



<http://dx.doi.org/10.35596/1729-7648-2022-20-1-55-64>

Original paper

UDC 621.396.218:614.89.086.5

REFINED ANALYSIS OF THE CORRELATION BETWEEN THE ACCEPTED MAXIMUM PERMISSIBLE LEVELS OF RADIO FREQUENCY ELECTROMAGNETIC FIELDS FOR THE POPULATION AND THE LETHALITY RATE OF COVID-19

VLADIMIR I. MORDACHEV

Belarusian State University of Informatics and Radioelectronics (*Minsk, Republic of Belarus*)

Submitted 13 September 2021

© Belarusian State University of Informatics and Radioelectronics, 2022

Abstract. In this paper, the results of a refined analysis of the correlation, previously discovered by the author, between the accepted maximum permissible levels (MPL) of radio frequency electromagnetic fields (RF EMF) for population and the mortality rate of COVID-19, carried out using the data samples from the World Health Organization (WHO), taken monthly from May 2020 to July 2021, are presented. To explain the results obtained, correlation between the accepted MPL for RF EMF, the level of vaccination of population against COVID-19, and the level of gross domestic product per capita in different countries were analyzed additionally. Analysis results confirm the presence of a noticeable correlation between the RF EMF MPLs and the COVID-19 mortality rate, especially in the first months of the analyzed period. The subsequent decrease in correlation between them by the end of analyzed period is a result of significantly larger efforts in struggle against COVID-19 in those countries where high RF EMF MPLs are adopted taking into account only the danger of thermal effects in human body, in comparison with countries where more stringent standards that take into account the danger of non-thermal bioeffects, are used. The first of these countries, having on average a higher level of economic development, ensured mass COVID-19 testing of population, imposition of tougher and longer restrictions (quarantines, lockdowns, etc.), as well as significantly higher rates of vaccination of the population. The presence of a confirmed correlation between these characteristics does not necessarily mean the existence of an unambiguous causal relationship between them. In countries of the first group with passive regulation of population protection from environmental factors, this principle is used not only in relation to RF EMF, but also in relation to the other factors. This determines the relevance of a deeper system analysis of the impact of the adopted legal systems for protecting the population from the entire set of anthropogenic factors on its health and collective immunity.

Keywords: COVID-19, lethality, habitat, electromagnetic pollution, regulations, correlation, mobile communications, 4G, 5G, 6G, electromagnetic ecology, electromagnetic safety, electromagnetic protection.

Conflict of interests. The author declares no conflict of interests.

For citation. Mordachev V.I. Refined Analysis of the Correlation Between the Accepted Maximum Permissible Levels of Radio Frequency Electromagnetic Fields for the Population and the Lethality Rate of Covid-19. Doklady BGUIR. 2022; 20(1): 55-64.

Introduction

Differences in maximum permissible levels (MPL) of radio frequency electromagnetic fields (RF EMF) accepted in different countries are determined by differences in approaches to ensuring the

electromagnetic safety of the population in these countries [1–3]. The first approach is based on the principle of passive regulation, which provides for the use of recommended RF EMF maximum permissible levels (MPL), exceeding which will cause harm to health. In countries where it is adopted, MPL values of RF EMF for the population are determined taking into account the danger of thermal bioeffects only and take on values 1000–4000 $\mu\text{W}/\text{cm}^2$, the burden of proof of possible harm from exposure to RF EMF has been transferred to the court. In a number of countries, this principle is implemented with particular socially-oriented additions aimed at limiting the RF EMF levels at socially significant objects, in places of residence, etc. An alternative second approach is based on the establishment of MPL values of RF EMF, that can guarantee the absence of harm to health, taking into account the long-term consequences of their impact on the human organism. In countries where it is adopted, the MPL values of RF EMF for the population are determined taking into account the danger of non-thermal bioeffects, and for continuous RF EMFs of the 0.3–300 GHz range they take on values 2.5–10 $\mu\text{W}/\text{cm}^2$; the state implements control and supervisory functions for their compliance.

