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Impact of Ukrainian Refugees on the COVID-19 Pandemic Dynamics after February 24, 2022

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Abstract: On February 24, 2022 Russia started the full-scale invasion of Ukraine, which created an unprecedented number of refugees. To estimate the influence of this humanitarian disaster on the COVID-19 pandemic dynamics, the averaged daily numbers of cases and reproduction numbers in Ukraine, the UK, Poland, Germany, the Republic of Moldova, and in the whole world were calculated for the period February-April 2022. The registered numbers of cases were compared with ones calculated with the use of the generalized SIR-model and corresponding parameter identification procedure for the previous epidemic waves in Ukraine, Poland, Germany, and the world. Since before February 24, 2022 the estimation of the number of infectious persons per capita in Ukraine 3.6 times exceeded the global figure, the increase of the number the new cases and the pandemic duration was expected. In March 2022 the increase of the averaged number of new cases in the UK, Germany, and worldwide was visible. A simple formula to estimate the effective reproduction number based on the smoothed accumulated numbers of cases is proposed. The results of calculations agree with the figures presented by John Hopkins University and demonstrate a short-term growth of the reproduction number in the UK, Poland, Germany, Moldova, and worldwide in March 2022.

Keywords: COVID-19 pandemic; epidemic waves; epidemic dynamics in Ukraine; Poland; Germany; Moldova; the UK; global pandemic dynamic; mathematical modeling of infection diseases; SIR model; parameter identification; reproduction number; statistical methods

1. Introduction

Russia's full-scale criminal war in Ukraine has caused a real humanitarian catastrophe, the scale of which deserves appropriate assessment and punishment. As of March 23, 2022, more than 3.5 million Ukrainians have been forced to flee their homes and seek refuge abroad [1]. Such mass migration can lead to a significant increase in the numbers of COVID-19 cases [2, 3] and in the reproduction rates.

In this paper we will try to reveal these trends by comparing the averaged numbers of new cases in the UK, Poland, Germany, the Republic of Moldova, and the world registered after February 24, 2022. In addition, simple formulae for the reproduction number will be proposed and used for calculations and comparisons with the values available in [4]. The relationships predicted for the previous epidemic waves with the use of a generalized SIR-model and a corresponding parameter identification procedure [5, 6] will be applied to identify the changes in the pandemic dynamics after February 24, 2022. In particular, results of SIR simulations for the 14th epidemic wave in Ukraine [7], 7th global pandemic wave [7], 4th wave in Poland [8] and 5th wave in Germany [8] will be used for comparison.

2. Data, Smoothing Procedure, and Generalized SIR Model

We will use the data set regarding the accumulated numbers of laboratory-confirmed COVID-19 cases V_j in Ukraine, the UK, Poland, Germany, the Republic of Moldova and the whole world from the COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU), [4] (see Tables 1-6, where the figures corresponding to the version available on April 13, 2022 are listed). It must be noted the JHU figures for Ukraine [4] are approximately 3% higher than the values reported by Ukrainian national sources [9, 10]. Due to the war, the figures for Ukraine have not been updated long time after February 24, 2022 (see Table 1). The corresponding moments of time tj (measured in days) are shown in Tables 1-4 for the period of November 2021 to April 2022.

Table 1. Cumulative numbers of laboratory-confirmed Covid-19 cases in Ukraine for the period of November 1, 2021 to February 24, 2022 according to JHU report on April 13, 2022, [4].

Day in corresponding month of 2021 and 2022	Number of cases in November 2021, Vj	Number of cases in December 2021, Vj	Number of cases in January 2022, Vj	Number of cases in February 2022, Vj
1	3073125	3619223	3852397	4287117
2	3093661	3633386	3854405	4323009
3	3118140	3647777	3856359	4363754
4	3146617	3661583	3858248	4408776
5	3174223	3668794	3862959	4452612
6	3200411	3673839	3869728	4481918
7	3218967	3683044	3877032	4506669
8	3233178	3692939	3880371	4542568
9	3253327	3705823	3883316	4582137
10	3277772	3717640	3885416	4625614
11	3303694	3728246	3890974	4668581
12	3328934	3733967	3898240	4708604
13	3353694	3738390	3908469	4735258
14	3369387	3746106	3919151	4753922
15	3381399	3754567	3929950	4785138
16	3398913	3764485	3936582	4818112
17	3418792	3773700	3941923	4853339
18	3440602	3781506	3950774	4890332
19	3461873	3785395	3963917	4923680
20	3481347	3788209	3982738	4943428
21	3493203	3794490	4003280	4959461
22	3501815	3801079	4026198	4986161
23	3515641	3808612	4042152	5012980
24	3530969	3815440	4055643	5040518
25	3548842	3820891	4075351	No data
26	3565644	3823879	4100292	No data
27	3580671	3825917	4133396	No data
28	3588916	3828336	4168560	No data
29	3595410	3833952	4206731	No data
30	3606622	3840041	4232143	No data
31	-	3847226	4255206	No data

Table 2. Cumulative numbers of laboratory-confirmed Covid-19 cases in the world for the period of November 1, 2021 to April 12, 2022 according to JHU report on April 13, 2022, [4].

