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Original Article

Influence of Possible Natural and Artificial Collective Immunity on New COVID-19 Pandemic Waves in Ukraine and Israel

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Abstract

Background and objectives: The percentage of vaccinated people in Ukraine and Israel extensively varies. Based on this large difference, the influence of possible collective immunity on the COVID-19 pandemic dynamics in summer 2021 was evaluated.

Methods: To clarify the presence of a natural collective immunity, the visible and actual characteristics of the COVID-19 epidemic in Ukraine were estimated based on the number of laboratory-confirmed cases (accumulated in May and June 2021), using a generalized SIR-model and parameter identification procedure, and considering the difference between registered and real number of cases.

Results: The calculated optimal value of the visibility coefficient shows that most Ukrainians have already been infected with coronavirus, some of whom have been infected more than once. This suggests that Ukrainians have probably achieved a natural collective immunity. Despite the large percentage of fully vaccinated people in Israel (approximately 60%), the emergence of a new epidemic wave after June 15, 2021 was not prevented, and the number of deaths increased after July 5, 2021. A new wave of the pandemic in Ukraine after July 10, 2021 is characterized by a smaller daily number of new COVID-19 cases per capita and new deaths per capita, despite having a much lower number of vaccinated people than in Israel. This can be explained by a much lower level of testing (many cases in Ukraine remain undetected) and possibly by the probable natural immunity of Ukrainians.

Conclusions: High levels of vaccination and natural collective immunity are unlikely to prevent new waves of the COVID-19 pandemic caused by mutated coronavirus strains.

Introduction

The dynamics of the COVID-19 pandemic in Israel and Ukraine have been extensively investigated in previous reports,[1–13] particularly focusing on the influence of vaccinations and possible natural immunity.[1–3,12–14] In Ukraine, the early stages of the COVID-19 pandemic outbreak[6,8] and pandemic dynamics were investigated using the classical SIR model,[15–17] and the statistics-based method of its parameter identification proposed in 2017.[18] Results have shown that this approach is able to predict only the first epidemic wave and when the number of registered cases reflects the real figures (first predictions based on the data-sets corresponding to the initial stages of the epidemic were two optimistic).[7,8]

As quarantine restrictions were reduced, changes in social behavior and subsequent coronavirus mutations impacted the epidemic dynamics and corresponding parameters of models. To detect these new epidemic waves, a simple method was proposed based on the numerical differentiations of the smoothed number

Keywords: COVID-19 pandemic; Epidemic dynamics; Mathematical modeling; Infection diseases; SIR model; Parameter identification; Statistical methods.

Abbreviations: DCC, daily number of new COVID-19 cases per capita; DDC, daily number of new deaths per capita; DTC, daily number of tests per capita; VC, percentage of fully vaccinated people; JHU, Johns Hopkins University.

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of cases.[11,19] To simulate different epidemic waves, the generalized SIR model[20] and corresponding parameter identification procedure[21] were introduced. In particular, ten epidemic waves were identified and simulated in Ukraine between March 2020 and March 2021.[8–11]

Due to the large number of asymptomatic COVID-19 patients, the actual number of infected individuals exceeds the number of laboratory-confirmed cases.[22] In order to assess the extent of data incompleteness, the identification algorithm for SIR parameters was modified[10] to determine the true characteristics of the COVID-19 epidemic in Ukraine[10,23] and Qatar.[24] In this article, we present the results of SIR simulations of the new pandemic wave in Ukraine based on the dataset for the number of cases registered by national statistics[25] in the period of May 25 to June 7, 2021. The visible and real dimensions of the 11th pandemic wave in Ukraine will be estimated and discussed.

The daily number of new COVID-19 cases per capita (DCC), new deaths per capita (DDC), daily number of tests per capita (DTC), and percentage of fully vaccinated people (VC) are important characteristics of the pandemic dynamics that may indicate the effectiveness of quarantine, testing, and vaccination. These values are available in the COVID-19 Data Repository by the Center for Systems Science and Engineering at Johns Hopkins University (JHU).[26] Herein, we compared the recent pandemic dynamics in Ukraine and Israel with the use of JHU datasets corresponding to the period of June 1 to August 31, 2021. It should be noted that the pandemic dynamics in Israel in the summer of 2021 were not analyzed in previous studies.[1–3] Moreover, the wide variation in vaccination rates in Israel and Ukraine allowed us to compare new epidemic waves and make some preliminary conclusions about the efficiency of vaccinations and natural collective immunity.

Materials and methods

Data

We obtained a dataset regarding the accumulated numbers of laboratory-confirmed COVID-19 cases in Ukraine from national sources connected with the Ukrainian government.[25] The corresponding numbers, V_j , and moments of time, t_j (measured in days), are shown in Table 1. The values for the period T_{c10}: March 11–24, 2021 were used for SIR simulations of the 10th epidemic wave in Ukraine.[11] Herein, we employed the fresher dataset,[25] corresponding to the period T_{c11}: May 23 to June 5, 2021 to simulate the 11th wave of the pandemic. Other V_j and t_j values were used to control the accuracy of predictions and pandemic dynamics.

We also employed datasets regarding the DCC, DDC, DTC and VC reported by JHU[26] for Israel and Ukraine for the period of June 1 to September 3, 2021. The values of DCC, DDC, DTC, and VC (also denoted as c_j) corresponding to the moments of time t_j (measured in days) are shown in Table 2. It must be noted that JHU regularly updates its data. The datasets presented in Table 2 correspond to the moment of time September 4, 2021.

Since c_j values are random and demonstrate some weekly periodicity, proper smoothing was required. Following a previously reported approach,[7,8,11] we averaged the c_j values (calculated with the use of the nearest 7-day figures) by:

$$\bar{c}_i = \frac{1}{7}\sum_{j=i-3}^{j=i+3} c_j$$

Generalized SIR model and parameter identification procedure

The description of the generalized SIR model and exact solution of the set of non-linear differential equations relating the number of susceptible S, infectious I, and removed persons R (who are or were infected, but not spread the infection at fixed moment of time t) can be found in previous reports.[10,20] This solution uses the function:

$$V(t) = I(t) + R(t) \quad (1)$$

where $V(t)$ corresponds to the number of victims or the cumulative confirmed number of cases, and its derivative is:

$$\frac{dV}{dt} = \alpha_i SI \quad (2)$$

which yields the estimation of the average daily number of new cases. When the registered number of victims V_j is a random realization of its theoretical dependence (1), the exact solution[10,20] depends on five parameters (including α_i). The details of the optimization procedure for identifying these parameters can be found in a previous report.[21]

If we assume that data set V_j is incomplete and there is a constant coefficient $\beta_i \geq 1$, then the registered and real number of cases during the *i-th* epidemic wave can be related as:

$$V(t_j) \cong \beta_i V_j \quad (3)$$

It means that the number of unknown parameters increases by one. The procedure to identify the unknown parameters was presented previously.[10] The values V_j corresponding to the moments of time t_j during March 11–24, 2021 were used[10] to find the optimal values of these parameters corresponding to the 10th epidemic wave in Ukraine. In particular, the optimal value of the visibility coefficient was determined to be $\beta_{10} = 3.7$.

