FOLIA MEDICA CRACOVIENSIA
Vol. LXII, 1, 2022: 103–120
PL ISSN 0015-5616
DOI: 10.24425/fmc.2022.141694

Forecasting of COVID-19 incidence in Ukraine using the method of exponential smoothing

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Abstract: Coronavirus infection (COVID-19) is a highly infectious disease of viral etiology. SARS-CoV-2 virus was first identified during the investigation of the outbreak of respiratory disease in Wuhan, China in December 2019. And already on March 11, 2020 COVID-19 in the world was characterized by the WHO as a pandemic. In Ukraine the situation with incidence COVID-19 remains difficult. The purpose of this study is to to develop a mathematical forecasting model for COVID-19 incidence in Ukraine using an exponential smoothing method. The article analyzes reports on basic COVID-19 incidence rates from 29.02.2019 to 01.10.2021. In order to determine the forecast levels of statistical indicators that characterize the epidemic process of COVID-19 the method of exponential smoothing was used. It is expected that from 29.02.2019 to 01.10.2021 the epidemic situation of COVID-19 incidence will stabilize. The indicator of "active patients" will range from 159.04 to 353.63 per 100 thousand people. The indicator of "hospitalized patients" can reach 15.43 and "fatalities" — 1.87. The use of the method of exponential smoothing based on time series models for modeling the dynamics of COVID-19 incidence allows to develop and implement scientifically sound methods in order to prevent, quickly prepare health care institutions for hospitalization.

Keywords: COVID-19, forecasting, method of exponential smoothing.

Submitted: 14-Mar-2022; **Accepted in the final form:** 30-Mar-2022; **Published:** 29-Jun-2022.

Introduction

Coronavirus infection (COVID-19) is a highly infectious disease of viral etiology [1, 2]. SARS-CoV-2 virus was first identified during the investigation of the outbreak of respiratory disease in Wuhan, China in December 2019. And already on March 11, 2020 COVID-19 in the world was characterized by the WHO as a pandemic [3].

According to the WHO, the highest number of confirmed cases of COVID-19 was registered in America (95,549,241) and Europe (82,693,729), the lowest — in the countries of the Western Pacific (9,894,731) and Africa (6,195,229) [4].

In Ukraine the situation with incidence remains difficult despite instituting a quarantine and introduction of restrictive anti-epidemic measures: isolation of patients and contacts, wearing masks and social distancing in public places, active vaccination campaign. Health care institutions are overloaded with patients. COVID-19 was confirmed in 3,322,308 persons or 8% of the population. 80,895 people died from COVID-19. The epidemic process was characterized by several waves of rise in incidence with the maximum in November 2020, April and October 2021 [5].

The use of methods of forecasting epidemic processes and mathematical modeling of incidence rates allows to develop and implement measures to prevent and suppress the epidemic spread of COVID-19 [6–8].

At the same time, an increased incidence of COVID-19 not only in the world but also in Ukraine requires searching for new more accurate and effective mathematical models of the epidemic process, which will be widely used as one of the tools for making management decisions.

Research objective — as exemplified by a separate region (Sumy Oblast) to develop a mathematical forecasting model for COVID-19 incidence in Ukraine using an exponential smoothing method and to evaluate the possibility of its usage by health care institutions.

Materials and Methods

The article analyzes "Daily reports on the situation with COVID-19 in Sumy Oblast", "Operational certificates on basic COVID-19 incidence rates in Sumy Oblast", daily reports "Epidemic situation of COVID-19 incidence in Sumy Oblast" from 29.02.2019 to 01.10.2021.

Sumy oblast is situated in the north-east of Ukraine. The population of the region as of January 01, 2021 was 1,053,500 people, population density — 47.7 people/km^2. Distribution of the permanent population by age groups: 0–17 years — 163,400 people, 18 years and over — 887,900 people (including 279,100 — over 60 years old).

In order to determine the forecast levels of statistical indicators that characterize the epidemic process of COVID-19, namely, "active patients", "patients requiring hospitalization", "fatalities", the method of exponential smoothing was used.

Generalizing model of exponential smoothing is written as:

$$S_t = \alpha \cdot X_t + (1 - \alpha) \cdot S_{t-1} \tag{1}$$

where X_t — level of time series at time t

α — smoothing parameter, which takes values from zero (when all current observations are ignored) to one (when all previous observations are completely ignored)
$S_t,\ S_{t-1}$ — exponentially smoothed value at time t and (t-1), respectively

Forecasts for one step forward were calculated (for models without trend, for linear and exponential trend models, a trend component is added to the model) according to the formula:

— additive model:

$$\begin{aligned} F_t &= S_t + I_{t-p} \\ I_t &= I_{t-p} + \delta \cdot (1-\alpha) \cdot e_t \end{aligned} \tag{2}$$

— multiplicative model:

$$\begin{aligned} F_t &= S_t \cdot I_{t-p} \\ I_t &= I_{t-p} + \delta \cdot (1-\alpha) \cdot e_t / S_t \end{aligned} \tag{3}$$

where δ — seasonal smoothing parameter, which is specified only for seasonal models
S_t — simple exponentially smoothed value of the time series at time t
I_{t-p} — smoothed seasonal factor at time t minus p (season length)
e_t — residuals at time t

In addition, the formulas were used to calculate smoothed values for the first season based on the initial values of seasonal components to create forecasts by the method of exponential smoothing on the basis of time series models that contain:

— both exponential component of the trend and additive seasonal component:

$$\begin{aligned} T_0 &= exp\left(\frac{(log(M_k) - log(M_1))}{p}\right) \\ S_0 &= exp((log(M_1) - p \cdot log(T_0)/2)) \end{aligned} \tag{4}$$

where S_0 — initial seasonal component
T_0 — initial trend
k — number of complete seasonal cycles
M_k — average for the last seasonal cycle
M_1 — average for the first seasonal cycle
p — duration of seasonal cycle

— both exponential component of the trend and multiplicative seasonal component:

$$\begin{aligned} T_0 &= exp\left(\frac{(log(M_2) - log(M_1))}{p}\right) \\ S_0 &= exp((log(M_1) - p \cdot log(T_0)/2)) \end{aligned} \tag{5}$$

where M_2 — average for the second seasonal cycle
M_1 — average for the first seasonal cycle

— both linear trend and multiplicative seasonal component in the form of triple exponential smoothing or three parameter Winter method and the seasonality method:

$$T_0 = \frac{M_k - M_1}{(k-1)\cdot p} \qquad S_0 = M_1 - p\cdot T_0/2 \tag{6}$$

Using the method of classical seasonal decomposition and the default time series module, we estimated the values of these data.

