Vol. 7, No. 3, 2022

MATHEMATICAL MODELING OF ASSESSMENT OF THE INFLUENCE OF ELECTROMAGNETIC FIELDS ON POLLUTION OF AGRICULTURAL LAND

Sergij Vambol[1], Viola Vambol[2], Valeriy Dubnitskiy[3], Mykolay Kundenko[1], Ihor Cherepnov[1], Altaf Hussain Lahori[4]

[1]Biotechnological University,
44, Alchevskih Str.,61002, Kharkiv, Ukraine,
[2] National University "Yuri Kondratyuk Poltava Polytechnic",
24, Pershotravneva Av., Poltava, 36011, Ukraine,
[3] "Karazin Banking Institute" of V.N. Karazin Kharkiv National University,
55, Peremohy Av., 61174, Kharkiv, Ukraine;
[4] Sindh Madressatul Islam University,
Hasrat Mohani Road, 74000, Karachi, Pakistan
sergvambol@gmail.com

https://doi.org/10.23939/ep2022.03.109

Received: 12.05.2022

Abstract. This work studies the impact of electromagnetic fields on the degradation of agricultural land. During the analysis of available sources of information, it was found that in the scientific publications by domestic authors, there is no mention of such a factor of land degradation as the action of electromagnetic fields (EMF) of man-made origin. Numerous scientific works by foreign experts present the results of experimental studies that confirm the negative impact of electromagnetic radiation (EMR) of power lines (PL) on agricultural land. The application of mathematical methods of modelling the dynamics of the distribution of the number of microorganisms or other soil components in the irradiation zone of power lines can be the basis for biomonitoring in the system of construction technologies to protect agricultural land from electromagnetic pollution. The paper presents statistical models designed to assess the impact of electromagnetic fields on pollution of agricultural land and conduct appropriate biomonitoring. The dependence of the number of fungi in the soil on the distance to the 110 kV power line at different seasons and the dynamics of the intensity of adaptation processes in the soil at different distances from the power line (PL) was constructed. The methods of regression, variance and cluster analysis were used in the development of models, and the corresponding elasticity functions were constructed. It is shown that the application of modern data processing methods allows obtaining additional information even from the already published results of work performed by various researchers.

Keywords: environmental protection technologies, biomonitoring, the influence of electromagnetic fields on land degradation, statistical models, regression analysis, analysis of variance, cluster analysis.

1. Introduction

The motivation for this publication is to study the impact of electromagnetic fields of power lines on the degradation of agricultural land. Namely, the use of mathematical approaches for processing experimental data obtained on the basis of bioindication.

Agricultural production makes a significant contribution to Ukraine's economy. As of 2020, the domestic agro-industrial complex employed about 35 % of all workers in the field of material production, which created almost 15 % of gross domestic product (Matrosova, 2020). In (Vambol et al., 2021) it was noted that the main component of agricultural

For citation: Vambol, S., Vambol, V., Dubnitskiy, V., Kundenko, M., Cherepnov, I., Lahori, A. H. (2022). Mathematical modeling of assessment of the influence of electromagnetic fields on pollution of agricultural land. *Journal Environmental Problems*, *7*(3), 109–117. DOI: https://doi.org/10.23939/ep2022.03.109

production, which depends on the quality of products available to man, is the soil and its ecological condition. Based on the analysis of a number of literature sources, it is concluded that the condition of agricultural land on a large part of the territory of Ukraine is far from ideal, and its quality continues to deteriorate. In particular, pollution by radionuclides (Sydorenko et al., 2022), pesticides, organic matter and heavy metals together leads to the degradation of over 13 % of the total arable land. In addition, the percentage of land used for solid waste storage is growing every year (Storoshchuk et al., 2021; Ziarati et al., 2022; Ratushniak et al., 2021). However, almost until the end of the twentieth century, researchers paid insufficient attention to such a specific source of pollution as electromagnetic fields (EMF) of man-made origin. The situation changed after 1995 when the World Health Organization officially introduced the concept of "electromagnetic pollution". Among the sources of man-made EMFs, power lines (transmission lines) occupy a special place as they cover a large part of the earth's surface, and large areas are constantly exposed to their radiation. In the course of scientific research, including those by Ukrainian scientists, the following data were obtained:

– the zone of electromagnetic pollution in Europe already occupies more than 1 % of the total area of the continent and is constantly increasing (Roshko V. V., Roshko V. H., 2017);

– power lines, which represent an antenna whose length can reach several thousand kilometres, emit electromagnetic waves with a frequency of 50 or 60 Hz. This can affect the population of charged particles, changing their energy and pitch angle, which leads to their increased eruption from radiation belts with unknown consequences for the environment (Korepanov et al., 2015).

In (Cherepnov et al., 2021), the authors analyzed a number of specialized scientific papers, which considered various theories that explain the mechanism of action of EMF on the soil. Here are the three most common, namely: the direct action of electromagnetic fields, changes in the structure of the population of soil microorganisms under the influence of EMF, the impact of electromagnetic radiation of ultrahigh frequencies (UHF) on the physicochemical properties of soils. Despite the different approaches to explaining the process of EMF interaction with the soil, presented in the works, their authors draw the same conclusion: the action of transmission line radiation for a long time leads to the degradation of soils used in crop production and, above all, their varieties such as chernozem (Cherepnov et al., 2021).

There are objective circumstances that make it difficult to study the impact of man-made EMF on bioelements of the agrosphere, namely (Bakhareva, 2016): their complex structure and relatively low rate of degradation wave compared to the life expectancy of one generation.

The basic legal document defining the areas of environmental monitoring (Postanova Kabinetu Ministriv Ukrainy, 1998) provides an exhaustive list of parameters controlled by the Ministry of Agrarian Policy in monitoring the condition of agricultural soils, namely, radiological, agrochemical and toxicological parameters, residual pesticides and pesticides. metals. That is, there is no monitoring of electromagnetic pollution of land. In our opinion, this is a serious shortcoming that reduces the objectivity of the results of monitoring the processes of degradation of agricultural land. It is the presence of this component of environmental control and protection technology that can solve the problem of optimizing the allocation of resources to address environmental security issues.

To solve this problem, it is advisable to use an integrated approach. Monitoring of natural and man-made EMRs should be carried out using both bioindication and traditional control methods. This will make it possible to objectively control the ecological condition of the soil and take measures to neutralize degradation processes.

During the selection of biological indicators, the following requirements are imposed on them (Cherepnev et al., 2011):

– the bioorganism must have a certain level of sensitivity to man-made stressors;

– the response of the bioindicator should depend on the level of action;

– the bioindicator must have visually observable morphological (biometric) changes;

– provide sufficient accuracy and information;

– be distributed in the relevant region and evenly distributed in the control area.

To implement any monitoring method, it is necessary to build its analytical or statistical models that describe the response to the stimulus – electromagnetic radiation (EMR), the distribution in the EMF range of those biological organisms selected as a test system. In [(Bakhareva, 2016; Smyrnova et al., 2019), the soil is considered as a complex ecosystem. In the upper fertile layer, there is a complex combination of so-called vibrators: mineral particles, detritus, i.e. dead organic matter of animal and plant decay, including waste products at different stages of decomposition, as well as many living organisms from reducers (fungi, bacteria) to large detritophagous (earthworms, molluscs and insects), which form a complex food chain and exist using detritus.

In (Cherepnev et al., 2010), the authors studied the effects of EMR on biological objects of different levels of the organization and their responses based on the analysis of data from more than 480 sources published in the last few decades. The results of ecological and biochemical monitoring of soil composition and activity of catalase enzymes in the arable soil layer in the zone of electromagnetic fields of power transmission lines are given in (Sarokvasha, 2006; Shcherbakov 2013), and in (Hapochka, 2013), the change in the number of microalgae as a result of electromagnetic radiation is considered. However, the lack of proper statistical analysis does not make it possible to make reasonable conclusions about the results of this monitoring. In (Beliuchenko, Melnyk, 2020), it is noted that there are almost no publications in which a comparative analysis of the ecological characteristics of soil and root zone of plants is conducted based on quantitative indicators with subsequent mathematical processing of the results.