Day in corres-ponding month of 2021 and 2022	Number of cases in November 2021, Vj	Number of cases in December 2021, Vj	Number of cases in January 2022, Vj	Number of cases in February 2022, Vj	Number of cases in March 2022, Vj	Number of cases in April 2022, Vj
1	247862074	263807528	289927623	382057655	438638152	489570107
2	248266150	264513551	290847589	385246182	440298642	490615023
3	248790581	265242947	293206749	388418808	442054923	491403738
4	249310490	265778142	295706744	391363495	443808766	492308878
5	249834773	266237498	298280821	393663274	445278431	493667646
6	250272210	266836489	300938774	395535273	446490779	495121230
7	250632969	267476824	303882579	398131340	447913616	496337008
8	251103998	268189875	306061605	400756040	449664409	497530264
9	251571331	268887169	308097605	403194717	451503752	498298585
10	252148459	269580734	311285781	405974555	453364661	498866902
11	252669280	270101373	314317623	408396208	455215091	499842091
12	253267145	270557090	317770589	410315599	456963450	500878952
13	253708184	271167762	320952544	411833078	458244773	
14	254086682	271805943	324268400	413532555	459874155	
15	254613141	272545359	326765265	415412111	461676661	
16	255118609	273288038	328943173	417649604	463900108	
17	255737422	274055576	331604331	419706593	465953017	
18	256358930	274625828	335364892	421685829	467866738	
19	256975072	275138218	339453918	423314385	469575841	
20	257475402	275874759	343159424	424639646	470645978	
21	257896061	276631163	346995120	426035583	472116618	
22	258497626	277541705	349784219	427747662	474092054	
23	259087921	278548452	352240761	429674701	475864692	
24	259748956	279440261	355663188	431442819	477616071	
25	260347371	280142385	359314204	433079615	479457172	
26	260957671	280722452	362976531	434508761	480813689	
27	261441136	281990658	366732889	435655616	481725638	
28	261871606	283317208	370352923	437014406	483218323	
29	262502486	285013613	373093920	-	484967067	
30	263102705	286956097	375410506	-	486559347	
31	-	288702042	378897181	-	488405398	

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Table 3. Cumulative numbers of laboratory-confirmed Covid-19 cases in Poland for the period of November 1, 2021 to April 12, 2022 according to JHU report on April 13, 2022, [4].

Day in corres-ponding month of 2021 and 2022	Number of cases in November 2021, Vj	Number of cases in December 2021, Vj	Number of cases in January 2022, Vj	Number of cases in February 2022, Vj	Number of cases in March 2022, Vj	Number of cases in April 2022, Vj
1	3030151	3569137	4120248	4925270	5680034	5966970
2	3034668	3596491	4127428	4981321	5694767	5969071
3	3045102	3623452	4133851	5035796	5708827	5969621
4	3060613	3649027	4145518	5083332	5721316	5970114
5	3076518	3671421	4162715	5129080	5734041	5971998
6	3091713	3684671	4179292	5163780	5741739	5973557
7	3104220	3704040	4191193	5188184	5747322	5975040
8	3111534	3732589	4202090	5223507	5760498	5976364
9	3125179	3760048	4213197	5270363	5774938	5977773
10	3143725	3785036	4220984	5312450	5788363	5978215
11	3162804	3808798	4232386	5348224	5799996	5978596
12	3175769	3828248	4248559	5379551	5811109	5980220
13	3190067	3839625	4265433	5401615	5818687	
14	3204515	3857085	4281482	5415088	5823982	
15	3214023	3881349	4298375	5437343	5836672	
16	3230634	3903445	4313036	5466198	5851147	
17	3254875	3923472	4323482	5495432	5863414	
18	3279787	3942864	4343130	5519411	5875072	
19	3303046	3958840	4373718	5540302	5885446	
20	3326464	3968450	4406553	5553989	5891140	
21	3345388	3982257	4443217	5563446	5895304	
22	3357763	4000270	4484095	5582217	5905463	
23	3377698	4017420	4518218	5602680	5915888	
24	3406129	4032796	4547315	5620946	5924876	
25	3434272	4043585	4584360	5637646	5933107	
26	3461066	4049838	4637776	5651596	5939735	
27	3487254	4054865	4695435	5660493	5943227	
28	3507828	4064715	4752700	5667054	5945594	
29	3520961	4080282	4804390	-	5952200	
30	3540061	4094608	4852677	-	5957940	
31	-	4108215	4886154	-	5962931	

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Table 4. Cumulative numbers of laboratory-confirmed Covid-19 cases in Germany for the period of November 1, 2021 to April 12, 2022 according to JHU report on April 13, 2022, [4].