The feasibility of applying the method of building exponential smoothing forecasts based on time series models that contain a damped trend and additive seasonal component arises when, for example, the value of time series levels will increase, but this trend will be suppressed over time as saturated:

$$T_0 = \frac{1}{\phi}\cdot\frac{M_k - M_1}{(k-1)\cdot p} \qquad S_0 = M_1 - p\cdot T_0/2 \tag{7}$$

where ϕ — trend smoothing parameter used in case of models with a fading trend

The formula (8) was used to produce forecasts of exponential smoothing based on time series models that contain a damped (fading) trend and a multiplicative seasonal component.

When performing this study, Statistica software package was applied, Statistics / Advancedlinear / NonlinearModels / TimeSeries / Forecasting / ExponentialSmoothingandForecasting command was used.

Results

Based on the research findings, it was established that for the period from 29.02.2019 to 01.10.2021 two waves of rising incidence of COVID-19 were observed in Sumy Oblast: in autumn 2020 and spring 2021. The median incidence was 107.559 per 100 thousand people. Maximum indicators of detecting "active patients" were registered from 07.11.20 to 13.11.20 and from 03.04.21 to 09.04.21 and were 764.8 and 815.9 per 100 thousand people, respectively (Fig. 1).

The frequency of hospitalization of patients with COVID-19, since the first cases of the disease were detected, gradually increased with slight fluctuations and reached its maximum in early April 2021 (from 03.04.2021 to 09.04.2021), when the hospita-

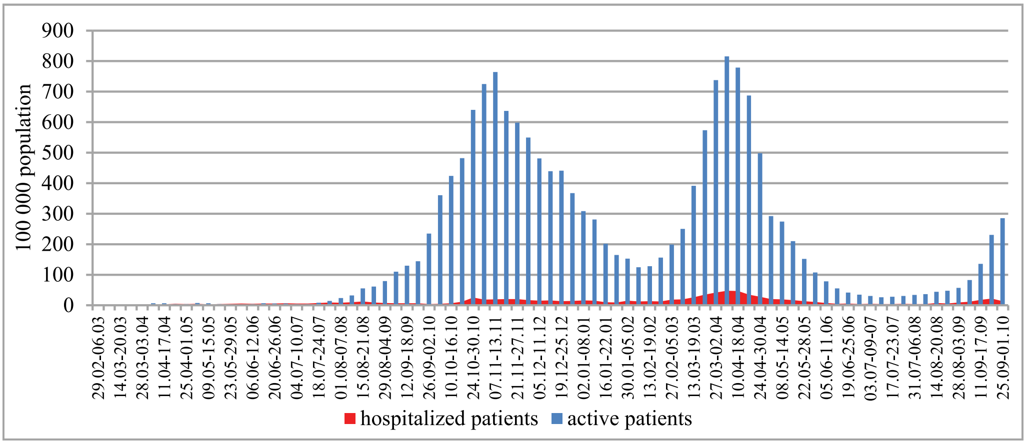


Fig. 1. Dynamics of the indicators of “active patients” with COVID-19 and “hospitalized patients” in Sumy Oblast from 29.02.2019 to 01.10.2021.

lization indicator was 47.6. In general, in the period under study, the median rate of “hospitalized patients” was 8.8. In total, 5.9% of patients with COVID-19 were hospitalized.

For the period from 29.02.2019 to 01.10.2021, 0.8% of patients died from COVID-19 in Sumy Oblast and 13.5% of hospitalized patients. COVID-19 fatality indicator achieved its maximum in the period of 10.04.2021–18.04.2021 and was 7.96. In the researched period, the median fatality rate was 0.936 (Fig. 2).

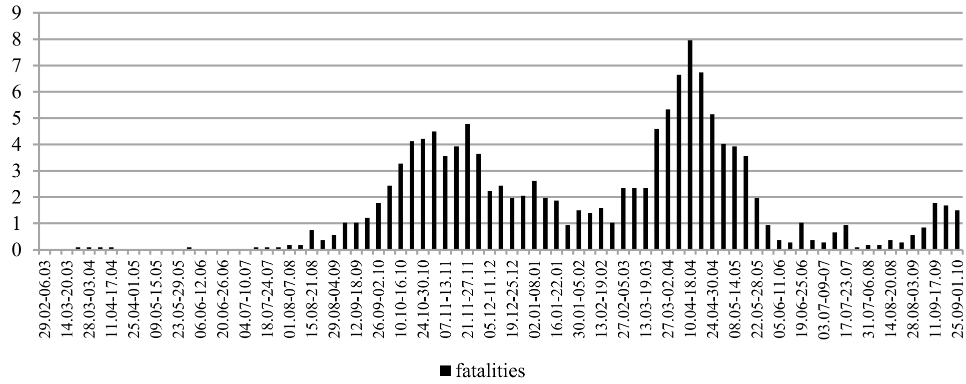


Fig. 2. COVID-19 fatality indicator in Sumy Oblast from 29.02.2019 to 01.10.2021.

Thus, the epidemic situation with COVID-19 was difficult in the region, required intensive work of health care institutions, rapid response of the authorities to prevent its further complication.

To develop appropriate preventive and epidemic control measures, prepare material resources of health care institutions to admit patients and provide them with effective medical care, we have established a mathematical model for forecasting COVID-19 incidence using the method of exponential smoothing.

According to the results of calculations, forecast models of exponential smoothing of indicators characterizing the epidemic process of COVID-19 (“active patients”, “hospitalized patients”, “fatalities”) were obtained (Table 1).

Table 1. Forecast models of exponential smoothing of indicators characterizing the epidemic process of COVID-19 (“active patients”, “hospitalized patients”, “fatalities”).