Monitoring changes in epidemic parameters and selection of epidemic waves

Changes in the epidemic conditions (in particular, the peculiarities and violations of quarantine, situations with testing and isolation of patients, vaccinations, and emergence of new pathogen strains) affect the dynamics or, in other words, lead to new epidemic waves. To control these changes, we can use daily or weekly numbers of new cases and their derivatives.[7,8,11,19] Since these values are random, smoothing is needed, especially for daily amounts, which are also characterized by some weekly periodicity. For example, we can determine the smoothed daily number of accumulated cases by:

$$\bar{V}_i = \frac{1}{7}\sum_{j=i-3}^{j=i+3} V_j \quad (4)$$

The first and second derivatives can be estimated with the following formulas:

$$\left.\frac{d\bar{V}}{dt}\right|_{t=t_i} \approx \frac{1}{2}\left(\bar{V}_{i+1} - \bar{V}_{i-1}\right) \quad (5)$$

$$\left.\frac{d^2\bar{V}}{dt^2}\right|_{t=t_i} \approx \bar{V}_{i+1} - 2\bar{V}_i + \bar{V}_{i-1} \quad (6)$$

Table 1. Cumulative numbers of laboratory-confirmed COVID-19 cases in Ukraine, V_j, in the spring and summer of 2021 according to the national statistics[30,31]

Day in corresponding month of 2021	Number of cases in March, V_j	Number of cases in April, V_j	Number of cases in May, V_j	Number of cases in June, V_j	Number of cases in July, V_j	Number of cases in August, V_j	Number of cases in September, V_j
1	1,357,470	1,711,630	2,083,180	2,206,836	2,236,497	2,253,534	2,290,848
2	1,364,705	1,731,971	2,085,938	2,209,417	2,237,202	2,254,361	2,293,541
3	1,374,762	1,745,709	2,088,410	2,211,683	2,237,579	2,255,345	2,296,155
4	1,384,917	1,755,888	2,090,986	2,213,580	2,237,823	2,256,397	2,297,534
5	1,394,061	1,769,164	2,097,024	2,214,517	2,238,364	2,257,478	2,298,307
6	1,401,228	1,784,579	2,105,428	2,215,052	2,238,974	2,258,532	2,300,504
7	1,406,800	1,803,998	2,114,138	2,216,654	2,239,591	2,259,151	2,303,276
8	1,410,061	1,823,674	2,119,510	2,218,039	2,240,246	2,259,451	2,306,939
9	1,416,438	1,841,137	2,122,327	2,219,824	2,240,753	2,260,232	2,310,554
10	1,425,522	1,853,249	2,124,535	2,221,427	2,241,043	2,261,354	2,314,423
11	1,438,468	1,861,105	2,129,073	2,222,701	2,241,217	2,262,601	2,316,619
12	1,451,744	1,872,785	2,135,886	2,223,558	2,241,698	2,263,864	2,317,824
13	1,460,756	1,887,338	2,143,448	2,223,978	2,242,245	2,265,217	2,321,156
14	1,467,548	1,903,765	2,150,244	2,224,992	2,242,868	2,265,912	2,325,796
15	1,477,190	1,921,244	2,153,864	2,226,037	2,243,605	2,266,329	2,331,540
16	1,489,023	1,936,228	2,156,000	2,227,225	2,244,196	2,267,219	2,338,164
17	1,504,076	1,946,510	2,160,095	2,228,192	2,244,495	2,268,666	2,344,398
18	1,519,926	1,953,016	2,165,233	2,229,044	2,244,677	2,270,226	2,348,381
19	1,535,218	1,961,956	2,170,398	2,229,523	2,245,275	2,271,826	2,350,646
20	1,546,363	1,974,118	2,175,382	2,229,846	2,245,930	2,273,558	2,355,805
21	1,554,256	1,990,353	2,179,988	2,230,142	2,246,656	2,274,561	2,362,559
22	1,565,732	2,004,630	2,182,521	2,230,977	2,247,419	2,275,171	2,370,425
23	1,579,906	2,017,341	2,183,855	2,231,914	2,248,164	2,275,863	2,379,483
24	1,596,575	2,025,271	2,186,463	2,232,790	2,248,450	2,276,590	–
25	1,614,707	2,030,333	2,189,858	2,233,546	2,248,663	2,278,171	–
26	1,632,131	2,038,248	2,193,367	2,233,996	2,249,344	2,280,203	–
27	1,644,063	2,047,838	2,196,673	2,234,281	2,250,061	2,282,285	–
28	1,652,409	2,059,465	2,199,769	2,234,463	2,250,907	2,284,191	–
29	1,662,942	2,069,537	2,201,472	2,235,096	2,251,869	2,284,940	–
30	1,674,168	2,078,086	2,202,494	2,235,801	2,252,785	2,286,296	–
31	1,691,737	–	2,204,631	–	2,253,269	2,288,371	–

Results

In this work, SIR simulations of the 11^{th} pandemic wave in Ukraine were performed based on the number of laboratory-confirmed cases (in the period T_{c11}: May 23 to June 5, 2021, presented in Table 1), supposing $\beta_i = 1$ for $i = 11$. The optimal values of parameters and other characteristics of this wave were calculated and are listed in Table 3 (middle column). Comparison with the corresponding values for the 10^{th} epidemic wave in Ukraine indicates a large difference between the optimal values of SIR parameters for the 11^{th} and 10^{th} pandemic waves.[10] In particular, the estimated average time of spreading the infection in the 10^{th} wave, $1/\rho_{11} = 4.1$ days, is much less than $1/\rho_{10} = 22.3$ days in the 10^{th} wave. Moreover, the duration of the 11^{th} epidemic wave (ended on August 25, 2021, corresponding to the moment when the number of infectious persons becomes less than one) was optimistic compared to the 10^{th} wave (ended on March 29, 2022).

