Public health risk assessment of environmental pollution with pesticides

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Introduction

Using toxicity assessment methods for pesticides it is a common procedure to accept that any pesticide is a potentially hazardous substance for human health. It is also necessary to account for the high degree of mobility of many pesticides, i.e. their transfer capacity for considerable distances via air, water discharges and living organisms. Those pesticides have high affinity to be accumulated in soil, plants and animals.

The analysis of pesticide use in the Volgograd Region during the period 1995-1999 showed primary use of various recipes containing the amino salt of 2,4-dichlorphenoxyacetic acid (2,4-D) and organic phosphorous compounds (See Table 1). However, 2,4-D and its derivatives, when compared with organic phosphorous pesticides, are much more persistent in the environment. Besides, during the synthesis of 2,4-D, a mixture of chlorinated dioxins and furans are generated, which are the most toxic of the synthetic poisons. According to technical standards their quantities may reach 0.01 mg/kg in the mass of the preparation. Therefore, the recipes based on the amino salt 2,4-D were selected to assess public health risks of pesticides exposure.

Table 1. Decomposition % of the total pesticide quantities applied to the farmland soil in the Volgograd Region during the period 1995-1999.

Title of pesticide group	1995	1996	1997	1998	1999	$\sum/5$
1	2	3	4	5	6	7
2,4-D amino salt	45.6	80.6	63.7	79.0	80.1	66.6
Organic Phosphates	34.0	16.5	8.9	7.2	2.4	13.8
Others	20.4	2.9	27.4	13.8	17.5	19.6

Comprehensive research has been done in the Volgograd Region to assess the degree of soil and plant pollution. The presence of different pesticides in the soil and sediments was confirmed. The mean content of 2,4-D in the soil was 0.0043 mg/kg, which remains considerably less than Russian MPC (Maximum Permissible Concentration = 0.15 mg/kg).

It might seem that the results of the research could justify that the situation in the Region in terms of pesticide pollution is good. At least that is true for the amino salt 2,4-D content.

The universally accepted methodological procedures, to prevent deadly impact on human health enforce maximum permissible concentrations of pesticides in various environmental media and in food products. Unfortunately this approach does not guarantee the absence for human health risk even if the pollution level does not exceed the allowable standards. In that case, the hazardous impact can be explained by a combined chronic effect of different pesticides against the background of the contamination with heavy metals, nitrates and nitrites, which aggravate likelihood of the exogenic synthesis of nitrosamines.

Modelling of pesticides transfer in the ecosystem

One of possible methods, which give answers to some questions of monitoring pesticides content in the soil and other environmental media, makes it possible to determine structural and functional interdependencies among the components of the ecosystem as well as the nature of the internal systemic damages. That is mathematical modelling. Although mathematical models only present simplified images of the real ecosystems, they help the researcher to assess the behaviour of an object in such conditions that were not created (or were not observed) in the experiment.

The decomposition and migration process that the pesticide undergoes in the environment as a whole and in every single block of the ecosystem depends on a large number of factors. These factors include migration pathways, locations of accumulation and pace of substances decomposition in different natural landscapes.

At present, there are a large number of plants, surface and groundwater sources. The mathematical models, which we used in our research, describe pollution with pesticides in different chains of the ecosystem. They are presented in publications [1, 2].

Atmosphere

Dispersion of pesticides in the atmosphere and their settling on land surface when sprinkled with surface means or with aviation was calculated with the help of turbulent diffusion equations [3,4]. This approach provides the computation of pesticide concentrations on land surface based on atmospheric parameters. However such method requires the setting of a number of parameters, which are hard to determine, as well as lengthy computation.