Indicators	Models	
active patients	AF1	Exponentialsmoothing: Additiveseason (12) S0 = 217.1 Notrend,add.season; Alpha = 1.00 Delta = 1.00
	AF2	Exp. smoothing: Additiveseason (12) S0 = −11.2 T0 = 2.444 Lin.trend,add.season; Alpha = .951 Delta = 1.00
	AF3	Exp. smoothing: Additiveseason (12) S0 = −22.2 T0 = 4.272 Dampedtrend,add.season; Alpha = .628 Delta = 1.00 Phi =.572
hospitalized patients	GF1	Exponentialsmoothing: Additiveseason (12) S0 = 12.24 Notrend,add.season; Alpha = .911 Delta = 1.00
	GF2	Exp. smoothing: Additiveseason (12) S0 = 1.823 T0 = .1473 Lin.trend,add.season; Alpha = 1.00 Delta = .185
	GF3	Exp. smoothing: Additiveseason (12) S0 = −.976 T0 = .6138 Dampedtrend,add.season; Alpha = .849 Delta = 0.00 Phi = .240
	GF4	Exp. smoothing: Multipl. season (12) S0 = 1.823 T0 = .1473 Lin.trend,mult.season; Alpha = 1.00 Delta = .079
	GF5	Exp. smoothing: Multipl. season (12) S0 = −.021 T0 = .4547 Dampedtrend,mult.season; Alpha = .716 Delta = 0.00 Phi = .324
fatalities	LF1	Exponentialsmoothing: Additiveseason (12) S0 = 1.733 Notrend,add.season; Alpha = 1.00 Delta = .279
	LF2	Exp. smoothing: Additiveseason (12) S0 = −.154 T0 = .0308 Lin.trend,add.season; Alpha = 1.00 Delta = .378
	LF3	Exp. smoothing: Additiveseason (12) S0 = −.300 T0 = .0552 Dampedtrend,add.season; Alpha = .579 Delta = 0.00 Phi = .558

The established seasonal components of the studied 6 time series for a period of 12 months are given in Table 2.

Table 2. Seasonal factors of indicators characterizing the epidemic process of COVID-19 ("active patients", "hospitalized patients", "fatalities").

Case/Model	Active patients	Hospitalized patients	Fatalities
1	31.40	1.46	0.24
2	−28.57	−0.33	−0.10
3	−34.50	−0.88	0.08
4	−44.51	−2.46	−0.21
5	−57.21	−1.87	−0.48
6	−63.95	−2.31	−0.63
7	−23.41	−2.13	−0.63
8	11.03	−0.63	−0.16
9	37.14	1.24	0.33
10	55.36	3.15	0.46
11	62.25	3.85	0.68
12	54.96	0.91	0.43

Based on the data given in Table 1, the forecast models of exponential smoothing by the indicator of "active patients" are written as:

$$\begin{aligned}
&AF1_t = \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1} + I_{t-p}, I_t = I_{t-p}, S0 = 217.1 \\
&AF2_t = LT_t + \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1} + I_{t-p}, I_t = I_{t-p} + (1-\alpha) \cdot e_t, \\
&S0 = -11.2 \quad T0 = 2.444 \\
&AF3_t = DT_t + \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1} + I_{t-p}, I_t = I_{t-p} + (1-\alpha) \cdot e_t, \\
&S0 = -22.2 \quad T0 = 4.272
\end{aligned} \tag{8}$$

where $AF1_t$ — additive seasonality model
$AF2_t$ — additive trend and seasonal model
$AF3_t$ — additive trend and seasonal model with damped trend
LT_t — linear trend (value at time t)
DT_t — damped trend (value at time t)

Visualization of the ratio of theoretical levels calculated by formulas (8), actual data and model residuals are presented in Figures 3-4.

Forecast levels of the "active patients" indicator from 18.02.2022 by three forecast models (8) are shown in Figure 5.

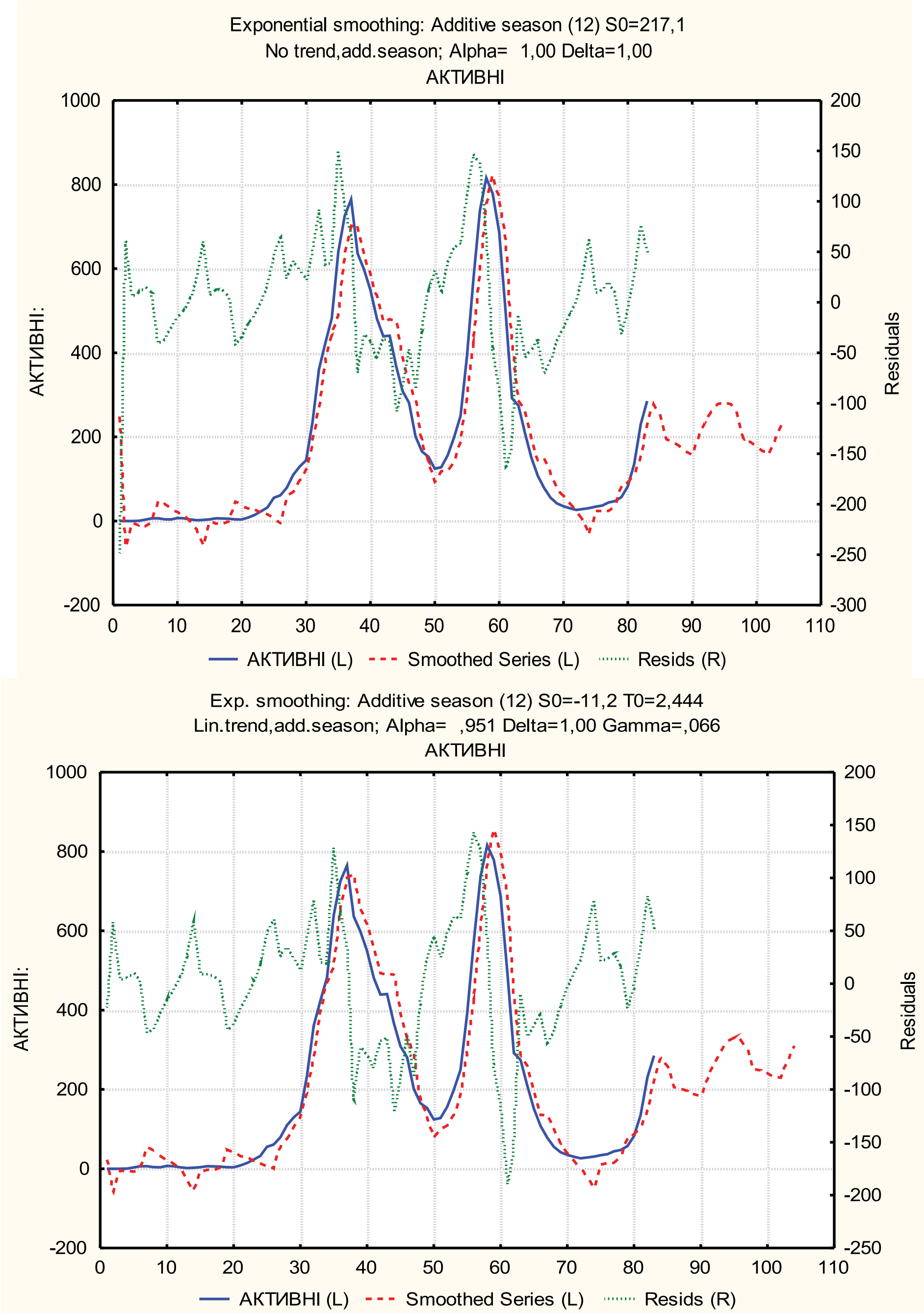


Fig. 3. Actual and forecast levels of the "active patients" indicator from 29.02.2019 to 18.02.2022 (left fragment — additive seasonality model, right fragment — additive trend and seasonal model).