Given the above, the purpose of this work is to investigate the impact of electromagnetic fields on the degradation of agricultural land.

The objectives of this work are:

– construction of statistical models designed to assess the impact of electromagnetic fields on land pollution;

– conducting biomonitoring of agricultural lands under the influence of EMF power lines.

The second chapter of this publication will provide a mathematical justification for ecological – biochemical monitoring of soil composition. On the basis of regression analysis, regression equations were obtained that describe the corresponding processes. Accounting for the influence of several factors is taken into account using classical and nonparametric analysis of variance. To take into account changes in established weather conditions that have an active influence on the physicochemical processes in the soil, including soil biota, grouping was performed by the cluster analysis method.

In the third chapter, an assessment will be made of the overall influence of the factor of distance to the power line (row factor) and the area where the measurements were taken (column factor). A two-way analysis of variance was performed without repetition.

2. Experimental part

2.1. Materials and methods

To achieve the goal and solve the tasks, the methods of regression, variance, and cluster analysis were used, and the corresponding elasticity functions were constructed. In building mathematical models, modern data processing methods described in (Skyena, Styven, 2020; Kaplan et al., 2008; Pen R., Pen V., 2021; Kotliar, 2000) were used. They were used to evaluate the results of experiments in the literature. In this work, we used the methods of cluster, variance and regression analysis in the form in which they are implemented in software systems STATGRAPHICS XV. I and Atte Stat (Vadzynskyi, 2008; Haidyshev, 2015).

Cluster analysis is designed to divide the set of studied objects and features into homogeneous in a certain sense groups or clusters. Methods of regression analysis within the work was used to construct empirical relationships. In this work, the obtained regression equations were used to construct the elasticity and instantaneous growth functions.

2.2. Mathematical justification for the use of statistical analysis

It is known from (Pen R., Pen V., 2021; Kotliar, 2000) that the functions of instantaneous growth are used to study the dynamics of processes occurring in different environments. It is known that for any differentiated function $y = f(x)$, its elasticity $E_x(y)$ is determined by the formula:

$$E_x(y) = \frac{y'(x)}{y}x. \quad (1)$$

The function $y = f(x)$ is called elastic, as if the elasticity index $E_x(y) > 11$, ie change the argument by 1 %, the value of the function changes more than 1 %. The function $y = f(x)$ is inelastic when the elasticity index $E_x(y)<1$.

In (Kaplan et al., 2008), it was shown that for a function $y = f(x)$ defined on [a, c], a fair relation with the name of a divisor of the first kind $V(x)$ is valid, namely:

$$V(x) = \lim_{\Delta x \to 0}\left[\frac{f(x+\Delta x)}{f(x)}\right]^{\frac{1}{\Delta x}} = exp\left[\frac{f'(x)}{f(x)}\right]. \quad (2)$$

Its possible interpretation is as follows: the dividend of the first kind is the average growth rate over an infinitesimal time interval $[t_1, t_2]$, $t_1 < t_2$; $\Delta t = t_2 - t_1 < \varepsilon_1$, $\varepsilon \to 0$. In (Kotliar, 2000), it was shown that the definition of a second-order divisor coincides with the definition of the elasticity of a function. The use of these functions makes it possible to obtain more detailed estimates of the impact of electromagnetic fields on agricultural land pollution than the usual regression equations.

In the statistical analysis of the experimental results, there is a need to assess the influence of some not quantifiable (qualitative) factor or group of factors on the studied random variable. The task of the variance analysis is to use the results of observations on the studied random variable Y to assess the dependence of its mathematical expectation (average) on the factors under consideration. This problem is solved by comparing the sample variance caused by the influence of the qualitative factor (factors) under consideration with the sample variance due to random causes (the influence of uncontrolled factors in this experiment, measurement errors, etc.). If the difference between these variances is significant, it is believed that the analyzed factor (factors) significantly affects the studied random variable (investigated performance trait).

