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O.S. Chaban [1],
O.O. Khaustova [1],
V.O. Omelyanovich [1],
O.O. Sukhoviy [2]

STATISTICAL MODEL OF SEASONAL FORECASTING THE COMPLETED SUICIDES NUMBER IN THE REGIONS OF UKRAINE

Bogomolets National Medical University [1]
T. Shevchenko boul., 13, Kyiv, 01601, Ukraine
SI "Institute of Psychiatry, Forensic Psychiatric Examination and Drug Monitoring of the Ministry of Health of Ukraine" [2]
Kyrylivska str., 103, Kyiv, 04080, Ukraine
Національний медичний університет імені О.О. Богомольця [1]
бул. Т. Шевченка, 13, Київ, 01601, Україна
ДУ «Інститут психіатрії, судово-психіатричної експертизи та моніторингу наркотиків» Міністерства охорони здоров'я України [2]
вул. Кирилівська, 103, Київ, 04080, Україна
e-mail: andy.sh2014@gmail.com

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Ключові слова: *самоушкодження, завершені суїциди/запобігання та контроль, завершені суїциди/статистика та числові дані, сезонність, смертність, прогностична модель*

Abstract. Statistical model of seasonal forecasting the completed suicides number in the regions of Ukraine. Chaban O.S., Khaustova O.O., Omelyanovich V.O., Sukhoviy O.O. *Suicide prevention efforts require conscious coordination and close collaboration between health agencies. They should be based on an understanding of the true picture of the prevalence of this phenomenon in a particular area, the characteristics of the dynamics of changes in the frequency of suicides, and high-risk factors, namely age, gender, climatic and social components. The purpose of this study was an attempt to create for each region of Ukraine a statistical model of the dynamics of the frequency of completed suicides depending on the time component (months of the year) and to build on its basis a forecast of the dynamics of the indicator of the number of deaths due to intentional self-harm. For this, the autocorrelation of absolute indicators was carried out and correlograms of time series of indicators of the deaths' number due to intentional self-harm were constructed. The obtained correlograms had sufficiently pronounced features, which made it possible to structure them into 4 separate groups. For further analysis, we used the time series of the areas that made up the first two groups, characterized by a trend and seasonality. For further analysis, only models of exponential smoothing of the time series of areas were used, whose indicators of Ljung-Box Q-statistics, coefficient of determination, mean modulus of error, and smoothing of the mean were in an acceptable range. Based on the created time series model, it is possible to assume that the period from August 2021 to September 2022, will increase in the absolute indicator of the number of deaths due to intentional self-harm in the spring months and, for most regions, in January. For the autumn period, on the contrary, a decrease in the number of completed suicides is characteristic. the characteristics of the time series models for a whole group of regions did not allow us to use them to build a forecast. These regions are represented by two different geographical groups – a group of regions of Western Ukraine and three Black Sea regions. Created for each region of Ukraine, a statistical model of the frequency dynamics of the completed suicides depending on the time component (months of the year) made it possible to build an annual forecast for the number of deaths dynamics due to intentional self-harm. Longer-term forecasts are possible by analyzing more data.*

Реферат. Статистична модель прогнозу сезонної кількості завершених суїцидів у регіонах України. Чабан О.С., Хаустова О.О., Омелянович В.Ю., Суховій О.О. *Зусилля щодо запобігання самогубствам вимагають усвідомленої координації та тісної співпраці закладів охорони здоров'я та повинні базуватися на розумінні істинної картини поширеності цього явища в конкретній місцевості, особливостей динаміки зміни частоти самогубств, факторів підвищеного ризику, а саме віку, гендерної приналежності, кліматичних і соціальних складових. Метою роботи було створення для кожного регіону України статистичної моделі динаміки частоти вчинення завершених суїцидів залежно від часової складової (місяці року) та побудови на її основі прогнозу динаміки показника кількості смертей унаслідок умисних самоушкоджень. Було здійснено автокореляцію абсолютних показників та побудовано корелограми часових рядів показників кількості смертей внаслідок умисних самоушкоджень. Отримані корелограми мали досить виражені особливості, що дозволило структурувати їх у 4 окремі групи. Для подальшого аналізу використовувалися часові ряди областей, які склали*