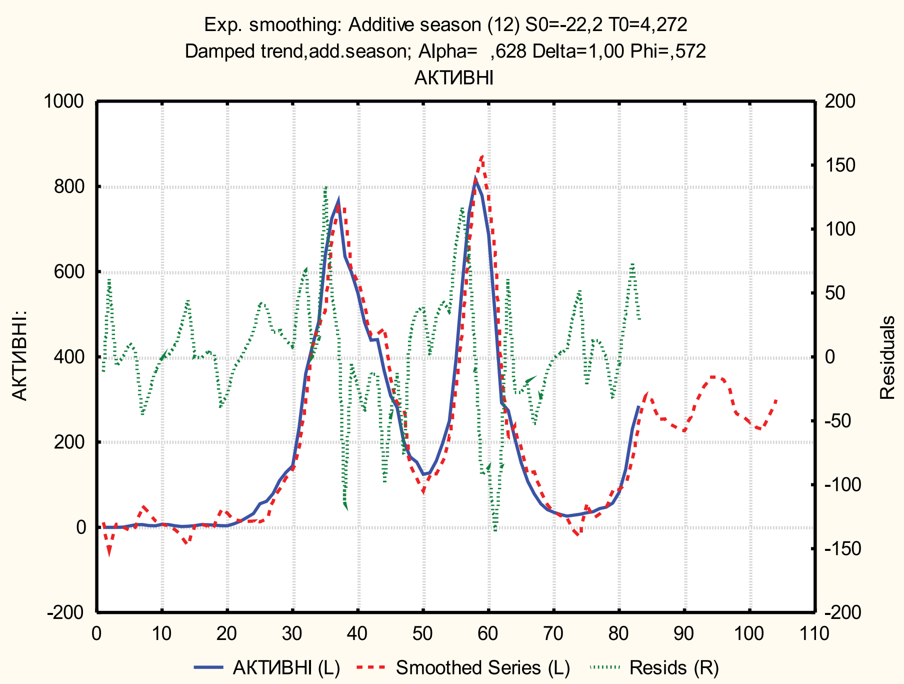


Fig. 4. Actual and forecast levels of the "active patients" indicator from 29.02.2019 to 18.02.2022 (additive trend and seasonal model with damped trend).

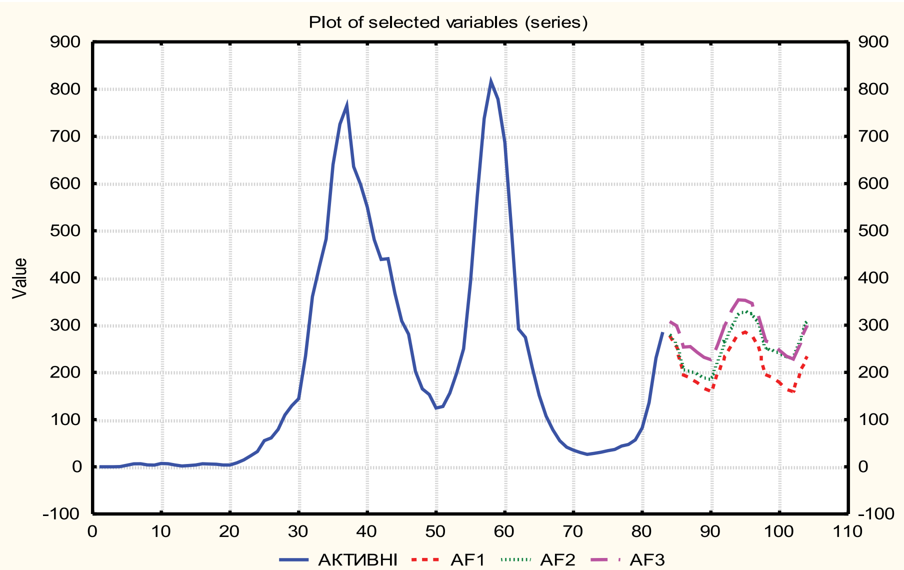


Fig. 5. Actual and forecast levels of the "active patients" indicator from 29.02.2019 to 18.02.2022 by three forecast models (8).

Based on the data of Table 1, the forecast models of exponential smoothing by the "hospitalized patients" indicator are written as:

$$\begin{aligned}
&GF1_t = \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1} + I_{t-p}, I_t = I_{t-p}, S0 = 12.24\\
&GF2_t = LT_t + \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1} + I_{t-p}, I_t = I_{t-p}, S0 = 1.823 \quad T0 = .1473\\
&GF3_t = DT_t + \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1} + I_{t-p}, I_t = I_{t-p}, S0 = -.976 \quad T0 = .6138\\
&GF4_t = LT_t \cdot (\alpha \cdot X_t + (1-\alpha) \cdot S_{t-1}) \cdot I_{t-p}, I_t = I_{t-p}, S0 = 1,823 \quad T0 = .1473\\
&GF5_t = T_t \cdot (\alpha \cdot X_t + (1-\alpha) \cdot S_{t-1}) \cdot I_{t-p}, a, S0 = -.021 \quad T0 = .4547
\end{aligned} \tag{9}$$

where $GF1_t$ — additive seasonality model
$GF2_t$ — additive trend and seasonal model with linear trend
$GF3_t$ — additive trend and seasonal model with damped trend
$GF4_t$ — multiplicative trend and seasonal model with linear trend
$GF5_t$ — multiplicative trend and seasonal model with damped trend
LT_t — linear trend (value at time t)
DT_t — damped trend (value at time t)

Visualization of the ratio of theoretical levels calculated by formulas (8), actual data and model residuals is presented in Figures 6-8.

Forecast levels of the "hospitalized patients" indicator until 18.02.2022 are graphically represented in Figure 9.

