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WHY DO REGIONS DIFFER IN VULNERABILITY TO COVID-19? SPATIAL NONLINEAR MODELING OF SOCIAL AND ECONOMIC PATTERNS

Olha Kuzmenko
Sumy State University,
Sumy, Ukraine
E-mail:
o.kuzmenko@uabs.sumdu.edu.ua
ORCID 0000-0001-8575-5725

Tetyana Vasylieva
Sumy State University,
Sumy, Ukraine
E-mail:
tavasilyeva@fem.sumdu.edu.ua
ORCID 0000-0003-0635-7978

Sergej Vojtovič
Alexander Dubcek University of Trencin, Trencin, Slovakia
E-mail: sergej.vojtovic@tnuni.sk

Olena Chygryn
Sumy State University,
Sumy, Ukraine
E-mail:
o.chygryn@econ.sumdu.edu.ua
ORCID 0000-0002-4007-3728

Vytautas Snieška
Kaunas University of Technology,
Lithuania
vytautas.snieska@ktu.lt
ORCID 0000-0001-8777-273X

ABSTRACT. Certain groups of determinants (economic, environmental, social, healthcare) with the highest vulnerability identify the reasons for regional differentiation in morbidity and mortality from COVID-19. This defines the necessity to find appropriate combinations of factors characterizing the vulnerability of a region. The methodology and tools to explain the regional specifics of population vulnerability to COVID-19 are investigated through a systematic consideration of many public health factors, environmental, social and economic specific nature of regions. The aim of the article is to study the reasons for regional differentiation of population vulnerability (morbidity and mortality rates) from COVID-19. The authors investigate a nonlinear spatial model in which the stepwise algorithm of individual factor variables is added/removed from the model specifications step by step by the Aitken method depending on their correlation with morbidity and mortality from COVID-19 in the region. The Farrar-Glober method is used to eliminate the multicollinearity of factors, the Spearman test is used to detect the heteroskedastic effect, and the Darbin-Watson test is used to check the presence of autocorrelation between the residues. As a result, the specification of the model with the highest adequacy in terms of p-value and t-statistics is formed. Relevant socioecological-economic vulnerability indices of regions to mortality and morbidity from COVID-19 are identified. The obtained results allow making adjustments in the state and regional programs concerning the mobilization of economic and healthcare systems.

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Introduction

At the beginning of October 2020, the number of reported deaths in the world caused by COVID-19 exceeded 1 million. At the same time, a high reproductive index (as of October 2020, it was - 2.5-2.9) indicated the extraordinary rate of growth in infected people around the world, thus characterizing the rapid spread of the virus. For comparison, during the Spanish flu pandemic, when in 1918 about 50 million people on the planet died, that index was 1.7-2.09. The catastrophic rate of COVID-19 spread has led to a rapid and powerful response from international institutions and governments, which take different measures, primarily to reduce the pandemic rate and the catastrophically rising incidence. At the level of individual states and between the countries, appropriate measures include: closure of educational institutions, prohibition of mass gatherings, social distancing, restriction of movement, closure of borders, etc.

The global increase in morbidity and mortality caused significant changes in the regional socioeconomic development, emphasizing the relevance of studying the impact made by existing regional features on the vulnerability of population to COVID-19. It is evident that the morbidity and mortality level among the patients with COVID-19 depends on many factors, including employment and unemployment rates; migration movement; birth and death rates; income; the number of first registered cases by 19 classes of diseases; the number of laboratory tests performed on COVID-19, the number of contracts for medical care for population under various programs, the readiness of medical institutions to receive patients; environmental pollution; economic indices of regional development. Therefore, the definition of the most important economic, environmental, social, and public health factors, which have accumulated over the years and eventually formed the so-called "retrospective portrait of the vulnerability of population from different regions to COVID-19", is especially relevant today.

1. Literature review

The scientific community, namely, Cuddington et al., 1994; Haacker, 2002; Arndt et al., 2001; Bell et al., 2004, Bhargava et al., 2001, has made significant progress in identifying socio-economic drivers or inhibitors of the spread of infectious diseases similar to COVID-19. Recent studies include an analysis of the national and regional specifics of the population‘s vulnerability to COVID-19: the study (Farseev et al., 2020) statistically finds links between the dynamics of the COVID- 19 spread and economic environment and public health factors; the work of Y. Ji et al. (2020) - links between mortality from COVID-19 and the availability of resources in the healthcare system. Recent studies have empirically confirmed that the level of interstate, interregional and intraregional migration is an important catalyst for the disease spread: the work of Z. Chen et al. (2020) proves the statistical relationship between the initial emigration from Wuhan and the infection spread dynamics to other cities in China; the work of Y. Bai et al. (2020) discovers that asymptomatic migrants could transmit COVID-19.

Besides, some traditional socio-economic factors are determinants of regions' vulnerability to COVID-19. The article studies the migration phenomenon and its linkages on fiscal revenues and budget expenditures with social benefits (Cristea et al., 2019; Levchenko et al., 2017; Didenko et al., 2020b). The research (Osabohien et al., 2020; Rajan, 2018; Shammi et al., 2020) showed that social protection positively affects employers' health and work outcomes through various channels, namely, building human resources and equity, the use of public resources, social inclusion. In their study, authors (Sasongko et al., 2019; Vasilyeva et al., 2019) implemented the Granger Causality test and Vector Autoregression to define the causality between inflation and unemployment. The article (Vydrová & Bejtkovský, 2018; Papo et al., 2020) identified the key features of management bodies in public healthcare organizations that directly affect social maturity, intelligence, workers. The conclusions (Hedvicakova et al., 2018; Yelnikova et al., 2020) showed that the benefits, offered to employee, do not affect the labour market situation and public health. The authors (Lewandowska et al., 2020; Dutta et al., 2020; Jafarzadeh et al., 2019; Vasylieva et al., 2020) examined the institutional and educational determinants. Authors (Çera et al., 2019; Kashyap et al., 2020) used the principal component analysis and non-parametric methods to explore the linkages between entrepreneurial and social factors. The paper (Didenko et al., 2020a) investigated the relationship between behavioral aspects of populations' financial inclusion and social safety level. Authors (Mihi-Ramire et al., 2020; Bagmet et al., 2018) concluded that social strategies and policies use and promote the interaction between employer mobility factors since they allow companies and employees to diversify their risks and find new trade and investment opportunities. The paper (Melnyk et al., 2018) determined the relationships between institutional efficiency and identified areas of stability achieved by local governments in their roles. The studies (Grabara et al., 2019; Lyulyov, 2017) analyzed industry development stages with their management strategies, impact on employees, and their social and health state.