Day in corres-ponding month of 2021 and 2022	Number of cases in November 2021, Vj	Number of cases in December 2021, Vj	Number of cases in January 2022, Vj	Number of cases in February 2022, Vj	Number of cases in March 2022, Vj	Number of cases in April 2022, Vj
1	4607208	5903999	7176814	9978146	14867218	21357039
2	4618021	5977208	7189329	10186644	15053624	21553495
3	4638419	6051560	7207847	10422764	15264297	21668677
4	4672368	6116070	7238408	10671602	15481890	21668677
5	4709488	6158125	7297320	10889417	15674100	21849074
6	4743490	6185961	7361660	11022590	15790989	22265788
7	4767033	6222020	7417995	11117857	15869417	22441051
8	4782546	6291621	7473884	11287428	16026216	22591726
9	4804378	6362232	7510436	11521678	16242070	22647197
10	4844054	6423520	7535691	11769540	16504822	22677986
11	4894250	6477217	7581381	12009712	16757658	22878428
12	4942890	6509863	7661811	12219501	16994744	23017079
13	4987971	6531606	7743228	12344661	17141351	
14	5021469	6562429	7835451	12421126	17233729	
15	5045076	6613730	7913473	12580343	17432617	
16	5077124	6670407	7965977	12800315	17695210	
17	5129950	6721375	8000122	13035941	17990141	
18	5195321	6764188	8074527	13255989	18287986	
19	5248291	6793536	8186850	13445094	18548225	
20	5312215	6809622	8320386	13563126	18680017	
21	5354942	6833050	8460546	13636993	18772331	
22	5385585	6878709	8596007	13762895	18994411	
23	5430911	6923636	8681447	13971947	19278143	
24	5497795	6959067	8744840	14188269	19596530	
25	5573756	6981281	8871795	14399012	19893028	
26	5650170	6991381	9035795	14574845	20145054	
27	5717295	7005289	9238931	14682758	20256278	
28	5761696	7026369	9429079	14745107	20323779	
29	5791060	7066412	9618245	-	20561131	
30	5836813	7109182	9737215	-	20829608	
31	-	7150422	9815533	-	21357095	

The JHU periodically update its data sets for the previous moments of time [4]. Here we will use the version of JHU file, corresponding to April 13, 2022 (for numbers of COVID-19 cases accumulated in the UK correspond to the version available on July 13, 2022). It must be noted that the data sets presented in Tables 2 and 4, which are slightly different from the previous versions used in [8]. The reproduction numbers will be shown according to the JHU datasets available on September 9, 2022.

The generalized SIR-model relates the numbers of susceptible S(t), infectious I(t) and removed persons R(t) versus time t for a particular epidemic wave i, [5, 6]. The exact solution of the set of non-linear differential equations uses the function $V(t) = I(t) + R(t)$, corresponding to the number of victims or the cumulative laboratory-confirmed number of cases [5, 6]. Its derivative dV/dt yields the estimation of the average daily number of new cases. The exact solution presented in [5, 6] depends on parameters listed in Table 7. One of them can be treated as the average time of spreading infection τ_i during i-th epidemic wave:

$$\tau_i \approx \frac{1}{\rho_i} \qquad (1)$$

The details of the optimization procedure for their identification can be found in [5, 6].

Since daily numbers of new cases are random and characterized by some weekly periodicity, the smoothed characteristics will be used (see [5, 6]):

$$\bar{V}_i = \frac{1}{7}\sum_{j=i-3}^{j=i+3} V_j, \qquad (2)$$

To estimate the smoothed numbers of new daily cases DVi, the numerical derivatives of the smoothed values (2) will be used as in [5, 6]:

$$DV_i \equiv \left.\frac{d\bar{V}}{dt}\right|_{t=t_i} \approx \frac{1}{2}\left(\bar{V}_{i+1} - \bar{V}_{i-1}\right) \qquad (3)$$

3. Effective Reproduction Number

The effective reproduction number Rt(t) shows the average number of people infected by one person, [11-17]. Due to the mass migration after February 24, 2022, the increase in the Rt values can be expected. For the COVID-19 pandemic, Robert Koch Institut (RKI) recommends using the generation time of 4 days and to calculate the reproduction number as "the ratio of new infections in two consecutive time periods each consisting of 4 days", [13]. In terms of the accumulated numbers of cases Vj , the RKI formula can be written as follows:

