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RISK MAPS FOR INDUSTRIAL OCCUPATIONAL HEALTH AND SAFETY

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Abstract. *Risk assessment is a complex process, of which the outputs are often to be used by decision makers for policy development and risk management. Risk communication in Environmental sciences is often made simpler using risk maps, a method introduced in the early 60s in the United States, but evolved and rapidly developed following the advances in computer science and wide availability of personal computers. This methodology is widely used in Environmental sciences, but due to many similarities, it can be successfully applied to occupational health and safety, where workers may be exposed to multiple chemical, physical or biological agents. In this article we introduce the basic principles of risk mapping, and demonstrate an example of exploring risk using risk maps in a theoretical industrial site where workers are exposed to noise. Advantages and disadvantages of this system are discussed, and recommendations for successful use of risk maps in the field of occupational health and safety are outlined.*

Key words: *occupational and environmental health, risk map, exposure map, occupational safety, Geographical Information System (GIS)*

1. INTRODUCTION

Risk assessment is not a simple process, since it is comprised of several related steps: risk identification, risk estimation, also called risk analysis in a more practical framework of ISO 31000:2009 standard, and risk evaluation. When decisions are made about accepting, averting or modifying risk, it is the results of risk assessment that are being used [16]. Risk identification, the discovery and definition of the risk associated with an activity, is the first step in the assessment of risk. It provides qualitative and descriptive

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information about risks, and can occur separately or in combination with other phases of risk assessment. There are several contexts in which risk identification is carried out [16]:

1. Routine monitoring of risk events
2. Routine monitoring of exposures
3. When alarms are raised by experts, victims or interest groups
4. On the basis of learning from events which have occurred
5. On the basis of warning events ("near accidents")
6. As a result of specific risk studies
7. On experts' intuition based on a priori knowledge

Risk estimation determines the probability of the occurrence of events which involve risk, and it is concerned with determining the consequences of events which involve risk and with determining the associations between causative factors and outcome. Finally, risk evaluation, which is a process of social judgement, gives a social value for an identified, estimated risk. It should balance the negative consequences of a risk event with the social benefit of the particular activity. One of the most important areas of decision making today is the management of various kinds of risks. The process of risk management is comprised of risk modification, risk aversion and the acceptance of risks. Risk management, according to ISO 31000:2009, is comprised of establishing the context, risk assessment, risk treatment, monitoring, review, communication, and consultation. When setting the priorities in risk management, there are three main headings:

1. Importance, which entails criteria indicating risks with consequences that would affect the overall health and safety of the population. Refers both to volume of the problem and the intensity of risk involved.

2. Relevance indicates the willingness of a society or the scientific community to regulate or analyze the particular risk.

3. Feasibility indicates criteria related to the technical, economic, methodological, material and intellectual capacities of a society or the scientific community to regulate or assess risk.

All over the world, surveillance systems are created to improve the detection and description of epidemiologically significant changes in work-related injury, diseases, disability and mortality [4]. In the process of risk identification and priority setting, occupational health surveillance, together with the identification of hazards and effects on the health of workers, is a crucial activity. Since funds for these activities are usually very low or there are no funds, it is necessary to develop efficient methods for information collection, analysis and dissemination. The aim of this paper is to analyze the methods developed for risk mapping in Environmental Sciences, to advance them, and demonstrate how they can be applied to analogous scenarios in industrial settings, improving surveillance of work-related hazards, diseases and injuries, as well as plant design.

2. COMMUNICATING RISK USING MAPS

Risk Communication can be defined as the "interactive process of exchange of information and opinions between individuals, groups and institutions, involving discussions of types and levels of risk and measures of dealing with risk" [17]. Its goal is to assist stakeholders in taking decisions based on balanced judgement that reflects the factual

evidence about the matter at hand. In the field of risk mapping, it is necessary to take into account how risks are being perceived, to identify the target audience, and to use accurate cartography and visualization techniques (scale, colors, and symbols).