2.3. Ecological – biochemical monitoring of soil composition

Consider the application of the proposed methods for ecological – biochemical monitoring of soil composition in the area of high-voltage power lines. The change in the number of fungi in the soil, depending on the distance to the power line, was chosen as a bioindicator. At the same time, there is an assumption that in the characteristic size of the area of EMF influence, we have the same conditions for the development of bioorganisms. Methods for obtaining the initial data required for this are described in (Pen R., Pe, V., 2021). We consider the variant of the dependence of the number of fungi in the soil on the distance to the 110 kV power line in different seasons. This information is borrowed from (Beliuchenko, Melnyk, 2020) and formed in Table 1. A detailed analysis of these data revealed two zones that differ in the number of fungi: a nearby, not further than 300 m from the power line and a remote one, located at a distance of more than 300 m from the power line.

A characteristic feature of the nearby zone (L <300 m) is that the process of changing the number of fungi is unstable and is found only in the remote zone. In the remote zone (L> 300 m), the process of changing the number of fungi is stabilized, which allows its further analysis using the method of regression analysis.

Table 1

Dependence of the number of fungi in the soil on the distance to the 110 kV power line in different seasons

No.	Distance to 110 kV power lines (L, m)		Number of fungi in the soil in different seasons		
			Autumn (Au)	Spring (Sp)	Summer (Su)
1	Nearby zone	0	40	65	92
2		10	51	95	100
3		20	72	125	126
4		30	71	111	152
5		40	37	142	106
6		50	86	181	169
7		60	79	150	174
8		70	70	166	168
9		80	40	101	122
10		90	38	70	98
11		100	40	68	92
12		150	37	65	95
13		180	40	66	90
14		240	40	64	91
15	Remote zone	300	40	68	90
16		400	36	64	94
17		500	32	62	106
18		600	29	54	110
19		700	28	52	120
20		800	29	48	128
21		900	30	51	120
22		1000	32	62	110
23		1100	36	68	105
24		1200	38	71	92
25		1300	41	74	86

Method of regression analysis. Using this approach, we compile regression equations that describe the corresponding process of changing the number of fungi in this area of the power line in different seasons. The regression functions are limited to the second-degree order and for each season are shown in Table 2. The same table shows the elasticity of the number of fungi for different seasons depending on the distance from the power line (argument L) obtained by relation (1).

Table 2

Regression equations that describe the change in the number of fungi in a remote area in different seasons

Regression equation	Elasticity of the regression equation
QAu = 64.7719 – 0.0836384·L + 0.0000543928·L^2	$E_L(QAu) = \frac{2 \cdot L \cdot (27 \cdot L - 2.09 \cdot 10^4)}{27 \cdot L^2 - 4.18 \cdot 10^4 \cdot L + 3.238595 \cdot 10^7}$
QSp = 112.041 – 0.139633·L + 0.0000931131·L^2	$E_L(QSp) = \frac{2 \cdot L \cdot (93 \cdot L - 6.98 \cdot 10^4)}{93 \cdot L^2 - 1.396 \cdot 10^5 \cdot L + 1.12041 \cdot 10^8}$
QSu = 35.4046 + 0.252843·L – 0.000160017·L^2	$E_L(QSu) = \frac{8 \cdot L \cdot (L - 790)}{4 \cdot L^2 - 6320 \cdot L - 8.85115 \cdot 10^5}$

Based on the data given in Table 3, and in accordance with works (Lytvyn, 2006; Vadzynskyi, 2008), the quality of the obtained regression equations should be considered satisfactory.

