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USE OF RISK ASSESSMENT METHOD IN DECISION-MAKING FOR THE BROWNFIELDS RECLAMATION

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Abstract. Rational use and protection of land is one of the most important priorities in the ecological State policy. At the same time, the soil protection is one of the strategic priorities of the European Commission, called *Towards Thematic Strategy for Soil Protection*. The soils quality in Europe is not satisfactory. Soils fertility is decreasing, erosion is increasing, and soil function is getting limited because of general use of soils for farming. In Polish law, soil quality standards are set by the Ministry of Environment decree. According to this Act, maximum admissible concentrations of impurities in different layers of soils are established for three types of sites. The preliminary qualification consists of the comparison of measured concentration of substances, listed in the above mentioned act, with the environmental standards. When the measured concentrations exceed the standards, the site is qualified as polluted. After the preliminary qualification, the site is designed for more detailed classification on the base of risk assessment method. The preliminary qualification of contaminated sites does not provide the real solution of urgent problems because of the limited amount of funds. The real threat for human health and environment depends not only on the level of particular pollutant concentration but also on the local conditions, for instance groundwater level, land use, etc. For those reasons, the site specific analysis should be used. The proper method for such an analysis is the risk assessment procedure. Following this procedure, the assessor is able to give the true information on the hazard posed by the contaminated sites.

Key words: risk, environment, contamination, soils.

Abstrakt. Racjonalne wykorzystanie terenów jest jednym z najważniejszych priorytetów w państwowej polityce ekologicznej. Ochrona gleb jest także jednym z najważniejszych strategicznych celów Komisji Europejskiej, nazwanym *Towards Thematic Strategy for Soil Protection*. Jakość gleb w Europie nie jest zadowalająca: żyzność gleb ulega obniżeniu, wzrasta ich erozja, ponadto funkcja gleb jest poważnie ograniczona z powodu ich rolniczego wykorzystania.
W polskim prawie standardy jakości gleb są określone zarządzeniem wydanym przez Ministra Środowiska. W akcie tym jest określona maksymalna dopuszczalna zawartość zanieczyszczeń w różnych warstwach gleb dla trzech typów lokalizacji. Kwalifikacja gleb polega na porównaniu zmierzonych koncentracji zanieczyszczeń z zawartością określoną w zarządzeniu. Jeśli zmierzona zawartość przekracza standardy, dana lokalizacja jest kwalifikowana jako zanieczyszczona. Po przeprowadzeniu kwalifikacji miejsce jest poddawane bardziej szczegółowej ocenie na podstawie metod oceny ryzyka. Kwalifikacja zanieczyszczonego miejsca nie daje realnego rozwiązania nawet naglącego problemu z powodu zwykle ograniczonych funduszy. Realne zagrożenie dla środowiska i zdrowia ludzi zależy nie tylko od stężenia poszczególnych zanieczyszczeń, ale również od lokalnych warunków, np. od poziomu wód gruntowych, zagospodarowania terenu itd. Z tego powodu szczegółowa analiza powinna być wykonana odpowiednią metodą — procedurą oceny ryzyka. Wypełniając tę procedurę można uzyskać rzeczywistą ocenę zagrożenia, jakie stwarza zanieczyszczone miejsce.

Słowa kluczowe: ocena ryzyka, środowisko, zanieczyszczenie, gleby.

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INTRODUCTION

Rational use and protection of land are one of the most important priorities of the State Ecological Policy. Nonetheless, historical legacy linked with extensive industrial and rural development has contributed to the limited efficiency of the existing system of land protection as compared to the results achieved in the spheres of air and water protection. In these two letter spheres, a considerable improvement of the environment has taken place recently (The Assumptions..., 2003).

