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Application of Fuzzy Logic for Risk Assessment

Andrejs Radionovs [1], Oleg Uzhga-Rebrov [2], [1, 2] *Rezekne Higher Education Institution*

Abstract **– Risk assessment is an important task in many areas of human activity: economic, technical, ecological etc. Preliminary data adequacy in risk assessments is carried out on the basis of statistical methods and experts' evaluation on potential losses and probabilities of the event. But in many cases, risk assessment must be carried out under the conditions of lack of initial information or uncertainty of information. For that reason, special risk assessment approaches (methods) are necessary. One of them is the usage of fuzzy logic approach. In this paper, fuzzy logic approach is used to manage this uncertainty in information concerning accidental releases of toxic chemicals at chemical plants. This approach can be used by plant risk advisers in Latvia to make right decisions in the situations where chemical releases can harm not only the environment but also human health.**

Keywords **– Fuzzy logic, fuzzy representation of knowledge, fuzzy rules, fuzzy set theory, knowledge-based systems.**

I. Introduction

Growing concern connected with environmental changes for the worse and rise in potential risks, which happened due to many kinds of human activities, and usage of new technologies are the reason for a rapid increase in the assessment and management of environmental risks. There are many studies devoted to the analysis of ecological risks, for example, [1] and [2]. In this research, a considerable emphasis is placed on the risk assessment of human lives in the case of chemical release. In this point risk assessment, in principle, can be divided into two parts according to the type of the released substance: liquid and gaseous. The assessment of environmental risks and people's health on the territory of the plant and out of it, because of the accident at the chemical plant and release of gaseous substance will be considered in this article.

Assessment of environmental risk involves identifying the events that imply hazards and assessing the magnitude of their consequences and frequency [3]. A lot of data are necessary for a complete ecological risk assessment. A question then arises: how to obtain the necessary initial data for ecological risk assessment? If sufficient statistical material is available, the task in many cases can be achieved successfully. There are many studies, describing the analysis of ecological risks thanks to estimating the statistical data, e. g., [4]. Real life example can be the assessment of cost of car insurance policy. There is enough statistical information about possibilities of accidents and the cost of cars. Estimated losses caused by car crashes can be easily calculated as average losses related to the previous cases. Based on the obtained evaluations, the risk can be easily estimated and the cost of insurance policy can be determined. Unfortunately, having enough statistical material, while giving evaluation of ecological risks, is mostly an exception not a rule. Exceptional situations and their rare origin do not allow using an effective statistic system for getting a necessary evaluation. To overcome a lack of objective information, expert estimation is often used. Experts-specialists based on their professional knowledge, experience and, sometimes, intuition can provide the necessary data.

Many methods are developed for obtaining and using uncertain probabilistic evaluations such as interval probabilities, second order probabilities etc. The shortcomings of these methods are: their complexity and bad interpretability of the uncertain results. In 1965, L. Zadeh in his work [5] proposed a principally new conceptual basis for dealing with imprecise information – a fuzzy set theory. The theory has widely been developed during the past years. Nowadays, fuzziness is used practically in all fields of scientific and practical activities, including risk assessment.

II. Fuzzy Logic and Fuzzy Sets

These days there are a lot of textbooks and reference books available on the theory of fuzzy sets and fuzzy logic. Work [6] can be used as an example, but a more detailed and complete description of the theory can be found in [7]. Fuzzy sets theory presents a number of mathematical principles for knowledge representation based on degrees of membership.

The definition "fuzzy logic" has appeared recently. That was in the sixties with the 1965 proposal of fuzzy set theory by Lotfi A. Zadeh, when he published his work "Fuzzy Sets" in order to provide a model for inexact and not precise concepts and subjective judgments. Fuzzy sets deals with degrees of membership to a certain class and degrees of truth. Fuzzy logic uses fuzzy rules that should receive desired results from input linguistic data or variables. The linguistic variable – a variable whose values are sentences in a natural language. For example, a linguistic variable "temperature", which can contain values: cold, hot etc.

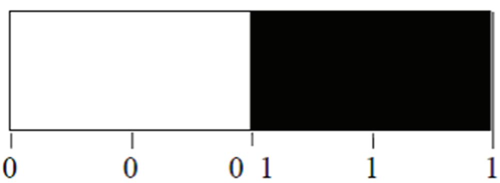

Fig. 1. (a) Boolean logic.