$$R_t(t_j) = \frac{V_{j+4} - V_j}{V_j - V_{j-4}} \qquad (4)$$

The mean UK household generation time was estimated as 3.2 days for the Delta variant and 4.5 days for than the Alpha variant [18]. The values τ_i (see eq. 1) calculated in [5-8] for different waves of the COVID-19 pandemic can be also used to estimate the reproduction rates in different countries. In particular, during the first epidemic wave in UK, the τ_1 value was estimated as 3.03, [5]. The information about serial intervals (the periods between symptom onset moments of time in infector–infectee pairs, [18, 19]) can be also useful for estimations of the reproduction numbers. Thus, formula (4) can be generalized as follows:

$$R_t(t_i) = \frac{\bar{V}(t_i+\tau) - \bar{V}_i}{\bar{V}_i - \bar{V}(t_i-\tau)} \qquad (5)$$

where, τ corresponds to the values τ_i from formula (1), generation time or serial intervals, calculated in [18, 19]. To minimize the influence of random daily numbers of cases, the smoothed values $\bar{V}_i$ (according to formula (2)) are recommended. Smoothed values $\bar{V}(t_i+\tau)$ and $\bar{V}(t_i-\tau)$ can be calculated using a linear (or other) interpolation of $\bar{V}_k$ numbers.

The generalized SIR model and corresponding identification procedures of its parameters identification allow estimating the reproduction numbers with the use of the formula, [20]:

$$R_t(t) = \frac{S(t)}{v_i} = \frac{N_i - V(t)}{v_i} = \frac{N_i - I(t) - R(t)}{v_i} \tag{6}$$

where i corresponds to the number of the epidemic wave. Optimal values of parameters Ni and v_i for different waves of the COVID-19 pandemic in Ukraine, Poland, Germany and the world are listed in Table 7. For successful SIR simulations, it is enough to have information about the accumulated numbers of cases during 14 days [5-8, 20]. Thus, the reproduction number can be calculated with the use of this number of observations. Calculations with the use of formula (5) need approximately the same volume of information.

The Kalman filter was used in [15] to reduce random pulsations in the daily numbers of cases. Corresponding reproduction rates are calculated and listed by JHU [4] for almost every country and region. For the summer COVID-19 epidemic wave in Japan, a good agreement between the method proposed in [15] and calculations with the use of eq. (6) was demonstrated in [20]. In this study we will compare the corresponding Rt(t) values (version of JHU file available on September 9, 2022) for Ukraine, the UK, Poland, Germany, Moldova, and the whole world with the results of calculations based on formulae (4)-(6).

4. Results and Discussion

The optimal values of parameters of the generalized SIR model and other characteristics of the 14th pandemic wave in Ukraine [7], the 4th wave in Poland [8], the 5th wave in Germany [8] and the 7th wave in the whole world [7] are listed in Table 7. Corresponding SIR curves are shown in Figures 1 and 2. The laboratory confirmed accumulated numbers of COVID-19 cases Vj (Tables 1-6) are shown by "stars" and "circles" (data used for SIR simulations). "Crosses" represent the averaged daily numbers of new COVID-19 cases calculated with the use of the Vj values and eq. (3).

Table 5. Cumulative numbers of laboratory-confirmed Covid-19 cases in the Republic of Moldova for the period of November 1, 2021 to April 12, 2022 according to JHU report on April 13, 2022, [4].

Day in corres-ponding month of 2021 and 2022	Number of cases in November 2021, Vj	Number of cases in December 2021, Vj	Number of cases in January 2022, Vj	Number of cases in February 2022, Vj	Number of cases in March 2022, Vj	Number of cases in April 2022, Vj
1	339114	364433	376434	445046	502386	513757
2	340188	365165	376602	449840	502956	514014
3	341675	365713	376844	455095	503690	514199
4	343261	366162	377496	460307	504307	514222
5	344563	366256	378202	464234	504875	514428
6	345517	366751	378904	467271	505393	514650
7	345964	367339	379572	468782	505644	514882
8	347105	367948	379901	471524	505996	515121
9	348588	368497	380290	474548	506222	515312
10	349568	369013	380985	477419	506681	515445
11	350697	369402	382124	480289	507028	515488
12	351940	369659	383544	482842	507599	515649
13	352670	370003	385047	484516	507994	
14	352822	370459	386905	485563	508235	

15	353778	370951	387920	487283	508578
16	354755	371410	388959	488899	508917
17	355646	371850	390742	490751	509367
18	356448	372154	393423	492604	509834
19	357211	372200	396678	494219	510206
20	357831	372429	400585	495184	510460
21	358202	372983	404556	495415	510700
22	358857	373373	407003	496976	510973
23	359401	373752	409397	497946	511231
24	360261	374120	412231	499015	511662
25	361116	374349	417369	500144	512047
26	361828	374526	423568	500812	512386
27	362326	374763	428934	501312	512602
28	362433	375065	434549	501800	512638
29	363110	375358	438249	-	512942
30	363774	375780	438249	-	513146
31	-	376155	440698	-	513442

Table 6. Cumulative numbers of laboratory-confirmed Covid-19 cases in the UK for the period of November 1, 2021 to April 30, 2022 according to JHU report on December 11, 2023, [4].