Based on the data of Table 1, the forecast models of exponential smoothing by "fatalities" indicator are written as:

$$\begin{aligned}
&LF1_t = \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1} + I_{t-p}, I_t = I_{t-p}, S0 = 1.733\\
&LF2_t = LT_t + \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1} + I_{t-p}, I_t = I_{t-p}, S0 = -.154 \quad T0 = .0308\\
&LF3_t = DT_t + \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1} + I_{t-p}, I_t = I_{t-p}, S0 = -.300 \quad T0 = .0552
\end{aligned} \tag{10}$$

where $LF1_t$ — additive seasonality model
$LF2_t$ — additive trend and seasonal model
$LF3_t$ — linear additive trend and seasonal model with damped trend
LT_t — trend (value at time t)
DT_t — damped trend (value at time t)

Visualization of the ratio of theoretical levels calculated by formulas (8), actual data and model residuals is presented in Figures 10–11.

Forecast levels of the "fatalities" indicator until 18.02.2022 are graphically represented in Figure 12.

The calculated forecast levels of statistical indicators are systematized in Table 3.

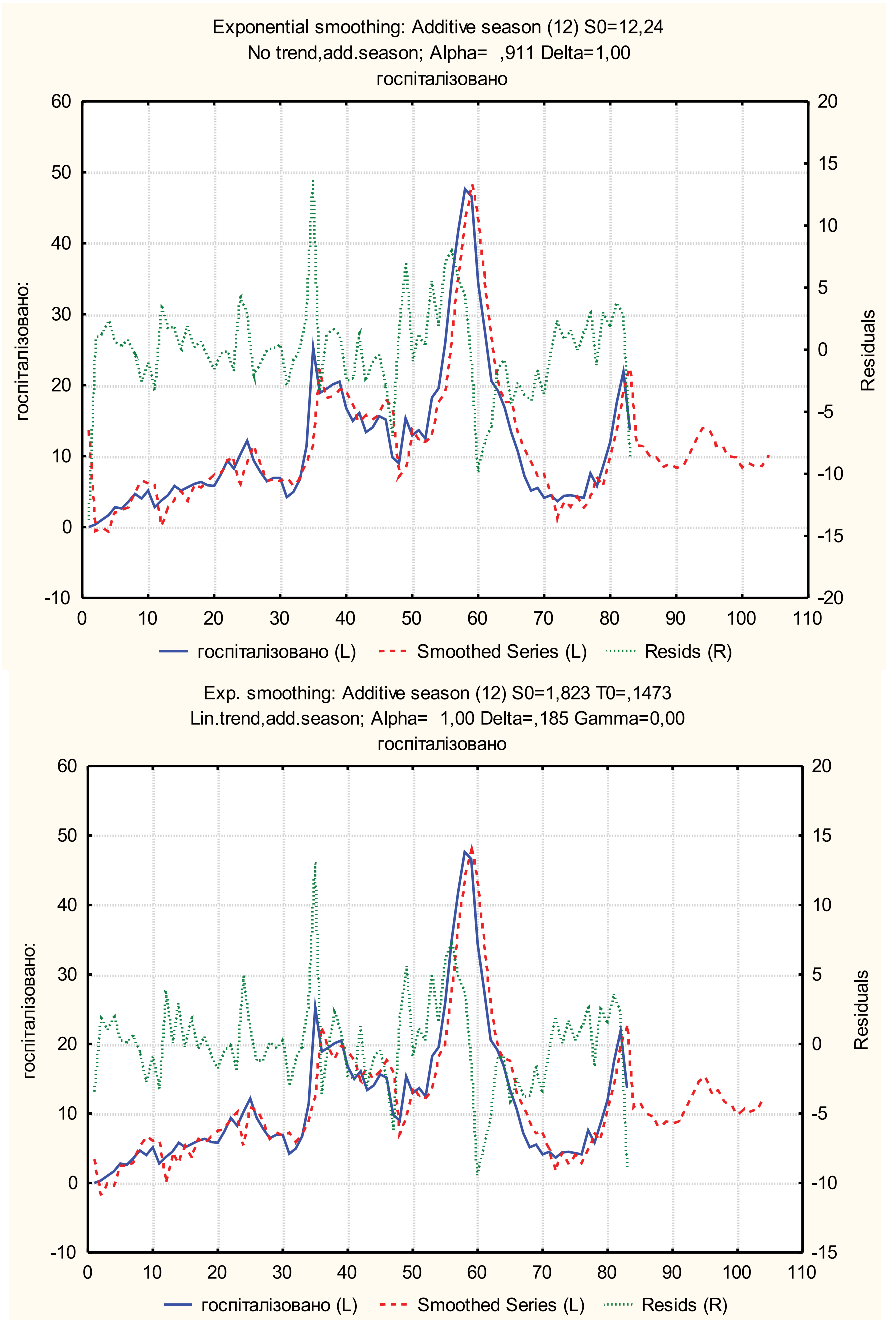


Fig. 6. Actual and forecast levels of the "hospitalized patients" indicator from 29.02.2019 to 18.02.2022 (left fragment — additive seasonality model, right fragment — additive trend and seasonal model with linear trend).

