Geoinformational technologies in the problem of assessing the pesticides' impact on the arid zones soils' condition

A V Kosarev1, N E Komleva1,2, V N Dolich1, D E Ivanov1,3

1 Saratov Hygiene Medical Research Center of the Federal Budget Scientific Institution «Federal Scientific Center for Medical and Preventive Health Risk Management Technologies», 1a Zarechnaya st., Saratov 410022, Russian Federation
2 Federal State Budgetary Educational Institution of Higher Education «Saratov State Medical University named after V.I. Razumovsky», Saratov 410012, Russian Federation
3 Federal State Budgetary Educational Institution of Higher Education «Saratov State Law Academy», Saratov 410056, Russian Federation

E-mail: aleteia@inbox.ru

Abstract. The work is devoted to establishing the influence of aridity on the risk of negative soil changes caused by residual pesticides presence in spring and autumn. Using the Earth's remote sensing method, it is shown that the NDMI index is decreasing and aridity is increasing in the following direction: Lipetsk Oblast - Kursk Oblast - Voronezh Oblast-Belgorod Oblast-Ulyanovsk Oblast -Samara Oblast -Saratov Oblast -Penza Oblast -Orenburg Oblast -- Stavropol Krai-Karachay-Cherkessia. Correspondence was established between the increase in region's aridity and the increase in the risk increment value for the period from spring to autumn due to the presence of residual pesticide content in the soil. This circumstance can be associated with pesticides accumulation in the soil cover, an increase in their consumption and a decrease in destruction in conditions of arid climate. DDT and hexachlorocyclohexane cause the highest risk increment due to soil accumulation, trifluraline is more subjected to conversion in the soil, has less effect on risk change of soil agroecological condition.

1.Introduction
Assessment of agro-ecological safety due to the presence of pesticides in the soil is one of the urgent tasks of environmental hygiene. On the one hand, it is due to the multidimensional nature of pesticides conversion in the environment and metabolic processes with their participation in the body, and on the other hand, due to increase in volumes and expansion of assortment spectrum of products grown with the use of agro-stimulants.

The heterogeneity of climatic zones in different regions significantly complicates the cultivation of agricultural products. One of the historical problems of domestic agriculture is the aridity of various territories, as well as instability of climate indicators. The main territories that are accompanied by arid climate in Russia are: Middle and Lower Volga region (Zavolzhye), Urals, Northern Kazakhstan, steppe regions of Western and Eastern Siberia [1].

However, the availability of hygienically safe agricultural products for the population of arid regions is insufficient. On the one hand, this is due to economic factors of the AIC development, among which a significant role is played by the cultivation of grain and sunflower demanded by the...
domestic and foreign market, and as a consequence, the violation of crop rotation and the properties of arable land in conditions of cultivation priority to a particular crop. On the other hand, the reason for the lack of supply of quality agricultural products is the prevalence of areas with inefficient agriculture, one of the significant causes of which was the increasing climate aridization process in a number of regions of the Russian Federation. About 70% of the territory of Russia is at risk for agriculture, which is one of the reasons for high prices for products of vegetable origin. The situation is amplified by the fact that about 30% of grown vegetables and fruits are disposed of due to low storage periods, rotting processes, exposure to pests, etc. [2]. The use of pesticides is one of the effective methods of solving these crop problems. Their application in the fields allows to prevent the loss of 25-30% of the crop [3]. The highest use of pesticides is observed in arid regions of Russia, such as Krasnodar Krai and Rostov oblast (about 20 kg per 1 ha), with these regions being the main fruit sources distributed throughout the country [4]. The lack of natural moistening significantly reduces agricultural production since low moisture levels adversely affect plant crops, but not deleterious plants (weeds). The use of pesticides in arid territories adversely affects the entire agro-ecosystem. In conditions of arid climate, the ability to suppress and eliminate harmful agents decreases, which increases the cumulation of used pesticides in arid territories. However, the lack of use of these pesticides leads to a significant decrease in yield in arid territories. For example, Altai Krai is characterized by extremely continental climate (hot short summers, strong winds, small amount of precipitation). Thus, about 700 tons of pesticides are used annually on the territory of the Altai Krai, most of which are herbicides (80%), the remainder are insecticides and fungicides (20%) [5]. In the Republic of Kazakhstan, various insecticides are also actively used to preserve the wheat harvest in conditions of aggressive winds and drought. Currently there is a total of 1021 trademarks of pesticides registered in Kazakhstan, of which 386 drugs of various purposes contain one or more active substances included in the PAN list of highly hazardous pesticides actively used to preserve crops, especially spring wheat [6]. The relationship between diseases of the circulatory system, cardiovascular diseases and pesticide load in the Republic of Tatarstan was revealed. At the same time, the contribution of chemical environmental footprints in the region to the prevalence of the studied diseases' classes is largely conditioned by exposure to pesticides [7]. In Orenburg, the most contaminated among the products were: meat and meat products, milk and dairy products, fish and fish products, oil of vegetable and animal origin. At the same time, the level of non-carcinogenic load decreased in the following sequence: cardiovascular system > endocrine system > central nervous system. [8]. Honey and beekeeping products accumulate DDT and HCH due to their translocation into the nectar of plants flowers and further transfer through food chains [9]. The agricultural economy type of the Republic of Khakassia is characterized by xerophytic climate, which causes the use of pesticides and irrigation farming and tends to increase the load of pesticides on soil. Thus, arid climate creates additional conditions for pesticides accumulation in soil and plant products, which necessitates careful monitoring of residual pesticides content in food grown in arid territories [10].