Similar problems have been observed in the European Union where the legal regulations concerning soil protection are less comprehensive than those dealing with other environmental areas. Therefore, one of the strategic priorities of the European Union VI Framework Programme of Research and Technological Development is soil protection against contamination and erosion. In 2002, the European Commission has prepared for Council and European Parliament a draft document called *Toward the Strategy of Soil Protection* (Communication..., 2002). This EC proposal indicated the most important reasons of soil contamination, that is the industrial and mining activity as well as landfilling with waste. The period of interest covers the operational and post-operational activity. This document has also clearly pointed out to the advancing deterioration of soil quality in Europe, manifested by decrease of the soil fertility, acceleration of its erosion, and limitation of the important, from the environmental and rural use point of view, soil function. Lack of reaction to these phenomena can foster further soil degradation. Poland also has to undertake necessary measurements for prioritising and consolidating the soils legal protection, at least to the similar degree as the protection of other environmental elements, and to prepare the soil protection strategy.

Experiences of the OECD countries have proved that for the intensification of the post-industrial areas reuse, government intervention is indispensable. The Canadian experiences showed, that in case of about 15 to 20% of the post-industrial areas with promising location, the value of site exceeds the cost connected with its reclamation, and, therefore, no State assistance is required. The reclamation cost of another 15–20% of the post-industrial areas is so tremendous that no-one can expect the real reuse of those areas in the near future.

For the remaining 60–70% of the post-industrial areas, it is difficult to define costs and benefits connected with their reusing, and such situation causes the elimination of these sites from the economic considerations, and leads to the substantial losses in their economic and social values. In those cases, there is necessary to elaborate appropriate criteria in order to restore such sites for the economic appraisals. Such exemplary criteria could be, for instance, the health and environment protection, and the method of their analyses would be the risk assessment. The quantitative criterion such as risk assessment allows to determine the priority list of sites prior to their reclamation. The priority list establishes the order of projects importance in conditions of the limited availability of financial funds.

ENVIRONMENTAL QUALITY STANDARDS

By the environmental quality standards, it is understood the requirements that have to be fulfilled by the environment as a whole or by its specific elements in defined time. Environmental quality standards can be differentiated in accordance with the areas and they are expressed as levels of substances and energies. Environmental quality standards refer to the properties of air, soil, groundwater, as well as surface and drinking water.

Substantial problems arise during the introduction of criteria values concerned with admissible levels of soil contaminants, uniform for the whole EU, mainly because of the large generic variability of soils. Nevertheless, in some countries where such variability was found to be less significant (The Netherlands), the criteria values (qualification and intervention values) have been established in relation to the content of organic substances and clay particles in soils.

European legislation in this field is fragmentary, so far, and the harmonisation of definitions and standards appears very difficult to introduce. The EU announced a number of research programs, for example: CLARINET — Contaminated Land Rehabilitation Network for Environmental Technologies, CARACAS, NICOLE, and others, in order to overcome the obstacles caused by problems complexity concerned with the soil protection.

The Polish Act of 27 April 2001, *the Environmental Protection Law*, in section IV entitled *Land Protection*, lays out rules for land protection. In particular, Article 102 describes the basis of reclamation practices, and Article 103 defines the concept of quality standards for soils. The most important within this scope Article 105 binds the Minister of Environment to issue the regulation on the soil quality standards. On this base, the Minister of Environment has issued the regulation on the soil and land quality standards in which the maximum values of admissible concentrations of metals, inorganic contaminants, hydrocarbons and theirs derivatives, plant protection chemicals, and others in soils, have been set. The values have been determined for three types of sites and three depths. Thus for each contaminant nine criteria values are ascribed.

PRELIMINARY QUALIFICATION OF SITES FOR THE RECLAMATION

Initially, the preliminary assessment of information concerning the contaminant sources, ways of transport, and receptors, is performed. Definitions are required for:

— type of activities in a given area, and boundary of contaminated site,
— present and future use of land (information used for the identification of existing and potential receptors),
— potential sources and types of contaminants, potential contaminated media (soil, air, water), ways that contaminants are transported, ways of exposure and potential receptors.