Day in corres-ponding month of 2021 and 2022	Number of cases in November 2021, Vj	Number of cases in December 2021, Vj	Number of cases in January 2022, Vj	Number of cases in February 2022, Vj	Number of cases in March 2022, Vj	Number of cases in April 2022, Vj
1	9266373	10476077	13678283	17515752	18987410	21209728
2	9301187	10531772	13866850	17620803	19032059	21264519
3	9346296	10586592	13985125	17714752	19076854	21311981
4	9384315	10636911	14166193	17803170	19123033	21349573
5	9420301	10682578	14396094	17879814	19166794	21391752
6	9453963	10721362	14671741	17943078	19208202	21445479
7	9484281	10762413	14893915	17995383	19246961	21494580
8	9511717	10822107	15066895	18055935	19295987	21539330
9	9542303	10878365	15187182	18132418	19364507	21578039
10	9586429	10937192	15280797	18202079	19434619	21611027
11	9628675	10994187	15376587	18266418	19508150	21638912
12	9671617	11046679	15509546	18318711	19578660	21669864
13	9712616	11095273	15624791	18363270	19645690	21707235
14	9750379	11148431	15728010	18400799	19707768	21741006
15	9783264	11235600	15824422	18442554	19783507	21772691
16	9818796	11338388	15910747	18497299	19883341	21799330
17	9869744	11451091	15988697	18549801	19977049	21820947
18	9916174	11557146	16086794	18601373	20068800	21840872
19	9962069	11653043	16218308	18646089	20151653	21861016
20	10006131	11741926	16337165	18679330	20226938	21886239
21	10045737	11831059	16448925	18713977	20294355	21912011
22	10081072	11965025	16549249	18751697	20375409	21933468
23	10118322	12115318	16640979	18796829	20484695	21951932
24	10169055	12276878	16722712	18836017	20583790	21967635

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25	10217252	12437511	16825077	18872493	20677975	21980845
26	10264024	12574779	16952441	18903124	20760880	21995560
27	10307449	12645142	17065643	18930961	20833310	22012669
28	10346779	12761429	17174311	18956050	20894766	22027229
29	10380082	12956440	17270512	-	20963102	22040284
30	10419788	13168909	17354538	-	21055959	22051892
31	-	13441707	17428050	-	21136085	-

Table 7. Optimal values of parameters and other characteristics of the COVID-19 pandemic waves in Ukraine, Poland, Germany, and the world .

Characteristics	**14th epidemic wave in Ukraine, i=14, [7]**	**4th epidemic wave in Poland, i=4, [8]**	**5th epidemic wave in Germany, i=5, [8]**	**7th epidemic wave in the whole world, i=7, [7]**
Time period taken for calculations, Tci	January 22 – February 4, 2022	November 22 – December 5, 2021	November 22 – December 5, 2021	January 22 – February 4, 2022
Ii	64,676.7037685832	182,880.050730977	175,036.042911984	11,190,879.9375884
Ri	3,956,648.86765999	3,181,514.23498331	5,301,466.81423087	337,916,505.348126
Ni	5,678,291.86675200	5,410,976	10,300,000	815,388,678.72
ν_i	1,064,719.47680477	1,574,583.94143908	4,370,737.14176735	453,226,448.070179
α_i	1.7392861614679e-7	5.96394337877141e-08	6.8098348012594e-08	6.51375439773073e-10
ρ_i	0.185185185185185	0.0939072947186539	0.297639978951643	0.295220576928501
$1/\rho_i$	5.4	10.6488	3.35976371024561	3.38729776360470
ri	0.998361163644707	0.998395644300319	0.996581480894305	0.999439451877399
$S_{i\infty}$	552,746	854,850	3,186,419	359,119,917
$V_{i\infty}$	5,125,546	4,556,126	7,113,581	456,268,762
Final day of the epidemic wave	December 2023	September 2025	April 2023	April 2085 ?