перші дві групи, що характеризуються трендом та сезонністю. Для подальшого аналізу використовувалися лише моделі експоненційного згладжування часових рядів областей, чиї показники Q-статистики Льюнга-Бокса, коефіцієнта детермінації, середнього модуля помилки та згладжування середнього перебували в прийнятному діапазоні. Виходячи зі створеної моделі часових рядів, можна припускати, що в період із серпня 2021 р. до вересня 2022 р. можливе зростання абсолютного показника кількості смертей внаслідок навмисних самоушкоджень у весняні місяці і, для більшості областей, у січні. Для осіннього періоду, навпаки, характерним є зниження кількості завершених суїцидів. Характеристики моделей часових рядів групи регіонів не дозволили нам використовувати їх для побудови прогнозу: група областей Західної України та три причорноморські області. Створена для кожного регіону України статистична модель динаміки частоти вчинення завершених суїцидів залежно від часової складової (місяць року) дозволила побудувати річний прогноз динаміки показника кількості смертей внаслідок умисних самоушкоджень. Більш довгострокові прогнози можливі під час аналізу більшої кількості даних.

According to the latest data of the World Health Organization (WHO) [1], more than 700,000 people die every year due to suicide, and suicide is the fourth leading cause of death for people aged 15 to 29 worldwide. Significantly, 77% of the world's suicides occur in low- and middle-income countries. It should be noted that in the countries that gained independence after the collapse of the Soviet Union, this problem has been highly acute in the last quarter of a century. Thus, in Ukraine, the death rate due to completed suicides averaged (per 100,000 population) – 21.2; in the Russian Federation – 21.4; Latvia – 22.9; in the Republic of Belarus – 25.3, Kazakhstan – 30.0, and Lithuania – reached 31.5 [2, 3].

The mortality level due to suicide varies significantly in different regions of these countries, ages, and social groups of the population. Thus, an analysis of adolescent suicides committed in the Russian Federation from 1991 to 2018, conducted by Vorsina O.P. [4], points to the predominance of the suicides number of rural residents over urban ones by 1.1-9 times.

The seasonality of the increase in the rate of completed suicides in the spring-summer period has been established [5-14], although in different countries these may be different months: in Ukraine, the peak number of suicides occurs in March, August, September [6], in Spain – in February [7]], in Turkey – – June-August [8], and in South Korea – April and October [10].

Thus, in different countries, the months with the maximum death rate due to completed suicides do not always coincide.

Based on a comparison of the dynamics of the number of completed suicides in the north of Europe and the south of Ukraine, it is suggested that the factor influencing the dynamics of suicides is not so much the temperature itself in the region, but the magnitude and sign of its change during the year, which ultimately leads to its preemption or one month late [11].

Efforts to prevent suicide require conscious coordination and close cooperation of health care institutions [14], and, no doubt, should be based on an understanding of the accurate picture of the prevalence of this phenomenon in a particular area, the characteristics of the dynamics of changes in the frequency of suicide, increased risk factors, such as age, gender, climatic and social components.

Based on the foregoing, the purpose of our study was an attempt to create a statistical model of the dynamics of the frequency of completed suicides depending on the time component (months of the year) and building on its basis a forecast of the dynamics of the indicator of the number of deaths due to intentional self-harm (X60-X84) for each region of Ukraine and for the country as a whole within the following year.

MATERIALS AND METHODS OF RESEARCH

The material of the study was the absolute indicators of the number of deaths due to intentional self-harm (codes X60-X84 of the International Classification of Diseases, 10th revision [15]) for Ukraine as a whole and each of its regions separately, monthly, over the period from January 2005 to August 2021. The data were available due to their placement with free access on the official electronic resource of the State Statistics Service of Ukraine [16] (except the Autonomous Republic of Crimea, Donetsk and Luhansk regions, where there are no objective data on mortality). The specified data array was further used in the form of dynamic time series created for each separate region of Ukraine and separately for national data.

To identify the periodicity in the dynamics of the number of completed suicides, an autocorrelation analysis was carried out with the calculation of the Ljung-Box statistics [17, 18] and correlograms were constructed for each region of Ukraine. The number of lags was calculated by the formula: $k \leq n/4$, where k is the maximum number of lags, n is the number of observations [19], and amounted to 50 lags for each time series.