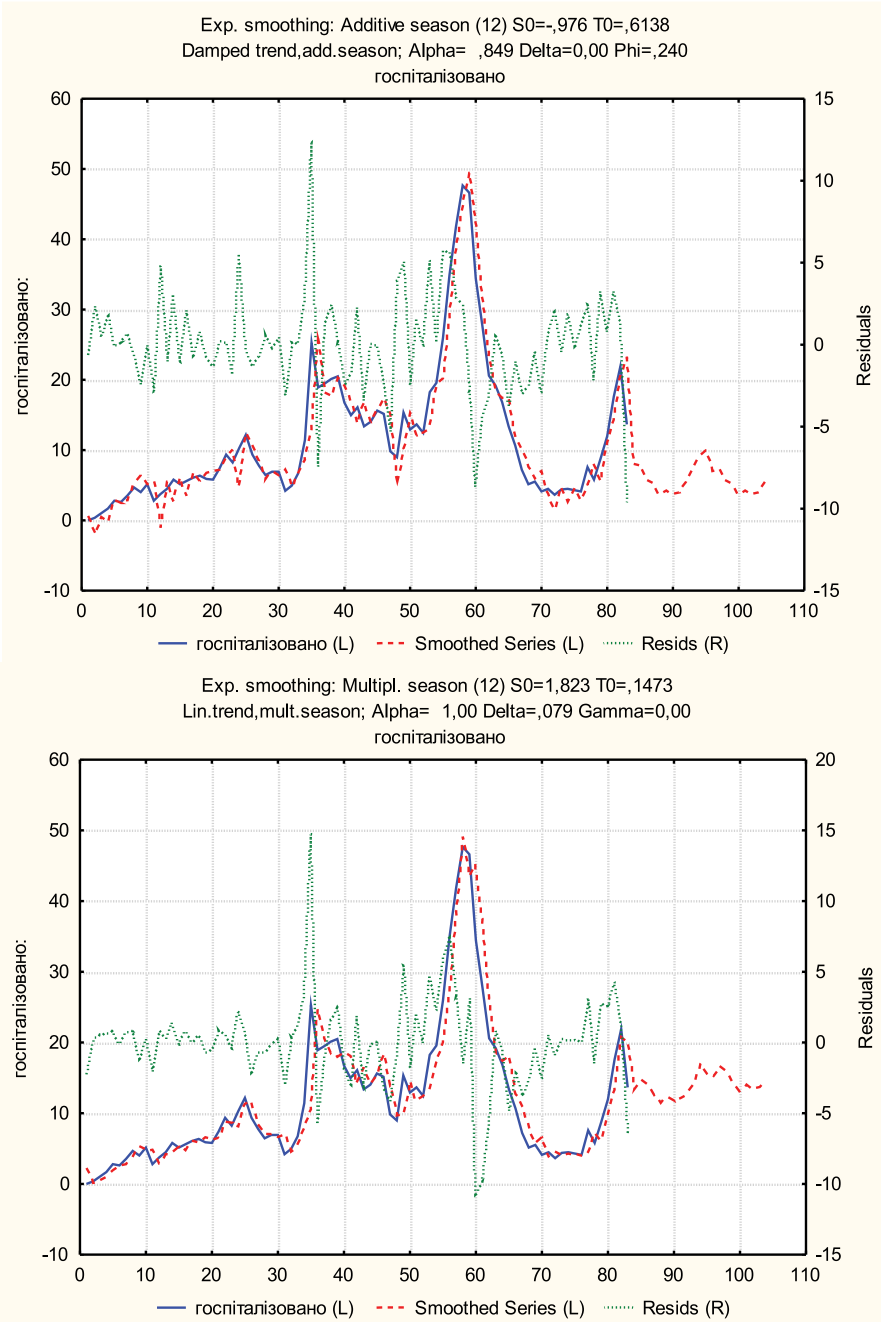


Fig. 7. Actual and forecast levels of the "hospitalized patients" indicator from 29.02.2019 to 18.02.2022 (left fragment — additive trend and seasonal model with damped trend, right fragment — multiplicative trend and seasonal model with linear trend).

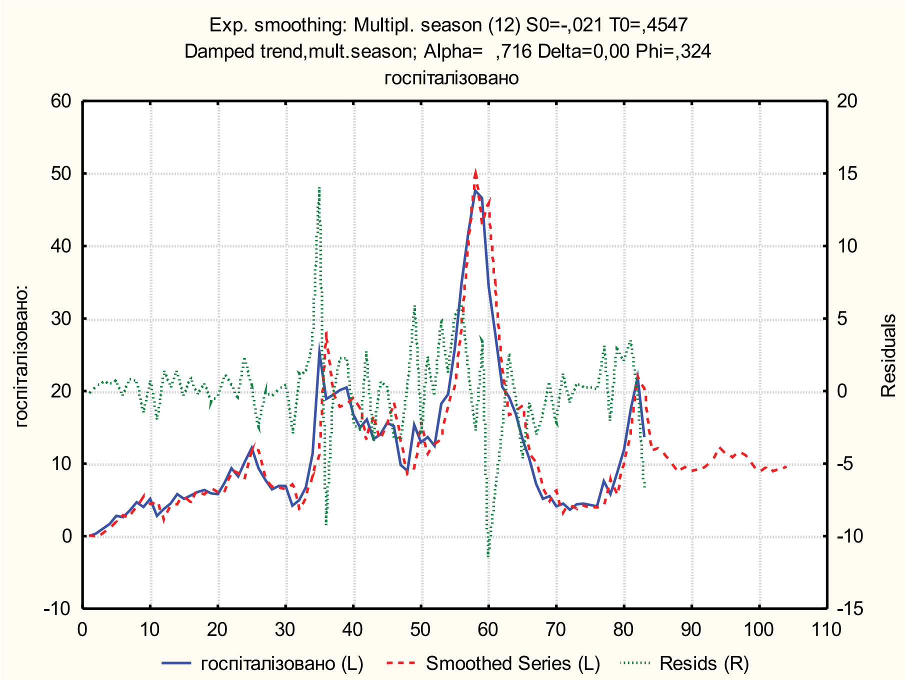


Fig. 8. Actual and forecast levels of the "hospitalized patients" indicator from 29.02.2019 to 18.02.2022 (multiplicative trend and seasonal model with damped trend).