The aim at this stage is to describe the actual conditions prevailing at a given site depending upon the types and sources of contaminants, existing and potential ways of migration, and potential migration targets and receptors. Preliminary qualification of sites designed for reclamation relies on the analyses of empirical data on the concentrations of respective contaminants, listed in the Regulation on the soil and land quality standards, and on the comparison of their values to the values of the binding criteria (environmental quality standards).

In case of groundwater or surface water contamination, the results are compared to the quality standards for groundwater, surface water, and drinking water. Sites on which these values have been exceeded are classified as contaminated and designated for further analyses of the risk assessment for human health and the environment.

THE PRINCIPLES OF THE HUMAN HEALTH AND ENVIRONMENT RISK ASSESSMENT METHODS

The assessment of exposure and risk analysis for the environment and human health are considered separately because the human exposure takes place indirectly via the environment. In the first case, performing risk assessment, the concentrations measured in each element of the environment (water, soil, and air) are related to the values considered as safe (determined on the base of toxicological and ecotoxicological studies). In case when obtaining the data by direct measurements is too costly or impossible to perform, the assessor can use mathematical models describing the migration of contaminants in different elements of environment.

Output values (expressed as concentration), obtained as a result of the environment exposure assessment and risk analysis, become the input values to the humans exposure assessment. In this case, risk analysis is carried out by consideration of ratio between doses possible to intake and doses that do not cause any unacceptable effect for the most exposed target group, as compared to the reference group.

Risk analysis for the environment

Exposure assessment for the environment originating from contaminated sites includes:

— identification of the exposure sources,
— scenarios of contaminants release from the contaminated sites.
— ways and rates of contaminants distribution in the specific element of environment (water, soil, air),
— determination of contaminants bioaccumulation rate in living organisms, *and ipso facto* the critical food-chain for each of them.

For the environment risk analysis performance, it is indispensable to consider the following problems:

• Concentration — effect assessment

The aim of this assessment is a prediction of the contaminant concentration in each component of the environment below which no adverse effect on the environment is observed or occurrence of such effect is unlikely. Such concentrations are defined as PNEC (*Predicted Non Effect Concentration).*

The PNEC concentrations are the base for the standards determination, and for the admissible and proposed concentrations. In case of absence of the existing data, it is allowed to calculate PNEC by using the modification coefficients that correct values of the indicators LC_{50}, EC_{50}, IC_{50}, and LD_{50} obtained as a result of tests performed on living organisms. A coefficient represents the degree of uncertainty regarding the data extrapolation.

• Exposure assessment

The aim of exposure assessment is to predict most likely concentration of a substance in the environment. Such indicator, named PEC (Predicted *Environmental Concentration*), is determined by collecting data from in-site measurements in each of the environmental compartments. When the data collection is too costly or impossible to perform, it is acceptable to use mathematical models for the calculation of contaminant distribution in the environment.

• Risk analysis for the environment

The risk analysis for the environment is performed by comparing the measured or calculated PEC with the determined PNEC. The risk is determined by calculating the PEC/PNEC ratio. The risk rate can reach the value of <1, equal 1, and >1. When the value of the risk estimation is <1 or equal to 1, it is considered that there is no risk for the environment. When the risk rate value is >1, it is considered that there is a risk for the environment and it is necessary to take into account others factors, including:

— indicators of the potential bio-accumulation in the food-chain,
— toxicity shape vs. time curve obtained from toxicity tests,
— indicators of adverse effects for other bio-systems obtained as a result of the toxicological study,

— other data for substances behaving similarly in the environment or possessing similar physico-chemical and toxicological properties.