The creation of an adaptive seasonal time series model for each region of Ukraine and the construction of a forecast for a year on its basis was carried out using the method of seasonal exposure smoothing with a seasonal component of "12" [18, 19]. The creation of the model and all calculations were carried out using the software "IBM SPSS Statistics 23".

RESULTS AND DISCUSSION

To study the features of the suicidal activity dynamics and identify possible trends in dynamic characteristics, we carried out autocorrelation of absolute indicators and built correlograms of time series of the number of deaths due to intentional self-harm (codes X60 - X84 class XX ICD-10 [15]) in Ukraine as a whole and in each region of the country. According to the results of the autocorrelation, the standard deviation of the sampling distribution of statistics (standard error) was in the range of $0.71 \geq sx \geq 0.61$ for all areas. The significance level of Ljung-Box Q-statistics was quite high for all lags in Ukraine as a whole ($p \leq 3E\text{-}25$) and for each region ($p \leq 0.013$). The only exception was the significance level for some lags of three regions – Ternopil (for 1, 2, 3, and 4 lags $p \geq 0.16$), Chernivtsi (for 1, 2, 3, 4, 13, 14, 15, 16 and 17 lags $p \geq 0.0.51$) and Volyn (for lag 4 $p=0.0.53$), while for the rest of the lags of these regions this indicator was less than 0.04.

Based on the described features of the Ljung-Box Q-statistics, it seems possible to assert that the residual errors of all lags (except the noted lags of the Ternopil, Chernivtsi, and Volyn regions) should be regarded as non-random, indicating the presence in the time series of some structure that goes beyond the boundaries of the calculated models.

Obtaining 16 correlograms based on the conducted autocorrelation analysis requires sufficiently pronounced features that their structural connection in 4 separate groups. Because of the limited scope of a significant publication, we take advantage of the exercise of its graphical ability, confining ourselves to a description of the correlogram.

Correlograms of Ukraine (as a whole), as well as most of the regions (Vinnytsia, Dnepropetrovsk, Zhytomyr, Zaporizhzhia, Ivano-Frankivsk, Kyiv, Kherson, Khmelnytsky, Cherkasy, Kirovograd, Mykolaiv, Odesa and Poltava regions), constitute the first group. These correlograms were characterized by pronounced seasonality and positive correlation in settings from 1 to 3-4 lags, from 8-9 to 14-15 lags, from 21-22 to 27-28 lags, from 33-34 to 38-39 lags, from 46 -47 to 50 lags, as well as a negative correlation from 4-5 to 7-8 lags, from 15-16 to 20-21 lags, from 28-29 to 32-33 lags and from 39-40 to 45-46 lags. Increasing values of large correlation coefficients of the graphs and falling outside the confidence interval, the structural-autocorrelation function of the content of pronounced seasonal periodicity, which tends to a sinusoid, with an increase throughout 5-7 lags, followed by a decrease in a decrease at a frequency of the same number of lags, after which the cycle repeated.

Thus, the features identified for the regions that made up the first group make it possible to assert that the dynamics of changes in the completed suicides number of their residents have a clear seasonality, which can lead to an overestimation of the true correlation coefficients.

The second group consisted of correlograms of the Sumy, Kharkiv, and Chernihiv regions, which had a completely different look. Although on them, as well as on the correlograms of the first group, one can notice the presence of a trend and seasonality (with a gradual decrease from 1 to 6-7 lags, followed by an increase from 7-8 lags to 12-13 lags and further similar cyclical ups and downs for each 6-7 lags), they, unlike the first group, presented exclusively positive correlations (except five lags of the Chernihiv region correlogram).

In the third group, we assigned the correlograms of five regions: Rivne, Transcarpathia, Volyn, Ternopil, and Chernivtsi: most of the correlogram lags of this group were outside the confidence interval; the frequency of rises and falls of lags, although grouped in the range from 5 to 7 lags, did not have the sinusoidal pattern that was inherent in the correlograms of the first and second groups. Thus, in these regions, there is no trend and/or seasonal periodicity of indicators of completed suicides.