The difference in saturation levels (final sizes) was found to be rather small ($V_{11\infty} = 2,226,797$ and $V_{10\infty} = 1,783,175$). As of July 18, 2021, the registered number of COVID-19 cases in Ukraine

Table 2. The daily number of new COVID-19 cases per capita (DCC), new deaths per capita (DDC), daily number of tests per capita (DTC), and the percentage of fully vaccinated people (VC) in Israel and Ukraine in the period of June 1 to September 3, 2021[32]

Day in 2021	New cases per million DCC	New deaths per million DDC	New tests per thousand DTC	People fully vacci-nated, %, VC	New cases per million DCC	New deaths per million DDC	New tests per thousand DTC	People fully vacci-nated, %, VC
	Israel				Ukraine			
June								
1	4.096	0.114	2.474	58.47	52.178	3.888	0.609	0.3
2	0.683	0.228	1.962	58.48	53.719	3.796	0.643	0.32
3	1.707	0.114	1.798	58.5	62.277	2.485	0.609	0.33
4	0.796	0.114	2.047	58.5	55.053	2.347	0.66	0.34
5	3.072	0.114	0.834	58.5	46.725	2.163	0.669	0.34
6	0.569	0	1.824	58.51	24.732	1.081	0.385	0.34
7	1.593	0	2.618	58.52	15.345	0.851	0.247	0.35
8	0	0	2.417	58.53	39.939	2.876	0.767	0.37
9	0	0	1.927	58.55	34.992	1.91	0.583	0.42
10	5.12	1.138	2.011	58.56	44.264	2.393	0.667	0.47
11	2.617	0	1.988	58.56	40.192	1.748	0.594	0.53
12	0.91	0	1.187	58.56	32.761	1.725	0.621	0.55
13	0.569	0.228	2.11	58.58	23.443	0.851	0.394	0.55
14	2.73	−0.228	2.996	58.59	13.597	0.391	0.268	0.6
15	1.251	0	2.56	58.61	27.538	1.886	0.743	0.66
16	2.162	0	2.093	58.62	28.366	1.979	0.652	0.72
17	3.072	−0.114	1.887	58.63	31.932	1.403	0.622	0.78
18	2.503	0	2.309	58.63	27.101	1.288	0.596	
19	6.94	0	1.44	58.63	24.824	1.035	0.609	0.83
20	4.209	0	2.805	58.65	16.633	0.667	0.319	0.83
21	13.994	0	3.688	58.66	13.505	0.483	0.206	0.83
22	10.125	0.114	3.517	58.67	13.182	0.644	0.273	0.91
23	16.61	0	3.374	58.68	25.905	1.817	0.605	1
24	24.915	0.114	3.4	58.7	28.712	1.541	0.518	1.13
25	22.071	0	4.524	58.71	27.699	1.449	0.448	1.27
26	21.047	0	2.487	58.71	25.514	1.012	0.5	1.32
27	7.395	0	3.457	58.75	18.842	0.575	0.32	1.33
28	35.041	0	5.423	58.79	15.575	0.437	0.278	1.36
29	32.993	0	5.331	58.83	13.367	0.322	0.251	1.49
30	33.107	0	4.965	58.86	23.972	1.15	0.518	
July								
1	32.993	0	5.074	58.9	25.767	1.449	0.481	1.76
2	34.586	0	5.654	58.92	25.836	0.989	0.455	
3	31.514	0	3.089	58.92	26.25	1.104	0.459	1.94
4	36.52	−0.114	4.153	58.95	19.003	0.529	0.327	1.96
5	56.429	0.114	6.12	58.99	16.15	0.598	0.228	2.07
6	48.579	0	6.904	59.02	22.845	0.713	0.464	2.2

(continued)

Table 2. *(continued)*

Day in 2021	New cases per million DCC	New deaths per million DDC	New tests per thousand DTC	People fully vacci-nated, %, VC	New cases per million DCC	New deaths per million DDC	New tests per thousand DTC	People fully vacci-nated, %, VC
	Israel				Ukraine			
7	55.292	0	6.24	59.05	24.432	1.035	0.466	2.34
8	69.513	0.341	5.929	59.08	24.709	0.782	0.413	2.49
9	44.37	0.228	6.997	59.1	25.813	0.529	0.422	2.63
10	49.148	0.114	3.933	59.1	22.592	0.736	0.426	2.68
11	36.747	0.341	4.832	59.13	17.922	0.345	0.296	2.71
12	21.957	0	7.069	59.17	15.299	0.391	0.221	2.8
13	145.055	0.228	7.076	59.23	22.362	1.127	0.481	2.9
14	81.913	0.114	7.177	59.32	23.995	0.828	0.427	3
15	108.308	0.228	7.464	59.42	25.836	0.713	0.449	3.13
16	94.428	0.114	9.315	59.49	28.827	0.621	0.42	3.24
17	98.296	0.228	3.754	59.5	25.698	0.621	0.414	3.27
18	85.895	0.341	6.451	59.61	19.256	0.437	0.309	3.29
19	138.798	0.114	9.582	59.74	16.495	0.299		3.36
20	169.629	0.228	10.307	59.87	26.089	0.874		3.45
21	127.193	0.228	9.77	60	27.492	0.552		3.58
22	163.144	0.341	8.967	60.15	28.965	0.782		3.72
23	112.745	0	11.178	60.24	29.862	0.736		3.87
24	161.665	0.114	6.908	60.26	29.839	0.828		3.92
25	142.666	0.228	8.763	60.43	19.348	0.506		3.94
26	234.932	0.114	11.693	60.59	17.807	0.276		4.05
27	249.722	0	12.063	60.74	28.228	0.897		4.18
28	264.853	0.114	11.701	60.88	29.149	0.667		4.31
29	207.4	0.455	11.611	61.04	32.116	0.92		4.46
30	259.392	0.341	12.643	61.16	34.739	0.736		4.6
31	304.331	0.455	8.4	61.2	33.566	0.805		4.65
August								
1	202.849	0.455	9.176	61.23	23.558	0.483		4.68
2	437.895	1.138	12.947	61.27	18.497	0.437		4.8
3	358.143	0.91	12.59	61.3	31.426	1.081		4.95
4	337.665	0.91	13.344	61.34	34.969	1.472		5.1
5	504.563	0.683	13.21	61.38	36.994	1.104		5.25
6	330.384	0.796	13.198	61.4	38.374	0.851		5.41
7	480.217	2.162	9.542	61.41	37.891	1.012	0.512	5.48
8	359.054	0.796	10.565	61.44	27.929	0.713	0.42	5.53
9	673.851	1.934	16.164	61.47	20.843	0.529	0.216	5.65
10	473.732	1.365	15.112	61.51	32.07	1.081	0.499	5.8
11	872.377	1.82	15.894	61.54	39.916	0.92	0.544	5.94
12	742.34	1.934	14.768	61.58	42.975	1.012	0.507	6.06