The increase in climate aridity causes an increase in pesticide consumption in agricultural areas. This is due to a decrease in the fertility of dry soils compared to non-dry zones and as a result, an increase in the load of pesticides on soils. In addition, the hydrolytic decomposition of pesticides in soils of dry areas decreases several times compared to non-dry areas. Even with the control of pesticides content in the soil and compliance with hygienic standards, their residual concentration in food will increase every time while providing toxic effect on the human body due to high capacity for cumulation not only in the external environment, but also in biological environments of the human body.

Earth's remote sensing techniques implemented on GIS platforms include decoding of satellite imagery and analysis of available monitoring materials based on biocenoses development characteristics and water supply parameters. These methods are used to assess the possibilities of local water resources in the problem of increasing the water resource potential of arid zones, as well as to clarify water supply indicators of arid regions with their subsequent graphical visualization [11].
The scientific novelty of the work is that it is the first time of using the method of Earth's remote sensing to study the relationship between the aridity indices of the regions of Russia and the magnitude of ecological risk, caused by the residual presence of pesticides in soils in spring and autumn.

Objective: to determine hygienic risks caused by food use

To achieve the goal, the following tasks were solved:

(a) determine the average perennial aridity coefficients of the regions of the Volga and the central chernozem area by means of Earth's remote sensing methods;

(b) determine the change in environmental risk caused by the residual presence of pesticides in soils in spring and autumn;

(c) carry out mapping of the residual pesticides content in soils of regions with varying degrees of aridity.

2. Materials and methods

The assessment of the aridity factor was based on Earth's remote sensing data. Analog and digital satellite images of Landsat-8 with 30 m spatial resolution were used to identify desertification processes in dynamics; those were obtained with the help of geoinformation catalog earthexplorer.usgs.gov. The mapping of the studied territories was carried out using the QGIS program, version 3.12.3. Satellite images were processed using the ArcGIS program. The orientation of aridity changes in the areas under consideration was determined by comparison of their morphological and geometric characteristics for 2017-2020. Decoding of satellite images included small elements of landscape: fields, arable land, acreage.

When interpreting the aridity level of the territories, the normalized vegetation difference moisture index (NDMI) was applied; this index is sensitive to the moisture level in vegetation and is applied to track droughts. It is based on the application of NIR and SWIR channels and is calculated using the formula:

\[ NDMI = \frac{NIR - SWIR}{NIR + SWIR} \]

where NIR-, SWIR are the reflection coefficients of near IR ranges of 0.845—0.885 μm and 1.560—1.660 μm, respectively. Data to determine these characteristics were channel satellite images from the Landsat-8 satellite. The determination of the vegetation index was carried out by classifying the spectral data of the image followed by image conversion into a shp file, which is most preferable to be used in GIS -analysis [12].