Significant scientific progress has been made in predicting the macroeconomic and social consequences of introducing certain restrictive measures during pandemics and identifying the channels through which quarantine mostly affected the economy and society. In the work of Liu et al. (2005), authors consider such channels as a reduction in the consumption of specific goods and services, an increase in the business's operating costs, and a reassessment of macroeconomic risks. The study of Lee et al. (2003) investigated the global trajectories of financial and economic shocks from epidemics outside the affected countries, the dependence of their spread dynamics on the morbidity level in countries where the virus originated, and the population's vulnerability degree to the migration flows. The work of Meltzer et al. (1999) described various models (including Oxford) to predict the probable economic consequences of past pandemics for the economy.

Scientists (Kusuma et al., 2020; Dave, 2019; Harafonova et al., 2017) emphasize that long-term investment is a new area for the researcher given the Covid-19.

Their results show the positive association between defensive pessimism, purchase intention and long-term investment, and mindset priming's positive mediation. The article (Sułkowski, 2020; Grshybowskyj, 2019) attempts to diagnose the impact of the Covid-19 pandemic on global trends, including organizational processes in enterprises and challenges for organization leaders in many areas. The papers (Bryl, 2020; Rudenko, 2020) indicates the influence of the long-term development of the chosen human capital indices and public health policies. The articles (Bobáková, 2017; Kot, 2020; Chygryn, 2018) assess fiscal decentralization in self-governing regions and improve the public health sphere. The papers (Bilan et al., 2019; Djalilov et al., 2015; Luchko, Arzamasova & Vovk, 2019; Sumiyana, 2020; Vasylieva et al., 2019) investigate the relationship between macroeconomic stability, aggregate of accounting earnings, and national indicators economies. Authors (Lapinskienė et al., 2017; Tunčikienė et al., 2017) investigated economic growth, greenhouse gas emissions and other factors concerning health system occupational safety and health services. Implications created by (Senol et al., 2020) bring the conclusion that life insurance contributes more to economic growth with the long-term and regular resources it provides to save public health. Scientist (Svabova et al., 2020) analyzed the earnings level and fraudulent manipulation in financial reporting in decreasing the population's wealth.

The studies (Rui et al., 2019; Cebula et al., 2018; Bilan et al., 2018) analyzed *t*he environmental factors and their effects on the economy's resilience to systemic crises. The work (Mentel et al., 2018) theoretically substantiates that the regional environmental state is a driving force for the stable growth of the overall national health. The authors in the study (Lyulyov et al., 2015; Hens et al., 2019) systematized the theoretical aspects, analyzing the environment in the regional and sectoral context.

The existing system of public health management, the level of funding, and the medical sector's development significantly impact regional vulnerability to COVID-19 (Khomenko et al., 2020; Smiianov et al., 2017). The paper (Sokol et al., 2020) generalized methods to assess risk factors of treatment failure outcomes; the authors (Sułkowski, 2020; Shammi et al., 2020) investigated the impact of COVID-19 on global development trends; the article (Smiianov, 2014) studied the internal audit system in healthcare system management.

At the same time, all these studies do not consider the healthcare system specifics in a particular country, differences in national statistical accounting systems, approaches to determining mortality, etc., so the intergovernmental analysis may not give accurate estimates and conclusions.

2. Methodological approach

The study hypothesizes the regional differentiation conditionality of morbidity and mortality from COVID-19 by specific patterns of factors in which the vulnerability is the highest.

The study of the regional vulnerability to COVID-19 includes the following stages:

1) formalization of the nonlinear multifactorial regression equations of dependence between the result (morbidity and mortality of the population from COVID-19) and variables - public health factors (over 20 major classes of diseases) and determinants of environmental, social and economic specificity region (formula 1):

$$y = a_0 + a_1x_1 + a_2x_2 + \cdots + a_{23}x_{23} \quad (1)$$

where a_0- free member, a_i – coefficients of the linear regression equation, x_i –factors, which are independent variables, $i = (1{,}23)$.

2) formation of correlation matrices that settle at which combinations of factors the studied influence will be the most statistically significant. A gradual algorithm will be used to add and remove variables from the equation due to their importance regarding the impact on the morbidity/mortality level from COVID-19;

3) the investigation of several models is planned step by step, by Aitken's method with a decrease in the number of variables. They will be compared with each other in terms of adequacy and the strength of factor variables' influence on the effective one. The parameters of the model adequacy will be p-values and t-statistics. The variables will not be included in the model if there is no improvement in the level of adequacy of the model;

4) the Farrar-Glober method will be used to eliminate the multicollinearity of factors, the Goldfeld-Kwantt parametric test - to detect the heteroskedasticity effect, the Aitken method - to eliminate this effect, and the Darbin-Watson test - to check the residual autocorrelation.

3. Conducting research and results

24 regions of Ukraine and Kyiv are selected as the object to study the regional differentiation of morbidity and mortality from COVID-19.

The information base of the study consists of indices of social (68 indicators), economic (42 indicators) development, state of the environment (12 indicators) and public health (39 indicators) for the period March - September 2020.

According to the stages defined in the research methodology, we present an assessment of regions' vulnerability to COVID-19.

We calculate the critical value of the χ-square criterion, with a significance level of 95% and the number of freedom degrees v (2):

$$v = \frac{1}{2}(m-1)m = 253, \quad (2)$$
$$\chi^2_{tab}(0{,}05; 253) = 291. \quad (3)$$

where m - number of independant variables of the investigated model, χ^2_{tab}- table value of the xi-square criterion.

The empirical value of χ-square is as follows:

$$\chi^2_{emp} = -\left[n - 1 - \frac{1}{6}(2m+5)\right] ln(\Delta r), \quad (4)$$

where χ^2_{emp} – empirical value of chi-square criterion, defined by the investigated model, n – row length for each factor, Δr - determinant of the matrix.

The result is $\chi^2_{emp} \approx 5489$, which significantly exceeds the critical value (3).

Thus, there is multicollinearity in the input array, and it is necessary to determine the correlation for each variable. So, we find the matrix C inverse to the correlation matrix of even coefficients r. We find the empirical value of Fisher's criterion for each diagonal element c_{jj} of this matrix. It will allow confirming or refuting the hypothesis regarding the studied index multicollinearity with others:

$$F_{jemp} = (c_{jj} - 1)\frac{n-m}{m-1} \quad (5)$$

where F_{jemp} – empirical value of Fisher‘s critrion, c_{jj} – diagonal element of the matrix r, n – row length for each factor, m – number of independant variables of the observed model.

We divide data into two parts $m_1 = m_2 = 19$ to perform calculations by this algorithm. The critical value of $F_{tab}(0.05; 6; 18) = 2.6$. Each calculated value of the Fisher‘s criterion exceeds the tabular one. Thus, it is necessary to determine the pairwise correlation coefficients using Student's t-test to exclude the factors with the highest absolute value (table 1).