(continued)

Table 2. *(continued)*

Day in 2021	New cases per million DCC	New deaths per million DDC	New tests per thousand DTC	People fully vaccinated, %, VC	New cases per million DCC	New deaths per million DDC	New tests per thousand DTC	People fully vaccinated, %, VC
	Israel				Ukraine			
13	513.324	0.796	14.911	61.6	43.228	1.472	0.513	6.19
14	639.607	1.251	9.46	61.61	45.23	0.943	0.574	6.25
15	507.863	5.233	10.546	61.66	30.115	0.759		6.3
16	989.559	2.162	17.379	61.71	23.65	0.713		6.42
17	938.818	1.934	16.989	61.77	34.486	1.081		6.56
18	669.3	2.162	17.277	61.82	47.139	1.38	0.622	6.69
19	957.135	3.299	16.666	61.87	49.67	1.265	0.543	6.86
20	865.324	0.796	17.135	61.91	50.383	1.081	0.54	7.05
21	827.894	1.82	11.656	61.92	53.328	1.334	0.631	7.15
22	572.825	6.257	12.624	61.98	36.58	0.943		7.22
23	976.817	2.958	18.03	62.03	27.354	0.644		7.32
24	1,378.078	2.73	17.703	62.08	29.103	1.081		7.34
25	751.1	3.186	16.907	62.13	29.701	0.989		7.62
26	1,188.426	3.299	16.991	62.18	48.704	1.518	0.532	7.89
27	722.658	1.138	15.938	62.21	58.872	2.002	0.53	8.14
28	1,271.591	0.341	12.222	62.23	59.54	1.794	0.635	8.27
29	660.881	4.437	10.385	62.3	55.076	1.219	0.422	8.33
30	1,123.919	6.144	17.296	62.38	27.975	0.782	0.218	8.56
31	553.37	0	18.467	62.45	41.296	1.61	0.491	8.8
September								
1	1,891.857	4.892	17	62.51	57.239	1.426	0.647	8.99
2	1,581.383	4.096	16.038	62.59	66.05	1.449	0.541	9.23
3	920.388	0.796		62.63	70.836	1.449	0.542	9.5

(2,244,677) had already exceeded the saturation level of the 11th epidemic wave. Since the difference recorded on day 43 after the last day of the period, T_{c11}, was only 0.8%, we can confirm the suitability of the generalized SIR model for forecasting pandemic dynamics. The corresponding SIR curves (black lines), registered number of cases, and the derivatives (5) and (6) (red markers) are shown in Figure 1.

The rapid increase in values of the second derivative (6) (red dots in Fig. 1) illustrates the changes in the epidemic dynamics in the first half of May 2021 (most likely due to the holidays). The values of the first derivative (5) (represented by red crosses in Fig. 1) are in good agreement with the theoretical estimation (2) (black dotted line) for the period T_{c11} but deviate for the previous moments of time, indicating significant changes in the epidemic dynamics. We can see also higher values of the first derivative (5) in comparison with the estimation (2) (see black dotted line) after the period T_{c11}. In particular, as of July 15, 2021, the estimation (2) yielded a value of 13, but the average registered daily number of new cases (5) was 503. This finding and the second derivative values close to zero (eq. (6), red "dots") indicate the beginning of a new epidemic wave.

The last column of Table 3 presents the results of SIR simulations with the non-prescribed value of β_i. The maximum of the correlation coefficient r_{11} was achieved at $\beta_{11} = 20.376$, which suggests that the vast majority of COVID-19 cases in Ukraine are undocumented (the real number of cases is probably approximately 20 times higher than the registered number). The real final size of the 11th epidemic wave, $V_{11\infty}$, is expected to be around 45.4 million persons, which exceeds the population of Ukraine. If we multiply the number of registered cases (2,244,677 as of July 18, 2021) by the visibility coefficient $\beta_{11} = 20.376$, the result of 45.7 million persons is even higher. It is likely that millions of Ukrainians have already been re-infected and that the nation has achieved natural collective immunity (as of July 18, 2021, the percentage of fully vaccinated persons was only 3.5%).

If the calculated value of the visibility coefficient β_{11} is correct, the mortality rate in Ukraine is not high. To estimate the actual value of the deaths per case ratio, we considered the registered number of deaths (52,726 as of July 17, 2021). While all deaths caused by coronavirus have not likely been reported, the visibility rate of mortalities is less than 20.376 due to the fact that critically ill patients usually go to hospitals and the corresponding deaths are properly recorded. Thus, the most optimistic estimation of the mortality rate is 52,726*100%/(2,244,495*20.376) = 0.12%.

Table 3. Visible and real characteristics of the eleventh COVID-19 pandemic wave in Ukraine; results are the calculated optimal values of SIR parameters and other characteristics

Characteristics	11th epidemic wave, $i = 11$, $\beta_{11} = 1$	11th epidemic wave, $i = 11$, $\beta_{11} = 20.376$
Time period taken for calculations T_{ci}	May 23 to June 5, 2021	May 23 to June 5, 2021
I_i	10,190.8327995721	207,648.409124103
R_i	2,180,167.16720043	44,423,086.1988759
N_i	2,258,464	46,018,462.464
v_i	60,891.3982283695	1,240,723.13030139
α_i	3.98540619731056e−06	1.95593158486001e−07
ρ_i	0.242676955862249	0.242676955862287
$1/\rho_i$	4.12070440082342	4.12070440082277
r_i	0.996838194153353	0.996838194153390
$S_{i\infty}$	31,667	645,251
$V_{i\infty}$	2,226,797	45,373,211
Final day of the epidemic wave	August 25, 2021	September 20, 2021

As in the case of $\beta_i = 1$, there is a large difference between the optimal values of SIR model parameters of the 10th and 11th epidemic waves (comparing last column of Table 3 with a table from a previous report[10]). In particular, this difference is correlated with the much higher value of the visibility coefficient for the 11th wave ($\beta_{11} = 20.376$ in comparison with $\beta_{10} = 3.7$). The optimistic prediction that the 11th epidemic wave ended on September 20, 2021 is most likely not reliable since the beginning of a new epidemic wave was already visible in Figure 1. In addition, there is no guarantee that the emergence or import of new coronavirus strains, which could cause new epidemic waves, can be prevented in Ukraine.

Using the optimal values of parameters in the last column of Table 3, SIR curves corresponding to the real epidemic dynamics with the use of the exact solution[10,20] were calculcated. These results are represented by blue lines in Figure 2, in which the solid line indicates complete accumulated number of cases (visible and invisible); the dashed line refers to the complete number of infectious persons multiplied by 100, i.e. $I(t)x100$; and the dotted black lines represent the derivative dV/dt (which is an estimation of the real daily number of new cases) calculated with the use of (2) and multiplied by 100.