3. Results and discussion

The NDMI index has more sensitivity to the vegetation layerage as it can estimate moisture content in multiple vegetation layers, while other indices determine this indicator in the surface layer. Water absorption takes place more intensely in the shortwave IR range than in the near IR region. Accordingly, increased aridity leads to a decrease in the proportion of NIR and an increase in the proportion of SWIR components in the vegetation reflection spectrum. This is due to the difference in the nature of reflection by plant and soil covers. The decrease in the NDMI value corresponds to the increasing aridity degree of the territory. The results show that aridity is increasing in the following order: Lipetsk Oblast- Kursk Oblast- Voronezh Oblast- Belgorod Oblast- Ulyanovsk Oblast - Samara Oblast-Saratov Oblast- Penza Oblast-Orenburg Oblast--Stavropol Krai -Karachay-Cherkessia. The contribution of the agricultural sector to the GDP of these regions is high, while the lack of moisture in the soil is one of the factors that lead to the use of pesticides in order to increase soil fertility. This is especially true for chestnut soils inherent in arid territories.

Let us estimate the risk caused by residual pesticide content in soil, defined as the probability of adverse effects due to the presence of residual pesticide concentration in the soil, where agricultural crops were grown:
\[
\frac{dR}{dx} = \lambda e^{\lambda x},
\]

where \( x \) is the mass fraction of residual pesticide in the soil, The solution of the equation (1) is the function:

\[
\Delta R = e^{\lambda x} - e^{\lambda x_a}
\]

The ratio (2) characterizes the change in the risk magnitude \( \Delta R \) in conditions of changes in the pesticide content in the soil from spring to autumn. The \( \lambda \) coefficients are determined by the pesticide type and define the intensity of environmental risk change when the pesticide content in the soil changes per unit. Values \( x_s \) and \( x_a \) — residual pesticide content in the soil in spring and autumn in MPC shares respectively [13]. Calculation data are presented in Table 1.

**Table 1.** Change in the risk value \( \Delta R \) in conditions of changes in the pesticides content in the soil from spring to autumn. Values of risk from residual pesticide content in soil defined as the probability of adverse effects due to the presence of residual pesticide concentration in the soil.

| Region           | NDMI | \( \Delta R \) trifluraline | \( \Delta R \) DDT | \( \Delta R \) hexachlorocyclohexane |
|------------------|------|----------------------------|-------------------|-----------------------------------|
| Lipetsk Oblast   | 0.112| 0.0676                     | -0.0036           | -0.0041                           |
| Kursk Oblast     | 0.105| 0.0643                     | -0.0036           | 0                                 |
| Voronezh         | 0.092| 0.0465                     | -0.0105           | -0.0054                           |
| Belgorod         | 0.088| 0               | -0.0036           | 0                                 |
| Ulyanovsk        | 0.052| 0.0242                     | -0.0059           | -0.0093                           |
| Samara           | 0.044| 0.0160                     | -0.0048           | -0.0177                           |
| Saratov          | 0.038| -0.0015                    | -0.0056           | -0.0188                           |
| Penza Oblast     | 0.031| -0.0322                    | -0.0102           | -0.0154                           |
| Orenburg         | 0.021| -0.0431                    | -0.0144           | -0.0232                           |
| Stavropol        | 0.009| -0.0532                    | -0.0170           | -0.0403                           |
| Karachay-Cherkessia | 0.007| -0.0760                    | -0.0199           | -0.0466                           |

As can be seen from Table 1, the change in environmental risk \( \Delta R \) due to the presence of pesticide in the soil tends to decrease with a decrease in the NDMI index. This may be due to an increase in the aridity of the region, and as a result - an increase in the volume of pesticides introduced into the soil. At the same time, positive values of \( \Delta R \) corresponding to a decrease in pesticide content in autumn compared to spring may be due to the transition of pesticides to crops grown at studied territories, as well as flushing from fields. The increase in the content of pesticides in the soil in autumn compared to the spring period can be associated with the accumulation of pesticide due to regular application. This effect causes negative values of magnitude \( \Delta R \). At the same time, the development of aridity is due both to a long-time annual average decrease in the groundwater level and extremely uneven precipitation. In the Volga region (Saratov, Samara, Penza oblast) erosion processes contribute to the reduction of soil moisture supply. The dynamics of aridity in the Stavropol Krai and Karachay-Cherkessia is due to a decrease in precipitation and an increase in summer temperatures, as well as the development of dust storms. As a consequence, the thermal and hydrological balance of the territories are disturbed and aridity develops, leading to a change in the reflectivity of the landscape in the near IR ranges: NIR (0.845—0.885 \( \mu \text{m} \)) and SWIR (1.560—1.660 \( \mu \text{m} \)).
**Fig. 1.** Influence map of the aridity degree of regions on residual pesticides accumulation in soil.