Today, the main source of electromagnetic pollution of the habitat is electromagnetic radiation of base stations and a user's equipment of cellular (mobile) communication systems. At the same time, despite the very significant difference in the accepted restrictions on the RF EMF levels for the population, the differences in the degree of electromagnetic pollution of the habitat in countries with different approaches to ensuring the safety of the population were not so significant until recently [4–7, etc.] due to the prevalence of low-speed mobile telephony services, as well as the deterrent effect of the danger of massive lawsuits and huge costs of compensation for the damage caused. However, in conditions of extremely intensive development of wireless information systems and services and its penetration in all spheres of human life in the framework of the evolution 2G/3G→4G→5G→6G of mobile communications [8, 9], and in conditions of corporate pressure [10, 11], restrictions on RF EMF MPL for population adopted in different countries are associated undoubtedly with the potentially permissible levels of electromagnetic pollution of the environment in these countries.

In [12], the initial results of analysis of the correlation between the potential level of electromagnetic pollution of the environment and the danger of COVID-19 are presented, which confirmed the presence of a noticeable correlation between the RF EMF MPLs adopted in different countries and the relative mortality of the population from COVID-19 in these countries. **The presence of a correlation does not mean the presence of an established causal relationship between analyzed characteristics, but an extremely high cost of the item determines the relevance of its further in-depth study.**

The analysis performed in [12] was preliminary in nature, since the analyzed samples of data on relative lethality from COVID-19 were taken at intervals of only 7 days over 2 weeks and, therefore, were significantly correlated (Pearson's correlation coefficient 0.996–0.999 with a sample sizes of 31, their representativeness was ensured by approximately equal representation of countries using different approaches to ensuring the electromagnetic safety of the population). The analysis of correlated samples was justified by considerations of increasing the reliability of research results in conditions of varying degrees of reliability and regularity of data updating for different countries in WHO reports¹.

A goal of the work is to perform a more detailed analysis of correlation between the accepted RF EMF MPs for the population in different countries and the lethality of COVID-19, for a more objective assessment of the possible relation between the potential danger of electromagnetic pollution of the environment and the danger of COVID-19 for the population.

Analysis results

A deeper analysis of correlation between considered characteristics was performed using samples of COVID-19 data in various countries taken at longer intervals and over a longer period. This paper presents the results of analysis of correlation between samples of RF EMF MPL values in various countries and fifteen WHO data samples from on COVID-19 infection and mortality taken at monthly intervals from May 2020 to July 2021. This analysis is supported by correlation analysis

¹ WHO Coronavirus (COVID-19) Dashboard. <https://covid19.who.int/table> (on-line resource).

of associated factors (the level of vaccination against COVID-19, the level of gross domestic product (GDP) per capita in various countries), which makes it possible to find an explanation of the nature of the time dependence of the analysis results.

The numbers of the data samples correspond to the following dates: No. 1: 05/18/2020; No. 2: 06/18/2020; No. 3: 07/19/2020; No. 4: 08/19/2020; No. 5: 09/18/2020; No. 6: 10/19/2020; No. 7: 11/18/2020; No. 8: 12/18/2020; No. 9: 01/19/2021; No. 10: 02/19/2021; No. 11: 03/19/2021; No. 12: 04/19/2021; No. 13: 05/18/2021; No. 14: 06/18/2021; No. 15: 07.20.2021.

MPL values for RF EMF adopted in various countries, correspond to the published data [1–3, 12, etc.] at the beginning of the analyzed period (May 2020). Changes in the hygienic standards of separate countries (Poland, Ukraine) during the analyzed period were not taken into account, since the processes of changing the electromagnetic environment and its influence on the collective immunity of population are quite inertial and are determined by rather slow processes of corresponding changes in the infrastructure of mobile radio networks, the legal system for protecting the population, etc.

Results of a refined analysis of the correlation between the potential level of electromagnetic pollution of the environment and the lethality of COVID-19 in relation to the number of detected infected and the population size are presented below in Tables 1, 2 (in a reduced volume with data samples at two-month intervals) and in full in graphical form on parts "a", "b" in Fig. 1. These parts of Fig. 1 show both the initial dependencies in the form of broken lines, which break points correspond to the obtained estimates of the Pearson's correlation coefficient, and the curves obtained by the root-mean-square smoothing of the estimated data.

To explain the results obtained, the following was additionally performed:

1. Analysis of the correlation between the adopted EMF RF MPL for the population and the level of vaccination of population against COVID-19 in the same countries according to the official WHO data. Samples of these data were also taken strictly at monthly intervals from the beginning of mass vaccination (12/20/2020) to 07/20/2021 (8 samples). The results of this analysis are presented in Table 3 and are illustrated by graphs in the original and smoothed form on the part "c" in Fig. 1.

