EVALUATION OF MILITARY ACTIVITY IMPACT ON HUMANS THROUGH A PROBABILISTIC ECOLOGICAL RISK ASSESSMENT. EXAMPLE OF A FORMER MISSILE BASE

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The current article provides a methodology focused on the assessment of environmental factors after termination of military activity and uses a former missile base as an example. The assessment of environmental conditions is performed through an evaluation of the risks posed by the hazardous chemicals contained by underground and surface water sources and soil to human health . Moreover, by conducting deterministic and probabilistic risk assessments, the article determines that the probabilistic assessment provides more accurate and qualitative information for decision-making on the use of environmental protection measures, which often saves financial and material resources needed for their implementation.

Key words: *military activity, human impact, ecological risk, probabilistic risk assessment.*

1. INTRODUCTION

Military activity is conducted in ‘military areas’ [1]. that are of significant value to environmentalists despite the widespread outcry about being badly polluted. Such areas often occupy hundreds of thousands of hectares of land. After the ‘cold war’and the inherent reduction of armies and weapons, these areas can be used as reserves, or used for agricultural or recreational purposes. It is clear that, as case may be, in order to decide their further use it is necessary to evaluate the degree of land contamination and the possible impact of pollutants on environmental objects to be used in the conduct of activities in such areas.

To make the right decision it is desirable to have particular criteria - certain indicators of environmental condition that characterize both the danger to humans and for biota. The environmental risk – „probable damage to human life or health, environment, life or health of animals and plants considering the severity of the damage" [2] is a convenient criterion in this regard.

The method of ecological risk assessment of chemical pollutants' impact on humans and the biota is given by this article using an active military range as an example [3]. Deterministic assessment criteria, namely fixed parameters (e.g. assumed human body weight of 70 kg, the concentrations of chemicals in the soil - the average of several etc.) are employed to evaluate risks.

The following cases are used depending on the importance of the problem, when deterministic data use:

• risk assessment based on the use of average reference values;

• risk assessment based on the largest values of reference variables that should be expected at a given location, usually 90th or 95th percentiles of value distribution.

Obviously, the latter case is used for conservative estimation when it is important to avoid underestimating the danger. In this case, if the level of acceptable risk is exceeded it is neccessary to apply measures to reduce it, and excessive conservatism may cause serious unjustified expenses. At the same time, using only averaged values of reference values while estimating the risk can lead to its underestimation for certain vulnerable categories of population or ecosystem components.

Probabilistic risk assessment uses probability distributions instead of point values of reference variables to calculate the risk, ultimately getting to a probabilistic distribution of risk values. In this case it is possible to derive the value of the probability of exceeding the risk level that is of interest, namely to quantify the uncertainty value, which is not possible while using determined values. Thus, probabilistic risk assessment provides unique and important additional information that is used for optimal risk management.

The aim of this paper is to show the importance and usefulness of applying the probabilistic risk assessment method for people living in a polluted environment by using a specific example.

2. RESEARCH SCOPE AND RESULTS

The scope of this article is supported by research [4] dealing with the condition of environment after termination missile base related activities.

The geographic area of concern for the article is the Zhytomyr Region (Ukraine) that housed the missiles complexes of the former Soviet Union (medium-range missiles 8K63, SS-4 «Sandal», by NATO classification) between 1958 and 1989.

After the termination of the base its area was not exploited, and the locals living near the base had free access to its former area. The analysis of soil and water from open sources near the base, as well as the composition of water from underground springs, that local population use as drinking water, was conducted to determine the degree of contamination of the territory. The content of chemicals in objects under the study is given in **Table 1**.

Table 1. Qualitative characteristics of soil and water from surface and underground water sources of former missile base (2007-2009)

Name of the examined object	The content of element, mg / kg					
	Cu	Ni	Pb	Zn	Mn	Fe
Soil	56.7±14.1	4.75±1.18	26.45± 6.6	280.3±69.3	12.8±3.2	21.34±5.3
Water from surface sources	0.0032 ±0.0008	0.25±0.06	0.034 ±0.008	0.026 ±0.007	0.13±0.03	4.75±1.20
Water from underground sources	0.0042 ±0.001	0.093 ±0.02	0.00	0.024 ±0.001	0.089 ±0.22	5.20±1.3

2.1. Deterministic risk assessment

The evaluation of chemical compounds effect on human health and biota was initially conducted via deterministic risk assessment. The risk of chemical effects is determined by comparing the values of cancer risk *CR* and noncancer hazard index *HI* of acceptable values (Table 2).

The impact of pollutants on humans occurs with the use of contaminated water from underground sources and consumption of plants growing on contaminated soil as small surface water sources are used neither for agricultural, nor for recreational purposes. For the puposes of the analysis, let us consider the risk of carcinogenic and noncarcinogenic compounds on human health.