Soil

The main and most deadly chain in the pollution with pesticides is the soil. Accumulation of pesticides in the various kinds of soil proceeds in different ways. While getting into the soil, pesticides become part of sorption processes, degraded, washed away, migrated and accumulated by plants. Depending on the ecosystem description details, dynamic models for the data in the given research were used to calculate the accumulation of pesticides in the soil [2]:

$$C^s(t_0) = \omega^s \cdot D,$$

$$C^s(t) = K_j^{voi}\, C^s(t_0) \cdot \exp\{- g_j^s F^s t\},$$

$$F^s = f_1^s(pH) \cdot f_2^s(HU) \cdot f_3^s(E) \cdot f_4^s(GL) \cdot f_5^s(T) \cdot f_6^s(W) \cdot f_7^s(OP),$$

$$f_j^s(x_j) = \gamma_j^s \{ [\alpha_j^s + \exp(b_j^s - c_j^s x_j)]^{-1} - d_j^s \}, \quad j=1,2,5,6,$$

$$f_j^s(x_j) = 1.0 - \alpha_j^s \ (1.0 - \exp(-b_j^s\, x_j)^{Cjs}, \qquad j=3,4,7,$$

$$C^s(t) = C^s(t_0) \cdot (1.0 - K_m^s),$$

$C^s(t)$ is the concentration of pesticides in the soil at a given moment of time t (mg/kg); $C^s(t_0)$ is the concentration of pesticides in the soil at the zero time t_0 (mg/kg); D is the dose of the chemical, which was used (kg/hectare); pH is soil acidity; E is the amount of saturation (mg-equivalent/100g); HU is the content of humus (in percentage points); GL is clay content (%); T is soil temperature (°C); W is soil humidity (%); OP is sediment and substrate ratio; P is soil resistance index; f_j^s is specific functions of soil resistance index response; g_j^s is characteristic process time, which depends on physical and chemical properties of the pesticide (1/day); j is the pesticide or the class of pesticides ranked by persistence levels; K_m^s is the washing away ratio from the soil surface for each pesticide (m is the geographical zone) [5-7]. Volatility ratio is determined as a constant ratio according to evaporation pace from the surface of the soil for different pesticides.

Plants

Pesticide absorption is taking place both by the plants roots and the parts of the plants above the ground. Further the substances undergo a rather active metabolism. The migrating capacity of the pesticide in the chain link "soil-plant" depends on the absorbing capacity of the soil. The dynamics model of pesticide content in plants has the following structure: [2]:

$$C^v(t) = (K_n^v\, C^s(t) + \omega_j^v)\exp\{-g_n^v F^v t\},$$

$$F^v = f_1^v\,(pH) \cdot f_2^v\,(E) \cdot f_3^v\,(HU) \cdot f_4^v\,(SOL) \cdot f_5^v\,(UF),$$

$$f_j^v\,(x_j) = \gamma_j^v \{ [\alpha_j^v + \exp(b_j^v - c_j^v x_j)]^{-1} - d_j^v \}, \quad j=2,3,5,$$

$$f_j^v\,(x_j) = 1.0 - \alpha_j^v\,(1.0 - \exp(-b_j^v\, x_j)^{Cjv}, \qquad j=1,4,$$

$$C(t) = C(t_0) \cdot (1.0 - K_m),$$

Where C^v (t) is pesticide concentration in the vegetable mass at the moment of time t (mg/kg); $C^s(t)$ is pesticide concentration in the soil at the moment of time t (mg/kg); K_n^v is the proportionality ratio between pesticide content in plants and in the soil, which depends on the properties of the vegetable object; F^v is the resistance index of plants; f_j^v is the specific plant resistance response function index; pH is the soil acidity; E is the absorption capacity of soil (mg-equivalent/100g); HU is the humus content (%); g_j^v is a characteristic process time, which depends on the properties of the vegetable object (1/day); SOL is the pesticide solubility in water (mg/liter); UF is the ultraviolet radiation sum (Kilocalories/m^2); j is the pesticide or pesticide class; n is the species of the plant community; γ_j^v, α_j^v, b_j^v, c_j^v, d_j^v, ωj^v are parameters.

Assessment of environmental pollutants impact on humans

By means of the penetrating impact ratio, the interrelation between pollutants concentrations in the environment and their impact on humans is determined. Thus it includes the information on human physiology and one way of life; it also translates the concentration in the environment into a chronic daily intake dose for the whole lifetime period. The quantitative characteristics of the pesticide impact on public health conditions (H) for a given population size N and the dose level D is correlated with the dose response function to dose Q in the following way:

$$H = Q(D)D(e_h,e_g,e_d)N$$

H is the quantitative characteristics of the pesticide impact on public health for the population numbers N people who have received an average dose D of the pollutant. Q(D) is the response function to the given dose, which relates the average dose D to the lifetime probability of health deterioration for each person $(mg/kg\text{-}day)^{-1}$. $D(e_h,e_g,e_d)$ is the dose level function, which relates the e_h,e_g,e_d impact to the dose of the whole human body, of a separate organ or tissue.