Table 1. Features of multiple regression

Multiple correlation coefficient	Determination coefficient	Adjusted determination coefficient	Fisher‘s criterion F(1,23)	Standardized error
0,728	0,530	0,510	25,967	4548,657

Source: own calculation

Ridge regression will effectively reduce the dimension of the regression model. We determine the most significant coefficients and exclude the least influential predictors (have the lowest value of R or the largest value of P or F criterion (table 2) on the resulting variable. The gradual exclusion will continue until we obtain a data set at which the equation regressions will contain only significant coefficients (table 3).

Table 2. Ridge regression of inclusion/exclusion

	Step - +in/-out*	Multiple - R*	Multiple – R-square*	R-square - change*	F - to - entr/rem*	p-level*	Variables - included*
Volumes of capital investments in environmental protection, 2019, thousand UAH	-1	0,9370	0,8780	-0,0001	0,0008	0,9820	22
Volumes of light oil product stocks and gas at gas stations (motor gasoline) - total, tons	-2	0,9369	0,8778	-0,0001	0,0021	0,9674	21
Enterprises' costs for staff by their size by region in 2019, million, UAH	-3	0,9368	0,8777	-0,0002	0,0042	0,9524	20
Number of junior staff, persons	-4	0,9367	0,8775	-0,0002	0,0064	0,9399	19
Transferred on a part-time basis (week) for economic reasons, thousand people	-5	0,9366	0,8772	-0,0003	0,0110	0,9205	18
Labor costs of enterprises by their size Total, million UAH	-6	0,9364	0,8769	-0,0003	0,0144	0,9083	17
Symptoms, features and divergencies detected during laboratory and clinical studies (not classified in other sections)	-7	0,9362	0,8764	-0,0005	0,0294	0,8687	16
Migration growth, ages 0–4	-8	0,9355	0,8752	-0,0012	0,0753	0,7907	15
Average monthly salary by sex (men) and regions per the quarter, UAH	-9	0,9346	0,8735	-0,0018	0,1280	0,7287	14
The number of registered diseases of the endocrine system, eating disorders, metabolic disorders	-10	0,9334	0,8713	-0,0022	0,1708	0,6882	13
Volumes of stocks of light oil products and gas at gas stations, propane and butane liquefied, tons	-11	0,9320	0,8687	-0,0026	0,2210	0,6475	12
Volume of accumulated waste in specially designated places and facilities, thousand tons	-12	0,9306	0,8659	-0,0028	0,2529	0,6241	11
Volumes of carbon dioxide emissions into the atmosphere by region, thousand tons	-13	0,9278	0,8608	-0,0051	0,4940	0,4946	10
The average number of agricultural part-time, workers, thousand people	-14	0,9246	0,8549	-0,0060	0,6022	0,4507	9
Number of employees with a scientific degree involved in the research and development, persons	-15	0,9209	0,8480	-0,0069	0,7108	0,4124	8
Retail turnover under bank loan agreements	-16	0,9173	0,8415	-0,0065	0,6875	0,4192	7
Number of specialized doctors (infectologists, therapists, pediatricians)	-17	0,9092	0,8266	-0,0148	1,5891	0,2245	6
Number of agreements on medical care for the population under the program of medical guarantees	-18	0,9010	0,8118	-0,0149	1,5431	0,2301	5
Number of interstate migrants (migration increase), reduction (-), persons	-19	0,8834	0,7804	-0,0314	3,1703	0,0910	4
Migration growth, aged 70-74	-20	0,8495	0,7216	-0,0588	5,3525	0,0315	3
Costs for environmental protection by regions in 2019 (thousand UAH)	-21	0,7976	0,6361	-0,0855	6,4472	0,0191	2
The number of laboratory tests performed by PCR on COVID-19 pf 01/10/2020	-22	0,7282	0,5303	-0,1058	6,3968	0,0191	1

* *Symbols*: Step - +in/-out – on/off step number; Multiple – R - multiple correlation coefficient; Multiple - R-square - coefficient of determination; R-square - change - determination coefficient, adjusted for the number of freedom degrees; F - to - entr/rem F on / off criterion; p-level - level of significance; Variables - included - the sequence number of the variable

Source: own calculation

The quality characteristics of the model (table 3) indicate a high quality of adjusted model to the studied variables, all values of t-statistics are greater than critical one. Indices of migration and carbon emissions are directly related to the number of infected patients. Indices which show the readiness of medical institutions and the population to respond to pandemic challenges are inversely related.

Table 3. The results of ridge regression

	Beta*	Std.Err. - of Beta*	B*	Std.Err. - of B*	*	p-level
Free member of the regression			-2708,59	2113,430	-1,282	0,217
Number of beds in infectious diseases departments	0,423	0,206	5,350	2,609	2,050	0,056
Volume of accumulated waste in specially designated places and facilities, thousand tons	-0,220	0,127	0,000	0,000	-1,735	0,101
The number of laboratory tests performed by PCR on COVID-19 pf 01/10/2020	0,289	0,108	1,390	0,523	2,668	0,016
Number of interstate migrants (migration increase), reduction (-), persons	-0,190	0,094	-3,330	1,654	-2,015	0,060
Volumes of carbon dioxide emissions into the atmosphere by region, thousand tons	-0,234	0,120	-0,230	0,118	-1,943	0,069
Number of agreements on medical care for the population under the program of medical guarantees	0,243	0,147	16,590	10,031	1,654	0,117
Number of specialized doctors (infectologists, therapists, pediatricians)	0,165	0,163	11,760	11,626	1,011	0,326
R= 0,91524950 R^2= 0,83768165 Adjusted R^2= 0,77084468 F(7,17)=12,533 p						

* *Symbols*: Beta Std.Err. - of Beta - standardized regression coefficient and its standardized error; B / Std.Err. - of B - non-standardized regression coefficient and its standardized error; t(17) - t - statistics with the number of freedom degrees 17; p-level - the level of coefficient significance; Multiple - R - multiple correlation coefficient; Multiple - R-square - determination coefficient; Adjusted R-square is a determination coefficient adjusted for the number of freedom degrees.

Source: own calculation

The gradual exclusion for the regressor "Number of confirmed cases of coronavirus (y)" gave the following result:

$$y = -3{,}33a_1 - 0{,}23a_2 + 1{,}39a_4 + 16{,}59a_5 + 5{,}35a_6 + 11{,}76a_7 - 2708{,}59, \quad (5)$$

where a_1 – number of interstate migrants (migration growth, reduction), persons; a_2 - volumes of carbon dioxide emissions into the atmosphere in regions, thousand tons; a_3 - the amount of waste accumulated during operation, in specially designated places and facilities, thousand tons; a_4 - the number of laboratory tests performed on COVID-19; a_5 - the number of agreements on medical care for the population under the program of medical guarantees; a_6 - the number of beds in infectious diseases departments; a_7 - the number of specialized doctors (infectologists, therapists and pediatricians).