Carcinogenic risk is determined based on equation (1)

$$CR = \sum ICR_i, \qquad (1)$$

where *CR* represents thevalue of full individual cancer risk caused by the action of carcinogens N_R;

ICR - the value of individual cancer risk caused by the action of the i^{th}-carcinogen;

N_R - total number of carcinogens.

$$ICR = ADD \cdot SF, \qquad (2)$$

where *ADD* is the daily dose of harmful chemical consumed by the recipient;

SF - cancer slope factor for the substance, which characterizes the degree of increase in cancer risk along with the increasing of dose per unit.

Table 2. Classification of risk levels

Risk		Risk level
Noncancerogenic HQ (HI)	**Cancerogenic CR**	
<1.0	$< 10^{-6}$	Minimum - desired (target) risk value during the conduct of health and environmental protection measures.
1.0–10.0	10^{-4} - 10^{-6}	Medium - acceptable for conditions of military service. If effects the civilian populationand requires a dynamic monitoring of the environment.
10.0–100.0	10^{-3} - 10^{-4}	Significant - unacceptable for population; for military service conditions, dynamic control and in-depth study of the sources and consequences of possible harmful effects deciding on risk management measures is required.
>100.0	$>10^{-3}$	High - not acceptable for military service during peacetime and for the population. It is necessary to implement measures to eliminate or reduce the risk.

Noncarcinogenic risk is determined by hazard index *HI*

$$HI = \sum_{j=1} HQ_j, \qquad (3)$$

where *HQ* - hazard quotient of j^{th}-substance;

N - total number of hazardous substances.

$$HQ = ADD/RfD, \qquad (4)$$

where *RfD* - reference dose, the value that characterizes the daily effect of the chemical during lifetime and probably does not put sensitive groups at health risk.

The average daily dose of *ADD* is determined from the equation (5),

$$ADD = \frac{(C_w \cdot CW_w \cdot EF_w \cdot ED_w) + (C_f \cdot CW_f \cdot EF_f \cdot ED_f)}{BW \cdot AT}, \qquad (5)$$

where *C* - concentration of the chemical;

CW - quantity of drinking water and food consumed by a person per day;

EF - frequency of action, the number of days per year;

ED – action duration, number of years;

BW - average human body weight during exposure;

AT - averaging period of exposure in days.

Indexes «w» and «f» relate to drinking water and food, respectively.

Obviously, when calculating food consuming risk, we mean the additional risk caused by consuming products grown on the territory of the former missile base.

The territory of the former base is not used for agriculture, but locals pick up and consume wild berries and mushrooms.

The concentration of chemicals in food C_f is determined from the equation (6)

$$C_f = C_s \cdot UF_p, \qquad (6)$$

where C_s - concentration of the chemical in the soil;

UF_p - factor of bioaccumulation of chemicals by plant from the soil.

UF_p values which borrowed from [5] are presented in Table 3.

Risk calculations were carried out separately for adults and children. Initial data are presented in **Table 3**. **Table 4** presents the results of calculations.

Table 3. Initial data for the determined coefficients of hazard and carcinogenic risks assessment

Parameter	Cu	Mn	Zn	Pb	Ni	Fe
Cw, mg/l	0.0042	0.089	0.024	0.00	0.093	5.20
C_s, mg /kg (dry mass)	56.7	4.75	26.45	280.3	12.8	21.34
UF_p	0.4	0.123	0.123	0.045	0.032	0.123
RfD chron., mg / kg	0.019	0.14	0.3	0.0035	0.02	0.3
SF, (mg /(kg ·day))$^{-1}$	---	---	---	0.047	0.91	---
	Children			Adults		
CW_w, l/ day	1			2		
CW_p, mg /(kg · day)	Berries– 35, mushrooms – 2			Berries – 35, mushrooms – 10		
EF_w, day	350			350		
EF_p, day	Berries – 90, mushrooms – 150			Berries – 90, mushrooms – 150		
ED, years	Children – 6			Adults – 30		
BW, kg	Children – 15			Adults – 70		
AT, day	Children – 2190 (6 years), carcinogens – 25550 (70 years)			Children – 10950 (30 years), carcinogens– 25550 (70 years)		

Note: The weight of food is given in dry mass per unit of human body weight [6]

Table 4. Results of determined coefficients assessment of hazard and carcinogenic risks from chemical contamination of soil and underground water sources

Parameter	Cu	Mn	Zn	Pb	Ni	Fe	Σ
Consumption of water from underground sources							
HQ (children)	0.05	0.04	0.01	0.00	0.30	1.11	*HI* = 1.47
HQ (adults)	0.0061	0.0174	0.0022	0.00	0.127	0.475	*HI* = 0.63
ICR (children)	---	---	---	0.00	4.64E-04	---	*CR* = 4.64E-04
ICR (adults)	---	---	---	0.00	9.94E-04	---	*CR* = 9.94E-04
Consumption of plants grown on polluted soil							
HQ (children)	1.70E-05	4.58E-06	1.38E-06	1.04E-06	8.35E-07	2.11E-05	*HI* = 0.0013
HQ (adults)	1.2E-03	4.0E-05	6.22E-06	4.01E-04	5.6E-05	9.0E-05	*HI* = 0.0018
ICR (children)	---	---	---	4.20E-09	6.51E-08	---	*CR* = 6.93E-08
ICR (adults)	---	---	---	2.83E-08	4.39E-07	---	*CR* = 4.67E-07

The above presented calculation shows that, from the toxicological point of view, underground water sources and plants grown in the soils of the former base, practically are not dangerous for people who consume them.