2. Analysis of the correlation between the adopted RF EMF MPL for the population and the level of GDP per capita, calculated according to the various methods: GDP at purchasing power parity (PPP), estimated according to the methods of the International Monetary Fund (IMF) and the World Bank (WB), and nominal GDP per capita (determining the level of the state economic development), estimated according to the methods of the IMF and the WB. Analysis results are shown in Table 4.

3. Analysis of the correlation between the relative level of vaccination against COVID-19 in various countries as of 07/20/2021 and the level of GDP per capita in these countries. Analysis results are presented in Table 5.

The presented results of the analysis indicate that countries using "thermal" hygienic standards for RF EMF MPL in combination with the principle of passive regulation in matters of population protection, on average, have a higher level of economic development compared to countries using significantly more stringent "non-thermal" EMF RF MPLs in combination with state control over their observance. This is confirmed by the presence of a noticeable correlation between the accepted value of the RF EMF MPL value and the level of GDP per capita in various countries. Depending on the methodology for GDP calculating, the coefficient of this correlation varies in the interval [0.418, 0.464]. It was the great economic opportunities of these countries that made it possible to provide:

– significantly more complete coverage of the population of these countries with testing for the presence of coronavirus infection, which significantly increased the number of detected infected and by the end of 2020 practically reduced to zero the correlation between the adopted MPL RF EMF for the population and the mortality rate determined in relation to the number of detected infected, and in the latter months of the analyzed period even provided a negative correlation between the analyzed characteristics (Table 1, part "b" in Fig. 1);

– the implementation of stricter and longer administrative restrictions (quarantines, lockdowns, entry/exit bans, etc.) in these countries aimed at limiting contacts between people in order to fighting the spread of infection, as well as, on average, significantly higher rates of vaccination of population, which is generally confirmed by the data in Tables 3, 4 and 5. Correlation between the relative level of vaccination against COVID-19 in different countries on the final day of the analyzed period (07/20/2021) and the level of GDP per capita in these countries exceeds 0.5 and, depending on the method of calculating this level, the correlation coefficient changes in the interval [0.540, 0.573].

Part "d" in Fig. 4 contains a graphical representation² of the time dependence of the number of new infected according to WHO data, illustrating the nature and approximate periods of waves of the COVID-19 pandemic (first wave: October 2020 – January 2021, second wave: March – May 2021, third wave: from July 2021). For the convenience of joint analyzing dependences on parts "a", "b" and "c" in Fig. 1 and their mutual influence, part "e" in Fig. 1 shows, on a single time scale, the smoothed dependences of the Pearson's correlation coefficient on time for the lethality of COVID-19 in relation to the number of detected infected (curve 1) and in relation to the population size (curve 2), as well as the dependence of the Pearson's correlation coefficient in relation to the population vaccination rate (curve 3).

An analysis of the shape and mutual arrangement of these curves gives sufficient grounds to assume that the fact of a correlation between the degree of severity of the hygienic restrictions of the RF EMF MPL for population and the lethality rate of COVID-19 in various countries can be recognized as objectively proven based on the results of the refined analysis. At the same time, significantly larger efforts of economically developed countries to overcome the pandemic (stricter administrative restrictions, more massive testing of the population, higher rates of vaccination) contributed to a noticeable weakening of this correlation, already from the middle of the analyzed period.

Table 1. The results of the analysis of correlation between the severity of the hygienic restriction on the RF EMF MPL for population in different countries and the mortality rate from COVID-19 according to the official WHO data, determined in relation to the number of detected infected