The fourth group contained only two regions correlograms – Kyiv city and Lviv region, which, unlike all three groups of correlograms considered above, were characterized by the presence of a linear trend with occasional increases in lag indicators. At the same time, the Kyiv city correlogram contained exclusively positive correlations and the Lviv region correlogram contained chaotic increases and decreases in lag indicators with episodic negative correlations. Thus, for Kyiv city and the Lviv region, it seems possible to assert the presence of a trend, combined with the complete absence of seasonal periodicity in the number of completed suicides.

Based on the features of the autocorrelation analysis described above, the indicators of Ljung-Box Q-statistics and the obtained correlograms, to create a real-time series of the dynamics of indicators, the number of deaths due to intentional self-harm, her modeling, assessing the probability of the reliability of the model and building a model of its changes in the future, we the exposure smoothing method was used (Table 1).

As a result of calculating the stationary R^2, it was found that the share of the total variation in the series, explained by the created model, is sufficient for all regions and for Ukraine as a whole, and the model can be assessed as consistent (stationary $R^2 \geq 0.656$).

Consideration of the coefficient of determination for Ukraine as a whole ($R^2=0.849$) also leads to the

conclusion about the consistency and quality of the created model, which explains well the variations in the time series. For most regions, the coefficient of determination can also be regarded as sufficient ($R^2 \geq 0.509$, for several regions, this indicator can be regarded as quite low, but acceptable ($R^2 \geq 0.388$), and for a certain group of regions, the coefficient of determination was unsatisfactory ($R^2 < 0.388$).

Table 1

Statistical model of time series exponential smoothing of the deaths number absolute indicators due to deliberate self-harm in 2005-2021

Model	Regression Model Fit Statistics			Q-statistics Ljung–Box	
Region	Stationary R^2	R^2	MAE*	Q	p
Ukraine	0.65608	0.84898	3.72111	40.4197	0.00068
Vinnytsia region	0.76602	0.46379	4.98963	24.759	0.07141
Volyn region	0.78258	0.22275	3.19973	15.7582	0.46996
Dnipropetrovsk region	0.73632	0.54903	7.43921	18.3763	0.30232
Zhytomyr region	0.74297	0.53115	4.17039	17.8588	0.33223
Transcarpathian region	0.71919	0.35400	2.97997	16.1740	0.44088
Zaporizhzhia region	0.72894	0.55385	4.90253	15.9184	0.45867
Ivano-Frankivsk region	0.73024	0.30917	2.89583	23.3977	0.10351
Kyiv region	0.73882	0.46597	4.84249	22.7604	0.12029
Kirovohrad region	0.75000	0.53319	4.05573	24.7168	0.07149
Lviv region	0.73852	0.21214	3.39215	22.0064	0.14298
Mykolaiv region	0.76319	0.37539	4.00325	16.7340	0.40301
Odesa region	0.75899	0.59652	5.87936	31.4713	0.01171
Poltava region	0.76538	0.61608	4.66359	21.5786	0.15733
Rivne region	0.70279	0.21278	2.98923	24.9626	0.07104
Sumy region	0.69914	0.70900	4.35392	20.9703	0.17966
Ternopil region	0.76569	0.16798	2.4804	27.4024	0.03722
Kharkov region	0.76172	0.66488	4.74861	23.6836	0.09665
Kherson region	0.69859	0.38835	4.63491	37.1682	0.00199
Khmelnytskyi region	0.76413	0.40496	3.87889	14.1407	0.58823
Cherkasy region	0.76464	0.50849	4.30481	19.7542	0.23149
Chernivtsi region	0.75362	0.16978	2.38717	20.07198	0.21665
Chernihiv region	0.69625	0.69039	4.44126	23.6932	0.09642
Kyiv city	0.67978	0.44188	2.74754	10.2806	0.85157

Note: * MAE – Mean Absolute Error.

Also, special attention is drawn to the fact that the coefficient of determination was extremely low precisely for the indicators of those areas whose correlograms did not contain either a trend or a

seasonal periodicity, and was assigned by us to the third and fourth groups (except the city of Kyiv), whereas all areas whose correlograms made up the second group had the highest indicators of the coefficient of determination ($R^2 \geq 0.665$).