Risk analysis for human health

Exposure assessment for human health originating from contaminated sites includes:

— Definition of type and size of population exposed to hazard. The population can vary in accordance with the different contaminants. The contaminants can posses carcinogenic or non-carcinogenic toxicity. For the quantity assessment of treated population, it is indispensable to study its structure from the point of view of sex and age of individuals living within the site determined by the assessment of exposure and risk analysis for the environment.
— Characteristics of exposure that takes into account, between others, determination of occupational and other activities, style of living, and state of health.
— Isolation of sub-populations under high hazard.
— Rate and duration of exposure.
— Likely way of exposure (inhalation, water and food consumption, skin contact).
— Chemical form, related metabolism, and toxicological and physico-chemical data.
— Type of toxicity (carcinogenic or non-carcinogenic).

For further risk analysis, definite exposure factors (metals) are assumed, and sub-populations especially exposed to these factors defined.

For the performance of the human health risk analysis, it is indispensable to consider the following problems:

• Dose-response assessment

For the dose-response evaluation, relationship models belonging to one of the two groups: statistical or developed on the biological bases, are listed. The statistical models use the assumption that every individual in a population is characterised by a specific resistance to the stress factor under study. It means that for each model, there is a certain critical dose below which the expected exposure effect is not observed. This type of a model is traditionally chosen by pharmacists and toxicologists. The most popular models in this class are models assuming the existence of the individual threshold that in the exposed population is distributed according to log-normal distribution.

In the models based on biology, preferred by molecular biologists, the assumption is used for various mechanisms of carcinogenesis. Each of them is based on the assumption that cancer arises from a single cell, through the stage of transformation of ordinary cell into the carcinogenic cell, and than by cloning, to clinically detected cancer. These can be either a model of single transformation or a multistage model.

The procedure of assessment of the dose-response relationship proceeds in a different manner depending on the nature of substance which can possess threshold or non-threshold toxicity.

• The assessment of the dose-response relationship for substances possessing the threshold toxicity

The assessment of the exposure to chemical substances not causing the genotoxic effects relies on the assumption that for each of them there is a certain threshold of exposure (threshold value) below which the adverse health effects does not occur, even under conditions of chronic (long time) exposures. The following concepts and symbols are used:

— NOEL — Non-Observed-Effect-Level. It is the highest exposure level (dose) that does not cause statistically or biologically significant increase in frequency of any effects within the exposed group, in comparison with the reference group.
— NOAEL — Non-Observed-Adverse-Effect-Level. It is the highest exposure level (dose) that does not cause statistically or biologically significant increase in the frequency of adverse effects within the exposed group, in comparison with the reference group.
— LOAEL — Lowest-Observed-Adverse-Effect-Level. It is the lowest exposure level (dose) that does not cause statistically or biologically significant increase in the frequency of adverse effects within the exposed group, in comparison with the reference group.
— BD — Benchmark Dose. It is a determination of the lower end of the dose confidence interval which causes some established, relatively small responses (risks) (0.01 or 0.1).
— ADI — Acceptable Daily Intake. It is the amount of substance which in the daily intake for lifetime with food or drinking water will not threaten the human health.
— RfD — Reference Dose. It is an estimated rate of daily exposure (including susceptible subgroups) that would likely not cause any significant increase in the frequency of adverse effects for lifetime.
— RfC — Reference Concentration. It is the same definition as for RfD.

• Determination of RfD, RfC, and ADI

Classical approach to risk assessment for non-carcinogenic effects of exposure to chemical substances relies on the determination of the acceptable daily intake (ADI)

$$ADI = NOEL/SF$$

where: SF means the safety factor, initially assumed as 100.

The USEPA (*United States Environmental Protection Agency*) suggested the ADI replacement by the reference dose (RfD):

$$RfD = NOAEL/UF*MF$$

where: UF means the uncertainty factor, and Mf means the modifying factor. UF is defined as a product of coefficients; each of them can bear integer value ranged from 1 to 10. These coefficients express uncertainty both between and within species; the uncertainty connected with the assumption of LOAEL value in these cases for which LOAEL can not be determined.