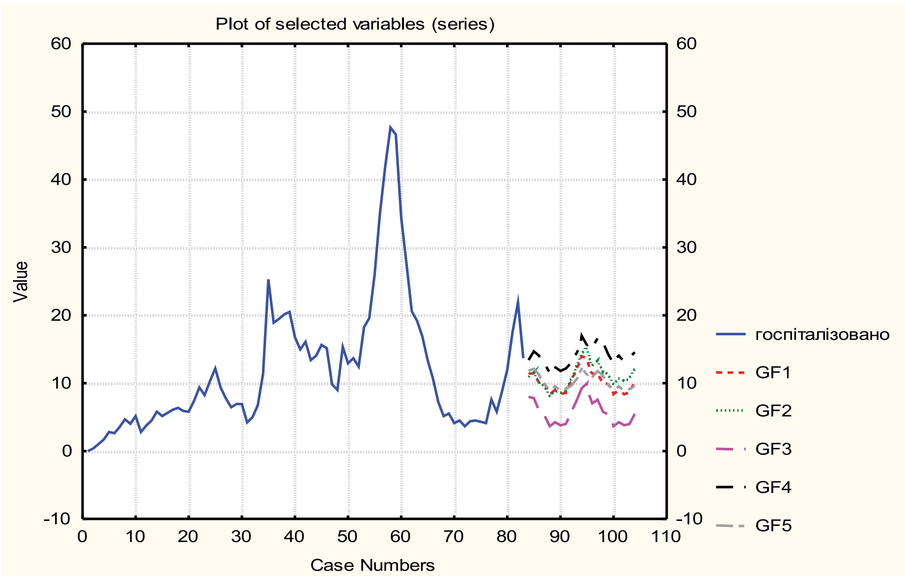
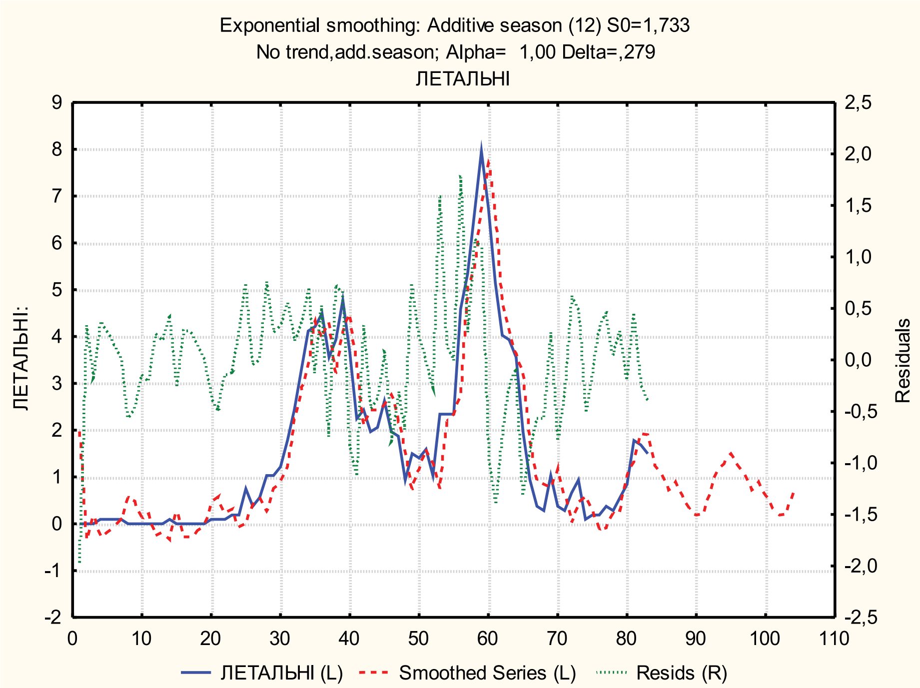


Fig. 9. Actual and forecast levels of the "hospitalized patients" indicator from 29.02.2019 to 18.02.2022 by five forecast models (9).



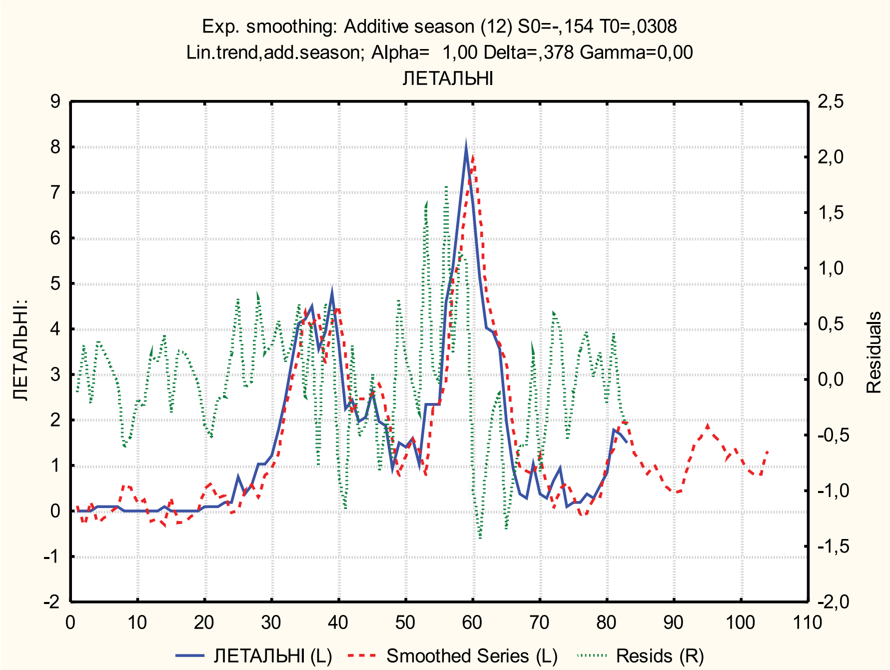


Fig. 10. Actual and forecast levels of the "fatalities" indicator from 29.02.2019 to 18.02.2022 (left fragment — additive seasonality model, right fragment — additive trend and seasonal model with linear trend).

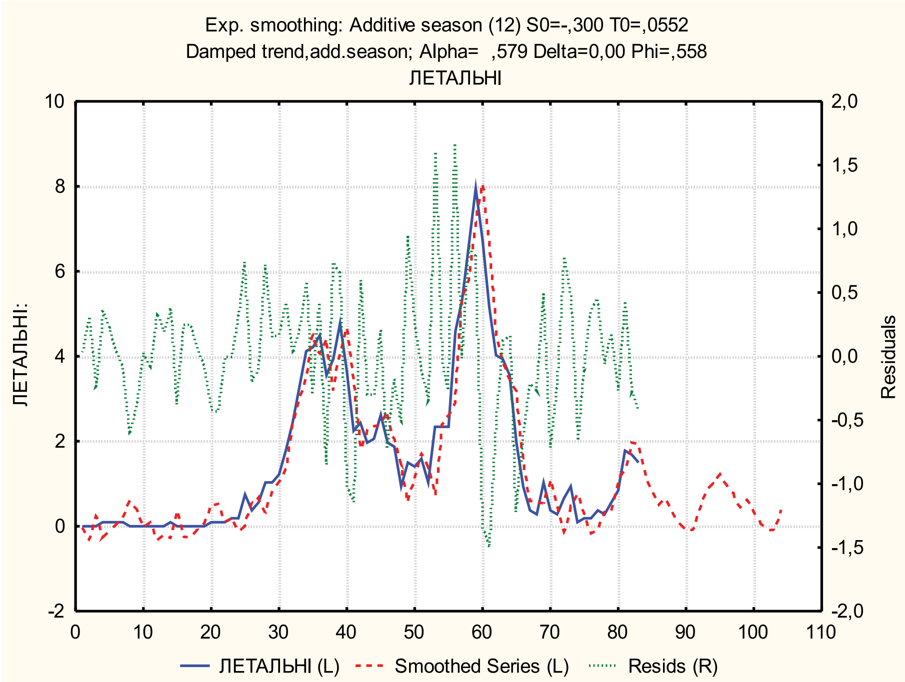


Fig. 11. Actual and forecast levels of the "hospitalized" indicator from 29.02.2019 to 18.02.2022 (additive trend and seasonal model with damped trend).