The average error modulus of the values predicted by the model ranged from 2.38717 (for the Chernivtsi region) to 7.43921 (for the Dnipropetrovsk region), and for Ukraine as a whole, it was 3.72111. However, the indicators of the Leung-Box Q-statistics for Ukraine as a whole, as well as for the Odesa, Ternopil, and Kherson regions, the level of significance does not allow to consider the errors as random ($p \leq 0.03722$), indicating that in the time series of these regions, there is a structure not described by our model. Exponential smoothing models for all other regions can be considered acceptable ($p \geq 0.07104$).

When considering the model of exponential smoothing of time series (Table 2), it was established that the average smoothing parameters for time series models of most regions tend to the value of 0.1, and for Ukraine as a whole, Sumy, Kharkiv, Chernihiv regions and Kyiv city, this indicator was still above and was $\alpha = 0.1996 \pm 0.0001$; $p \leq 0.00005$. The indicator of seasonal smoothing for all regions did not exceed $\Delta \leq 0.0001$, with a standard error of $sx \leq 0.04996$.

Table 2

Model parameters of the time series exponential smoothing of the deaths number absolute indicators due to deliberate self-harm in 2005-2021

Model / Region	Model evaluation		sx***		τ****		p	
	α*	Δ**	α	Δ	α	Δ	α	Δ
Ukraine	0.1995	2.85E-05	0.0460	0.0298	4.3347	0.00095	2.3E-05	0.9992
Vinnytsia region	0.0998	4.01E-06	0.036	0.0495	2.7124	8.1E-05	0.00727	0.9999
Volyn region	0.0996	1.11E-05	0.0390	0.0454	2.5497	0.00024	0.01154	0.9998
Dnipropetrovsk region	0.0998	1.53E-05	0.0336	0.0442	2.9686	0.00035	0.00336	0.9997
Zhytomyr region	0.0997	8.54E-05	0.035	0.0414	2.851	0.00206	0.00482	0.9983
Transcarpathian region	0.0998	4.26E-07	0.0376	0.0522	2.6506	8.2E-06	0.00868	0.9999
Zaporizhzhia region	0.0999	2.64E-05	0.0324	0.0418	3.0793	0.00063	0.00237	0.9995
Ivano-Frankivsk region	0.1001	1.33E-05	0.0310	0.0481	3.2246	0.00028	0.00148	0.9997
Kyiv region	0.0999	3.2E-05	0.0304	0.0450	3.2802	0.00071	0.00123	0.9994
Kirovohrad region	0.0997	3.49E-05	0.0358	0.0389	2.7806	0.0009	0.00595	0.9992
Lviv region	0.0994	6.36E-05	0.0401	0.0380	2.4826	0.00167	0.01387	0.9986
Mykolaiv region	0.0987	2.92E-05	0.0439	0.03	2.2457	0.00097	0.02583	0.9992
Odesa region	0.0997	1.76E-05	0.0358	0.0365	2.7802	0.00048	0.00596	0.9996
Poltava region	0.0999	1.94E-05	0.0318	0.0405	3.1407	0.00048	0.00194	0.9996
Rivne region	0.0997	2.76E-05	0.0355	0.0363	2.8064	0.00076	0.00551	0.9994
Sumy region	0.1995	9.62E-06	0.0464	0.0299	4.2987	0.00032	2.7E-05	0.9997
Ternopil region	0.0996	1.89E-05	0.0441	0.0553	2.2601	0.00034	0.0249	0.9997
Kharkov region	0.1996	0.000121	0.0462	0.0357	4.3210	0.0034	2.5E-05	0.9972
Kherson region	0.0996	2.79E-06	0.038	0.0386	2.6193	7.2E-05	0.00949	0.9999
Khmelnitsky region	0.0995	2.23E-05	0.0415	0.0447	2.3985	0.0005	0.01739	0.9996
Cherkasy region	0.0997	4.58E-07	0.0389	0.0474	2.5609	9.6E-06	0.01118	0.9999
Chernivtsi region	0.0996	1.72E-05	0.0439	0.0499	2.2639	0.00034	0.02466	0.9997
Chernihiv region	0.1995	2.75E-06	0.0462	0.0312	4.3154	8.8E-05	2.5E-05	0.9999
Kyiv city	0.1997	1.34E-05	0.0479	0.0374	4.1642	0.00036	4.7E-05	0.9997

Notes: * α – average decay rate; ** Δ – seasonal adjustment indicator; *** sx – standard error; **** τ – exponential moving average constant.