The estimated real average number of new daily cases for the 11th wave (red crosses in Fig. 2) were determined by multiplying the derivative (5) by $100\beta_{11}$. These values are in good agreement with the theoretical estimation (2) for the period T_{c11} (May 23 to June 5, 2021) but deviate for the moments of time before and after this period (similar to the visible dynamics in Fig. 1). The red line in Figure 2 represents the smoothed accumulated number of laboratory-confirmed cases (eq. (4)) multiplied by the optimal value of the visibility coefficient $\beta_{11} = 20.376$, which is in very good agreement with the theoretical blue solid line before a new epidemic wave that started in July 2021.

In Figure 3, crosses correspond to the cases in Israel, and triangles represent cases in Ukraine. The smoothed DCC, DDC, DTC, and VC values are indicated by blue, black, magenta, and red colors, respectively. It can be seen that the large percentage of vaccinated persons in Israel (approximately 60%, red "crosses") did not prevent the emergence of a new epidemic wave after June 15, 2021 (blue "crosses"), and an increase in the number of deaths (see black "crosses") occurred after July 5, 2021. In Ukraine, a new wave of the pandemic beginning after July 10, 2021 is characterized by lower DCC (blue "triangles") and DDC (black "triangles") values, despite having a much lower level of vaccinated people (VC) than in Israel (compare red markers in Fig. 3).

A possible reason for such a paradoxical situation may be due to the much smaller number of tests and, thus, higher number of undetected COVID-19 cases in Ukraine. Comparatively, the daily number of tests per capita in Israel was approximately 30 times higher (compare magenta markers). In addition, the corresponding visibility coefficients in Ukraine varied from 3.7 to 20.4 for different epidemic waves in the time period December 2020 – June 2021, but were most likely much smaller for Israel.

Discussion

It is pertinent to know the real characteristics of the COVID-19 pandemic in order to evaluate the effectiveness of vaccinations and natural immunity. From which, we can also estimate the probability of meeting an infected person with the use of simple formula:[7,8]

$$p(t) = \frac{I(t)}{N_{pop}}$$

where N_{pop} is the population volume. As of July 19, 2021, the theoretical estimations (using the parameters presented in the last column of Table 3) yielded the value $I = 1{,}656$ (blue dashed line in Fig. 2), and the probability p was estimated to be 0.00004, which is much lower than the corresponding estimation of 0.015 for the end of March 2021.[10] This indicates that Ukrainians could be welcome guests in many countries in July 2021, but probably not in September 2021 during the new epidemic wave.

To clarify the influence of vaccinations in Israel, we calculated the smoothed DCC, DDC, DTC, and VC values for the period of June 1, 2020 to June 1, 2021 using datasets from JHU.[26] According to the results in Figure 4, the maximal averaged number of daily new cases corresponding to previous pandemic waves in Israel (September 2020 and January 2021, i.e., before vaccinations) were lower than the DCC values in August 2021 (compare