Risk perception is influenced by many factors, such as the type of risk and social dimensions. For each person, there are also behavioral and personality factors involved. Therefore, the sender of the message must be perceived as a trustworthy and responsible source of information when communicating about risk, and good communications skills are necessary. In addition, risk communication is a two-way process, where stakeholder involvement and public participation is required to make good decisions, to lead to higher awareness of risks and greater acceptance of risk management strategies that are agreed upon. Finally, good risk communication before specific policies on workplace exposures are developed and implemented may prevent unnecessary concerns, or even the resistance to the proposed measures.

In risk communication, an important and necessary step is the target audience selection. Audience and stakeholders must be identified at the beginning of the risk assessment process, and the means of communication should be directed at this audience. The result is increased efficacy of the process. In the case of occupational health and safety, the major players and stakeholders to which risk communication should be directed are: workers and employees of companies, the press, general public, local, regional and national authorities [3]. Unfortunately, only a small number of risk maps available in the literature have been designed specifically to meet the requirements of defined end users. The rule by which the creation of maps should abide is: “Target your map to the person least prepared to understand your map’s message” [5].

Environmental and occupational risk maps allow scientists and risk assessors to explore the spatial nature of the effects of environmental stressors, e.g. toxic substances. They excel as a tool to communicate occupational risk assessment results to the general public and stakeholders [8], as they allow policy makers to take well informed decisions in work planning in relation to the position of potential hazards, and web-based risk maps could inform managers and organizational staff about sources of risk for the workers. Geographical Information System (GIS) allows also to combine different map layers in an easy way, and to apply algorithms in this process. This means that particular risk assessment models may be incorporated in the GIS [9].

Maps have been used in descriptive epidemiology in the United States since the early 60s [11], mostly for mapping cancer mortality, allowing for patterns to appear and actions to be taken. During the process of using maps to evaluate cancer, cardiovascular and infant mortality rates, as well as mortality data from occupational diseases, the need was recognized, as well as the opportunity, to produce hazard maps and mortality maps which could be used to generate surveillance leads [4]. In addition, adding a layer which shows causes of mortality on top of the hazard maps can suggest new hypotheses on causes of diseases. This information, when adapted to the intended use, can help and guide scientists, as well as decision makers (government, public bodies, and managers).

There are many elements crucial for the process of condensing the available information into a simple form, to allow for informed decisions to be made. Aggregations of model results and indicators of value or pattern for large zones are just some of the transformations routinely done. There are three basic steps/considerations in this operation: (1) the input of

data (what does data represent), (2) the algorithm (what behavior and sensitivity does the model contain), and (3) the post-processing (what information is retained and what is lost).

3. DATA PRESENTED WITH MAPS

There are many different types of risk maps, but as a first step it is necessary to understand what risk is. A definition offered by Leeuwen and Hermens defines risk as "the probability of an adverse effect on man or the environment resulting from a given exposure (to a chemical or mixture)". Hazard, on the other hand is "the set of inherent properties (of a chemical or mixture) which makes it capable of causing adverse effects in man or to the environment when a particular level of exposure occurs" [18]. The definition of hazard is used more loosely in this paper, which allows hazard to be also physical or biological, and not only chemical.

There is a large variety of maps that fall under the category of risk maps. They can show contaminant levels in the environment, or even outcome of complex risk assessment procedures. Table 1 represents categories of maps, adapted to an occupational health setting, from Lahr [8] and the European Commission report on risk mapping [19].