Table 3

Estimation of the quality of regression equations designed to determine the number of fungi in a remote zone

Equation	Size Pv	Adjusted coefficient of determination, %	Correlation coefficient
QAu	$1 \cdot 10^{-4}$	94.5	0.97
QSp	$1 \cdot 10^{-4}$	80.9	80.9
QSu	$1 \cdot 10^{-4}$	88.6	88.6

Analysis of variance. In general, the change in the number of fungi depending on the distance from the power line is influenced by two factors, which are listed in Table 1: distance from the power line (row factor) and season (column factor). Classical analysis of variance (Vadzynskyi, 2008) and non-parametric analysis of variance (Friedman and Freud criteria) in the form described in (Haidyshev, 2015) were used to statistically study the significance of the combined effect of these factors.

The results of the classical analysis of variance are shown in Table 4, and the results of the non-parametric analysis of variance are shown in Table 5.

Table 4

Results of analysis of variance of the joint influence of distance from power lines and seasons.

Source of variation	*SS*	*df*	*MS*	*F*	Size P_V	$F_{critical}$
Strings	45871.25	24	1911.302	7.211	3.86901E-09	1.746353
Columns	60205.15	2	30102.57	113.575092	6.31123E-19	3.190727
Error	12722.19	48	265.0456			
In general	118798.6	74				

Table 5

Results of non-parametric analysis of variance of the influence of distance from power lines and seasons.

Type of criterion	Value of the criterion	Size P_V	Number of degrees of freedom
Friedman's criterion	7.211	$3.87 \cdot 10^{-9}$	48
Quaid's criterion	49.017	$49.017 \cdot 10^{-12}$	48

This conclusion can be made using the results of (Haidyshev, 2015). In the case where statistical criteria are used to test the same hypothesis, the conclusion about their consistency is made by the ratio:

$$P_V = 1 - \boldsymbol{\Pi}(1 - Pv_i), \quad i = 1, 2, \ldots, k, \qquad (3)$$

where P_V is the final value evaluated by relation (3), the value of Pv_i corresponds to this value for each of the criteria used. For P values given in Tables 4 and 5, it is

$$P_V = 1 - (1 - 3.86 \cdot 10^{-9}) \cdot (1 - 6.31 \cdot 10^{-19}) \times$$
$$\times (1 - 3.87 \cdot 10^{-9}) \cdot (1 - 49.02 \cdot 10^{-12}) < 2 \cdot 10^{-9}.$$

Based on the fact that the value of PV<<0.05 for all criteria used, the conclusion on the statistical significance of the joint influence of seasonal factor and the factor of distance from the power line on the change in the number of fungi should be considered consistent with the experimental results.

Table 6

Results of cluster analysis of the number of fungi in the nearby zone

Cluster index	Distance to 110 kV power lines (L, m)	Number of fungi in the soil in different seasons		
		Autumn (Au)	Spring (Sp)	Summer (Su)
1	0	40	65	92
1	10	51	95	100
2	20	72	125	126
2	30	71	111	152
1	40	37	142	106
2	50	86	181	169
2	60	79	150	174
2	70	70	166	168
1	80	40	101	122
1	90	38	70	98
1	100	40	68	92
1	150	37	65	95
1	180	40	66	90
1	240	40	64	91
1	300	40	68	90

Cluster analysis. It is known that the change of seasons is accompanied by changes in steady weather conditions, which actively influence physicochemical processes in the soil, including soil biota. Accordingly, the electrophysical characteristics of the soil and the nature of their interaction with the electromagnetic fields of power lines change. Therefore, the grouping by the method of cluster analysis of the observations presented in (Smyrnova et al., 2019) and performed for all considered seasons and located in the near zone at equal distances from the power lines was performed. To do this, each observation shown in Table 1 and performed in the near zone, was considered as a multidimensional vector, the coordinates of which correspond to the observations made in all considered seasons.To perform the cluster analysis, the Ward method, described in (Kaplan et al., 2008), was chosen. The results of the analysis are shown in Table 6.

Subsequently, the results were obtained concerning the average values of the coordinates of the objects included in this cluster. The coordinates of the centres of the obtained clusters are given in Table 7. From this table, it follows that the obtained clusters differ significantly in their average values. Analyzing this result, we could not identify the reasons that caused such a big difference, and we believe that it needs further study.

