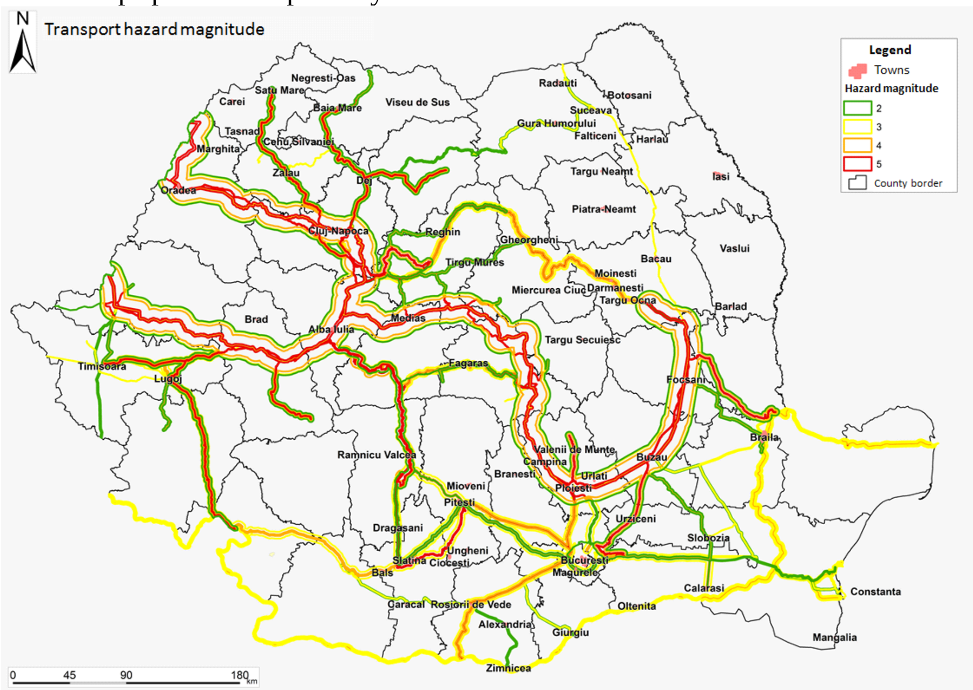

Fig. 3. Hazard map – transport of dangerous goods [6].

2. Environmental protection worldwide

Until the 50's, environmental protection actions had only a local character. The environmental issues, such as the toxic wastes in Minamata (Japan) or the Seveso industrial accident (Italy, 1976) lead to an increase in the environment protection preoccupations and legislation: the Silent Spring book of Rachel Carson in 1962 (drawing attention on the toxic substances in the environment), the Clean Air Act in U.S.A. in 1970 or the Seveso Directive in 1982.
At European level, the Integrated Pollution Prevention and Control – IPCC Directives legislate the entire aspects of pollution resulted in industry and agriculture: application of Best Available Techniques, pollution prevention, waste prevention or mitigation, energetic efficiency, accidents prevention. The first version of the IPPC

directive was released in 1996, followed by the second version in 2008. In 2010, the Industrial Emissions Directive – IED included the aspects in the IPPC directives, but also legal aspects regarding the large combustion plans, waste incinerators, organic solvent installations and other [7].

Regarding the sustainable development, the European Union's Development Strategy, which was published in 2001, was not implemented, due to several management issues. The new strategy was published in 2005 and implemented in 2006, and was supported by the Lisbon Treaty. However, in 2010 the Lisbon Treaty was replaced by the 2020 Europe Strategy, which reduces the environmental aspects to the energy sector and efficiency of resources [8].