Country	MPL W/m ²	The ratio of the total number of deaths from COVID-19 to the specified date, to the total number of cases (infected) ² , in %							
		05/18/20	07/19/20	09/18/20	11/18/20	01/19/21	03/19/21	05/18/21	07/20/21
1. Azerbaijan	0.1	1.19	1.29	1.47	1.27	1.33	1.36	1.45	1.48
2. Belarus	0.1	0.56	0.751	1.03	0.91	0.70	0.695	0.718	0.766
3. Belgium	10	16.37	15.4	10.2	2.75	3.01	2.75	2.39	2.28
4. Bulgaria ¹⁾	0.01	4.92	3.46	4.01	2.26	4.03	4.00	4.18	4.30
5. Canada	4	7.48	8.06	6.58	3.65	2.54	2.45	1.88	1.86
6. Chile ¹⁾	0.1	1.03	2.57	2.75	2.79	2.60	2.41	2.16	2.16
7. China	0.4	5.50	5.41	5.22	5.13	4.85	4.73	4.90	4.69
8. Denmark	10	5.01	4.64	2.97	1.19	0.95	1.07	0.936	0.828
9. France	10	20.04	18.3	7.84	2.30	2.45	2.22	1.85	1.92
10. Germany	10	4.54	4.51	3.50	1.57	2.32	2.83	2.40	2.44
11. Hungary	0.1	13.07	13.8	4.15	2.15	3.26	3.24	3.66	3.71
12. India	0.9	3.15	2.49	1.62	1.47	1.44	1.38	1.10	1.33
13. Ireland	10	6.40	6.81	5.59	2.90	1.50	2.00	1.94	1.76
14. Israel	0.9	1.63	0.822	0.678	0.842	0.73	0.735	0.761	0.756
15. Italy	0.1	14.15	14.3	12.2	3.75	3.45	3.14	2.99	2.98
16. Japan	10	4.59	4.00	1.91	1.58	1.36	1.93	1.69	1.78
17. Kazakhstan	0.1	0.53	0.533	1.45	1.45	1.37	1.26	1.19	1.52
18. Lithuania	0.1	3.63	4.18	2.48	0.81	1.48	1.66	1.55	1.57
19. Luxemburg	0.45	2.71	2.05	1.64	0.87	1.14	1.20	1.17	1.12
20. Netherlands	10	12.91	11.9	7.11	1.89	1.42	1.37	1.09	0.984
21. Poland	0.1	5.00	4.07	2.94	1.44	2.33	2.43	2.52	2.61
22. Portugal	10	4.19	3.48	2.84	1.54	1.62	2.05	2.02	1.85
23. Russia	0.1	0.94	1.60	1.75	1.73	1.84	2.12	2.35	2.50
24. Spain	10	11.95	10.9	4.86	2.30	2.40	2.27	2.20	1.95
25. Sweden	10	12.21	7.27	6.67	3.23	1.97	1.79	1.38	1.34
26. Switzerland	0.1	5.25	5.05	3.62	1.20	1.62	1.64	1.49	1.46
27. Turkey	0.56	2.77	2.50	2.45	2.78	1.53	1.01	0.877	0.914
28. UK	10	14.21	15.4	10.9	3.74	2.62	2.94	2.87	2.35
29. Ukraine	0.1	2.87	2.52	2.05	1.77	1.80	1.94	2.24	2.35
30. USA	10	6.09	3.88	2.98	2.21	1.67	1.82	1.78	1.79
31. Uzbekistan	0.025	0.43	0.511	0.834	0.848	0.79	0.767	0.692	0.667
Pearson's correlation coefficient:		0.551	0.485	0.431	0.189	-0.048	0.042	-0.071	-0.151

¹⁾ The lower limit of the range of normalized values.
²⁾ The number of detected infected is given in accordance with the data of the Johns Hopkins Center for Health Security (<https://covid19.who.int/>).

² Daily new confirmed COVID-19 cases per million people: <https://ourworldindata.org/> (on-line resource).

Table 2. The results of the analysis of correlation between the severity of the hygienic restriction on the RF EMF MPL for population in different countries and the mortality rate from COVID-19 according to the official WHO data, determined in relation to the country's population