Table 7

Coordinates of the centres of the obtained clusters

Cluster index	Coordinates of observations (seasons)		
	Autumn (Au)	Spring (Sp)	Summer (Su)
1	40.3	80.4	97.6
2	75.6	146.6	157.8

3. Results and Discussion

The activity of catalase enzymes can be one of the indicators of degradation processes in the soil under the influence of electromagnetic radiation from power lines. In [16], data on the activity of catalase enzymes in forest soils at different levels of the voltage of electromagnetic radiation from power lines are presented.

The activity of enzymes was determined independently of three indicators:

P1 – catalase activity in the soil, cm^3 O2 1g/2 мin,

P2 – catalase activity in plant tissues, cm^3 O_2 1g/2 мin,

P3 – the numerical value of ACRG (catalase activity plant – soil).

The numerical values of these indicators are presented in Table 8, compiled according to (Shcherbakov, 2013).

Table 8

Dynamics of tension of adaptation processes in soils at different distances from the power lines perpendicular to the centre of sagging wires

Distance from the power line, m	Indicator P1			Indicator P2			Indicator P3		
	area 1	area 2	area 3	area 1	area 2	area 3	area 1	area 2	area 3
0	3.7	3.2	3.9	15.6	20.9	19.7	4.2	6.53	5.1
30	5.0	4.8	4.4	11.6	20.9	23.7	2.8	4.2	5.4
60	4.8	7.3	4.0	15.0	19.9	28.1	3.13	2.72	7.1
1500	6.4	6.4	6.4	22.8	22.8	22.8	3.56	3.56	3.56

For each of these indicators, estimates of the combined impact of the distance to the power line (row factor) and the area where the measurements were performed (column factor) were performed. Two-factor analysis of variance was performed without repetitions. The main parameters of this analysis for Pi indicators are presented in Table 9.

Table 10 presents the results of the statistical evaluation to test statistical hypotheses about the significance of the influence of experimental conditions, i. e. the factor of distance to the power line (row factor) and the factor of the area where the values of each of the studied indicators (column factor) were determined.

Table 9

Results of the analysis of variance of the combined effect on the change of the P factor of the distance from the power line and the site factor

Source of variation	*SS*	*df*	*MS*	*F*	Size P_V	$F_{critical}$
Indicator **P1**						
Strings	12.36917	3	4.123056	4.72707	0.050639139	4.757062664
Columns	1.14	2	0.57	0.653503	0.553649986	5.14325285
Error	5.233333	6	0.872222			
In general	18.7425	11				
Indicator **P2**						
Strings	33.96	3	11.32	0.937539	0.478843482	4.757062664
Columns	110.915	2	55.458	4.593071	0.061675325	5.14325285
Error	72.445	6	12.074			
In general	217.32	11				
Indicator **P3**						
Strings	4.582967	3	1.527656	0.844897	0.517501108	4.757062664
Columns	7.003817	2	3.501908	1.936792	0.224403311	5.14325285
Error	10.84858	6	1.808097			
In general	22.43537	11				

Table 10

Testing statistical hypotheses about the significance of the influence of experimental conditions

Indicator	Factor	F	$F_{critical}$	P_v	Statistical significance of the influence of the factor
P1	Rows	4.727	4.757	0.050	Not specified
	Columns	0.653	5.143	0.55	Does not affect
P2	Rows	0.937	4.757	0.478	Does not affect
	Columns	4.593	5.143	0.061	Not specified
P3	Rows	0.844	4.757	0.517	Does not affect
	Columns	1.936	5.143	0.224	Does not affect

The obtained data of the analysis of the significance of the influence of the factor on some positions are uncertain. That is, we must assume that the study should be continued because the above observational data do not provide a clear answer to the question about the impact or non-impact of the studied indicators on the results of the experiment.

4. Conclusions

During the analysis of the available sources of information, it was found that in the scientific publications by domestic authors, there is no mention of such a factor of land degradation as the action of EMF of man-made origin.