Industrial ecology is a multidiscipline focusing on economic development objectives, in the context of maintaining environmental quality, and which ensures the relations and the connections between the industrial production, clean technologies, sustainable consume and the environment. The concept assumes that an industrial system must not be seen as an isolated item, but in a more global context, for optimizing the material balance through the entire life cycle of the products [9]. Similar to natural eco-systems, industrial ecology sets the connections and interdependence between the industrial systems, considering them as part of a unit [9]. By applying the ecological concepts to industrial systems, or in their networks, the reduction/reuse/recycling of waste is promoted within the systems, by energy efficiency, ecologic design and clean technologies. The analogy between the concept of industrial ecosystems and biologic ecosystems is not perfect, but, by imitating the autonomy and relations among the biologic ecosystems, the industrial ecosystem gains from several point of views: environmental performance, sustainable use of natural resources, energetic consumption efficiency, waste recycling and reuse.

3. Contaminated sites management

The past polluting activities resulted in numerous contaminated lands and habitats. Their remediation is necessary for the recovery of large areas for other purposes and is considered one of the most critical objectives in environmental management. According to the current national legislation, a contaminated site is the geographic area, with a specific length and width, polluted with biologic or chemical substances [10].

The decision-making process regarding the assessment and management of contaminated sites is controversial and difficult, due to the numerous aspects involved: economic interest, environmental restoration, social acceptance, land-use planning and so on. The main stages in the management of a contaminated site are the preliminary investigation, the detailed investigation, risk assessment and remediation, including the management and monitoring of residual risk. In order to include the principle of sustainable development in a real decision-making process, it is necessary to correctly identify the interest area and to establish an adequate management methodology [11, 12].

In order to assess the current attitude regarding the management of contaminated sites, a survey was conducted in 2012, through a sociological questionnaire sent to 130 Romanian stakeholders from universities, research institutes, the private sector, national authorities, contractors and developers, involved in the management of contaminated sites [13]. The results indicate a real gap between the policies and programs in place and the needs of the national development, as well as in the legal mechanisms intended to promote brownfield rehabilitation in the course of redevelopment. Furthermore, the respondents recommended, among others, the necessity to elaborate a risk assessment methodology that will establish the level of contamination which can pose a threat to human health or to the environment [13].

Generally, risk-based approaches are implemented by using decision support systems, whose purpose is to put in place the adequate strategies for the rehabilitation of contaminated sites, which require the assessment of soil and/or underground water quality for current or future site use [14]. A wide range of decision support systems were elaborated for contaminated sites management (for managing different aspects, such as: sampling strategies, site characterization, risk assessment, cost/benefit analysis, remediation method etc.), but there are only a few studies that support experts in selecting the most adequate ones for the specific analyzed site [15, 16].

4. Industrial and Natech accidents

Disaster management is a major subject of interest, mainly due to the increase of damages and human loses caused by extreme events, the increase of major consequences due to disasters which are becoming more and more complex, associated to the tendency of population concentration in urban areas. Risk management is part of the global process of disaster management and it is considered as part of the prevention step.

Following the Bhopal and Basel disasters, the Seveso I Directive was amended twice, in 1987 and 1988. These amendments widened the purpose of the directive, the storage of dangerous substances being also included. The Seveso II Directive replaced the first directive and it introduced new requirements related to safety management systems, emergency planning and land-use planning [17, 18, 19]. The tasks listed by this new directive are compulsory for industries and public authorities, starting from 1 February 1999, while the responsibility of implementing the regulations belongs to EU member states. Therefore, the Seveso II Directive completely replaces the first directive, by extending its application field and bringing significant procedural changes [20].

The occurrence of accidents with transboundary impact and international echo required other completions that were included in the Toulouse I Directive (2003/105/EC) which extends the scope and the application activities, and, at the same time, covers dangerous substances that were not included in the previous directives [21]. Further modifications and continuous extension of regulations referring to major industrial accidents involving dangerous substances determined the enacting of a new directive, the so-called Seveso III Directive, in 2012, which includes significant changes to the classification of dangerous substances [5].

Industrial development is also associated to risk increase. In the context of climate change, the increase of the number of natural disasters worldwide, risk has new characteristics, Natech accidents being more and more frequent [22]. Natech accidents are technologic accidents triggered by natural disasters [23].