Table 1 Categories of Risk Maps

Map category	Description
Contamination	Displays the distribution of measured or predicted concentration in a geographical area
Contamination risk	Maps the likelihood of (potential) contamination
Vulnerability	Uses the presence and geographical distribution of sensitive receptors (workers) of hazards to map vulnerable areas
Exposure (and potential exposure)	Combine contamination levels with the geographical distribution of receptors (workers)
Hazard	Divide measured or predicted contamination levels by a threshold value for effect or by an environmental quality standard and map the values of these ratios
Risk of single stressor	Compare workplace environment concentrations to simple threshold levels and map the results
	Map results of extensive modelling/simulation of contamination, exposure and effect
	Combine maps of vulnerability and maps of exposure (e.g. overlaying)
Risk of multiple stressors	Calculate combined risk from single stressors
	Use multivariate statistical analysis to reduce dimensionality and map the resulting statistical parameter values
	Present risk assessment results in more dimensions (e.g. a map with a matrix legend or visualization in 3D)

When levels of workplace contaminants in a workplace are measured (or predicted using a model) and mapped, we are creating a contamination map. These maps can be considered risk maps in the simplest form, because they mark the areas in the workplace where workers may get in contact with the contaminants. If we wish to map only the "risk of contamination", as the probability that certain areas of the workplace get contaminated, we can create a contamination risk map. In this kind of map, the

contamination has not yet taken place, and the extent of contamination is not yet measured, therefore unknown.

When contamination is compared to the presence and distribution of exposure receptors, in case of occupational health and safety – workers, we are speaking of exposure maps. In many cases there is not a large difference between pollutant levels mapping and potential exposure mapping, as we might assume that workers are present everywhere in the workplace. Nevertheless, for accurate exposure assessment, it is necessary to estimate (or measure) exactly which workers, and for how long, will be exposed to a specific contaminant.

Hazard maps are generated when measured or predicted concentrations of pollutants in the workplace are compared to threshold values for toxicity and mapped. Hazard maps allow us to visualize not only the presence or absence of pollutants, but also to visualize the areas/zones where these pollutants exceed levels considered "safe" by regulations.

Finally, when classic approach of risk assessment is applied, by following the chain of events that can lead from the release of pollutants, through exposure and hazard assessment, to risk characterization, we are discussing "true" risk maps [8].

4. Occupational Risk Mapping

Maps are necessarily simplifications of reality [20], and a flat map can display only a limited number of variables or parameters. As there are numerous methods to construct risk maps, there are many different indicators which can be used for mapping risk in an industrial setting. Often they are quotients, such as Toxicity Exposure ratios (TERs) and Hazard Quotients (HQs) that are calculated from measured or predicted environmental concentrations (ECs and PECs) divided by toxicological or administrative threshold values, such as Predicted No Effect Concentrations (PNECs), Maximum Tolerable Risk Limits (MTRs), Toxic Reference Values (TRVs), Reference Doses (RfDs) and Acceptable Operator Exposure Levels (AOELs).

When considering maps as a method of communication, it is necessary to mention some basic cartographic principles. Cartography is used as a form of spatial language for describing locations, discussing places and interpreting two-dimensional arrangements of features [1]. It is important to consider the message to be conveyed and the users to be reached. The questions: what is the goal of a map, who will read a map, and where will the map be used; are crucial for the improvement of the clarity of a map. Maps are used for their strong visual impact, and they create a more direct, dramatic and lasting impression than possible by any other mean of communication. In cartography, world is reduced to points, lines and areas, and each of these elements can be mapped in a different way. Six visual variables are proposed [2]: size, shape, greytone, value, texture, orientation, and hue. Based on the phenomena being mapped, we can choose the right symbolization. For example, when mapping quantitative differences size and greytone value is preferred. Wrong interpretations of the message can be caused by a poor match between the data and the visual variable. When evaluating the significance of color, we must keep in mind that in western civilization green is associated to something safe, good or acceptable, while the color red is considered as danger, bad or unacceptable. Nevertheless, some basic knowledge of color characteristics is necessary for a good selection of color, since visual perception, graphic logic and cultural preferences can affect the use of colors on a map [13].