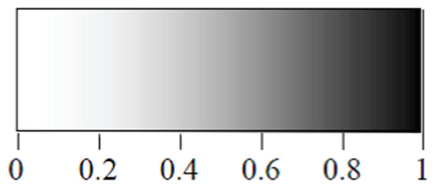

Fig. 1. (b) Multi-valued logic.

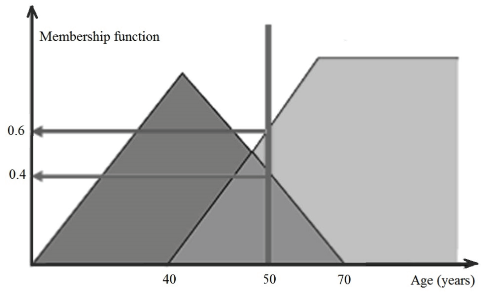

Fig. 2. Fuzzy age-classification scheme.

The advantage of fuzzy methods is their reflection in the human mind and in its ability to store and process information that is uncertain, imprecise, and resistant to classification [8]. Fuzzy logic is an alternative to the classical logic where every proposition must be either "1" (true) or "0" (false). Instead, fuzzy logic asserts that things can be simultaneously "true" and "false", with a certain membership degree [9]. For example, in ordinary Boolean logic a 50 year-old person can be old or young depending on the scale. But in fuzzy logic (see Fig. 2) a man can be simultaneously young with degree of membership of 0.4 and old with 0.6. Fuzzy set theory provides a way to use imprecise and uncertain information generated by the system and human judgments in a precise way. When the environmental data available do not provide a proper statistical treatment, fuzzy approaches can solve this problem, since they work well for addressing poorly characterized parameters and linguistic variables [10].

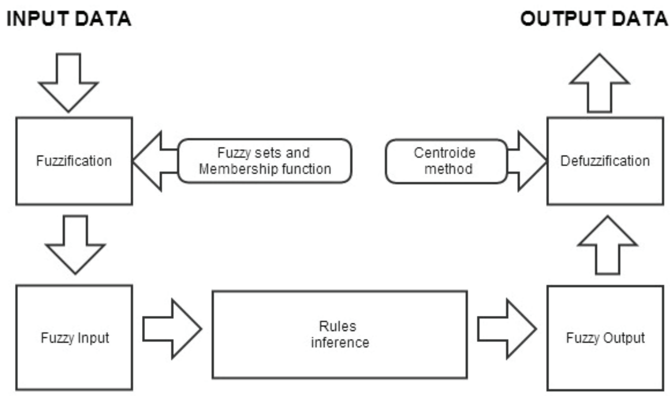

Fig. 3. Representation of the fuzzy methodology.

Fuzzy logic also can merge different kinds of parameters (e. g., environmental, health), quantitative and qualitative values.

III. Fuzzy Process

As it can be seen in Fig. 3, a suggested fuzzy model consists of different steps. First of all, the parameters of input and output must be defined and then converted from the original values into the linguistic categories by creating fuzzy sets for each of them. This process is called fuzzification. Secondly, a set of rules must be established. These rules will allow going from the input to the output. In this paper, the Mamdani's methodology will be used. Next, the obtained value must be defuzzificated in order to give an understandable risk assessment. This process is called defuzzification. Finally, an output is obtained which is directly related to a certain category of risk. All these steps are carried out using the fuzzy toolbox that is present in Matlab and they are explained further.