The up-to-date approach to risk assessment for chemical substances not possessing the carcinogenic properties relies on the use of the benchmark dose (BD) concept. At present, the ADI is defined as:

$$ADI = BD/SF$$

The risk assessment for exposure to chemical substances having the threshold toxicity relies on the certain "safety" dose determination, independently of its definition. The dose-response curve represents a relationship between the dose rate and percentage of individuals inside the population that show the adverse effect. This relationship is widely used in the assessment of the risk from carcinogenic substances.

USE OF RISK ASSESSMENT METHOD FOR DETERMINATION OF THE "WORST CASES" AND "PRIORITY LIST" SITES FOR RECLAMATION

Risk analyses applied for each site separately allow to establish a list of the "worst cases" and a priority list of the sites for reclamation. These qualifications are based on the following premises:

- for evaluation of the exposure on contaminants within a given site, the assessor uses a criterion defined as contaminants content in the soil,
- risk encountered within such areas is estimated as either insignificant, admissible or not admissible,
- the boundaries between respective exposures are determined by the assumed values of contaminants concentrations in the soil,
- quantitative criteria are used for the assessment of soil condition and degree of exposure of the ecosystem selected elements,
- quantitative values of these criteria are variable, depending on whether an element or the whole ecosystem is the subject in question.

As it is shown on Figure 1, the starting point represents the state defined as normal. This area is characterised by low exposure and can be defined at local, regional, and even at the geographical scale. Different countries may adopt different "normal" substances content in soil. In such cases, the concept of threshold values is often used. These values determine a lower limit of the increased risk zone showed on Figure 1. Within this area, the risk reduction measurements are not required but the risk ratio is increased in comparison with the areas showing the "normal" contaminants contents.

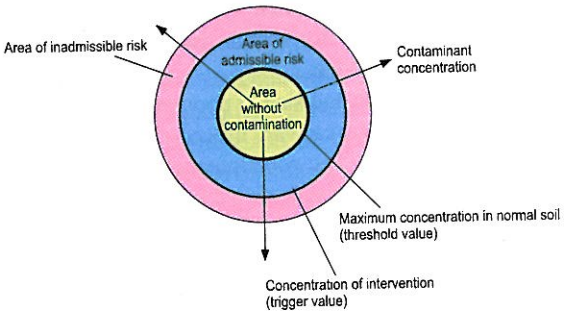

Fig 1. Criteria of risk areas division (Gworek *et al*., 2000)

The higher limit of the admissible risk zone is determined by the concentrations values for which it is indispensable to undertake the risk reduction measures. Similarly to the threshold values, in different countries different permissible values for land use are established. The reasons for these dissimilarities are different. They are rooted in the economic development history, geological characteristics, and other factors.

The intervention concentrations (trigger values) are defined by the risk assessment methods for human health and the environment.

CONCLUSIONS

A comparison of contaminant concentrations occurring in brownfields with the environmental quality standards is not sufficient for the definition of areas where urgent treatment is required. Assumption of the defined sites order (sequence) for the recultivation is necessary under the conditions of scarcity of the financial means. This is the main problem within the decision making process. The information on contaminants concentration exceeding the admissible values is not sufficient for the determination of risk rate for the environment and human health in the contaminated sites.

The method of risk assessment for the environment and human health can be used for the establishing of the "worst cases" list and priority list, on the basis of admissible risk assumption, i.e. of the contaminants concentrations that do not go beyond the state of admissible risks. During the risk analysis, a risk assessor takes into consideration all factors which cause exposition characteristic for a given area and contaminant types. On these basis, the admissible risk is determined as feature of the given site. On the base of such analysis, the risk manager can define indispensable measures necessary to undertake in order to reduce the risk.

REFERENCES

THE ASSUMPTIONS to the government programme for post-industrial areas, 2003. The paper of Ministry of Environment. Warsaw.

COMMUNICATION from the commission to the council, 2002. COM 2002, 179, Brussels, 16.4.2002.

GWOREK B. *et al*., 2000 — Procedure of risk assessment applied to the management of sites contaminated by heavy metals. Monograph of the Institute of Environmental Protection, Warsaw.