Country	MPL W/m ²	The ratio of the total number of deaths from COVID-19 to the specified date ²⁾ , to the total country population ³⁾ , in %							
		05/18/20	07/19/20	09/18/20	11/18/20	01/19/21	03/19/21	05/18/21	07/20/21
1. Azerbaijan	0.1	3.85	34.4	56.3	99.1	298	327	473	493
2. Belarus	0.1	17.5	52.4	81.6	112	168	225	287	353
3. Belgium	10	781	846	857	1280	1766	1952	2133	2175
4. Bulgaria ¹⁾	0.01	15.8	43.0	107	347	1233	1701	2496	2616
5. Canada	4	151	234	244	292	477	598	661	702
6. Chile ¹⁾	0.1	23.5	442	635	779	918	1150	1461	1807
7. China	0.4	3.23	3.23	3.30	3.30	3.34	3.37	3.38	3.90
8. Denmark	10	94.4	105	110	133	312	414	432	439
9. France	10	430	460	474	704	1077	1397	1640	1693
10. Germany	10	94.7	108	112	157	568	887	1031	1091
11. Hungary	0.1	47.8	61.7	69.3	350	1193	1847	3031	3108
12. India	0.9	2.19	19.4	61.1	94.9	111	115	202	300
13. Ireland	10	312	355	362	404	530	925	1001	1016
14. Israel	0.9	31.3	45.6	134	316	466	701	738	745
15. Italy	0.1	528	580	590	768	1365	1718	2058	2115
16. Japan	10	5.92	7.79	11.7	15.1	36.0	69.2	91.6	119
17. Kazakhstan	0.1	1.81	20.0	106	126	157	187	263	435
18. Lithuania	0.1	20.6	29.4	32.0	110	916	1268	1516	1618
19. Luxemburg	0.45	171	177	198	377	890	1126	1291	1312
20. Netherlands	10	331	358	365	502	762	945	1019	1038
21. Poland	0.1	24.4	42.8	59.5	287	890	1290	1900	1987
22. Portugal	10	119	165	185	348	885	1642	1668	1688
23. Russia	0.1	18.5	84.1	131	234	454	642	794	1021
24. Spain	10	591	608	650	872	1135	1557	1699	1735
25. Sweden	10	364	556	581	616	1022	1311	1414	1450
26. Switzerland	0.1	185	195	204	380	930	1090	1170	1192
27. Turkey	0.56	49.1	64.9	86.7	139	286	353	533	600
28. UK	10	510	667	614	777	1324	1855	1881	1896
29. Ukraine	0.1	12.7	35.2	82.3	240	499	700	1150	1251
30. USA	10	263	416	591	741	1186	1610	1754	1824
31. Uzbekistan	0.025	0.359	2.51	12.5	17.9	18.5	18.6	20.1	24.1
Pearson's correlation coefficient:		0.60	0.570	0.522	0.442	0.289	0.315	0.137	0.1

¹⁾ The lower limit of the range of normalized values.
²⁾ The number of detected infected is given in accordance with the data of the Johns Hopkins Center for Health Security (<https://covid19.who.int/>).
³⁾ The population of countries is given as of 05/04/2020 in accordance with the data of the electronic resource <https://www.worldometers.info/world-population/>.

Table 3. The results of the analysis of correlation between the severity of the hygienic restriction on the RF EMF MPL for population in various countries and the relative level of vaccination against COVID-19 according to the official WHO data (full cycle of vaccination with two injections)

Country	MPL W/m ²	Rates of vaccination against COVID-19 in % of country population ²⁾							
		12/20/20	01/20/21	02/20/21	03/20/21	04/20/21	05/20/21	06/20/21	07/20/21
1. Azerbaijan	0.1	0	0	0	0	4.43	8.04	10.16	17.50
2. Belarus	0.1	0	0	0	0.11	0.28	1.59	3.91	7.98
3. Belgium	10	0	0.01	2.53	3.94	6.42	13.92	30.54	49.49
4. Bulgaria ¹⁾	0.01	0	0.06	0.39	1.03	1.96	6.96	10.87	12.79
5. Canada	4	0	0.14	1.06	1.64	2.48	4.02	18.59	51.01
6. Chile ¹⁾	0.1	0	0.04	0.29	14.93	29.70	39.90	49.66	61.65
7. China ³⁾	0.4	0	0.10	0.50	1.00	3.00	7.50	15.00	25.00
8. Denmark	10	0	0.12	3.00	5.36	9.21	19.69	28.36	47.55
9. France	10	0	0	1.77	3.71	7.41	14.71	25.71	44.24
10. Germany	10	0	0.14	2.11	4.00	6.75	13.10	30.99	46.87
11. Hungary	0.1	0	0.04	1.98	4.93	14.79	29.96	46.62	55.30
12. India	0.9	0	0	0.06	0.54	1.25	2.96	3.57	6.22
13. Ireland	10	0	0.20	2.61	3.68	7.25	10.31	20.01	43.86