At this stage, the index a_4 - the number of laboratory tests on COVID-19, is a control point for the studied variable, characterizing the number of infected with coronavirus, i.e., the variable for checking the quality to reduce risk. These two indices are interrelated, and the model is adequate given the fact that as a result of our study (5) we obtained a direct relationship, i.e. with increasing number of tests, the number of new infections increases proportionally. To check the presence or absence of a relationship between two sets: the value of the dependent variable - the number of confirmed cases of coronavirus and the set of values that were included in the model (5), we use canonical analysis and univariate tests of significance, effect sizes, and powers for sigma-restricted parameterization. For canonical analysis we use the program Statistica Portable, the tools of Statistics/Multivariate Exploratory Techniques/Canonical Analysis. For sigma-restricted parameterization we use the program Statistica Portable, the tools of Advanced Linear/Nonlinear Models/General Regression Models.

The results of canonical analysis (table 4) confirmed the presence of relationship between the explained variable and the independent ones because the indicator total redundancy is 86% at the p-value less than 0,0001 that means: the variation of the number of confirmed cases of coronavirus by 86% is explained by exactly 7 considered regressors. Also, the value of the actual chi-square (39,15) significantly exceeds the critical value (13,85), which confirms the presence of a close relationship of factors $a_i, i = 1..7$, which were included in the model (5) and the explained variable. The analyses of sigma-restricted parameterization is also provided confirmation of the significance of the input data: the R square value for the indicators (the number of agreements on medical care for the population under the program of medical guarantees; the number of beds in infectious diseases departments; the number of specialized doctors) is over 0,817, indicating that these data describe the model well. For indicators the number of laboratory tests performed on COVID-19, the amount of waste accumulated during operation, in specially designated places and facilities, volumes of carbon dioxide emissions into the atmosphere in regions R square is in the range of 0,518-0,615, but with p-values less than 0,05, which confirms the significance of these factors for the dependent variable the number of confirmed cases of coronavirus.

Table 4. Results of canonical analysis: Chi-Square Tests with Successive Roots Removed

Root Removed	Canonicl R	Canonicl R-sqr.	Chi-sqr.	df	p	Lambda Prime
Number of confirmed cases of coronavirus	0,9304	0,8657	39,1529	7,0000	0,0000	0,1343
number of confirmed deaths from COVID-19	0,8877	0,7879	30,2425	7,0000	0,0001	0,2121

* Canonicl R-sqr. - total redundancy, Chi-sqr.- Chi square tests, p- the level of the coefficient significance

Source: own calculation

It is necessary to add nonlinear terms to the model, namely, consider a polynomial model of the second degree, clarify and strengthen the relationship between independent variables and factors. So, for variables $a_i, i = 1..7$, obtained at the previous stage, we add terms that will contain $a_i{}^2,\ i = 1..7$, and the final model will look like as follows (6):

$$y = k_{11}a_1^2 + k_{12}a_1 + k_{21}a_2^2 + k_{22}a_2 + \cdots + k_{71}a_7^2 + k_{72}a_7 + k_0. \quad (6)$$

where a_i- regressors, k_{i1} – coefficient with a_i^2, k_{i2} – coefficient with the linear constituent a_i, i = (1,7) – number of the variable, $k_0 - free\ member$.

According to Wald's criterion, the linear coefficients are the most significant in this model with such variables as carbon dioxide emissions into the atmosphere, the number of medical care contracts under the medical guarantees program, and the number of laboratory tests by PCR on COVID-19.

Table 5. Description of quadratic multiple regression coefficients

	Wald - Stat.*	p*
Free member of the regression	139,2081	0,000000
Number of interstate migrants (migration growth), reduction (-), persons	0,1210	0,727923
Number of interstate migrants (migration growth), reduction (-), persons ^ 2	-	-
Volumes of carbon dioxide emissions into the atmosphere by regions, thousand tons	19,9097	0,000008
Volumes of carbon dioxide emissions into the atmosphere by regions, thousand tons ^ 2	-	-
The amount of waste accumulated during operation in specially designated places and facilities, thousands tons	-	-
Volume of accumulated waste in specially designated places and facilities, thousand tons ^ 2	-	-

The number of laboratory tests performed by PCR on COVID-19 pf 01/10/2020	21,0981	0,000004
The number of laboratory tests performed by PCR on COVID-19 pf 01/10/2020 ^ 2	-	-
Number of medical care agreements for the population under the program of medical guarantees	6,4909	0,010843
Number of medical care agreements for the population under the program of medical guarantees ^ 2	3,2389	0,071908
Number of beds in infectious diseases departments	2,0133	0,155926
Number of beds in infectious diseases departments ^ 2	-	-
Number of specialized doctors (infectologists, therapists, pediatricians)	0,3515	0,553280
Number of specialized doctors (infectologists, therapists, pediatricians) ^ 2	2,1184	0,145537

*Symbols: Wald - Stat. – the value of the Wald‘s criterion; P – the level of the coefficient significance.

Source: own calculation

As a result of calculations by (7), we obtain the polynomial regression coefficients of the second degree with seven unknowns. The result of the calculations is as follows:

$$y = 7{,}5 \cdot 10^{-4} a_1^2 - 2{,}7 a_1 + 2{,}3 a_2^2 - 0{,}8 a_2 - 1{,}3 \cdot 10^{-10} \cdot a_3^2 + 4{,}4 \cdot 10^{-5} a_3 - 6{,}6 \cdot 10^{-4} a_4^2 + 6{,}7 a_4 + 2{,}2 \cdot 10^{-2} a_5^2 - 9{,}6 a_5 - 5{,}9 \cdot 10^{-6} a_6^2 + 11{,}2 a_6 + 1{,}4 a_7^2 - 18{,}5 a_7 - 670{,}2 \quad (7)$$

Determination coefficient $R^2 = 0{,}96$, indicating the strong relationship between the dependent and independent variables. Fisher's test also gives a positive result: $F_{em} = 9{,}3 > 2{,}6 = F_{tab}(0{,}05; 7; 17)$. Thus, the regression equation is statistically significant, the model is suitable. Table 6 shows the values of the Cook‘s distance D_i (1.15), used to determine the influence of data on the results of observations.

$$D_i = \frac{\sum_1^{25} \left(\hat{Y}_i - \hat{Y}_{i/j}\right)^2}{7MSE}, \quad (8)$$

where D_i – the Cook‘s distance; $\hat{Y}_i$ – theoretical value of $i - observation$; $\hat{Y}_{i/j}$ - theoretical value of $j - observation$ without i –observation; MSE - standard error.

We check the presence or absence of autocorrelation, i.e., the relationship between random deviations and residual values in other observations. We implement Darbin-Watson test to check (9):

$$DW = \frac{\sum (e_i - e_{i-1})^2}{\sum e_i^2} \quad (9)$$

where DW – Darbin-Watson test, e_i – difference between theoretical and empirical level of i – observation.

Table 6 demonstrates standardized residues and indicates the final observation error.

