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ENVIRONMENTAL RISK ASSESSMENT OF EXPLOSIVE RESIDUES TOXICOLOGICAL IMPACT ON HUMANS ON THE FORMER COMBAT AREA

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Abstract. This article evaluates the impact of explosives residues left after the explosion of low-detonation munitions on the health of population (children and adults) living on the former battlefield. To determine the toxicological impact of explosives on humans, we used data from artillery shelling near the village of Stepanivka, Donetsk region, during the fighting in 2014. By the number of craters formed on the battlefield and their size, the calibre of the shells and, accordingly, the mass of the explosives were determined. When calculating the mass of unexploded explosives, it was assumed that the number of munitions with low detonation was 2.5 %, while the mass of "unburned" explosives in them was 37 % from the total. The types of explosives were mixtures of 2, 4, 6-trinitrotoluene (TNT) – 40 % and 1, 3, 5-trinitro-1, 3, 5-triazacyclohexane (RDX) – 60 %. To assess the toxicological effects of explosives on humans, this study used the EPA's assessment model of health risk. Non-carcinogenic and carcinogenic risks associated with the influence of explosives on people were evaluated. The results of the risk assessment suggest that the residual amount of explosives in the soil does not lead to dangerous consequences for the health of people who are living on the territory of the former hostilities. However, the lack of data about the location of explosive objects (unexploded munitions, land mines etc.) into the soil of Donbas does not allow us fully assess their toxicological hazard to humans and the environment. The problem of the toxicological impact of explosive residues on residents and the environment of the Donbas region remains relevant.

Keywords: risk assessment, toxicological impact, explosives, low detonation.

1. Introduction

Usually, explosives are characterized by the risk of damage by the blast wave, fragments, debris and similar striking factors. However, we should not forget about the harm that can be caused by the explosives which did not explode and remained in the soil. Later, the substances are sprayed on the surface, get into groundwater, surface water and plants. They are consumed by animals and humans and cause harm to them. As a result, war zones with intense conflicts, military training areas, shooting sports zones, explosives and ammunition manufacturing/disposal locations are considered among the major sources of contamination for terrestrial ecosystems (Broomandi et al. 2020; Ryu, et al., 2007).

Ammunitions mainly use such explosives as 2, 4, 6-trinitrotoluene (TNT), 1, 3, 5-trinitro-1, 3, 5-triazacyclohexane (RDX) and their mixture (Oh,et al., 2016). Potential human exposure to them may lead to adverse effects including damage to vital organs such as liver and kidneys, pathology of red blood cells, and irritation of epithelial tissues (Lima et al., 2011; Ryu et al., 2007). Despite the danger, no environmental regulations for these explosives as pollutants have been established in many countries, including Ukraine. This makes the risk assessment of explosives in war zones with intense conflicts even more crucial.

The object of this article is the assessment of toxicological effects of explosives that for various reasons did not explode, remained on the battlefield and

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subsequently affect the population operating in the territory of the former hostilities.

2. Setting the task and its solution

To determine the toxicological impact of explosives on humans, we used data from artillery shelling near the village of Stepanivka, Donetsk region during the fighting in 2014 (Kravchenko ed., 2015). The authors estimated that because of the explosion of 15.505 various calibres munitions on an area of 225 km^2, at least 91.407 m^3 of soil was thrown out of the ground and dispersed. The diameter of the craters depended on the calibre of the munitions, and hence the mass of the explosive that was in them. A total of 76.172.8 kg of explosives was used.

It is known (Walsh et al., 2010) that the order of explosives detonation can be distinguished as high and low. The order of low detonation occurs mostly in approximately 2.5 % of cases. At high detonation, the mass of the unexploded substance is in the range of $2•10^{-3}$–$7•10^{-7}$ % and can be neglected. The main bulk of explosives enters the environment from low detonation, while the part of "unburned" explosives is in the range of 27–49 % (EPA, 2012).