In Romania, a Natech accident occurred at Iazul Aurul, near Baia Mare, in 2000. Due to massive rainfalls and snow melting, associated to dam design errors, a breach in the dam occurred, resulting in the discharge of approximately 100,000.00 mc water contaminated with cyanides and heavy metals. The accident caused transboundary pollution and attracted attention at international level.

Natech accidents do not represent the sum of singular disasters (the natural and the technologic disasters), they are the result of a negative chain of events. Understanding the way in which Natech accidents develop is an essential process for their management [24].

The natural disaster, that may be a flood, an earthquake, a landslide, an extreme weather phenomenon etc., triggers a failure of one or more equipment within a technologic facility. The failure generates the discharge of dangerous substances, which, depending on its nature and the conditions of the discharge, may cause toxic cloud dispersion, fires, explosions etc. [25].

The challenges in risk assessment for this type of events come from the fact that assessment methodologies should take into account the multi-hazards causes, as well as the complex characteristics of receptors.

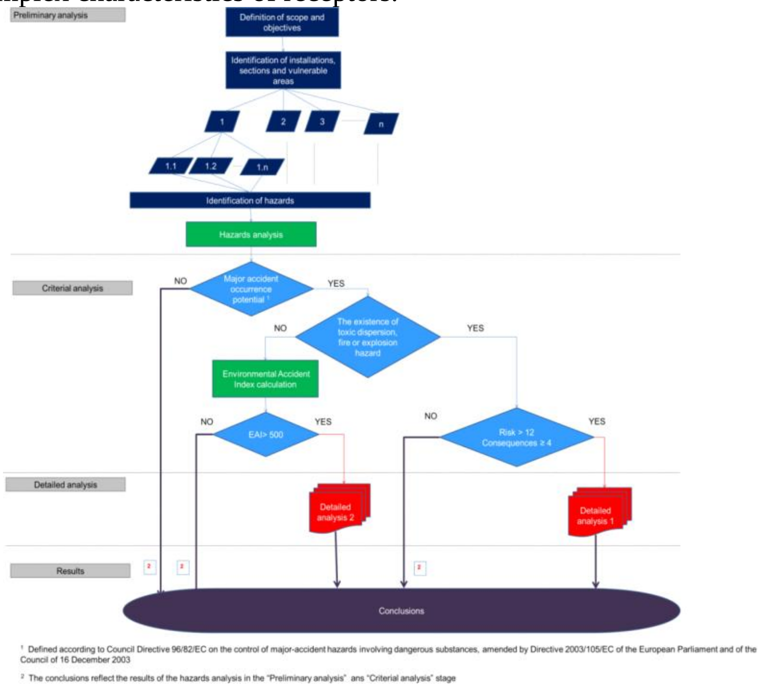

Fig. 4. The systematic risk analysis methodology [27]

At a national level, there is no accepted methodology for the assessment of multi-hazard risk. The Systematic Risk Analysis Methodology, elaborated by Ozunu et al., 2011 is based on three major steps: preliminary analysis, criterial analysis and detailed analysis, followed by conclusions (Fig. 4) [26]. Within the preliminary analysis, the hazard identification stage considers the possible technologic causes for industrial accidents, as well as the natural causes, therefore assessing the Natech potential.

Risk analysis and assessment may be a complicated, expensive and long-term process, depending on the complexity of the analyzed site. The criterial analysis stage selects those scenarios which significantly contribute to the site risk level, which will be further analyzed in the detailed analysis section through specific methods, either qualitative or quantitative. Thus, we avoided directing time/energy/financial resources to a detailed analysis of scenarios that have an insignificant contribution to the general risk, without compromising the accuracy of the conclusions [27].

5. Vulnerability and risk communication

Vulnerability is a concept in the scientific literature, defined as a function of exposure, sensitivity to impacts and the ability or lack of ability to cope or adapt. Vulnerability reduction measures and policies address each of the components of vulnerability: the particular pressures (exposure), the degree to which a set of pressures affect the system (sensitivity) and the ability of the system to resist or recover from the damage (resilience). Vulnerability reduction measures aim at the disaster prevention and mitigation of hazard impacts, which can affect a wide range of natural, economic, political and social activities and processes.