If the environmental pollution concentration is constant in time then the average impact on populations represented as a chronic daily dose at the concentration C_k, can be presented in the following way [8]:

$$CDI = \frac{CR_i}{BW} \times \frac{C_i}{C_k} \times \frac{EF \times ED}{AT} \times C_k = F_{ki} \times C_k \qquad (1)$$

CR_i/BW is the level of contact per one kilogram of body weight. C_i/C_k is a ratio of the concentration in the contacting media *i* to the pollutant concentration in the environment *k* and *EF* is the impact frequency in days per year. *ED* is the duration of the exposure, whereas *AT* is the mean time for each age group. F_{ki} is a penetrating impact ratio, which relates C_k to the chronic daily intake during the time period *ED*.

Computation of the daily chronic dose of pesticides, which is taken in as a result of agricultural crops consumption in the Volgograd Region (Table 2) gives enough ground to consider that the chronic daily dose of 2,4-D is not high. However, that type of the pesticide contains a mix of dioxins (up to 0.01 mg/kg of substance mass), which has a carcinogenic effect. Arsenic also is a carcinogen. Further computations gave us the ground for prognostication of possible development of 37 additional clinical cases (which are determined by chronic impact of 2,4-D amino salt) per one million of rural population in the region.

Table 2 represents a comparison of human health risk computations, which are determined by arsenic derivatives content in a local soil. Soils in the Volgograd Region are notorious for a high natural (background) level of arsenic content whereas anthropogenic soil pollution in rural areas is quite low. Unlike the computations, which were done for the amino salt of 2,4-D, and since arsenic is a carcinogen, the risk of its impact on human health was assessed taking into account the potential factor (SF).

Table 2. Possible accumulation levels of 2,4-D and arsenic in humans inhabit in the rural areas of the Volgograd Region

Substance Title	Substance concentrations (mg/kg)		Separation ratio soil/plant	Penetrating impact ratio (mg/kg /day)	Chronic dose (mg/kg /day)	RfD * (mg/kg /day) or SF ** (mg/kg /day)	Individual risk
	soil	plants					
1	2	3	4	5	6	7	8
2,4-D	0.0004	0.0002	0.500	2.00 E-04	1.12 E-08	3.33 E-03 *	3.7 E-05
As	9.8200	0.1690	0.017	1.60 E-06	4.70 E-08	1.75 E-00 **	8.2 E-08

Thus, 2,4-D concentrations both in soil and in farm crops (grain) are considerably lower than the MPC. However, taking into account 2,4-D capability to accumulate in the natural media, even the trace concentrations can trigger health risks for populations to the degree that is higher by an order of magnitude than that accepted by the WHO. At the same time health risk, which is caused by arsenic, is negligible (despite of the fact that its concentration in the soil is high compared to the MPC).

Conclusion

In the report general approaches are outlined and specific results of mathematical modelling are given for the dynamics of the intake, decomposition and migration of pesticides in the ecosystem and the influence, which the pesticides have on the public health. The ecosystem in this case is a combination of objects (blocks) in the human environment such as soil, water, air, farm crops, animal flesh, poultry, milk, fish, vegetables, fruit and grain.

As a possibility, it was considered that pesticides might get in any block of the ecosystem; they may accumulate and migrate to other blocks and decompose.

As a mathematical model a system of stochastic integrated equations was used, which describes the dynamics of change in the concentrations and the migration processes of pesticides in the ecosystem blocks. Those mathematical models take account of the influence, which random factors may have on the migration process of the pesticides and their intake in the humans.

Identification of the mathematical model parameters was performed with the help of statistical methods for random processes and by use of many years of observations of pesticide concentration values in the investigated ecosystem blocks.

The research was done based on natural investigations.

A specific nature of the research results is their focus on prognosis of possible consequences to public health, which pollution of certain ecosystem blocks with pesticides may have; the research was also targeted on the developing risk management suggestions.

Literature

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