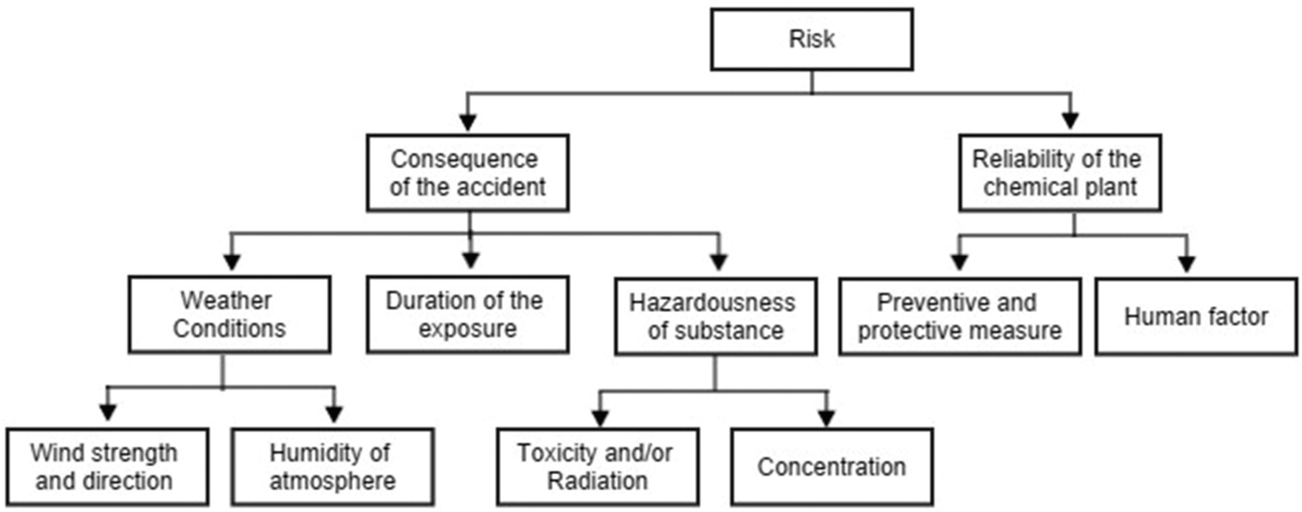

Fig. 4. Risk assessment scheme for releases of gas substances in chemical plants.

A. Input Definition

As we can see in Fig. 4, there are many factors, which participate in the risk assessment of release of chemical substances at a plant. At a minimum, two variables must be defined in order to achieve a proper risk assessment: "*consequences of the accident*" and "*reliability of the chemical plant*". Each of these variables depends on other factors, which in their turn depend on the following factors. Having a big number of variables, for better risk assessment it is needed to have rather much information, which we do not have at the moment or it might be expensive to get, because of timing, finances and other costs. For example, there are many parameters, such as "*concentration of substance*", "*duration of the exposure*", "*weather conditions*" etc., which can be found while using special measures, also such things as "*probability of accidents*", "*human factor*" cannot be measured with the help of special instruments. Therefore, the fuzzy model was rearranged in order to be based on a reduced number of input variables: in practice, all sub-variables (as it is shown in Fig. 3) have been grouped into two main variables. The fact that the information necessary by fuzzy logic is mostly more qualitative than quantitative, makes this method a good candidate to be used in order to perform the preliminary estimation of ecological risks. Besides, making a fuzzy model, in this case chemical plant managers will help to use methodology in an easier and more available and understandable way. As it is shown in Tables I and II, fuzzy sets were made for all inputs.

TABLE I

CRITERIA OF RELIABILITY OF THE CHEMICAL PLANT

Reliability of the chemical plant (V)	Criterion
H – High	• The plant fully corresponds to the safety requirements • The staff has been taught
M – Medium	• In general, the plant corresponds to necessary safety conditions • The level of the staff's preparation is not enough
L – Low	• The plant does not correspond to necessary safety requirements • The staff has no instruction

TABLE II

CRITERIA OF THE CONSEQUENCES OF THE ACCIDENT

Consequence of the accident (G)	Criterion
A	In case of release of chemicals, there is a high probability (50%) that it will lead to the fatal result – human deaths
B	In case of release of chemicals, injury to people might have a low probability of fatal result
C	In case of release of chemicals, minor damage to people's health may happen
D	In case of release of chemicals, there is a small probability that it will bring only minor damage to people's health
E	In case of release of chemicals, no damage to people's health will be observed

B. Output Definition

The main result of this fuzzy model is the definition of category of risk. The function of risk in the given example is presented in the form of equation (1).

$$R = GV \qquad (1)$$

where *G: consequences of the accident, V: reliability of the chemical plant.*

As it is shown in Table III, for output fuzzy sets were created.

TABLE III

CRITERIA OF RISK LEVEL

Risk level (R)	Criterion of evaluation
V – Very High	A high probability of fatal result at the plant and nearby territory
IV – High	A low probability of fatal result, but a high probability of damage to people's health
III – Medium	A slight probability of health damage and fatal result
II – Low	No risk of death, but slight probability of health damage
I – Very Low	No risk of death and health damage

C. Fuzzification

In the *fuzzification* process, the membership functions defined on the input and output variables are applied to actual values, to determine the degree of truth for each rule. In this paper, the Gaussian type of membership function was selected. The fuzzy sets and their membership function are demonstrated in Fig. 5(a), (b), (c) for each variable used in the fuzzy risk assessment.