Table 6. Additional statistical indices of adequacy and significance of the model

	General. - Cook's D*	Diff- - Chi2*	Diff- - Likelihd*	Std. D. – Residual*
Vinnytsia region	0,948	1,40908	1437863	1,18705
Volyn region	2,610	2,86844	2563999	-1,69365
Dnepropetrovsk region	-	-	-	-
Donetsk region	73,330	7,82532	1288072	2,79738

Zhytomyr region	0,786	2,70734	3581361	1,64540
Zakarpattia region	4,333	3,26122	2390733	1,80589
Zaporizhya region	8,394	7,01873	5456251	-2,64929
Ivano-Frankivsk region	83,267	1,50413	45561	1,22643
Kyiv region	0,385	0,04909	9478	0,22156
Kirovograd region	0,003	0,52734	894650	0,72618
Luhansk region	0,331	1,31862	1799110	-1,14831
Lviv region	1050,301	1,10672	1990	-1,05201
Mykolayiv region	11,625	2,96713	1029938	-1,72254
Odessa region	152,136	13,25711	1813998	-3,64103
Poltava region	0,000	3,82181	6524072	1,95494
Rivne region	237,717	3,74881	99358	1,93619
Sumy region	0,154	0,35727	426504	0,59772
Ternopil region	12,151	0,33090	14975	-0,57524
Kharkiv region	903,272	13,80214	354615	3,71512
Kherson region	2,435	7,13332	9078562	-2,67083
Khmelnytsky region	0,021	0,07588	101782	0,27546
Cherkasy region	0,936	1,95562	2257919	1,39843
Chernivtsi region	39,275	5,76919	1261386	2,40191
Chernihiv region	0,038	0,17442	244724	0,41764
Kyiv	-	-	-	-

* *Symbols*: General. - Cook's D – Cook‘s distance; Diff- - Chi^2 – the value of the Xi-square criterion; Diff- - Likelihd - likelihood ratio test; Std. D. - Residual - standardized residues.

Source: own calculation

Table 7 demonstrates the theoretical and empirical values of the COVID-19 diseases by regions and the residuals of the studied index. According to them, we see results quite close to the empirical ones in Donetsk, Dnipropetrovsk regions and Kyiv; and vice versa quite a high difference in such regions as Ivano-Frankivsk, Zaporizhia, Lviv, Mykolaiv, Chernivtsi and Kherson

Table 7. Theoretical and empirical values for regions of Ukraine

	Response – Value*	Pred. – Value*	Residual*	St. – Error*	Lower CL - 95, %*	Upper CL - 95, %*
Vinnytsia region	6574,00	7152,808	-578,808	0,154	3973,20	7271,07
Volyn region	8571,00	10183,972	-1612,973	0,089	8549,82	12102,55
Dnepropetrovsk region	6917,00	6927,485	-10,485	0,189	4779,14	10018,43
Donetsk region	3743,00	3676,039	66,961	0,476	1025,60	6632,26
Zhytomyr region	6285,00	5972,165	312,835	0,141	3331,17	5792,12
Zakarpattia region	10089,00	10570,456	-481,456	0,116	6811,84	10713,61
Zaporizhya region	4502,00	7766,111	-3264,111	0,141	5186,72	9014,63
Ivano-Frankivsk region	14147,00	11070,726	3076,273	0,093	11613,31	16717,37
Kyiv region	9717,00	10005,588	-288,588	0,128	7486,55	12360,50
Kirovograd region	1143,00	11,908	1131,092	0,521	71,06	546,90
Luhansk region	1140,00	1650,289	-510,290	0,235	1562,66	3940,00
Lviv region	21045,00	23229,409	-2184,409	0,061	18679,36	23810,82
Mykolayiv region	3553,00	5675,974	-2122,974	0,255	2769,50	7533,97
Odessa region	14434,00	15364,256	-930,256	0,079	13506,40	18438,29
Poltava region	2556,00	2385,164	170,836	1,811	0,05	61,83
Rivne region	12873,00	12278,627	594,373	0,103	10257,51	15373,93
Sumy region	4973,00	4419,829	553,171	0,166	3121,10	5979,22
Ternopil region	13977,00	13152,305	824,695	0,0914	11786,20	16866,53
Kharkiv region	19948,00	18027,606	1920,394	0,067	16970,87	22068,39

Kherson region	1259,00	4226,013	-2967,013	0,154	3157,32	5780,38
Khmelnytsky region	6700,00	6353,709	346,290	0,094	5299,36	7683,34
Cherkasy region	4476,00	2896,943	1579,057	0,249	1821,63	4853,29
Chernivtsi region	14754,00	10212,047	4541,953	0,089	11437,70	16244,63
Chernihiv region	4409,00	4587,556	-178,557	0,140	2969,99	5158,87
Kyiv	24317,00	24305,009	11,990	0,053	21888,35	27019,40

**Symbols*: Response – Value – empirical values; Pred. – Value – theoretical values; Residual – residuals; St. – Error – standard error; Lower CL,Upper CL – predicted values with a 95% confidence interval.

Source: own calculation

We compare the frequency histograms for theoretical and empirical values of the number of people infected with COVID-19 (Fig. 1, 2). According to calculations, there is an equal relative frequency at levels from 0 to 10,000 and from 20,000 to 25,000 patients. There is a distortion per unit between the data of 10-15 thousand and 15-20 thousand diseases, but this deviation is insignificant.

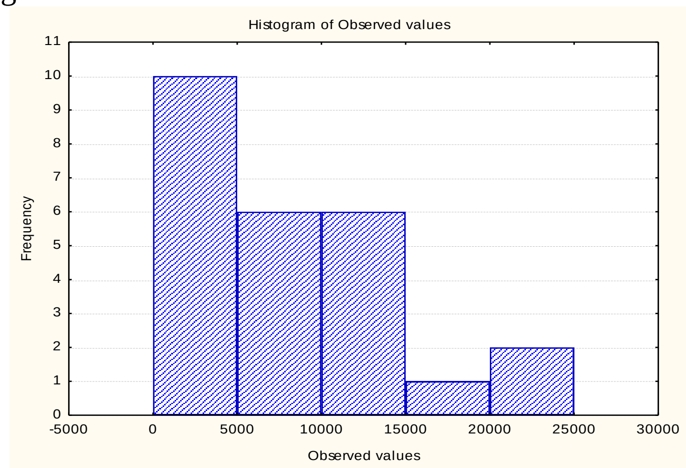

Figure 1. The relative frequency of empirical values for the number of infected with COVID-19
Source: own compilation