 doi:10.20944/preprints202401.0733.v1

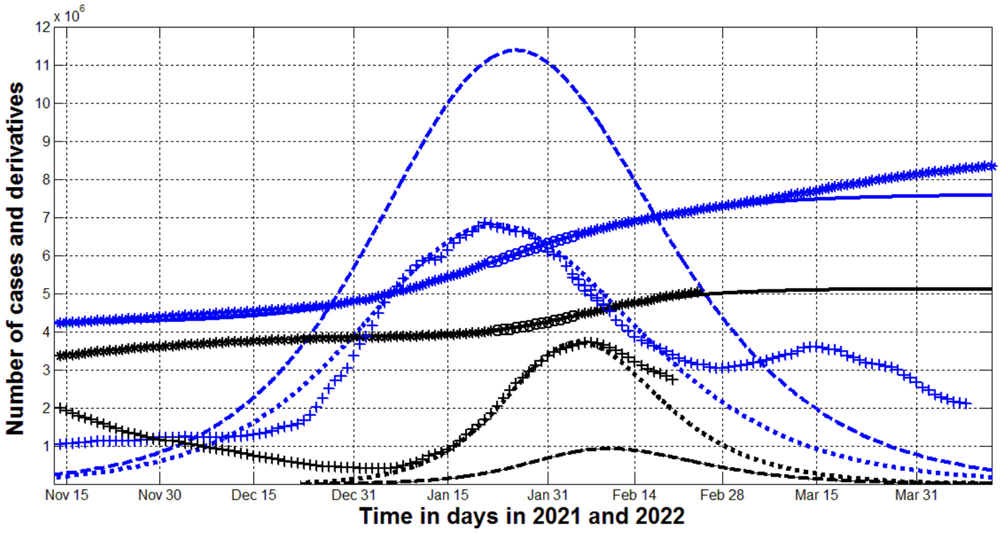

Figure 1. The omicron waves and further pandemic dynamics in Ukraine and in the whole world.

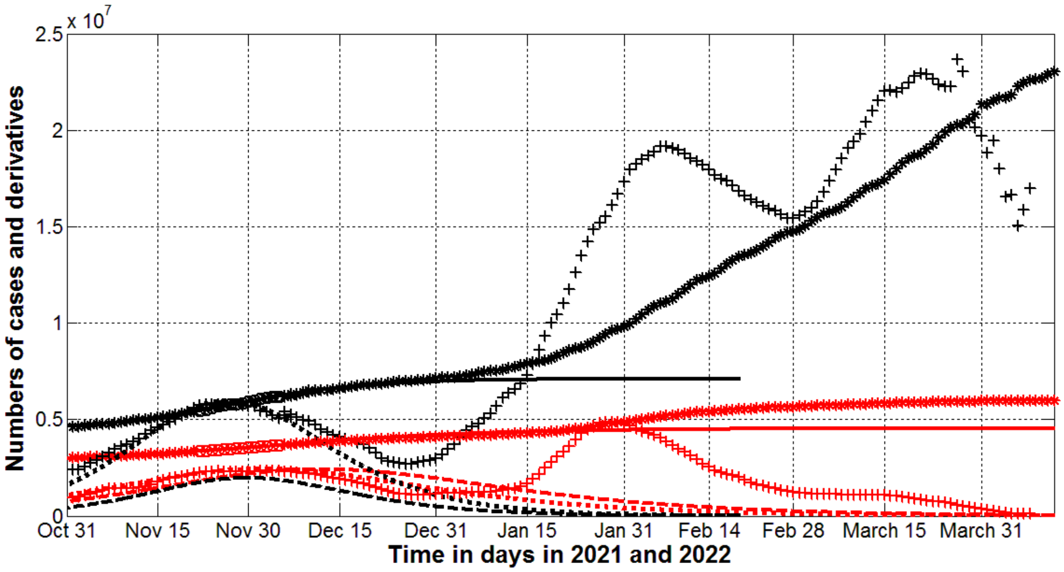

Figure 2. The COVID-19 pandemic waves in Poland (red) and Germany (black) in 2021 and 2022.

The results of SIR simulations of the 14th wave in Ukraine are shown by black lines. Blue lines represent the 7th pandemic wave in the world. Numbers of victims V(t)=I(t)+R(t) – solid lines (for the world divided by 60); numbers of infected and spreading I(t) (multiplied by 5 for Ukraine) – dashed; derivatives dV/dt, multiplied by 100 for Ukraine and by 2 for the world) – dotted. "Circles" correspond to the accumulated numbers of cases registered during the periods taken for SIR simulations (for the world divided by 60). "Stars" corresponds to Vj values beyond these time periods (for the world divided by 60). "Crosses" show the numerical first derivative multiplied by 100 for Ukraine and by 2 for the world. Black markers correspond to Ukraine ([7], Table 1), blue - for the world ([7], Table 2).

"Stars" and "crosses" in Figure 1 illustrate that before the full-scale invasion, which started on February 24, 2022, the accumulated number of cases ("stars") and the averaged daily numbers of new cases ("crosses") followed the corresponding theoretical solid and dotted lines. In March 2022, the real global dynamics started to deviate form the theoretical blue solid and dotted curves. In particular, the saturation level of the 7th pandemic wave $V_{i\infty}$ =456,268,762 (see the last column of Table 7) was exceeded. The increase in the global daily numbers of new cases (see blue "crosses") in

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March 2022 can be explained by the mass migration from Ukraine. As of March 23, 2022, more than 3.5 million Ukrainians were forced to flee abroad [1].