The use of methods of mathematical modelling of the dynamics of the distribution of microorganisms or other soil components in the irradiation zone of power lines can be the basis for biomonitoring in the system of technology for the protection of agricultural land from electromagnetic pollution.

The paper presents statistical models designed to assess the impact of electromagnetic fields on agricultural land pollution and appropriate biomonitoring, namely: models of the dependence of the number of fungi in the soil on the distance to power lines – 110 kV in different seasons, the dynamics of the intensity of adaptation processes in soils at different distances from power lines.

The methods of regression, variance, and cluster analysis were used in the development of models, and the corresponding elasticity functions were constructed. It is shown that the application of modern data processing methods allows obtaining additional information even from the already published results of the work performed by various researchers.

In the future, the results of this work can be used to build a biomonitoring system based on the processing of existing bioindication data. The presented algorithm and the obtained functional dependencies can serve as an example for conducting similar studies of the influence of other static factors on land pollution.

Acknowledgements

The authors are grateful to the administrations of the universities and institutes they represent for providing the opportunity to conduct research.

References

Bakhareva, N. P. (2016). Yzmenenye byotsenoza pochv pry vozdeistvyy na nykh эlektromahnytnыkh polei. *Sovremennye tendentsyy razvytyia nauky y tekhnolohyi, 1(1)*, 21–24. Retrieved from https://elibrary.ru/ item.asp?id=25430927

Beliuchenko, Y. S., & Melnyk, O. A. (2020). *Selskokhoziaistvennaia ekologiya*. Krasnodar: KHAU.

Cherepnov, I., Kolokolnikov, V., & Kanaieva, K. (2021). *Tyzhden ekoloha-2021.* Ukraine, Kamianske: Dnipro State Technical University.

Cherepnev, I. A. (2010). Prodovolstvennaya bezopasnost Ukrainy i ispolzovanye elektromahnytnykh tekhnolohyi v zhyvotnovodstve, i veterynaryy. *Systemy upravlinniya navigatsii ta zviazku, 2*(14), 164–175.

Cherepnev, I. A. (2011). Byomonytorynh pryrodnykh y tekhnohennykh elektromahnytnykh poley s tseliu snyzhenyia ykh nehatyvnoho deistvyiya na cheloveka. *Visnyk KhNTUSH. Mekhanizatsiia. vyrobnytstva, 107*(2), 356–366. Retrieved from https://khntusg.com.ua/wp-content/uploads/2020/01/107-2.pdf

Haidyshev, Y. P. (2015). *Modelirovanie stokhasticheskikh i determinirovannykh system. Rukovodstvo polzovatelia prohrammy AtteStat.* Kurhan: B. I.

Hapochka, M. H. (2013). Ekolohycheskie aspekty vzaymodeistvyia elektromahnytnykh polei myllymetrovoho dyapazona s byolohycheskimy obektamy. *Avtoreferat dyssertatsyy doktora byolohycheskykh nauk. "MGU M.V. Lomonosova"*. Retrieved from https://new-disser.ru/_avtoreferats/ 01007961873.pdf

Kaplan, A. V., Kaplan, V. E., Mashchenko, M. V., & Ovechkyna, E. V. (2008). *Reshenye ekonomycheskikh zadach na kompiutere*. Moscow: D M K Press.

Korepanov, V. E. (2015) Nabliudenyia yzluchenyia lynyi elektroperedach v okolozemnom prostranstve. *Heomahnetyzm y aeronomyia, 55*(5), 706–710. Retrieved from https://elibrary.ru/item.asp?id=24045183

Kotliar, V. Iu. (2000). Ob otnosytelnoi skorosty izmeneniay funktsyy. *Kibernetika i systemny analiz, 5*, 160–172.

Lytvyn, O. M. (2006). *Dividirialnye y multygralnye vychyslenia*. Kyiv: Naukova dumka.