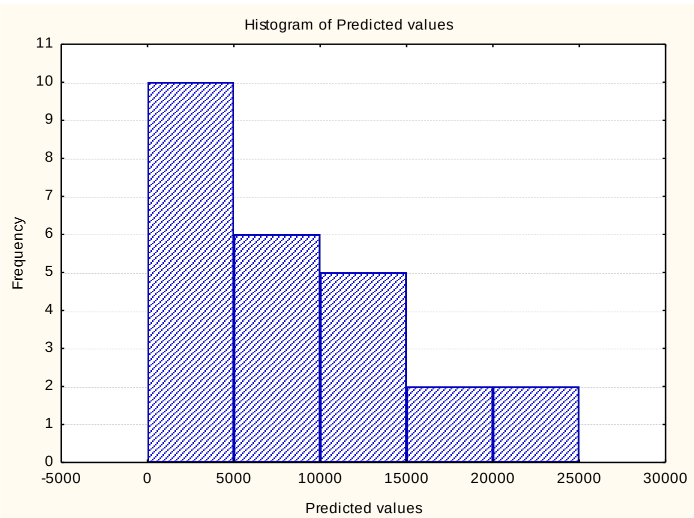

Figure 2. The relative frequency of theoretical values for the number of infected COVID-19
Source: own compilation

We check the presence or absence of autocorrelation, i.e. the relationship between random deviations and residual values in other observations. We apply Darbin-Watson test to check (10):

$$DW = \frac{\sum (e_i - e_{i-1})^2}{\sum e_i^2} \quad (10)$$

where DW – Durbin-Watson test, $e_i -$ the difference between theoretical and empirical level of i – observation. Having performed calculations, we receive DW=1,89. Critical values of this criterion for the significance level are α=0,05, n=25, m=7: $d_1 = 0{,}94,\ d_2 = 1{,}9.$
The obtained result is outside the critical values. It means that there is a little autocorrelation of the residuals. Given this, the model is spatial, and we can ignore this fact.

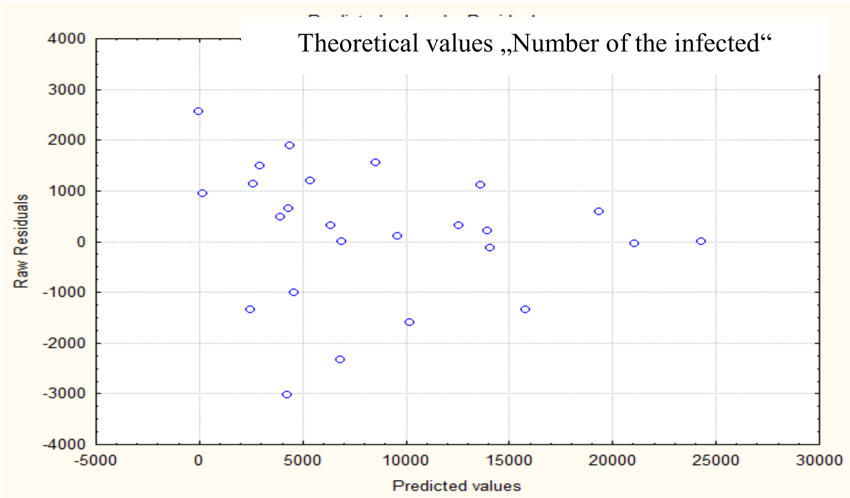

Figure 3. Residual graph (difference between empirical and theoretical values in the constructed model of the morbidity and mortality dependence on COVID-19 and on socio-ecological and economic factors
Source: own compilation

We analyze the graphs of the dependence of residuals e on the variables included in the final model (Fig. 3.) to define the presence or absence of heteroskedasticity.

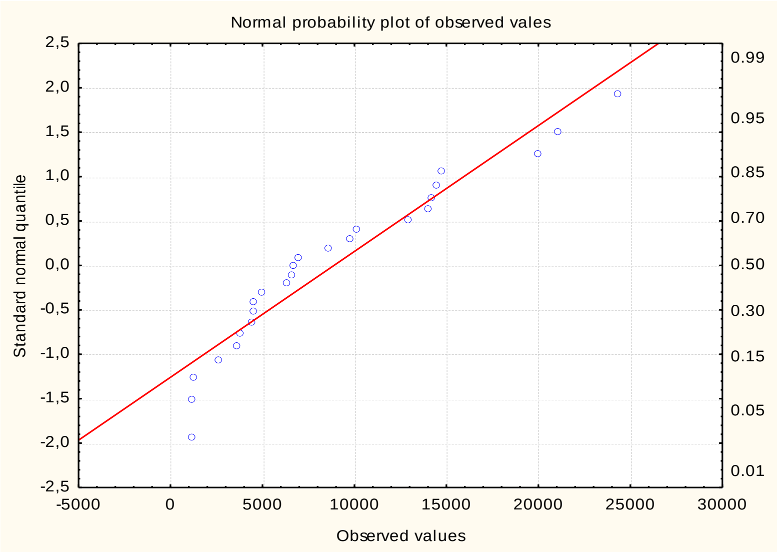

Figure 4. Normal probability plot
Source: own compilation

Figure 4 shows a normal probability plot, enabling to understand whether the studied values are normally distributed or not. First, all values are sorted from the smallest to the largest value, then the value of the z-test is calculated for each rank.

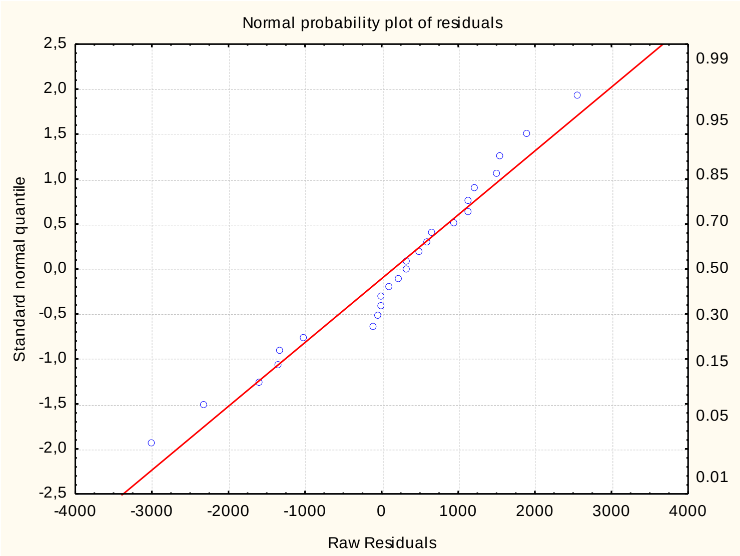

Figure 5. Normal residuals plot
Source: own compilation

In the case of a normal distribution, the obtained points should fall on a straight line. If there is a deviation from the straight line, the value is not normally distributed. In our case, there is a significant deviation from the line, indicating the lack of normal distribution in the studied data, which can distort the results.

Figure 5 shows a typical residual plot of the constructed model, which indicates that the residuals are distributed normally compared to the standard input data, although there are some emissions. Therefore, the model results are distributed closer to the normal distribution, and given the close relationship between empirical and theoretical values, the results can be used for further research.