Thus, summing up the conducted analysis, we can state that for further consideration of the fluctuating dynamics of the deaths number absolute indicator due to intentional self-harm and consideration of the forecast for the period from September 2021 to August 2022, we can only consider models built for time series, the model of which included the data of the regions assigned by us to the first and second groups of correlograms, and not all, but only twelve of them: Sumy, Kharkiv, Chernihiv, Vinnytsia, Dnipropetrovsk, Zhytomyr, Zaporizhzhia, Kyiv, Khmelnytskyi, Cherkasy, Kirovohrad, and Poltava regions (Fig. 1, 2).

For all regions during the autumn months, from September to November, a decrease in the number of completed suicides is expected (except for the Vinnytsia region, in which an increase in this indicator is possible in October). The downward trend in the number of completed suicides in Zhytomyr, Kyiv, Zaporizhzhia, Kirovohrad, Sumy, and Cherkasy regions will continue until January 2022. In these regions, as well as in Vinnytsia and Dnipropetrovsk regions, an increase in the number of completed suicides is expected in January 2022, followed by a decline in February, while in Kharkiv and Poltava regions, a decrease in the indicator is predicted until March 2022. In addition, in December 2021, a slight increase in the number of deaths due to intentional self-harm is expected in Dnipropetrovsk, Khmelnytskyi, and Chernihiv regions.