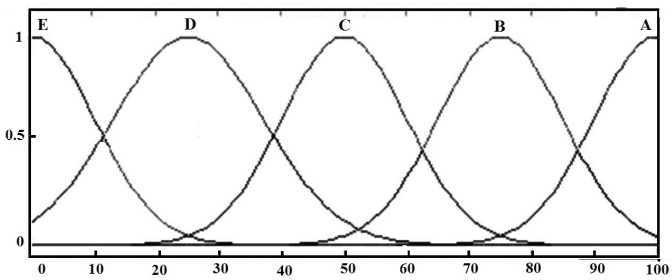

Fig. 5. (a) Graphs of membership functions of consequence of the accident.

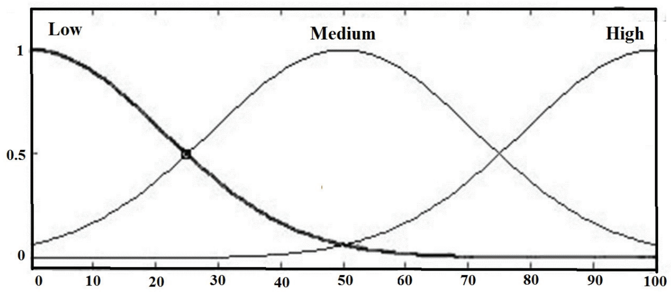

Fig. 5. (b) Graphs of membership functions of reliability of the chemical plant.

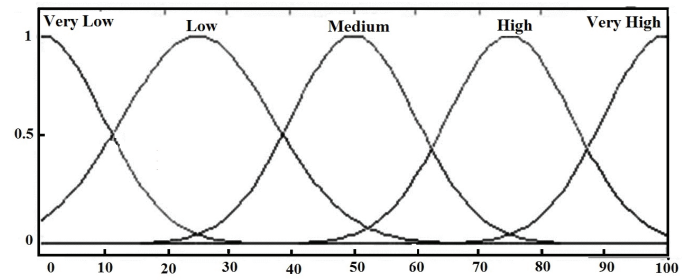

Fig. 5. (c) Graphs of membership functions of risk.

D. Setting up the Rules

Fuzzy logic is a decisional system based on linguistic rules [11]. Therefore, a next step is to connect fuzzy sets by rules. One type of fuzzy inference rule is called the max-min inference rule (Mamdani's methodology).

The most used rules are: "if *X* and *Y* then *Z*", where *X* and *Y* is the premise and *Z* is the consequence. As an example: "if *reliability of the chemical plant (V)* is *High* AND *consequences of the accident* (G) is "*In case of releases of chemicals, there is no damage to people*" THEN *Risk level (R)* is *Very Low*".

All the rules can be seen in Table IV. For example: if G=A and V = M, then R = IV.

TABLE IV
A SYSTEM OF RULES OF FUZZY INFERENCE

Consequences of a passible accident (G)	Reliability of the chemical plant (V)		
	H	M	L
A	III	IV	V
B	III	III	IV
C	II	III	III
D	II	II	III
E	I	II	II

E. Defuzzification

The *defuzzification* process, that is, the conversion of the fuzzy output set (represented as a surface as is shown in Fig. 6 and Fig. 7) to a crisp number, can be done by using different methodologies (Max, mean-max membership principle, centroid method, medium, weighted average method, center of the largest area method and other methods) [12]. In this paper, the most common and widely used *defuzzification* method has been selected: centroid method. The results can be seen at the top of Fig. 6. According to the centroid method or center of gravity method, the crisp value of the output variable is computed by finding the variable value of the center of gravity of the membership function for the fuzzy value. If you think of the area as a plate of equal density, the centroid is the point along the horizontal axis about which this shape would balance. More complete description of the algorithm can be found in [13]. For example, as it is shown in Fig. 6, if parameter *Consequence* (*consequences of the accident* (G)) is 30 units, but parameter *Reliability* (*reliability of the chemical plant (V)*) – 15, then Risk level will be 43.