Using a similar method of detecting multicollinearity among the studied factors by formulas (1) - (10) and applying the method of gradual inclusion of variables, we obtain the following final arguments for the regressor "Number of confirmed deaths from COVID-19 (z)":

$$z = -6{,}51b_1 - 3{,}11b_2 - 0{,}005b_3 + 0{,}029b_5 + 1{,}18b_6 + 0{,}008b_7 - 1255{,}9, \quad (11)$$

where b_1 – registered unemployment on average for the period, thousand people; b_2 - volumes of working time use and part-time employment per one full-time employee, h; b_3 - volumes of carbon dioxide emissions into the atmosphere, thousand tons; b_4 - volumes of waste accumulated during operation, in specially designated places and facilities, thousand tons; b_5 - volumes of stocks of light oil products and gas at gas stations, motor gasoline, t; b_6 - the number of lung ventilators; b_7 - the number of registered endocrine system diseases, eating disorders, metabolic disorders.

The quality description of the model shows a sufficient quality of fitting the model to the studied variables; all values of t-statistics are greater than critical. Such factors as light oil products and gas stocks, the number of migratory lung ventilators and carbon emissions positively correlate with the number of fatalities, the rest - harmful. Similar to the previous study, we will carry out an additional check for the presence or absence of a relationship between two sets: the values of the dependent variable: number of confirmed deaths from COVID-19 and the set of values that were included in the model (11), we use canonical analysis and univariate tests of significance, effect sizes, and powers for sigma-restricted parameterization. The results of canonical analysis (table 4) confirmed the presence of relationship between the explained variable and the independent ones because the indicator total redundancy is 79% at the p-value equal 0,000086 that means: the variation of the number of confirmed cases of coronavirus by 79% is explained by exactly 7 considered repressor's. Also, the value of the actual chi-square (30,24) significantly exceeds the critical value (13,85), which confirms the presence of a close relationship of factors $b_i, i = 1..7$, which were included in the model (11) and the number of confirmed deaths from COVID -19. The analyses of sigma-restricted parameterization also provided confirmation of the significance of the input data: the R square value for the indicators (the number of registered endocrine system diseases, eating disorders, metabolic disorders, the number of lung ventilators, volumes of stocks of light oil products and gas at gas stations, motor gasoline) is over 0,608, indicating that these data describe the model satisfactorily. For indicators: registered unemployment on average for the period, volumes of waste accumulated during operation, in specially designated places and facilities R square is in the range of 0,43-0,49, but with an average p-value of 0,05, which is also confirms the significance of these factors for the dependent variable number of confirmed deaths from COVID.

Table 8. The most significant variables

	Beta*	Std.Err. - of Beta*	B*	Std.Err. - of B*	t(17)*	p-level*
Free member of the regression	-	-	1255,9	1018,5	1,2330	0,2343
The endocrine system diseases, eating disorders	0,3815	0,1784	0,008	0,004	2,1384	0,0472
Registered unemployment on average over the period	-0,2779	0,1587	-6,514	3,721	-1,7506	0,0980
Number of lung ventilators	0,3412	0,1852	1,176	0,638	1,8416	0,0830
Emissions of carbon dioxide into the atmosphere by regions, thousand tons	-0,2373	0,1646	-0,005	0,004	-1,4413	0,1676
Volume of accumulated waste, thousand tons	-0,3182	0,1715	-0,000	0,000	-1,8555	0,0809

Stocks of light oil products and gas (motor gasoline) - total, tons	0,3764	0,2177	0,029	0,017	1,7283	0,1020
Use of working time and part-time work, hours	-0,1969	0,1566	-3,109	2,473	-1,2572	0,2256
R= 0,84319133 R^2= 0,71097162 Adjusted R^2= 0,59195994 F(7,17)=5,9740 p						

**Symbols*: Beta Std.Err. - of Beta - standardized regression coefficient and its standardized error; B / Std.Err. - of B - non-standardized regression coefficient and its standardized error; t (17) - t - statistics with the number of freedom degrees 17; p-level - the significance level of the coefficient; Multiple - R - multiple correlation coefficient; Multiple - R-square - determination coefficient; Adjusted R-square is a determination coefficient adjusted for the number of freedom degrees.
Source: own calculation

The adjusted correlation coefficient in Table 8 indicates an average relationship between predicates and the dependent variable with the number of indices n = 7. So we will construct a multiple quadratic regression:

$$z = 4{,}3 \cdot 10^{-1} b_1^2 - 22{,}7 b_1 - 1{,}5 b_2^2 + 10{,}5 b_2 - 7{,}2 \cdot 10^{-8} \cdot b_3^2 - 4{,}5 \cdot 10^{-3} b_3 - 8{,}4 \cdot 10^{-12} b_4^2 + 3{,}2 \cdot 10^{-5} b_4 + 1{,}3 \cdot 10^{-5} b_5^2 - 8{,}6 \cdot 10^{-2} b_5 + 8{,}4 \cdot 10^{-3} b_6^2 - 8{,}8 \cdot 10^{-1} b_6 - 2{,}2 \cdot 10^{-7} b_7^2 + 1{,}9 \cdot 10^{-2} b_7 + 1453{,}4$$

$$R^2 = 0{,}91 \qquad (12)$$

$F_{em} = 3{,}5$, $F_{tab}(0{,}05; 7; 17) = 2{,}6$.

$DW = 1{,}89$, the Darbin-Watson test indicates a little autocorrelation of the residuals. The heteroskedasticity hypothesis in the model is rejected using the Spearman test.

We compare the frequency histograms of theoretical and empirical values of the confirmed deaths from COVID-19 (Fig. 6, 7).

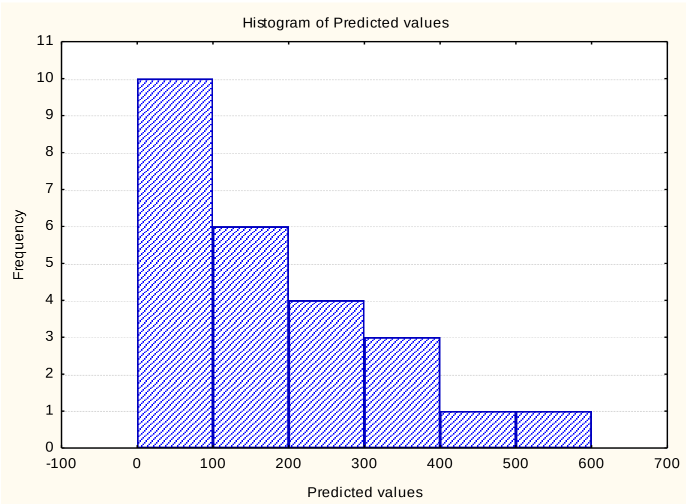

Figure 6. The relative frequency of theoretical values of deaths number from COVID-19
Source: own compilation

Thus, Figure 6 shows that the relative frequency is completely the same for regions with low (0-100 cases) and high mortality levels (400-600). There is a distortion between the data of 100-400, probably caused by the fact that there is a strong differentiation of regions by this index, and the real data are not normally distributed.