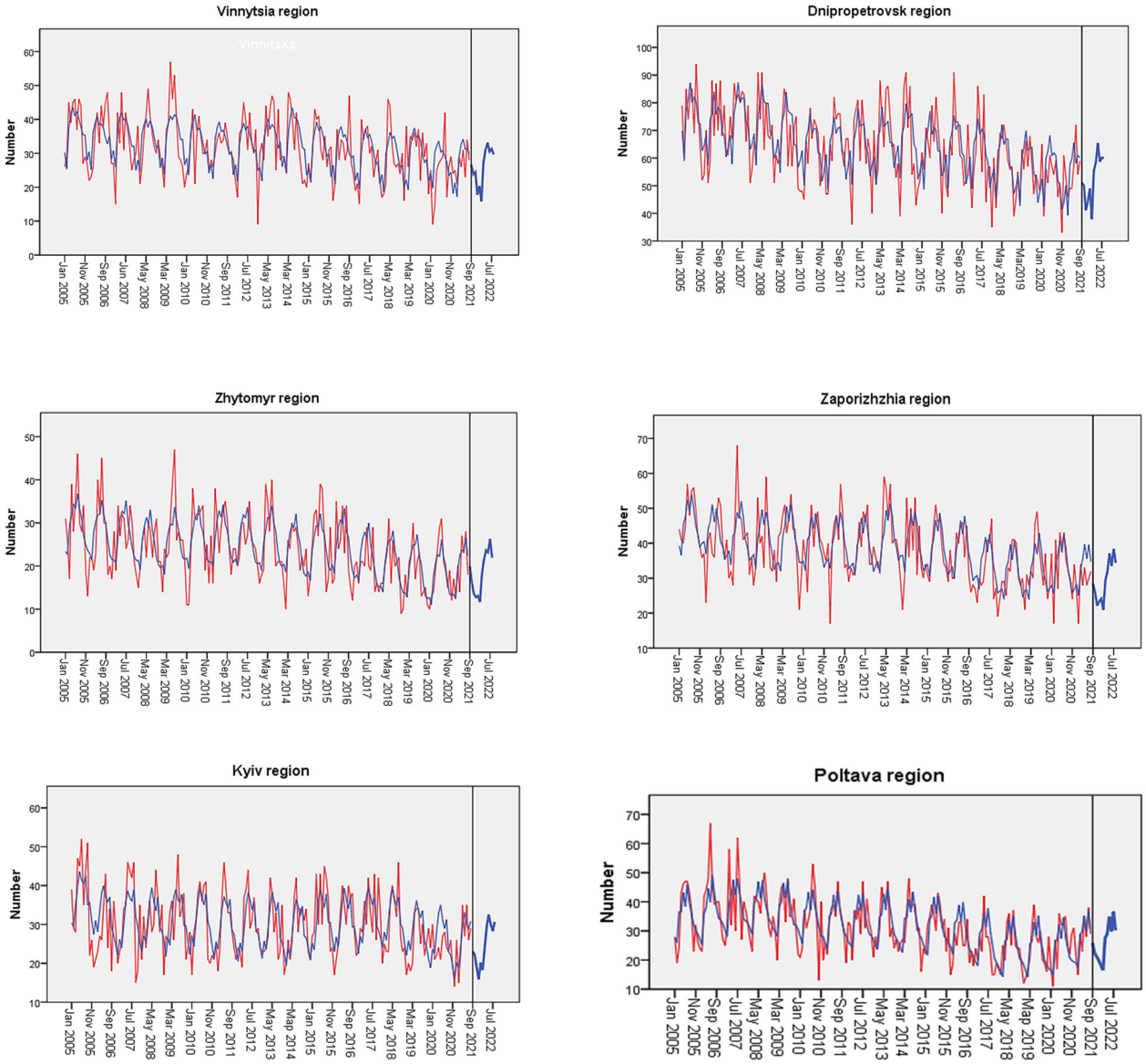

Fig. 1. Model graphs of the time series exponential smoothing of the deaths number absolute indicators due to intentional self-harm in 2005-2021 in Vinnytsia, Dnipropetrovsk, Zhytomyr, Zaporizhzhia, Kyiv and Poltava regions (forecast for September 2021 - August 2022) (blue – obtained model, red – absolute indicators)

Based on the created time series models, for the entire spring period, from March to May (and for the Khmelnytskyi and Chernihiv regions – until June), a progressive increase in the death rate is expected with a peak in April – May (in the Khmelnytskyi and Chernihiv regions – in May-June), and in June 2022 – a decrease, with a continuation of the decrease for the Zaporizhzhia, Kirovohrad and Poltava regions until August, and for the Kyiv, Kharkiv and Cherkasy regions – until July 2022.

An increase in the number of deaths due to intentional self-harm in the summer of 2022 is predicted for the Khmelnytskyi region (in June and August), Chernihiv region (in June-July), Vinnytsia, Dnipropetrovsk, Zhytomyr, Sumy regions (in July), Kyiv, Cherkasy, and Kharkiv regions (in August).