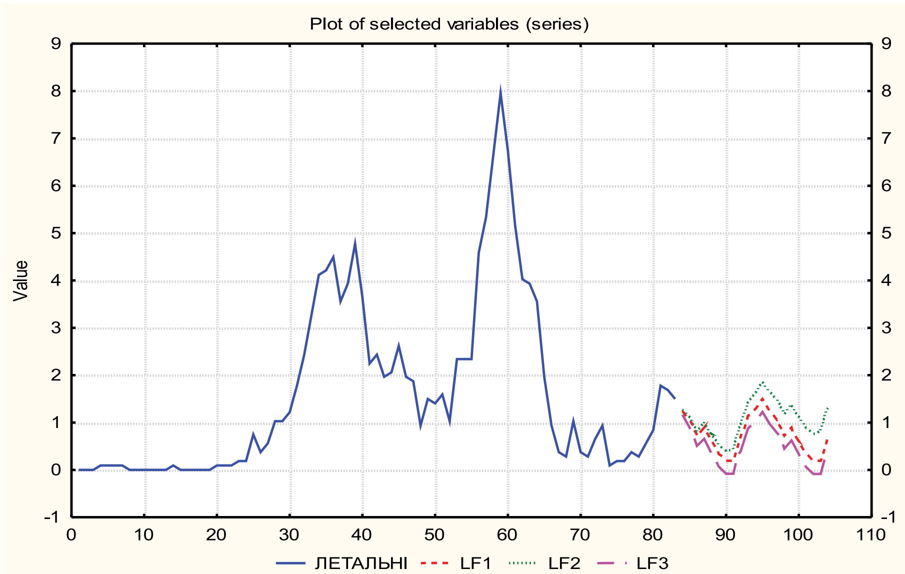


Fig. 12. Actual and forecast levels of the "fatalities" indicator from 29.02.2019 to 18.02.2022 by three forecast models (10).

Table 3. Forecast values of indicator levels ("active patients", "hospitalized patients", "fatalities") from 02.10.2021 to 18.02.2022 by three forecast models.

	AF1	AF2	AF3	GF1	GF2	GF3	GF4	GF5	LF1	LF2	LF3
02.10–08.10	277.94	279.73	307.53	11.42	10.88	7.97	13.40	11.82	1.24	1.28	1.17
09.10–15.10	254.39	259.03	298.79	11.41	11.57	7.80	14.69	12.12	1.05	1.12	0.89
16.10–22.10	194.42	205.96	253.55	10.01	9.93	5.84	14.02	11.23	0.72	0.81	0.51
23.10–29.10	188.49	203.19	254.58	9.82	9.53	5.24	12.58	9.90	0.90	1.02	0.66
30.10–05.11	178.48	196.17	242.42	8.39	8.10	3.66	11.46	8.90	0.61	0.76	0.35
06.11–12.11	165.78	187.86	231.98	9.01	8.84	4.25	12.42	9.53	0.33	0.52	0.07
13.11–19.11	159.04	184.83	226.83	8.36	8.54	3.80	11.81	8.96	0.19	0.40	–0.08
20.11–26.11	199.57	224.73	259.08	8.60	8.86	3.98	12.15	9.13	0.19	0.44	–0.08
27.11–03.12	234.02	265.08	298.94	10.14	10.51	5.48	12.91	9.60	0.66	0.94	0.39
04.12–10.12	260.13	297.10	331.22	12.26	12.54	7.36	14.36	10.56	1.14	1.45	0.87
11.12–17.12	278.34	321.27	353.63	13.95	14.59	9.26	16.98	12.35	1.28	1.62	1.01
18.12–24.12	285.23	330.13	352.66	13.67	15.43	9.96	15.59	11.23	1.50	1.87	1.22
25.12–31.12	277.94	324.63	346.10	11.42	12.65	7.02	15.27	10.88	1.24	1.64	0.97
01.01–07.01	254.39	303.93	320.85	11.41	13.34	7.57	16.71	11.79	1.05	1.49	0.78
08.01–14.01	194.42	250.86	266.17	10.01	11.70	5.78	15.93	11.13	0.72	1.18	0.45
15.01–21.01	188.49	248.09	261.80	9.82	11.29	5.23	14.27	9.87	0.90	1.39	0.62
22.01–28.01	178.48	241.07	246.55	8.39	9.86	3.65	12.99	8.89	0.61	1.13	0.33
29.01–04.02	165.78	232.76	234.34	9.01	10.60	4.25	14.05	9.53	0.33	0.89	0.06
05.02–11.02	159.04	229.73	228.18	8.36	10.30	3.80	13.34	8.96	0.19	0.77	–0.09
12.02–18.02	199.57	269.63	259.85	8.60	10.63	3.98	13.71	9.13	0.19	0.81	–0.08
13.02–18.02	234.02	309.98	299.38	10.14	12.28	5.48	14.56	9.60	0.66	1.31	0.39

Discussion

Wide prevalence of diseases with aerosol transmission in Ukraine, variety of their clinical forms causes difficulties in combating them [6].

In the light of the research results obtained, we concluded that the method of exponential smoothing can be used for mathematical modeling of the incidence rates in health care institutions, along with other methods proposed by other researchers [7–9].

Thus, it is expected that from 29.02.2019 to 01.10.2021 the epidemic situation of COVID-19 incidence will stabilize somehow but will be far from safe. The indicator of "active patients" will range from 159.04 to 353.63 per 100 thousand people. The indicator of "hospitalized patients" can reach 15.43 and "fatalities" — 1.87.

In our opinion, the above is explained by the fact that society adjusts to SARS-CoV-2 virus, despite its mutation. One part of the population has already been exposed to COVID-19 and has natural immunity and the other part is vaccinated to create an artificial immunity, while wearing masks is already a rule. The virus continues to be dangerous for people at risk and suffering from obesity, chronic kidney disease, hypertension, asthma. These individuals are at high risk of severe course of the disease and hospitalization. Therefore, additional preventive and therapeutic measures shall be planned and implemented for these groups of patients [10].

Conclusions

The use of the method of exponential smoothing based on time series models for modeling the dynamics of COVID-19 incidence allows to develop and implement scientifically sound methods in order to prevent, suppress the rapid spread of this infectious disease, quickly prepare health care institutions for hospitalization, provide hospitals with medical staff and facilities to provide medical care. The advantage of this method is its high accuracy. However, it should be noted that it does not allow identifying factors that affect the course of epidemic process.

Statement of contribution

The manuscript has been read and approved by all authors, and all the authors agreed to the submission of the manuscript to The Editor.

Funding

None declared.

Conflict of interest

None declared.

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