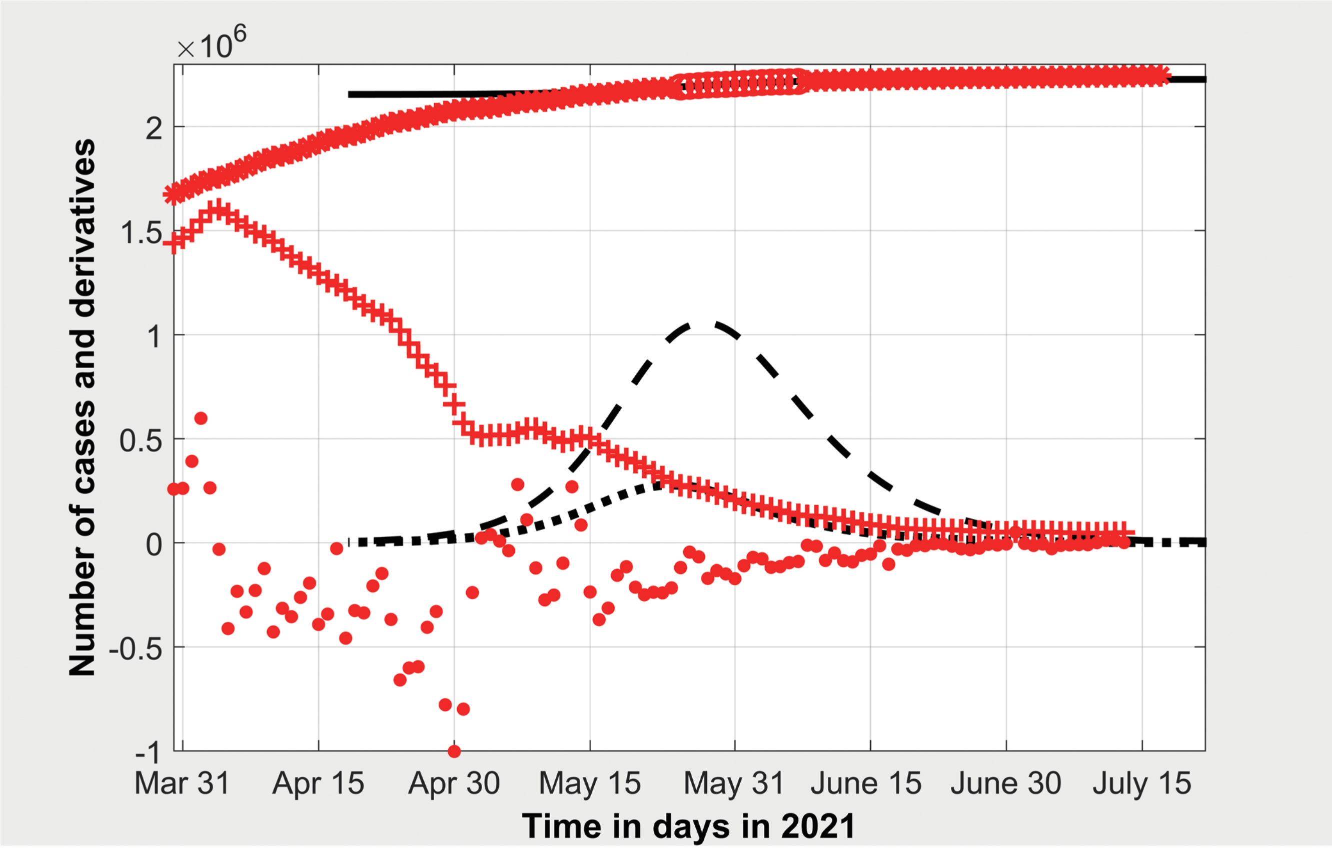

Fig. 1. Visible COVID-19 epidemic dynamics in Ukraine in the spring and summer of 2021. The results of SIR simulations of the eleventh wave at $\beta_{11} = 1$ are shown by black lines. Numbers of victims *V(t) = I(t) + R(t)* – solid line; numbers of infected and spreading *I(t)* multiplied by 100 – dashed line; derivatives *dV/dt* (eq. (2)) multiplied by 100 – dotted line. Red "circles" and "stars" correspond to the accumulated numbers of cases registered during the period of time taken for SIR simulations (May 23 – June 5, 2021, Table 1) and beyond this time period, respectively. The red "crosses" and "dots" show the first derivative (5) multiplied by 100 and the second derivative (6) multiplied by 1,000, respectively.

blue "crosses" in Figs. 3 and 4). However, this difference cannot be explained by testing levels, since DTC values in January and August 2021 were similar (compare magenta "crosses" in Figs. 3 and 4). Unfortunately, the mortality rates in August 2021 were close to their maximum values in October 2020 and January-February 2021 (compare black "crosses" in Figs. 3 and 4). It must be noted that some quarantine restrictions were reinstituted in Israel in the summer of 2021 (including the mandatory wearing of mask indoors on June 25, 2021 and the green pass requirement for indoor events with more than 100 participants on July 29, 2021).

We can conclude that even a high vaccination rate of 60% does not allow refusing quarantine and does not reduce overall mortality. While high vaccination rates are likely to reduce mortality in the elderly,[27] this requires specialized study. Probably, higher levels of vaccination will be able to reduce the mortality.[14] Nevertheless, further research on these issues is still needed, for which reports on the pandemic dynamics in Qatar may be useful.

In Qatar, the vaccination rate exceeded 74.4% as of September 6, 2021,[26] and an almost monotonous decline in DCC values was observed in summer 2021 (after a small increase at the end of August 2021, we again see smaller values in September[26]). The averaged registered DCC values are consistent with the forecast for the real dynamics in this country, considering the calculated visibility coefficient of 5.3.[24] According to this forecast, the end of the epidemic in Qatar is not expected to occur before January 16, 2022.

Future directions

Further monitoring of the COVID-19 pandemic is necessary to compare its dynamics in Ukraine and Israel. The visibility coefficients for these countries must be calculated with the use of datasets of laboratory-confirmed numbers of cases for same period of time in order to estimate the actual numbers of cases, including asymptomatic patients who were not tested or registered. It is highly important to clarify the effect of DTC values and the number of tests per case (DTC/DCC) on the visibility coefficients. This knowledge will allow us to clarify the effect of vaccinations and natural immunity on DCC and DDC. Based on the preliminary results of this study, we hypothesize that high levels of vaccinations and natural collective immunity are unlikely to prevent new waves of the COVID-19 pandemic predominantly caused by new mutated strains.

Conclusions

The high value of the visibility coefficient (20.4) calculated for the previous epidemic wave in Ukraine leads us to conclude that Ukrain-

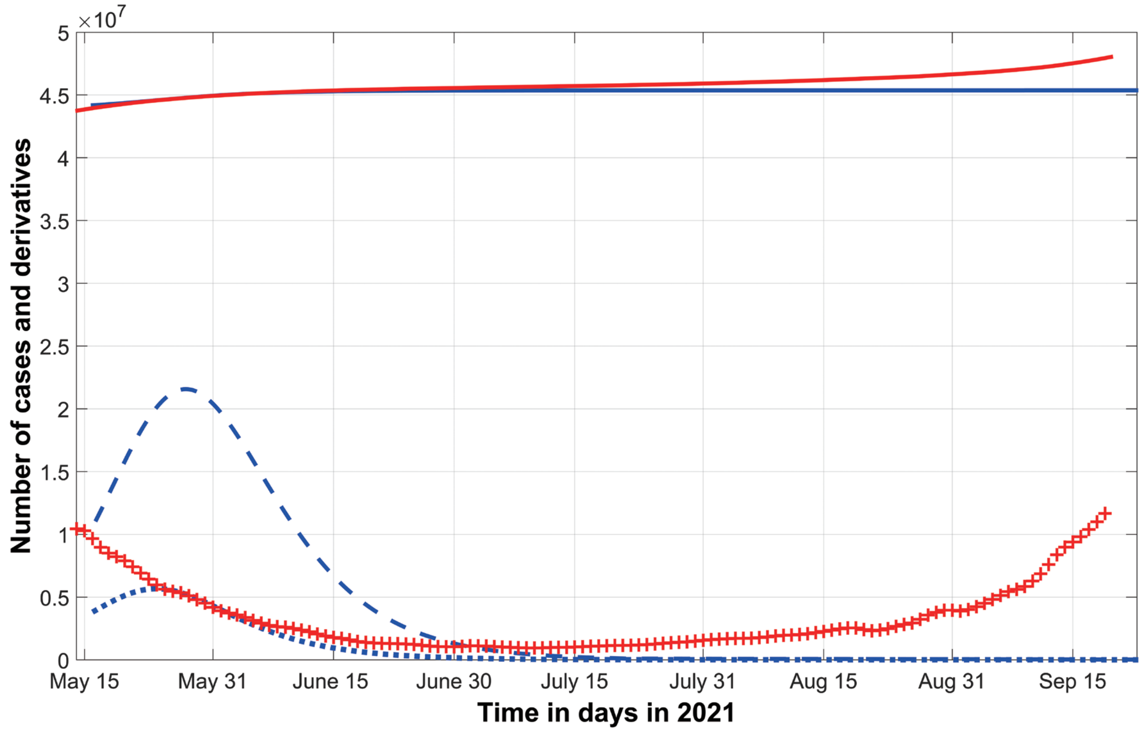

Fig. 2. Real COVID-19 epidemic dynamics in Ukraine in the summer of 2021. The results of SIR simulations of the eleventh wave at the optimal value β_{11} = 20.376 are represented by blue lines. Numbers of victims *V(t) = I(t) + R(t)* – solid lines; numbers of infected and spreading *I(t)* multiplied by 100 – dashed line; derivatives *dV/dt* (eq. (2)) multiplied by 100 – dotted line. The red solid line shows smoothed accumulated number of laboratory-confirmed cases (eq. (4)) multiplied by the optimal value β_{11} = 20.376. The red "crosses" indicate the first derivative (5) multiplied by $100\beta_{11}$.