A need exists to establish methods for the assessment of risk associated to an industrial installation (industrial plant or a site) [15]. Such a method can be considered a prerequisite to reach the Seveso II Directive goals. A Risk Severity Index can be defined taking into account the threshold levels used in the European countries. Nevertheless, there is no uniform criterion concerning these levels over different countries, although the threshold values found were similar [15]. The risk assessment of pollutants deals with the effects of hazardous substances that are present in the environment, which can include both human health risk and ecological risk assessment. The advances in Geographic Information Systems (GIS) have greatly improved spatial representation and spatial analysis of all kinds of data. The novelty is that Geographical data (topology) and attribute data (environmental characteristics, land use, concentrations of contaminants, etc.) can be combined into maps using spatial models. In the past decade, the GIS software (technology and tools) could be easily obtained and used, meaning that everybody can now make maps on their own personal computers [14]. Environmental and occupational risk maps can be used for many purposes, but the two principal uses are analysis and communication.

5. OCCUPATIONAL HEARING LOSS RISK – AN EXAMPLE

The above described principles can be demonstrated on an example of an industrial site where exposure of workers to noise is of high concern. Figure 1 shows the equivalent of a potential contamination map, with the outline of the said industrial site and three sources of noise as the potential contamination sources.

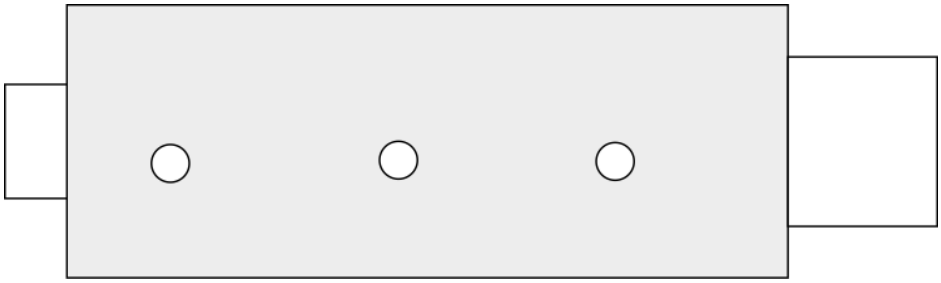

Fig. 1 Theoretical industrial site with noise sources (represented by white circles)

When noise is measured at several distances from the source, we are able to map the different levels, compared to a limit (e.g. regulatory limit of 85 dB for elevated occupational risk). Figure 2 shows a hazard map, with red zones which represent areas where the noise is above 85 dB, while the orange and yellow zones represent the areas with levels of 65-85 dB and under 65 dB respectively.

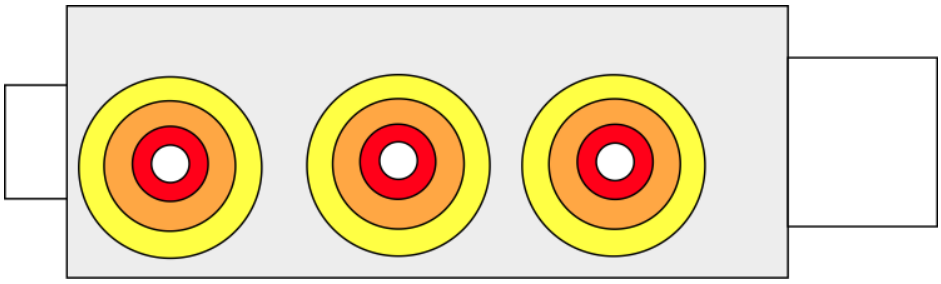

Fig. 2 Theoretical industrial site with different levels of noise measured and compared to the regulatory limits (hazard map)

After having an overview of the sources of exposure and potential hazard, we can examine the areas where work is done. Figure 3 shows a vulnerability map, with workers' positions during the work days (stars represent workers). Three groups of workers carry out their duties in the main area of the industrial site, where the sources of noise are. Two of these groups work in close vicinity to the sources of noise, while one group works farther away. One group of workers is usually located outside of the main area of the industrial site.