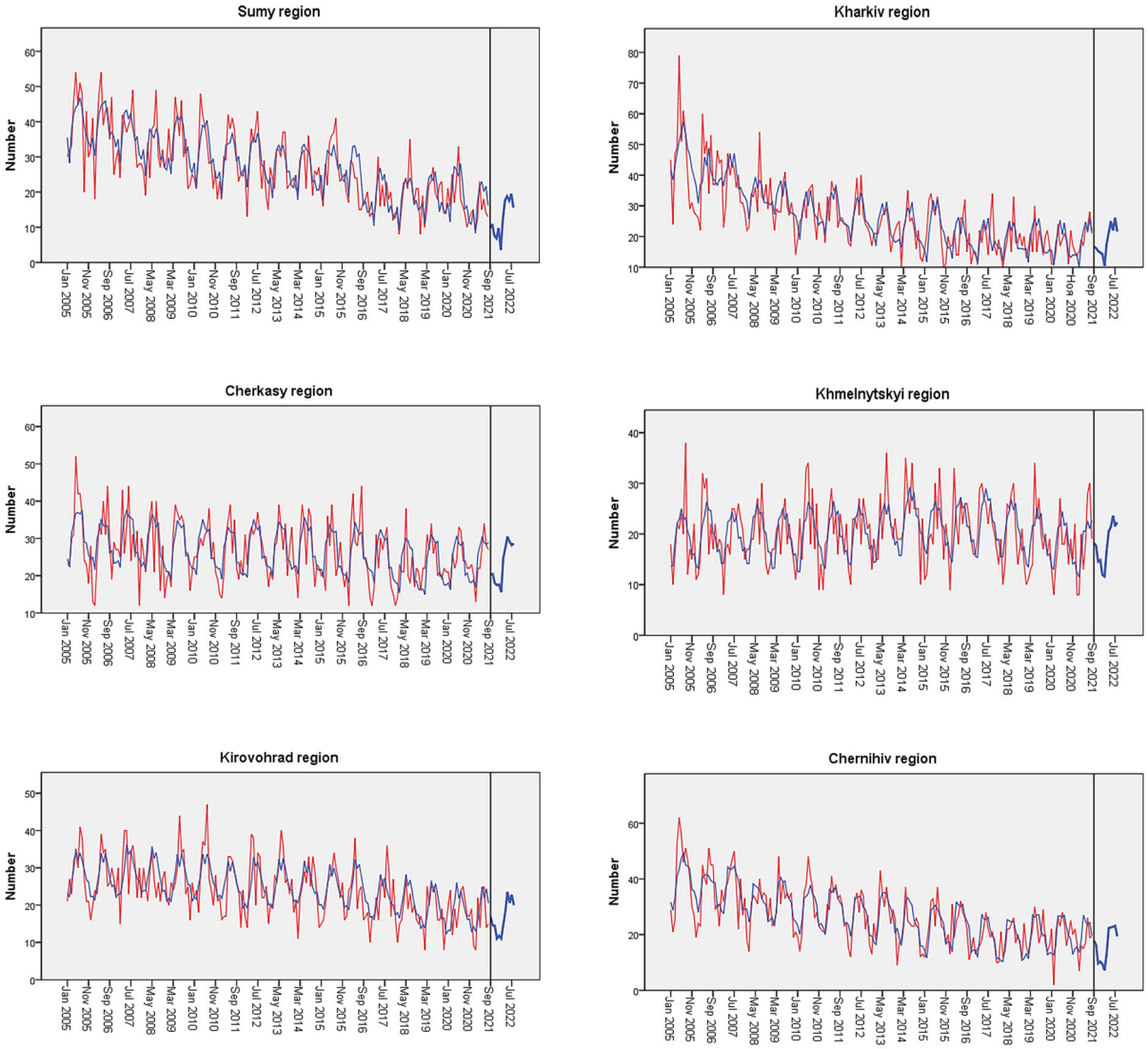

Fig. 2. Model graphs of the time series exponential smoothing of the deaths number absolute indicators due to intentional self-harm in 2005-2021 in Sumy, Kharkiv, Cherkasy, Khmelnytskyi, Kirovohrad, Chernihiv regions (forecast for September 2021 - August 2022) (blue – obtained model, red – absolute indicators)

CONCLUSIONS

1. Thus, based on the created time series model, it seems possible to assume that in the period from August 2021 to September 2022, for all considered regions of Ukraine, an absolute increase in the number of deaths due to intentional self-harm in the spring months is possible and, for most regions, in January. On the contrary, for the autumn period, a decrease in the number of completed suicides is characteristic.

2. The characteristics of the time series models of the entire group of regions did not allow us to use them to build a forecast, as well as led to the fact that

this forecast became impossible for the country as a whole. At the same time, if the majority of Western Ukrainian regions (Lviv, Rivne, Transcarpathia, Volyn, Ternopil, and Chernivtsi) when considering the external similarity of the correlograms were assigned by us to the third and fourth groups of regions, then the correlograms of the Ivano-Frankivsk and Black Sea regions (Odesa, Mykolaiv, and Kherson regions), had a pronounced external identity with the correlograms of the first group regions, i.e. bore the imprint of other dynamic processes.

3. All this allows us to assume the presence of various reasons that prevent modeling of changes in the number of deaths due to intentional self-harm in these regions. This can be both the extraordinary mobility of the population inherent in the regions neighboring the countries of the European Union and leading to an outflow of able-bodied (and, unfortunately, the most suicidally active) groups of the population, not always related to the seasons, as well as the peculiarities of the structuring of the causes of mortality in statistical reporting due to the peculiarities of professional traditions and views.

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