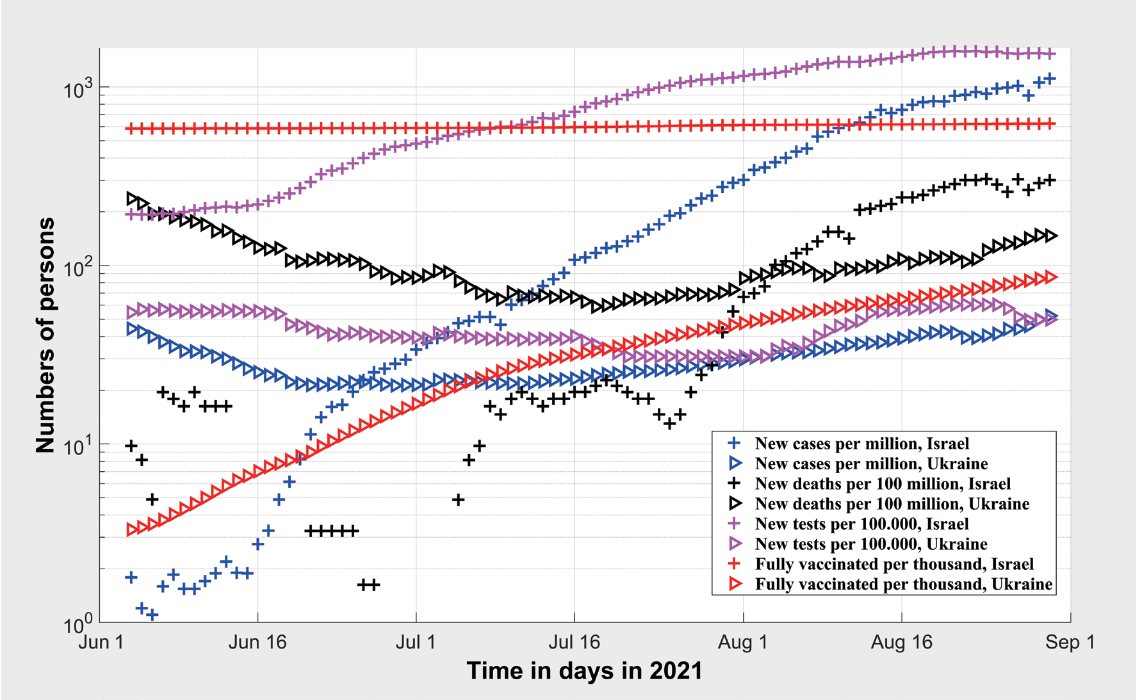

Fig. 3. COVID-19 pandemic dynamics in Ukraine and Israel in the summer of 2021. Averaged numbers of new cases per capita (DCC, blue), new deaths per capita (DDC, black), daily number of tests per capita (DTC, magenta) and the percentage of fully vaccinated people (VC, red) registered in Israel ("crosses") and Ukraine ("triangles") in the summer of 2021.

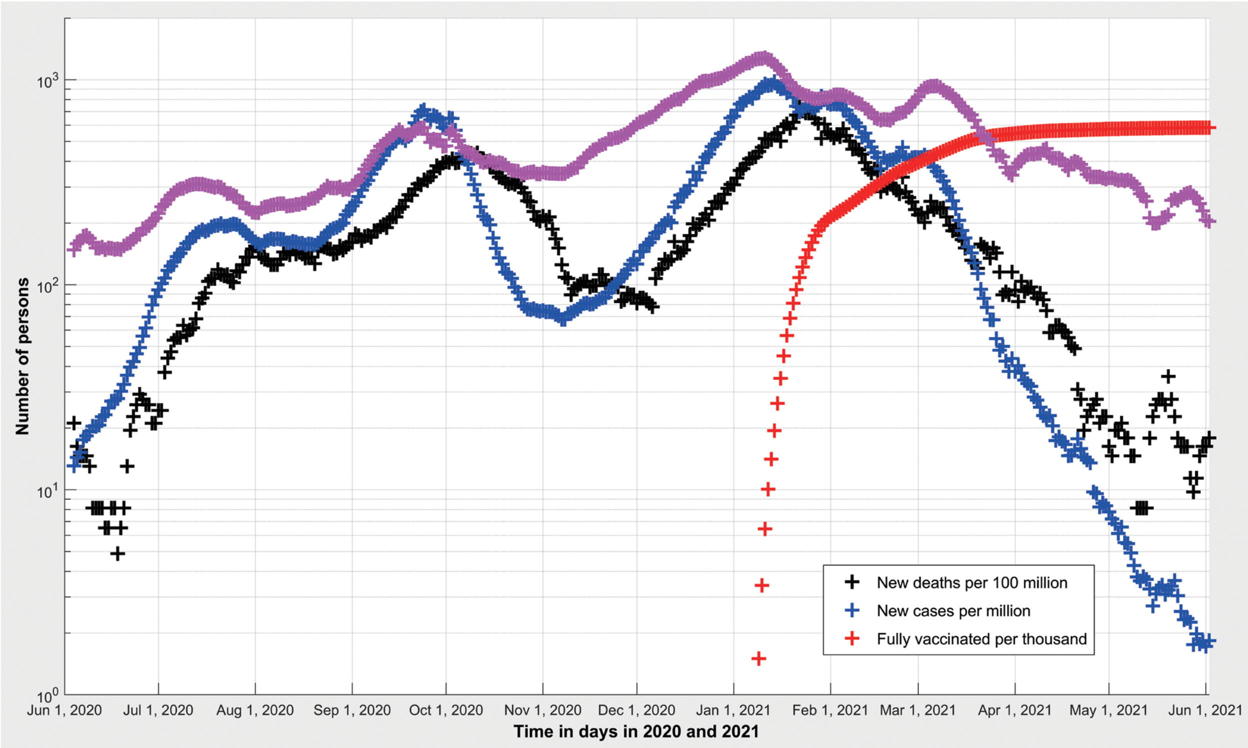

Fig. 4. COVID-19 pandemic dynamics in Israel for the period of June 2020 to May 2021. Averaged numbers of new cases per capita (DCC, blue), new deaths per capita (DDC, black), daily number of tests per capita (DTC, magenta) and the percentage of fully vaccinated people (VC, red) registered in Israel for the period June 1, 2020 – June 1, 2021.

ians have probably achieved collective immunity against coronavirus. Nevertheless, in the wake of the new epidemic wave that started in July 2021, we do not predict that the number of new cases and mortality rate in this country will not considerably increase. Similar dynamics occurred in Israel with a rather high level of vaccinations (more than 60%). Our study suggests that high levels of vaccination and natural collective immunity are unlikely to prevent new waves of the COVID-19 pandemic caused by mutated coronavirus strains.