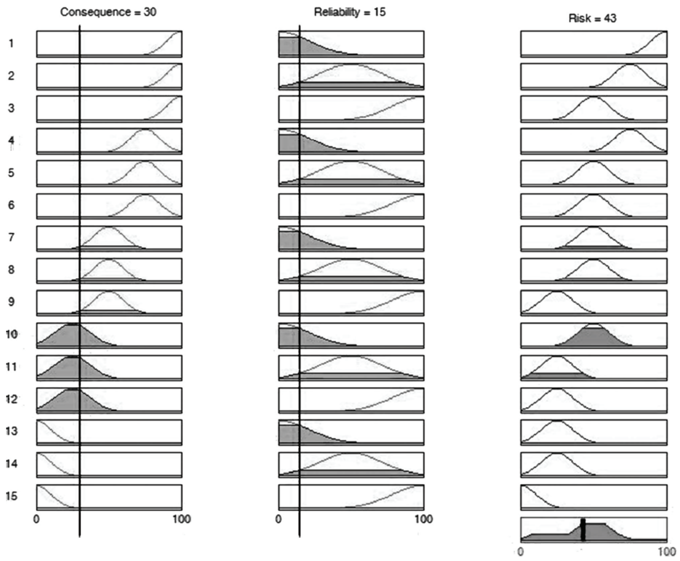

Fig. 6. Application of the centroid method to the inputs.

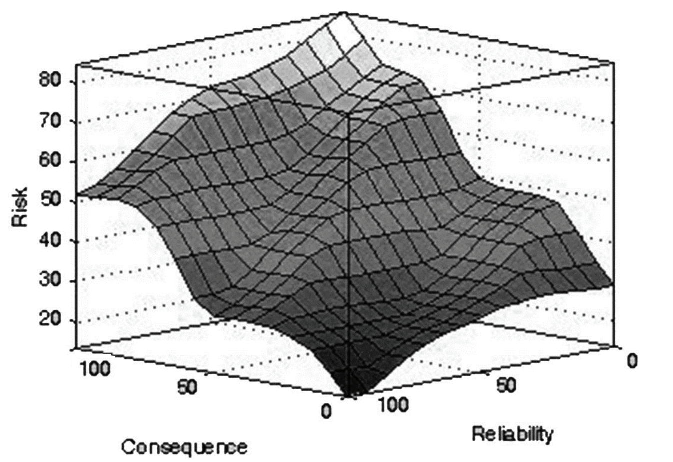

Fig. 7. Three-dimensional representation of the risk, consequence of the accident and reliability of the chemical plant.

IV. CONCLUSION

The application of the fuzzy logic to the assessment of risk of environment and people's health both at the plant territory and outside it in case of potential accident and releases of gaseous substance allows making a complex algorithm of analysis more affordable in order to obtain a risk assessment given incomplete and reduced input data.

The main variables of the model are as follows:

- Consequences of the accident;
- Reliability of the chemical plant.

For input and output variables, membership functions have been established. A a set of rules to link input and output variables has been set up and from there by the *defuzzification* method a crisp value can be obtained. The use of this model allows for a realistic preliminary assessment of the risk of accidental chemical releases. But, it is also important to highlight the model's user-friendly tool design and the effectiveness of achieving very appropriate results in a short time period.

The methodology can be used not only by public authorities but also by the same plant managers, since it is a method that allows for the evaluation of the risk level of the site and also it enables one to see whether the safety measurements are suitable. This application can be used as a preliminary risk assessment tool, able to highlight critical situations and the need for more in-depth and complete analysis; it can also be used in the case of necessity to be able to make a thoughtful decision to reduce a risk level.

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Andrejs Radionovs is a Doctoral Student at Rezekne Higher Education Institution (Latvia). He received the M.Sc. degree in Computer Science from Daugavpils University (Latvia). His research interests include information systems, fuzzy information, uncertain information and in particular, fuzzy set theory and its applications in risk assessment.
Address: Rezekne Higher Education Institution, 90 Atbrīvošanas Av., Rezekne LV-4600, Latvia.
E-mail: a.radionovs@gmail.com.

Oļeg Uzhga-Rebrov is a Professor at the Faculty of Economics, Rezekne Higher Education Institution (Latvia). He received the Doctoral degree in Information Systems from Riga Technical University in 1994. His research interests include different approaches to processing incomplete, uncertain and fuzzy information, in particular, fuzzy set theory, rough set theory, as well as fuzzy classification and fuzzy clustering techniques and their applications in bioinformatics.
Address: Rezekne Higher Education Institution, 90 Atbrīvošanas Av., Rezekne LV-4600, Latvia.
E-mail: ushga@ru.lv.