End of Table 3

14. Israel	0.9	0	7.86	31.42	48.58	53.53	54.82	55.24	56.39
15. Italy	0.1	0	0.02	2.23	4.08	7.77	15.85	26.28	45.24
16. Japan	10	0	0	0	0.02	0.64	1.95	8.69	24.36
17. Kazakhstan	0.1	0	0	0	0.1	0.65	4.37	8.69	15.12
18. Lithuania	0.1	0	0.32	2.52	4.67	8.06	18.71	32.96	44.36
19. Luxemburg	0.45	0	0	1.11	2.74	7.29	14.70	29.04	42.83
20. Netherlands	10	0	0	0.90	2.87	5.79	11.58	30.33	46.42
21. Poland	0.1	0	0.07	2.45	4.71	6.20	13.82	29.60	43.50
22. Portugal	10	0	0.18	2.44	4.39	6.90	14.55	28.51	48.38
23. Russia	0.1	0	0	1.16	1.86	4.27	7.04	10.44	14.78
24. Spain	10	0	0.03	2.50	4.03	7.38	16.82	30.85	52.81
25. Sweden	10	0	0	1.85	3.77	6.76	10.43	27.40	37.58
26. Switzerland	0.1	0	0.5	1.79	5.13	8.97	16.62	29.86	44.78
27. Turkey	0.56	0	0	1.21	5.88	9.21	13.57	16.98	24.87
28. UK	10	0	0.68	0.90	3.27	15.79	31.73	46.06	53.32
29. Ukraine	0.1	0	0	0	0	0	0.15	0.87	3.63
30. USA	10	0	0.65	5.37	12.92	25.89	38.01	44.93	48.52
31. Uzbekistan	0.025	0	0	0	0	0	0.84	2.95	3.01
Pearson's correlation coefficient:		---	-0.091	-0.015	-0.046	0.014	0.095	0.277	0.445

¹⁾ The lower limit of the range of normalized values.
²⁾ The percentage of vaccinated is given in accordance with the data of the electronic resource <https://index.minfin.com.ua/reference/coronavirus/vaccination/>.
³⁾ Estimated data based on total vaccine doses injected.

Table 4. The results of the analysis of correlation between the severity of the hygienic restriction on the RF EMF MPL for population in various countries and the level of GDP per capita in these countries

Country	MPL W/m ²	GDP per capita			
		Specific GDP PPP		Nominal GDP per capita	
		IMF List ²⁾ 2020	WB List ³⁾ 2019	IMF List ⁴⁾ 2018	WB List ⁵⁾ 2017
1. Azerbaijan	0.1	14431	15001	4569	4132
2. Belarus	0.1	20187	19943	6306	5726
3. Belgium	10	51096	54545	50050	43324
4. Bulgaria ¹⁾	0.01	23817	24561	9267	8032
5. Canada	10	48720	51342	45870	45032
6. Chile ¹⁾	0.1	23366	25155	16078	15346
7. China	10	17192	16785	9608	8827
8. Denmark	10	58933	59830	63640	56307
9. France	0.9	46062	49435	44770	38477
10. Germany	0.9	54046	56052	51970	44470
11. Hungary	10	33030	33979	15923	14225
12. India	10	6461	7034	2036	1940
13. Ireland	0.1	94392	88241	90480	69331
14. Israel	0.1	40547	42194	43440	40270
15. Italy	4	40861	44197	35060	31953
16. Japan	0.4	42248	43236	40730	38428
17. Kazakhstan	0.1	26565	27444	9236	8837
18. Lithuania	0.45	38824	38214	19143	16681
19. Luxemburg	10	118002	121293	125920	104104
20. Netherlands	0.1	57534	59687	58030	48223
21. Poland	10	34103	34218	15430	13812
22. Portugal	0.1	34043	36471	25100	21136
23. Russia	10	27930	29181	11326	10743
24. Spain	0.56	38392	42214	31180	28157
25. Sweden	0.025	54146	55815	57660	53442
26. Switzerland	0.1	72874	70989	90360	80190
27. Turkey	10	30253	27875	9346	10541
28. UK	0.1	44117	48710	42240	39720
29. Ukraine	0.1	13110	13341	2963	2640
30. USA	10	63416	65281	66140	59532
31. Uzbekistan	10	7449	7289	1262	1504
Pearson's correlation coefficient:		0.418	0.441	0.457	0.464

End of Table 4

- ¹⁾ The lower limit of the range of normalized values.
²⁾ International Monetary Fund: World Economic Outlook database: April 2021.
³⁾ The World Bank: GDP per capita, PPP (current international \$): 2020.
⁴⁾ International Monetary Fund: World Economic Outlook database: April 2019.
⁵⁾ The World Bank: GDP per capita (current US\$): 2018.