Matrosova, L. M. (2020). Problemy rozvytku ahropromyslovoho kompleksu Ukrainy yak napriam pidvyshchennia konkurentospromozhnosti ekonomiky. *Infrastruktura rynku*. (42), 83–90. Retrieved from http://market-infr.od.ua/journals/2020/42_2020_ukr/16.pdf

Pen, R. Z., & Pen, V. R. (2021). *Statystycheskye metody matematycheskoho modelyrovanyia analyza y optymyzatsyy tekhnolohycheskykh protsessov*, Sankt– Peterburh: Lan.

Postanova Kabinetu Ministriv Ukrainy (1998 March 30 No. 391) "Pro zatverdzhennia Polozhennia pro derzhavnu systemu monitorynhu dovkillia". *Resource:* Verkhovna Rada Ukrainy: vebportal. Retrieved from https://zakon.rada.gov.ua/laws/ show/391-98- %D0 %BF#Text

Ratushniak, M., Tymchuk, I., Berezyuk, D., & Malovanyy, M. (2021). Improvement of the municipal solid waste disposal system in ukraine, on the example of the town of chortkiv, ternopil region *Environmental Problems, 6(4)*, 275–280, doi: https://doi.org/10.23939/ep2021.04.275

Roshko, V. V., & Roshko, V. H. (2017). Doslidzhennia vplyvu elektromahnitnoho polia linii elektroperedach vysokoi napruhy na uhrupovannia khortobiontnykh artropod (aktnkoroba). *Naukovyi visnyk Uzhhorodskoho universytetu. Seriia Biolohiia, (43)*, 25–30. Retrieved from https://dspace.uzhnu.edu.ua/jspui/handle/lib/20434

Sarokvasha, O. (2006). Ekologo – byokhymycheskiy monitoring sostava pochvv v zone razmeshchenyia vysokovoltnoi LEP. *Vestnyk SamGU – Estestvennonauchnaia seryia, 7*(47), 198–206. Retrieved from https://elibrary.ru/item.asp? id=9272905

Shcherbakov, Y. (2013). Aktyvnost fermenta katalazy v pakhotnom sloe pochvy v zone elektromahnytnykh polei lynyi elektroperedach. *Ahrarnyi vestnyk Urala*, *6*(112), 74–75. Retrieved from https://www.avu.usaca.ru

Skyena, S., & Styven, S. (2020). *Nauka o dannykh*. Sankt– Peterburh: OOO "Diyalektyka".

Smyrnova, S., Smyrnov, V., & Babushkina, R. (2019). Kontseptsiia gruntovoi bioheosystemy, *Heolohiia, 4*(87), 81–88. doi: http://doi.org/10.17721/1728-2713.87.12

Storoshchuk, U., Malovanyy, M., Tymchuk, I., & Luchyt, L. (2021). Analysis of the main methods of solid waste management. *Environmental Problems, 6*(4), 238–243. doi: https://doi.org/10.23939/ep2021.04.238

Sydorenko, V., Yeremenko, S., Vambol, V., Vambol, S., & Poberezhna L. (2022). Distribution and influence of forest fires on the ecological and radiation situation in radioactively contaminated areas. *Procedia Structural Integrity, 36*, 318–325. doi: https://doi.org/10.1016/j.prostr.2022.01.041

Vambol, S. O., Cherepnov, I. A., & Kolokolnikov, V. O. (2021). *Metrolohichni aspekty pryiniattia rishen v umovakh roboty na tekhnohenno nebezpechnykh obiektakh*. Ukraine, Kharkiv: Kharkiv National Automobile and Highway University.

Vadzynskyi, R. (2008). *Statisticheskie vychislenia v srede Excel. Byblyoteka polzovatelia*, Sankt– Peterburh: Pyter.

Ziarati, P., Moradi, D., Rodriguez, L., Hochwimmer, B., Vambol, V., & Vambol, S. (2022). Biofortification of Oryza sativa L. with agri-food waste to improve the dietary value of crops. *Ecological Questions 33 (1)*, 1–13. doi: https://doi.org/10.12775/EQ.2022.004