Andrejs Radionovs, Oļegs Užga-Rebrovs. Izplūdušās loģikas pielietojums risku analīzē
Riska novērtēšana ir svarīgs uzdevums daudzās cilvēku darbības jomās: ekonomiskajā, tehniskajā, ekoloģiskajā u.c. Pēdējo gadu laikā pieaugošais uztraukums par ekoloģiskā stāvokļa pasliktināšanos un potenciālo risku paaugstināšanos, kas ir saistīts ar daudzām cilvēka aktivitātēm un jauno tehnoloģiju izmantošanu, rada palielinātu interesi par ekoloģisko risku novērtēšanu. Ja ir pietiekams daudzums pamatinformācijas, tad sākotnējo riska novērtējumu var balstīt uz statistikas metodēm. Diemžēl ekoloģiskā riska novērtēšanai trūkst statistiskās informācijas. Tādējādi riska novērtējums jāveic informācijas trūkuma, nepietiekamības vai nenoteiktības apstākļos. Vēsturiski pirmais nenoteiktības veids, kuram bija izstrādāti teorētiskie un praktiskie pamati, bija gadījuma notikumu iestāšanās izredzes (varbūtējā nenoteiktība). Pašlaik varbūtības teorija nodrošina spēcīgu matemātisko aparātu nenoteiktības vadībai dažādās cilvēku darbības jomās. Taču varbūtības teorija un statistika nevar palīdzēt atspoguļot izplūdušus subjektīvus priekšstatus par relevanto reālo lielumu nenoteiktību (izplūdušās nenoteiktības). Lai samazinātu trūkstošās objektīvās informācijas ietekmi, bieži izmanto ekspertu vērtējumu par iespējamiem zaudējumiem un notikuma varbūtību. Eksperti, pamatojoties uz savu kompetenci, pieredzi un dažreiz intuīciju, var sniegt datu analīzei nepieciešamos datus. Ir izstrādātas dažādas metodes izplūdušo varbūtību izmantošanai un aprēķināšanai. Pie šīm metodēm pieder: intervālu varbūtības metode, otrās kārtas varbūtības metode, izplūdušās loģikas metode utt. Šajā rakstā izplūdušās loģikas metode tiek pielietota ekoloģiskā riska analīzē, gadījumā, ja notikusi toksiskas vielas noplūde ķīmiskajā rūpnīcā. Izplūdušās loģikas pieeju var izmantot ķīmisko rūpnīcu konsultanti riska jautājumos, lai pieņemtu nepieciešamos lēmumus tādās situācijās, kad izplūdušās ķīmiskās vielas var būt bīstamas ne tikai videi, bet arī cilvēku veselībai.

Андрей Радионов, Олег Ужга-Ребров. Применение нечеткой логики для анализа рисков
Оценка рисков является важной задачей во многих областях человеческой деятельности: экономической, технической, экологической и т. д. Растущее беспокойство по поводу ухудшающегося состояния окружающей среды и возрастание потенциальных рисков, связанных со многими видами деятельности человека и использованием новых технологий, вызывают стремительное увеличение интереса к оценке и управлению экологических рисков. В случае наличия достаточной исходной информации предварительная оценка риска осуществляется на основе статистических методов. К сожалению, наличие достаточного статистического материала в оценке экологических рисков является скорее исключением, чем правилом. В таком случае, оценка риска должна проводиться в условиях отсутствия, недостаточности или неопределенности информации. Исторически первым типом неопределённости, для которого были разработаны теоретические и практические основы, были шансы наступления случайных событий (вероятностные неопределённости). В настоящее время теория вероятности предоставляет мощный математический аппарат для управления неопределённостью в различных областях человеческой деятельности. Для снижения влияния недостатка объективной информации часто используются оценки экспертов о потенциальных потерях и вероятности события. Эксперты на основе своих профессиональных знаний, опыта и, иногда, интуиции могут представить необходимые для анализа данные. Разработаны методы для получения и использования неопределенных вероятностных оценок, к ним относятся: интервальные вероятности, вероятности второго порядка, метод нечеткой логики и т. д. В данной статье описан процесс анализа экологического риска методами нечеткой логики на примере утечки токсических выбросов на химическом заводе. Заявленный подход на основе нечеткой логики может быть использован консультантами по оценке риска на химических заводах для принятия необходимых решений в ситуациях, когда химические выбросы могут нанести вред не только окружающей среде, но и здоровью людей.