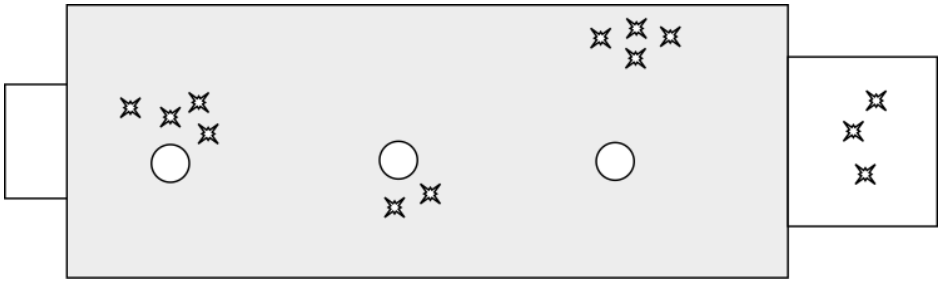

Fig. 3 Theoretical industrial site with standard workers' positions (vulnerability map)

When we put together the vulnerability map and the hazard map, an exposure map is generated. Figure 4 shows the above described groups of workers and their location respective to the different levels of noise measured. Two groups of workers are in the medium exposure zone (65-85 dB), while one group is outside of the exposure zone.

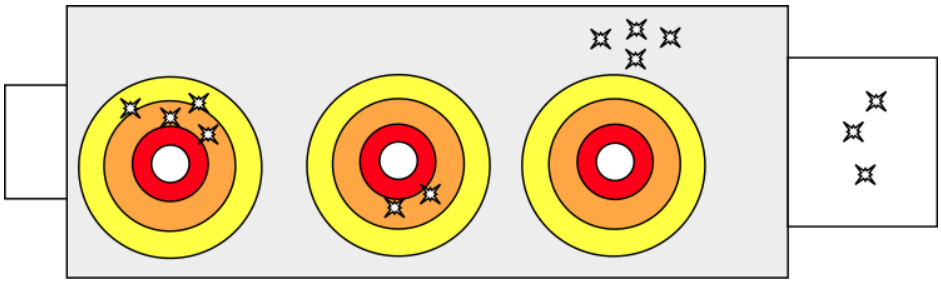

Fig. 4 Theoretical industrial site with workers' positions and hazards combined (exposure map)

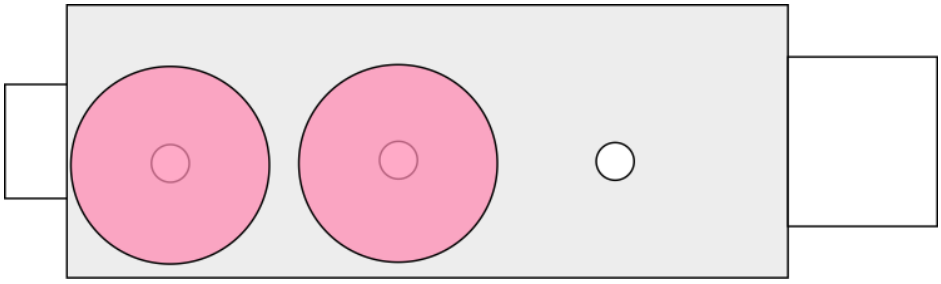

Fig. 5 Theoretical industrial site with risk zones (risk map)

Finally, by examining Figure 4 and identifying the groups of workers exposed to noise levels higher than those considered safe, we can generate Figure 5, which shows the industrial site with two risk zones for occupational hearing loss defined.

The risk of multiple stressors (see Table 1) can be created by combining several risk maps generated in the process described in this section. E.g. by adding a layer of carbon-monoxide risk over the hearing loss risk map, we can analyze which workers are at risk of both stressors, and make decisions based on it.

6. DISCUSSION

In this manuscript we have made an attempt to introduce the concepts of environmental risk mapping into the field of occupational health and safety. As industrial sites are becoming more complex in the nature of the products they produce, the risks for workers are also becoming more complex. Rarely a worker is exposed to only one stressor, such as noise in the example demonstrated above, which additionally complicates implementation of risk management procedures, as well as risk communication. Therefore, maps of exposure sources, hazards and risks in a workplace can make the creation and enforcement of risk management procedures much easier.