In 2005, a very comprising definition of vulnerability was proposed by Birkmann [28]: ”vulnerability refers to the characteristics of a person or a group of people which influence their capacity to anticipate, to cope, to resist and to recover after the impact of a natural hazard”. According to this definition, vulnerability implies a combination of factors which determine the level to which a person’s life, a community, goods and properties are exposed to the risk of an identifiable event. Another important element in this definition is the including of the measurement scale: vulnerability manifests itself differently at the level of a household than at a national level. Thus, the mitigation measures must be elaborated and implemented accordingly.

There are several stages in vulnerability assessment: identification and analysis of natural hazards and technological risks that impact the community, estimation of social vulnerability (coping and recovery capabilities), elaboration and implementation of adequate vulnerability reduction methods, considering the community’s characteristics and its development potential. The results may be graphically represented, offering a general and comprehensive overview of the hazards and vulnerabilities and including elements that can be easily understood and used by the decision-makers [29].

In the context of vulnerabilities, risk perception plays a key role, as it modifies the human behavior. A person or a community with a better risk perception will recover better after a negative event. Perception is multi-dimensional and is influenced by a large variety of factors, which determine a different perception of risks between communities and within the same community. As a psychological process, the information received by a person from the outside world is altered by a combination of socio-cultural processes, economic factors and individual elements (personality, values, past experiences etc.) [30]. As to risk perception, the human being has a low capacity of perceiving probabilistic or random phenomena [31]. That means that phenomena with a higher frequency of occurrence are remembered longer than those with a lower frequency. Risk perception is also different for the communities already affected by a disaster and for those who were not affected. Furthermore, the type of public participation to prevention and consequence mitigation actions will likely influence public perception [32].

In order to better understand individual and group risk perceptions and the way they can influence the social vulnerability, a research was developed in a community in Romania, namely the Băiuţ commune (Maramures county). This is a village in the North part of the country, with no stable sources of income and exposed to both natural and man-induced hazards. The main lesson learned from this case study is that for a community with accurate risk perceptions, better public education and future preparedness for disasters can be an adequate solution for mitigating risks and raising individual self-confidence when dealing with a potential natural hazard [33].

Risk communication is currently used in numerous extreme situations: natural hazards, industrial accidents, epidemics and so on. It addresses a wide range of target groups: employees, local community, authorities, institutions etc. Involving the community in the risk-related decisions contributes to the modification of their perception, reducing the potential worries [34].

Risk communication is an interactive process of exchanging information and opinions among individuals, groups and institutions. It involves multiple messages about the nature of risk and other messages, not strictly about risk, that express concerns, opinions, or reactions to risk messages or to legal and institutional arrangements for risk management [35].

Risk communication is a significant part in the process of risk prevention and management. An informed public represents an essential part of the process of acceptance of the management strategies in each community, and this informing is the result of an efficient risk communication. Risk communication is a continuous process, which must be developed before and during an emergency situation and in the recovery period [36]. A poor risk communication may have severe consequences: loss of confidence and mistrust of the public and the media (toward the company involved and municipal decision-makers or other levels of government), loss of credibility of managers and responders in emergency situations, confusion in the response, possible attack on the safety of the response team and the public, etc. On the other hand, a good risk communication plan helps in assuring the safety and wellbeing of the personnel, the public and the environment and facilitates operations in emergency situations [37].