**Fig. 2.** Distribution map of the aridity index (NDMI) in the territory of the Saratov Oblast.
It should be noted that the pesticides in question are characterized by a low capacity for destruction in the soil and a high adsorption capacity on humus particles. DDT is characterized by the prevalence of the risk value in the autumn period, which is due to high ability to accumulate this pesticide with the soil. Hexachlorocyclohexane also has similar properties. For a number of regions, reduced risks from the presence of trifluraline in the soil from spring to autumn may be due to the fact that this herbicide is prone to destruction in the light and is destroyed in all types of soils under the influence of
microorganisms. Clay soil structures are catalysts for pesticide hydrolysis, but this effect weakens with increasing soil aridity. In the transition from chernozems to forest podzolized and chestnut soil types, forest and mountain forest, the adsorption activity of pesticides on clay soil structures decreases. In addition, the development of erosion processes contributes to the reduction of interaction efficiency of pesticides with soils.

4. Conclusions

Using the Earth's remote sensing method, it is shown that the NDMI index is decreasing and aridity is increasing in the following direction: Lipetsk Oblast - Kursk Oblast - Voronezh Oblast-Belgorod Oblast-Ulyanovsk Oblast -Samara Oblast -Saratov Oblast - Penza Oblast -Orenburg Oblast -- Stavropol Krai-Karachay-Cherkessia. Correspondence was established between the increase in region's aridity and the increase in the risk increment value for the period from spring to autumn due to the presence of residual pesticide content in the soil. This circumstance can be associated with pesticides accumulation in the soil cover, an increase in their consumption and a decrease in destruction in conditions of arid climate. DDT and hexachlorocyclohexane cause the highest risk increment due to soil accumulation, trifluraline is more subjected to conversion in the soil, has less effect in changing environmental risk increments.

References
[1] Gorbunov M Yu and Mrachkovskaya A N 2018 Eurasian Scientific Association
[2] Lunze K, Yurasova E, Idrisov B, Gnatienko N and Migliorini L 2015 Food security and nutrition in the Russian Federation - a health policy analysis Glob Health Action 8 p 27537
[3] Rakitskyi V N 2015 Russian Journal of Occupational Health and Industrial Ecology 10 pp 5-7
[4] Grachev N N, Varfolomeeva M M and Denisova M N 2019 Technical support of agriculture 1 pp 167-174
[5] Medvedeva Zh V, Belokurenko S A, Dohodova N D and Kohtsova L F 2019 Design, usage and reliability of agricultural machines 1 pp 326-334
[6] Mustafina V V, Dushkina Yu N, Argygbaeva E M and Gor N V 2020 Chemical safety 4 pp 236-247
[7] Khamitova R Ya, Sabirzyanov A R and Ziatdinov V B 2017 Kazan medical journal 98 pp 116-121
[8] Setko A G, Mryasova Zh K and Tyurin AV 2018 Health Risk Analysis
[9] Galyautdinova G G, Egorov V I, Gurevich P A and Pistsov M F 2020 Antibiotics and pesticides in honey: ways of entry and methods of determination pp 46-48
[10] Kochunova L V and Eliseev VA 2011. Human ecology 10 pp 15-21
[11] Dunaeva E A 2017 Modern problems of Earth's remote sensing from space 14 pp 173–181
[12] Khrutskii V S and Golubeva E I 2011 Geography and Natural Resources 32 pp 394-400
[13] Yearbook "State of pesticide contamination of the natural environment of the Russian Federation in 2018" 2019 (Obninsk: Federal State Budgetary Institution" Scientific-Production Association"Typhoon") p 87