Some important concepts merit to be mentioned again. The first step in creating a risk map must be the exploration of the dataset and the selection of suitable classification of each parameter we wish to show on our map. The map creator must consider the message he or she wishes to convey, as well as the users to be reached. Since maps' visual impact is usually strong, misuse of some basic cartographic principles could lead to wrong interpretations of the message. The data presented should be thoroughly checked, and the match between the algorithm, data resolution, and content must be perfect, as this is most important to the output model [1].

Risk mapping usually suffers from three predominant problems: representativeness, instrument error, and data scarcity [7]. The representativeness of a map is based on the possibility that the interpolation of spatially and temporally resolved measurements could result in errors of estimation, misrepresenting the actual sample and its variance. Better-fitting spatial statistical models help produce maps with higher representativeness. Instrument error, on the other hand, occurs due to various issues including the accuracy, precision, and sensitivity of the measurement device. Finally, the completeness of a hazard map is related to data scarcity – maps with higher spatial and temporal sampling resolutions will be less sparse

(more complete). Sparse measurements can be interpolated to produce continuous estimates of risk intensity through space.

Type and level of spatial aggregation is another important issue. In risk mapping, areal units can be divided into grids and polygons, and these often have considerably different sizes. E.g. whole regions or counties may seem at risk, when the areal unit is large and data are averaged, whereas the risk might be high only in a small number of localities when analyzed on a finer grid [9; 12]. This is the case of risk "smearing", and such problem is referred to as the Modifiable Area Unit Problem (MAUP) [6; 10]. If the level of aggregation is wrong, a user, such as a policy maker, can be tricked into taking the wrong decision.

7. CONCLUSION

Risk assessment is a complex process, in which results are often used by decision makers for policy development and risk management. Risk communication can be made simpler by using risk maps, a method which has evolved rapidly following the advances in computer science. We have presented the basic principles of risk mapping, demonstrated an example of exploring risk using maps in an industrial site where workers are exposed to noise, and underlined the advantages and disadvantages of this system. Finally, we have outlined the most important recommendations for the successful use of risk maps in the field of occupational health and safety.

In the world of modern risk assessment and risk communication there might be no better way to visualize data that refer to the location of an object or phenomena distributed in a location such as an industrial site, or in environmental sciences, whole regions, countries or even the Earth. The introduction of GIS has caused a revolution in map making, which is a base for both storage and presentation of geospatial data, and offers the possibility to do spatial modeling. Today, this technology is available to almost anyone who would decide to make maps, but special attention should be paid to the principles of risk assessment, risk communication, and cartography. Principles described in this manuscript should improve development of better occupational health and safety risk maps, and contribute to the health and welfare of workers in any workplace.

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MAPE RIZIKA ZA ZDRAVLJE I BEZBEDNOST NA RADU U INDUSTRIJI

Procena rizika je kompleksan proces čiji se rezultati koriste za kreiranje politike bezbednosti i upravljanje rizikom. Za komunikaciju rizika u oblasti zaštite životne sredine često se koriste mape rizika, najpre u Sjedinjenim Američkim Državama početkom 60-tih godina. Ova metodologija u širokoj je upotrebi u oblasti zaštite životne sredine, a s obzirom na mnoge sličnosti, može se uspešno primeniti i na bezbednost i zradvlje na radu, gde su radnici često izloženi velikom broju hemijskih, fizičkih i bioloških štetnosti. U ovom radu su prikazani osnovni principi mapiranja rizika, praćeni teoretskim primerom konstrukcije mape rizika za industrijsko postrojenje gde su radnici izloženi buci. Predstavljene su prednosti i mane ove metodologije, uz preporuke za uspešnu upotrebu mapa rizika u oblasti bezbednosti i zdravlja na radu.

Ključne reči: *zdravlje na radu i zaštita životne sredine, mapa rizika, mapa izloženosti, bezbednost na radu, Geografski informacioni sistem (GIS)*