To estimate the possible impact of this humanitarian disaster, let us calculate the probability of meeting an infectious person in Ukraine with the use of simple formula, [5, 20]:

$$p(t) = \frac{I(t)}{N_{pop}} \tag{7}$$

where Npop is the volume of population. As of February 24, 2022 the numbers of people spreading the infection I(t) were around 100,000 in Ukraine and 5 million in the whole world (see dashed lines in Figure 1). Since before the war, the population of Ukraine was 178 times less than the global figure, the probability of meeting an infected person in Ukraine was 3.6 times higher (according to eq. (7)). It means that forced mass emigration of Ukrainians could cause an increase in the number of new cases in the world. Blue "crosses" in Figure 1 illustrate this fact. It is worth noting that after March 15, 2022 the growth stopped, which can be explained by a decrease in the flow of refugees.

Let us consider the situation in the Poland, which has accepted more than 2 million Ukrainian refugees [1]. In March 2022, the decline in the number of new cases slowed down (see red "crosses" in Figure 2). The number of new cases in Poland stopped to decrease in March 20221. This fact demonstrates the influence of the mass migration from Ukraine. The relatively small impact on the Polish epidemic dynamics can be explained by the approximately same probability of meeting an infectious Polish and Ukrainian person.

The results of SIR simulations of the 4th wave in Poland and the 5th wave in Germany are shown by red and black lines, respectively, [8]. Numbers of victims V(t)=I(t)+R(t) – solid lines; numbers of infected and spreading I(t) multiplied by 10 – dashed; derivatives dV/dt (multiplied by 100) – dotted. "Circles" correspond to the accumulated numbers of cases registered during the period taken for SIR simulations. "Stars" correspond to Vj values beyond this time period. "Crosses" show the averaged daily number of new cases calculated with the use of eq. (3) and datasets presented in Tables 3, 4 (multiplied by 100).

Unfortunately, we have results of SIR simulations only for the 4th wave in Poland (shown by red lines in Figure 2, [8]). In January 2022, a new Omicron wave started in this country and the daily numbers of new cases (red "crosses" in Figure2) became much higher than the theoretical estimation for the previous wave (the red dotted line). The maximum values of I(t) were approximately 200,000 both for Ukraine and Poland (see the black dashed line in Figure1 and the red dashed line in Figure2). Since the populations of these countries are also close, we can expect the close values for the probabilities of meeting of an infectious person (according to eq. (7)). Thus, the huge number of Ukrainian refuges did not significantly change the epidemic dynamics in Poland.

In early 2022, when a new powerful epidemic wave began in Germany, the number of infected in this country was about 4 times less than in Poland (compare black and red dashed lines in Figure 2). Taking into account the difference in population size, one can expect about eight times less chance of meeting an infectious person in Germany. Therefore, refugees from Ukraine could significantly increase the number of new cases in Germany in March 2022. Black "crosses" in Figure 2 illustrate this fact.

"Stars" represent accumulated numbers of laboratory confirmed cases Vj listed in Tables 5 and 6 (multiplied by 10 for Moldova). "Crosses" show the averaged daily number of new cases DVi (calculated with the use of eq. (3) and JHU datasets listed in Tables 5 and 6; multiplied by 100 for the UK and by 1000 for Moldova).

Figure 3 illustrates the COVID-19 pandemic dynamics in the UK and the Republic of Moldova. We can see almost no increase in the numbers of new cases in Moldova (blue "crosses") after the beginning of the Russian invasion (February 24, 2022). Only some stabilization in the decreasing trend is visible in March 2022. Probably it relates to characteristics of the pandemic dynamics in Ukraine and Moldova (similar as in the case of Poland). In the UK, the increase in the averaged daily numbers of new cases DVi (see eq. (3)) is visible after February 24, 2022 (red "crosses").

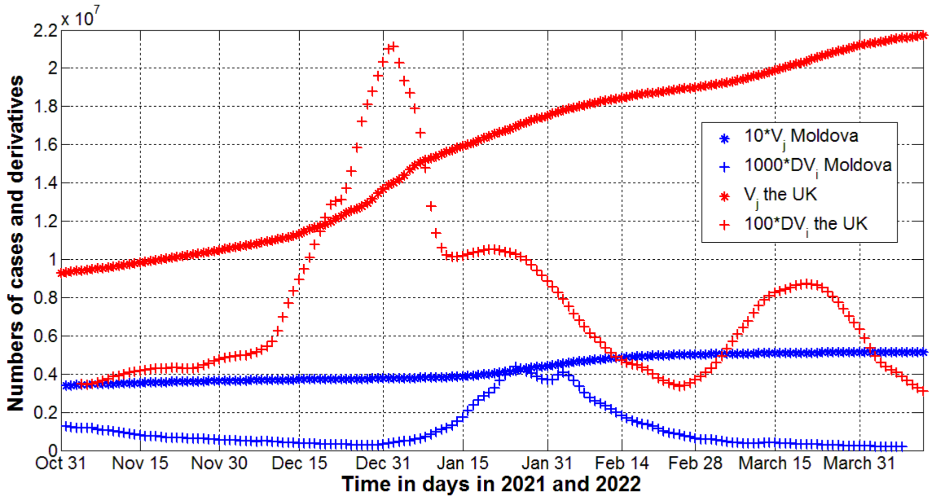

Figure 3. The COVID-19 pandemic waves in the UK (red) and the Republic of Moldova (blue) in 2021 and 2022.