As mentioned above, usually ammunitions contain TNT, RDX and their mixture. The most popular is a mixture of 60 % RDX and 40 % TNT, the so-called Composition B (Walsh, et al., 2010). Then, assuming the share of ammunitions with the low detonation of 2.5 % and part of "unburned" explosive in them of 37 %, 422.76 kg of RDX and 281.84 kg of TNT were dispersed in the environment. Let's assume that explosive is dispersed into the soil thrown out from craters of ammunitions with low detonation, which is confirmed by the data (EPA, 2012). Only the soil that was ejected by low-detonation ammunitions was taken into account in the calculations. Considering that the volume of the ejected soil (Vs) is almost directly proportional to the mass of the explosive (Adushkin, Khristoforov; 2004), Vs = 91,407.36 • 0.025 • (1-0.37) = = 1439.7 m^3 and, accepting an average soil density of 2100 kg/m^3, its mass (Ms), is Ms = 1439.7 • 2100 = = 3.023.370 kg. The average concentration of explosives in the soil, in this case, is CRDX = 140.0 mg/kg and CTNT = 93.2 mg/kg, which corresponds to the order of experimental data, for example (CRREL-TR-04-14 2004).

To assess the toxicological effects of explosives on humans, this study used the EPA's assessment model of health risk (USEPA, 1989), which was also used in other countries (WHO 2010, FCSAP 2012, Environmental Health Risk Assessment 2012). Non-carcinogenic and carcinogenic risks associated with the influence of explosives on people operating on the territory of the former combat area were evaluated. Nowadays, risk analysis is widely applied to assess the probability of health damage, disease or death of humans because of the exposure to risk factors in military-affected areas (Lima et al., 2011; Ryu et al., 2007). This method considers the three major soil-related exposure routes of ingestion: inhalation and dermal contact to evaluate the level of risk from the pollutants attached to surface soils. However, in the literature there are no reference values of explosive concentration for dermal contact and inhalation, so the calculation was carried out only for ingestion route for two susceptible groups of residents: adults (up to the age of 70 years old) and children (up to the age of 6 years). The average daily intakes of explosive (mg/(kg•day)) via the pathway of ingestion (ADI), were calculated using Equation (1) for non-carcinogenic and Equation (2) for carcinogenic risks.

$$ADI = Cs \cdot FI \cdot ET \cdot CF2 \cdot IRn \cdot EDn/(BWn \cdot ATn \cdot 365) \quad (1)$$

$$ADI = Cs \cdot FI \cdot EF \cdot ET \cdot CF2 \cdot ((EDc \cdot IRc/BWc) + +(EDa \cdot IRa/BWa))/(AT \cdot 365) \quad (2)$$

The definition and the applied factors selected by reference standards are presented in Table 1.

Table 1

Various factors for calculating human health risk (from EPA 2011)

Factor	Definition	Standard value
Cs	Explosive concentration in soil, mg / kg	
IRn	Intake rate, kg / day	*IRc* for children – 0.0002; *IRa* for adults – 0.0001
ET	Time of exposure, hour / day	1
CF2	Conversion coefficient, day / hour	*ET*/24
FI	Contaminated soil fraction, relative units	1 (100 %)
EF	Exposure frequency, day / year	350
EDn	Exposure duration, year	*EDc* for children – 6; *EDa* for adults – 24
BWn	Body weight, kg	*BWc* for children -15; *BWa* for adults – 70
ATn	Average time period, year	*ATc* for children – 6; *ATa* for adults – 30
AT	Average time period for carcinogens, year	70

Hazard quotient (HQ) was used to estimate the health risk of soil particles ingestion. Having a dimensionless value, HQ is calculated by dividing the average daily intake (ADI) by the reference dose (RfD) of each explosive (Equation 3). RfD characterizes a daily effect of a stressor throughout the life of the receptor and is not likely to cause an unacceptable risk to the health of its sensitive groups.

$$HQ = ADI / RfD. \quad (3)$$

The risk characteristic of non-carcinogenic effects in an aggregate and cumulative effect of explosives is based on calculating the hazard index (*HI*)

$$HI = \Sigma HQi. \quad (4)$$

In assessing the risk to human health caused by the influence of the stressors, it is advisable to focus on the criteria system of hazard acceptability (Table 2) (Lu et al., 2003).