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Conflict of interest

The author states no conflict of interests.

Ethical statement

No human or animal subjects were involved in this study.

Data sharing statement

The data used to support the findings of this study are available from the corresponding author upon request.

References

[1] Rossman H, Shilo S, Meir T, Gorfine M, Shalit U, Segal E. COVID-19 dynamics after a national immunization program in Israel. Nat Med 2021;27(6):1055–1061. doi:10.1038/s41591-021-01337-2.
[2] Aran D. Estimating real-world COVID-19 vaccine effectiveness in Israel using aggregated counts. medRxiv (Preprint) 2021:21251139. doi:10.1101/2021.02.05.21251139.
[3] De-Leon H, Calderon-Margalit R, Pederiva F, Ashkenazy Y, Gazit D. First indication of the effect of COVID-19 vaccinations on the course of the COVID-19 outbreak in Israel. medRxiv (Preprint) 2021:21250630. doi:10.1101/2021.02.02.21250630.
[4] Pardhan S, Drydakis N. Associating the Change in New COVID-19 Cases to GDP per Capita in 38 European Countries in the First Wave of the Pandemic. Front Public Health 2021;8:582140. doi:10.3389/fpubh.2020.582140.
[5] Chintala S, Dutta R, Tadmor D. COVID-19 spatiotemporal research with workflow-based data analysis. Infect Genet Evol 2021:88:104701. doi:10.1016/j.meegid.2020.104701.
[6] Nesteruk I, Kydybyn IB, Demelmair G. Global Stabilization Trends of COVID-19 Pandemic. KPI Science News 2020:2:55–62. doi:10.20535/kpi-sn.2020.2.205124.
[7] Nesteruk I. Simulations and predictions of COVID-19 pandemic with the use of SIR model. Innov Biosyst Bioeng 2020;4(2):110–121. doi:10.20535/ibb.2020.4.2.204274.
[8] Nesteruk I. COVID-19 Pandemic Dynamics: Mathematical Simulation.

1st edition. Singapore: Springer Nature; 2021. doi:10.1007/978-981-33-6416-5.
[9] Nesteruk I, Benlagha N. Predictions of COVID-19 Pandemic Dynamics in Ukraine and Qatar Based on Generalized SIR Model. Innov Biosyst Bioeng 2021;5(1):37–46. doi:10.20535/ibb.2021.5.1.228605.
[10] Nesteruk I. Visible and Real Sizes of New COVID-19 Pandemic Waves in Ukraine. Innov Biosyst Bioeng 2021;5(2):85–96. doi:10.20535/ibb.2021.5.2.230487.
[11] Nesteruk I. Detections and SIR simulations of the COVID-19 pandemic waves in Ukraine. Comput Math Biophys 2021;9:46–65. doi:10.1515/cmb-2020-0117.
[12] Nesteruk I. Will a natural collective immunity of Ukrainians restrain new COVID-19 waves? medRxiv (Preprint) 2021:21260840. doi:10.1101/2021.07.20.21260840.
[13] Nesteruk I. Comparison of the COVID-19 pandemics dynamics in Ukraine and Israel in the summer of 2021. ResearchGate (Preprint) 2021. doi:10.13140/RG.2.2.29989.22249.
[14] Nesteruk I, Rodionov O. Impact of Vaccination and Testing Levels on the Dynamics of the COVID-19 Pandemic and its Cessation. J Biomed Res Environ Sci 2021;2(11):1141–1147. doi:10.37871/jbres1361.
[15] Kermack WO, McKendrick AG. A contribution to the mathematical theory of epidemics. Proceedings of the Royal Society A 1927;115(772):700–721. doi:10.1098/rspa.1927.0118.
[16] Murray JD. Mathematical Biology II: Spatial Models and Biomedical Applications. New York: Springer; 2003. doi:10.1007/b98869.
[17] Langemann D, Nesteruk I, Prestin J. Comparison of mathematical models for the dynamics of the Chernivtsi children disease. Mathematics and Computers in Simulation 2016;123:68–79. doi:10.1016/j.matcom.2016.01.003.
[18] Nesteruk I. Statistics based models for the dynamics of Chernivtsi children disease. Naukovi Visti NTUU KPI 2017;5:26–34. doi:10.20535/1810-0546.2017.5.108577.
[19] Nesteruk I. Identification of the New Waves of the COVID-19 Pandemic. In: COVID-19 Pandemic Dynamics. Singapore: Springer Nature; 2021. doi:10.1007/978-981-33-6416-5_8.
[20] Nesteruk I. General SIR Model and Its Exact Solution. In: COVID-19 Pandemic Dynamics. Singapore: Springer Nature; 2021. doi:10.1007/978-981-33-6416-5_9.
[21] Nesteruk I. Procedures of Parameter Identification for the Waves of Epidemics. In: COVID-19 Pandemic Dynamics. Singapore: Springer Nature; 2021. doi:10.1007/978-981-33-6416-5_10.
[22] Weinberger DM, Cohen T, Crawford FW, Mostashari F, Olson D, Pitzer VE, *et al*. Estimating the early death toll of COVID-19 in the United States. medRxiv (Preprint) 2020:20066431. doi:10.1101/2020.04.15.20066431.
[23] Nesteruk I. Visible and real dynamics of the COVID-19 pandemic in Ukraine in the spring of 2021. medRxiv (Preprint) 2021:21258838. doi:10.1101/2021.06.13.21258838.
[24] Nesteruk I. The real COVID-19 pandemic dynamics in Qatar in 2021: simulations, predictions and verifications of the SIR model. September. Semina Ciências Exatas e Tecnológicas 2021;42(1Supl):55–62. doi:10.5433/1679-0375.2021v42n1Suplp55.
[25] Coronavirus in Ukraine - Statistics - Map of infections, graphs (in Ukrainian). Minfin.com.ua 2021. Available from: https://index.minfin.com.ua/ua/reference/coronavirus/ukraine/. Accessed October 09, 2021.
[26] COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU). Available from: https://github.com/owid/covid-19-data/tree/master/public/data. Accessed October 09, 2021.
[27] Covid, today's bulletin in Italy: 6,157 cases and 56 deaths (in Italian). la Repubblica 2021. Available from: https://www.repubblica.it/cronaca/2021/09/04/news/coronavirus_italia_il_bollettino_di_oggi_4_settembre-316467079/?ref=RHTP-BH-I315657642-P2-S2-T1. Accessed October 09, 2021.