Figure 4 represents the dependences Rt(t) for different countries and in the whole world. Solid lines represent the results of calculations with the use of eq. (5). The value τ = 4 days was used in all cases. Red "dots" illustrate the results of calculations for Poland with the use of formula (4). It can be seen that the use of unsmoothed accumulated numbers of cases in (4) leads to very random values of the reproduction number. Eq. (4) yields similar results for other countries and the whole world (not shown in Figure 4). The dashed lines in Figure 4 represent the JHU datasets for the reproduction rate. The results of calculations with the use of formula (5) are rather close to the JHU values.

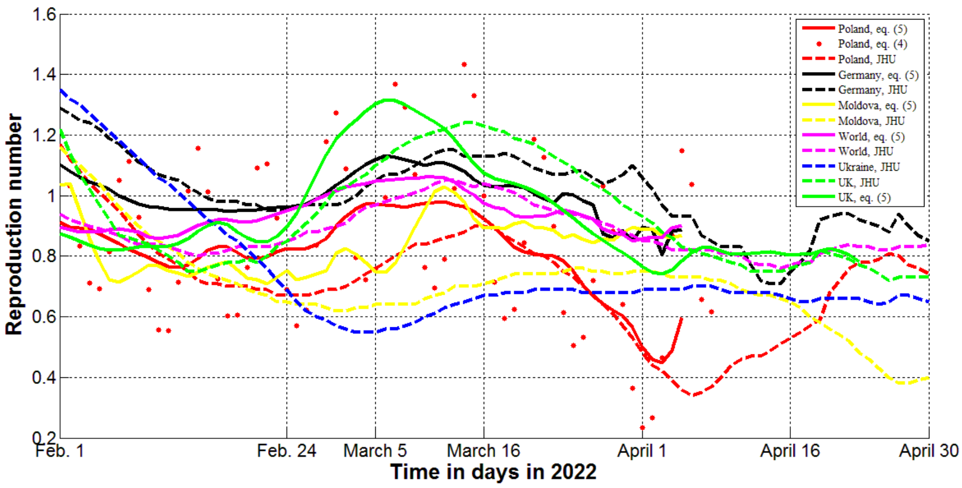

Figure 4. The effective reproduction numbers of the COVID-19 pandemic in different countries and worldwide for the period from February 1 to April 30, 2022.

Eq. (6) show that the reproduction number decreases monotonously during fixed epidemic wave. For example, as of January 22, 2022 the corresponding values were 1.56 for Ukraine and 1.03 for the world (parameters listed in Table 7 and formula (6) allow calculating these figures). Without changing the epidemic parameters, as of April 30, 2022 these values should monotonically approach 0.52 for Ukraine and 0.79 for the world. The blue line in Figure 4 demonstrates slight deviation from the values calculated for Ukraine. Magenta lines show that the global reproduction number increased after February 24, 2022 and was higher than the critical value 1.0 in March 2022. The increasing trends in Poland, Germany, the UK, and Moldova started immediately after February 24, 2022 (see red, black, green and yellows lines in Figure 4). Thus, the changes in COVID-19 pandemic dynamics are evident and could be caused by the huge numbers of Ukrainian refuges.

Solid lines represent the results of calculations with the use of eq. (5) and τ = 4 days, dashed ones – JHU datasets. Red "dots" show the results of calculations for Poland with the use of formula (4).

5. Conclusions

Smoothed values of the accumulated numbers of cases were used to estimate the average daily numbers of new COVID-19 cases and the effective reproduction numbers for Ukraine, the UK, Poland, Germany, Moldova and the whole world in February, March and April of 2022. The registered numbers of cases were compared with ones calculated with the use of the generalized SIR-model and corresponding parameter identification procedure for the previous epidemic waves in Ukraine, Poland, Germany, and the world. In March 2022 the increase of the averaged number of new cases in the UK, Germany, and worldwide is visible. A simple formula to estimate the effective reproduction number based on the smoothed accumulated numbers of cases was proposed. The results of calculations agree with the figures presented by John Hopkins University and demonstrate a short-term growth of the reproduction number in the UK, Poland, Germany, Moldova, and worldwide in March 2022. The biggest pandemic dynamic disturbances were observed in the UK and Germany, where at the beginning of the full-scale Russian aggression, the number of infectious persons per capita was probably much lower than in Ukraine.

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