Table 2

Hazard Level Classification

Hazard		Hazard Level
Non-carcinogenic *HQ (HI)*	Carcinogenic *CR*	
<1.0	$< 10^{-6}$	Minimum – a desired (target) risk value in conducting health and environmental activities.
1.0–10.0	10^{-4}–10^{-6}	Medium – acceptable for the conditions of military service. On the civilian population impact, it requires a dynamic monitoring of the environment.
10.0–100.0	10^{-3}–10^{-4}	Considerable – unacceptable to the civilian population, a dynamic control and an in-depth study of the sources and consequences of possible harmful effects are required for the conditions of military service to address the issue of risk management measures.
>100.0	$>10^{-3}$	High – not acceptable for the military service in a peacetime and for the population either. It is necessary to take measures to eliminate or reduce the risk.

Carcinogenesis is an increased risk of cancer during a person's lifetime as a result of exposure to carcinogens. The formula for the calculation of lifetime cancer risk is presented in Equation 5

$$CR = \Sigma ADIi \cdot SFi. \quad (5)$$

SFi – slope factor for the i-th explosive $(mg/(kg \cdot day))^{-1}$, which represents the degree of the carcinogenic risk increase with increasing a dose per unit and is a value that describes the danger of carcinogen.

Table 3 presents the *RfD* and *SF* values for *TNT* and *RDX* (Toxicological Profile for TNT 1995; Toxicological Profile for RDX 2012).

Table 3

Reference Doses (RfD) and Cancer Slope Factors (SF) of investigated explosives

Explosives	RfD (oral) (mg/kg-day)	SF (oral) $(mg/kg\text{-}day)^{-1}$
TNT	5E-04	0.03
RDX	3E-03	0.11

3. Results and Discussion

In accordance with the above assumptions about the explosives concentration in the soil on the territory of the former artillery shelling, the magnitudes of non-carcinogenic and carcinogenic risks were calculated using the standard values of Table 1 and Equations (1) – (5). The calculation results are shown in Table 4.

Obtained results indicate that despite the rather intense shelling, the residual amount of explosives in the soil does not lead to dangerous consequences for the health of people who are living on the territory of the former hostilities. However, it is worth mentioning that we made a rough estimate of the explosives effect on humans (children and adults) with only one route of exposure – oral.

Table 4

The magnitude of carcinogenic and non-carcinogenic risks from the toxicological effect of explosives on the former combat area

Explosives	Carcinogenic risk	Non-carcinogenic risk	
		Children	Adults
TNT	1.82E-07	9.93E-02	8.51E-03
RDX	4.12E-07	2.49E-02	2.13E-03
Total (CR, HI)	2.23E-07	0.12	0.0106

At the same time, the toxicological hazard of explosives is much higher. Approximately 5 % of all munitions do not explode and remain in the soil (MacDonald, et al. 2004). Even a greater danger is posed by land mines, a great number of which now lay in the conflict zone. Ammunitions rust, their shells lose strength so explosives leach into the surface and groundwater (solubility of TNT and RDX at 25 ºC is 130 and 60 mg/l, respectively) and can be spread over a large area, entering the human body through the food chain (Pichtel, 2012).

4. Conclusion

The results from the risk assessment suggest that the residual amount of explosives in the soil does not lead to dangerous consequences for the health of people who are living on the territory of the former battles. However, the article considers only one side of the problem – the assessment of the explosives effect on humans (children and adults) with only one route of exposure – oral. The lack of data about the location of explosive objects in the soil of Donbas does not allow us fully assess their toxicological hazard to humans and the environment, although the literature indicates the dangerous effects of explosives (Pichtel, 2012, Broomandi et al., 2020). The problem of the toxicological impact of explosive residues on residents and the environment of Donbas remains relevant. And after its liberation, along with the solution of many problems to restore housing, infrastructure, etc., this problem will also require a solution.

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