Table 5. The results of the analysis of correlation between the relative level of vaccination against COVID-19 in various countries as of 07/20/2021 ¹⁾ and the level of GDP per capita in these countries

Country	Percentage of fully vaccinated as of 07/20/2021 ¹⁾	GDP per capita			
		Specific GDP PPP		Nominal GDP per capita	
		IMF List ²⁾ 2020	WB List ³⁾ 2019	IMF List ⁴⁾ 2018	WB List ⁵⁾ 2017
32. Azerbaijan	17.50	14431	15001	4569	4132
33. Belarus	7.98	20187	19943	6306	5726
34. Belgium	49.49	51096	54545	50050	43324
35. Bulgaria	12.79	23817	24561	9267	8032
36. Canada	51.01	48720	51342	45870	45032
37. Chile	61.65	23366	25155	16078	15346
38. China ⁶⁾	25.00	17192	16785	9608	8827
39. Denmark	47.55	58933	59830	63640	56307
40. France	44.24	46062	49435	44770	38477
41. Germany	46.87	54046	56052	51970	44470
42. Hungary	55.30	33030	33979	15923	14225
43. India	6.22	6461	7034	2036	1940
44. Ireland	43.86	94392	88241	90480	69331
45. Israel	56.39	40547	42194	43440	40270
46. Italy	45.24	40861	44197	35060	31953
47. Japan	24.36	42248	43236	40730	38428
48. Kazakhstan	15.12	26565	27444	9236	8837
49. Lithuania	44.36	38824	38214	19143	16681
50. Luxemburg	42.83	118002	121293	125920	104104
51. Netherlands	46.42	57534	59687	58030	48223
52. Poland	43.50	34103	34218	15430	13812
53. Portugal	48.38	34043	36471	25100	21136
54. Russia	14.78	27930	29181	11326	10743
55. Spain	52.81	38392	42214	31180	28157
56. Sweden	37.58	54146	55815	57660	53442
57. Switzerland	44.78	72874	70989	90360	80190
58. Turkey	24.87	30253	27875	9346	10541
59. UK	53.32	44117	48710	42240	39720
60. Ukraine	3.63	13110	13341	2963	2640
61. USA	48.52	63416	65281	66140	59532
62. Uzbekistan	3.01	7449	7289	1262	1504
Pearson's correlation coefficient:		0.545	0.573	0.540	0.56

¹⁾ The percentage of vaccinated is given in accordance with the data of the electronic resource <https://index.minfin.com.ua/reference/coronavirus/vaccination/>
²⁾ International Monetary Fund: World Economic Outlook database: April 2021.
³⁾ The World Bank: GDP per capita, PPP (current international \$): 2020.
⁴⁾ International Monetary Fund: World Economic Outlook database: April 2019.
⁵⁾ The World Bank: GDP per capita (current US\$): 2018.
⁶⁾ Estimated data based on total vaccine doses injected.