However, consumption of water from underground horizons has a significant carcinogenic hazard. The value of risk is within 10^{-3} – 10^{-4} and basically is unacceptable for the civilian population. It is clear that in a case like this it is advisable to conduct more complex probabilistic risk assessment since the environmental decisions, based on the results of deterministic evaluation, require additional expenditures on risk reduction.

2.2. Probabilistic risk assessment

While applying probabilistic risk asement, instead of point values of reference variables we use their probabilistic distributions, which are used as substitutions in the models for risk assessment. Thus, by employing the Monte Carlo method [7] we ultimately determine probability distribution of risk values. The Monte Carlo method suggests random selection of fixed values of the probability distributions of reference values and using them in models that form a decision. After a number of iterations you can build a distribution of desired value.

A probabilistic approach should include all components of the evaluation process. However, in practice only the component of exposure assessment is usually employed, at least in assessing the impact of pollutants on human health. In this respect, it is recommended to use values *RfD* and *SF* as point values till receiving additional data [6].

Thus, to determine risk probability values (equation (1) and (3)), it is necessary to determine the distribution of the average daily *ADD* dose of chemical substances that enter a human body with drinking water (receiving carcinogens from plants grown in contaminated soil will be neglected). This can be done by substituting probabilistic values of reference values in equation (5) and determining distribution of *ADD* by the Monte Carlo method. Except for the concentration of a C_w chemical, other values are common physiological parameters of human body and for that reason surrogate data defined in a different place can be used. For example, according to [6]

$$ADD = (C_w \cdot IRW)/1000, \qquad (6)$$

where *ADD* - normalized per mass unit daily dose of a chemical mg / (kg · day);

C_w - concentration of the chemical in drinking water, mg / l;

IRW - normalized per mass unit amount of drinking water, consumed by person per day, ml / (kg · day).

It is estimated [6], that *IRW* has the form of lognormal distribution with parameters depending on the age of the person consuming water. Hypothesizing that the data scatter on the concentration of harmful substances in water has normal distribution and is defined only by time variability, equation (6) can determine the distribution of *ADD*, and equation (1) can determine the distribution of *CR*. Initial data for the lognormal distribution *IRW* are given in **Table 5**, and normal distributions of C_w are presented in **Table 1** (for each substance the values of the average concentration and its standard deviation are given).

Table no.5. The parameters for the lognormal distributions of drinking water consumed by person per day (*IRW*), ml / (kg · day) [6]

Age group,years	μ	σ	Lower limit	Upper limit
1-3	3.49	0.75	5.81	186.49
4-6	3.33	0.68	5.80	135.78
7-10	2.97	0.68	4.04	94.71
11-14	2.66	0.71	2.77	74.24
15-19	2.43	0.74	2.02	63.93
20-44	2.61	0.68	2.77	67.11
45-64	2.92	0.52	5.45	62.71
65-74	2.92	0.49	5.92	58.47
75+	2.88	0.50	5.61	56.84

μ - average value of the natural logarithm *IRW*; σ - standard deviation of the natural logarithm *IRW*.

Risk assessment was conducted for children aged 1-6 and for adults aged 20-75.

Modeling was performed using spreadsheet Excel® with adding superstructure Crystal Ball®. Graphically the distribution of risks is reflected in **Figure 1**. The same figure demonstrates the risk values while using determined risk values for children and adults (straight lines).

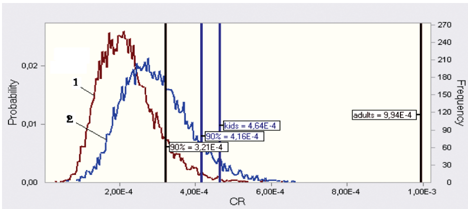

Fig. no. 1. Probabilistic distributions of cancer risk while consuming water from underground sources: 1 - children; 2 - adults.

From the figure it is clear that the use of deterministic exposure values gives rather too conservative risk assessment, especially for adults. More precise values are in smaller quantities. It is possible to state that for 90% of children, consuming water, risk value does not exceed $4{,}16\cdot10^{-4}$, for 90% of adults $3{,}21\cdot10^{-4}$.

3. CONCLUSION

Probabilistic risk analysis provides additional, more accurate information for decision making about the application of environmental protection measures. Often it enables to decrease expenses for conducting these measures.

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