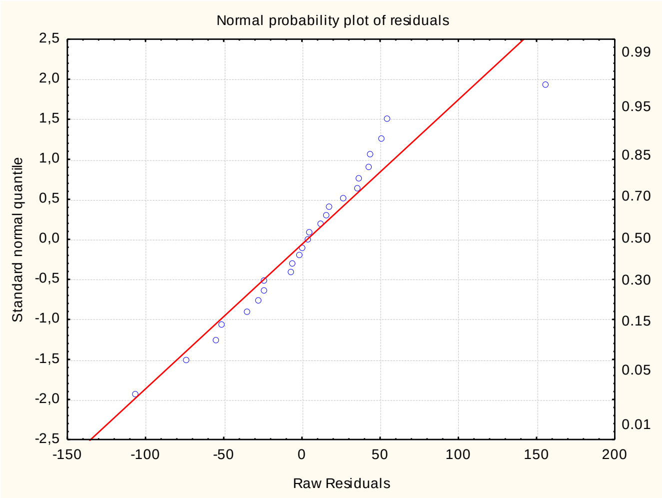

Figure 7. The relative frequency of empirical values of the deaths number from COVID-19

Source: own compilation

Table 9 shows data to compare theoretical and empirical data (Response - Value and Pred. - Value) regarding the number of confirmed deaths from COVID-19 and standardized residuals, according to which anomalous emissions from the model exist in such regions as Zakarpattia, Zaporizhia, Kyiv, Luhansk, Ternopil and Chernivtsi regions.

Table 9. Results of the quadratic regression model for the regressor: the number of deaths from COVID-19 for the Ukrainian regions

	General.-Cook's D*	Std. P. – Residual*	Response-Value*	Pred.-Value*
Vinnytsia region	14,6488	-1,40910	119,0000	143,5070
Volyn region	1,0228	1,12938	174,0000	131,6462
Dnepropetrovsk region	-	-	125,0000	124,8751
Donetsk region	0,0059	1,09029	56,0000	1,2501
Zhytomyr region	0,0778	0,76840	113,0000	76,6410
Zakarpattia region	178,7785	-3,75447	310,0000	361,0941
Zaporizhya region	51,6454	-2,91926	70,0000	125,3062
Ivano-Frankivsk region	280,3286	2,44252	331,0000	313,2507
Kyiv region	53,4271	-2,29869	199,0000	233,7146
Kirovograd region	0,0975	0,76727	60,0000	24,2238
Luhansk region	54,0827	-4,24808	16,0000	122,9651
Lviv region	405,1779	2,46430	573,0000	557,9254
Mykolayivska region	0,0020	0,10890	82,0000	76,9289
Odessa region	92,5583	-2,32771	217,0000	244,5553
Poltava region	27,5533	-0,88502	44,0000	51,4070
Rivne region	1,5573	1,37297	171,0000	119,8544
Sumy region	0,0149	-0,15871	77,0000	83,3311
Ternopil region	80,9138	-3,79654	171,0000	245,3152
Kharkiv region	103,7452	2,34406	364,0000	337,5360
Kherson region	0,0351	-0,51621	26,0000	50,4264
Khmelnytsky region	1,2473	1,18541	131,0000	87,5664
Cherkasy region	0,0002	-0,02935	59,0000	60,3308
Chernivtsi region	12,8129	4,09810	365,0000	209,6272
Chernihiv region	0,0086	0,25258	77,0000	65,0638
Kyiv	55,6128	0,73019	413,0000	409,4180

**Symbol*: General. - Cook's D – Cook‘s distance; Response – Value – empirical values; Pred. – Value – theoretical values; Residual – residuals; St. – Error – standard error.
Source: own calculation

A quadratic function is used to build the regression model. There are critical values at which the regression will take extreme values. Then, we find the critical values of the function for each variable (using a differential calculus) and critical minimum and maximum points.

The optimal values of each parameter have been found, at which either the greatest or the smallest influence on the dependent variable is achieved, using the differentiation function of many variables (7).

Conclusion

Thus, the determination of critical values for the defined models allow forming the optimal variables for the number of confirmed cases of death and mortality from COVID-19.

We obtained a corresponding result for the index characterizing the COVID-19 incidence, using the above technique.

1. The number of interstate migrants: $a^*_{1,min}$ =1782,4 peple; input data range from -979 to 854.

2. Volumes of carbon dioxide emissions into the atmosphere $a_{2,min}{}^* = 16998{,}8$ thousand t; input data range from 142 to 23528.

3. The amount of waste accumulated during operation, $a_{3,min}{}^{*} = 174374{,}3$ thousand t; input data range from 578 to 10689892.

4. The number of medical care contracts under the medical guarantees program $a_{5,min}{}^{*} = 214{,}9$; input data range from 121 to 503.

5. Number of beds in infectious diseases departments $a_{6,max}{}^{*}$ =949260,1 pcs.; input data range from 198 to 1964.

6. Number of specialized doctors (infectologists, therapists, pediatricians) $a_{7,min}{}^{*}$ =644,7 people; input data range from 89 to 397.

We will obtain the following result for the index characterizing mortality from COVID-19:

1. The level of registered unemployment, $b_{1,min}^{*} = 25{,}9$ thousand t; input data range from 5,5 to 27,7.

2. Volumes of working time per full-time employee, $b_{2,max}^{*} = 347{,}6\ hours$; input data range from 403 to 435.

3. Volumes of carbon dioxide emissions into the atmosphere $b_{3,max}^{*} = 31341{,}2$ thousand t; input data range from 142,3 to 23528,1.

4. Volumes of waste accumulated during operation $b_{4,max}^{*}$ =1897111 thousand t; input data range from 578,9 to 10689892,0.

5. Stocks of light oil products and gas at gas stations $b_{5,min}^{*} = 3249{,}3$ t; input data range from 1545,15 to 9605,0.

6. Number of artificial lung ventilators $b_{6,min}^{*} = 52$; input data range from 32 to 193.

7. The number of registered endocrine system diseases, eating disorders, metabolic disorders $b_{7,max}^{*} = 41711{,}5$; input data range from 4353 to 32634.

Evaluation of relevant socio-environmental and economic indices regarding their impact on the mortality rate from COVID-19 confirms the hypotheses regarding the effect of registered unemployment, working hours per employee, carbon dioxide emissions, the amount of registered endocrine system diseases, eating disorders, metabolic disorders for mortality from COVID-19, formed at the beginning of the study.

The study of the impact made by relevant socio-ecological and economic indices on the COVID-19 incidence confirms the hypotheses on the effect of the following indices: the number of interstate migrants, carbon dioxide emissions into the atmosphere, the amount of waste accumulated during operation.

The obtained results will allow making appropriate adjustments in advance to the state and regional programs for mobilization of the economy and the medical system, to carry out reactive and preventive control of the pandemic consequences.

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