6. Disaster management education

Recent experiences in emergency management in case of natural and technological disasters demonstrate a low level of population awareness regarding environmental hazards. Therefore, it is necessary to develop activities that will increase the population's level of preparedness [38]. This is supported through programs coordinated by organizations with specific interests in the field, and also through training within university studies, master and PhD level. The Faculty of Environmental Sciences and Engineering from Babeş-Bolyai University of Cluj-Napoca offers training alternatives within the following master programs: Risk Assessment and Environmental Security, Sustainable Development and Environmental Management and Disaster Management. The program of Risk Assessment and Environmental Security allows students to acquire knowledge on several types of threats and risks in the environment, during normal activities and emergency situations. The program offers the possibility for students to learn and to apply risk analysis as a tool for: identification of risks and possible intervention actions; implementation of risk reduction methods through prevention actions or mitigation of negative consequences on the population and the environment; elaboration and use of management systems within the fields of safety, health and environment. The MSc in Sustainable Development and Environmental Management (SDEM) is a 2 year full-time program taught in English. This Master's program aims to train future changemakers and leaders who are able to understand the integrated nature of the environmental subjects and to put into practice a number of methods and techniques for environmental management, in order to develop a sustainable human society. For the future period, the Faculty proposes a master program in Disaster management that aims to develop the adequate practical and scientific skills for the experts at local, regional or national level. The support of regional, national and international decision-making authorities, as basis for disaster management, may be associated to scientific and technologic knowledge, the development of new academic fields and institutions with activities in risks prevention and mitigation. One of these institutions is the **Research Institute for Sustainability and Disaster Management based on High Performance Computing**.

The Institute operates as a research unit dealing with topics like causes of disasters, the effects generated by various disasters, appropriate management strategies, short-, medium- and long-term effects on the population, economy and environment and proposed management strategies for various types of disasters. The institute provides the framework for interdisciplinary research, setting the basis for addressing challenges induced by the complex disaster management process. ISUMADECIP is a research community composed of teachers and researchers in a consortium including 8 faculties (Faculty of Environmental Science and Engineering, Faculty of Mathematics and Informatics, Faculty of Economics and Management of Affairs,

Faculty of Political, Administrative Sciences and Communication, Faculty of Geography, Faculty of Chemistry and Chemical Engineering, Faculty of Physics, Faculty of Biology and Geology).
The main research directions consists of: Accident risk assessment involving dangerous substances and hazard, development of exposure and vulnerability maps; development of Software and educational materials in order to prepare children for risk situations; 3D modeling and simulation of major industrial accidents for a better emergency situation planning; Forecast of dangerous particles intrusion at ground level and in the upper atmosphere; Scanning of the atmosphere vertically using LIDAR technology; Studies on disaster management; Inter-disciplinary research based on High Performance Computing (HPC); Big data analysis.
The activities are developed within the institute's centers and laboratories: Training Centre for Disaster Management, Modeling, Optimization and Simulation Center (MOS), High Performance Computing Center (HPC), Research Center for Disaster Management, Disaster Communication, Notification, Alarming and Evacuation of the Population Lab, Disaster Management Technical Devices and Equipment Lab, Scientific Databases Documentation, Processing and Management Lab, Risk Communication and Public Relations Lab, Disaster Information, Training and Prevention of Population Lab, Natural Disaster Management and Climate Change Reduction Research Lab, Technological Disaster Management and Mitigation Lab, Quantitative Risk Assessment (Modeling, Simulation and Databases) Lab, Natural Disaster Risk Reduction Research Lab. Furthermore, the research development activities are supported by specific infrastructure: High Performance Calculation Systems IBM IntelIiCluster HPC, Remote sensing system - mobile LIDAR, Computer license for software package for modeling and simulation of industrial accidents effects and consequences, Application for operational management of Sahana Eden disasters - improved version by adding the software module developed by iQuest Technologies and so on.

7. Conclusion

While the reduction of loses caused by disaster is a major prerequisite of sustainable development, and considering the fact that different communities are disproportionately affected by disasters, the issues approached by environmental engineers are varied, trying to solve problems in all disaster management fields. Some of these environmental issues include: contaminated sites, environmental pollution, technologic accidents, Natech accidents etc. Recent events demonstrated that the activities which increase the communities' awareness and preparedness level significantly contribute to the reduction of potential loses and, therefore, to a future sustainable development.

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