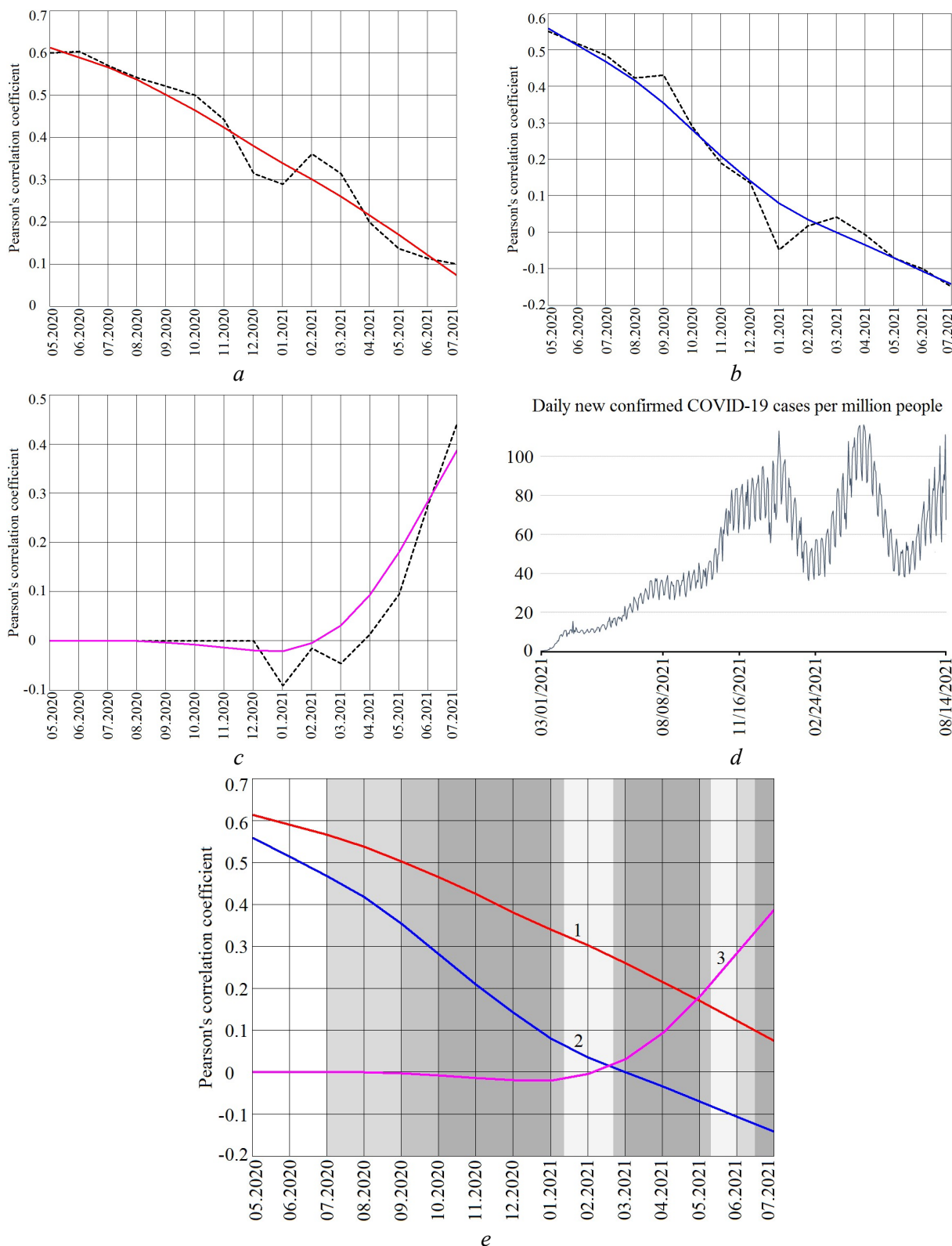


Fig. 1. Time dependences of the correlation coefficient between the potential level of electromagnetic pollution of the environment (the adopted EMF RF MPL for the population) and *a* – the lethality of COVID-19 in relation to the population size, *b* – the lethality of COVID-19 in relation to the number of detected infected, and *c* – the level of vaccination of population against COVID-19; *d* – well-known representation of the time dependence of the number of new infected according to WHO data, illustrating the nature and periods of waves of the COVID-19 pandemic; *e* – smoothed dependences of parts *a*, *b*, *c* for comparison placed jointly in a single scale; here the first, second and third waves of the pandemic are indicated by shading

Conclusion

1. Presented results of the analysis, despite some doubts about the reliability and comparability of the medical statistics of some countries in the information sources used, due to its integral nature with a relatively low sensitivity to such factors, in general, confirm the presence of a noticeable correlation between the RF EMF MPL for the population adopted in different countries (which determine the potential levels of electromagnetic pollution of the environment), and relative lethality of COVID-19. Before the beginning of the intensive struggle against the pandemic (at the arrival of its first wave), carried out through the implementation of strict administrative restrictions, mass testing and vaccination of the population, the Pearson correlation coefficient between these characteristics was 0.5–0.6.

2. The decrease in correlation between these characteristics by the end of the analyzed period, especially with the arrival of the second wave of the pandemic, can be explained by the larger efforts in struggle against the COVID-19 by countries where the first approach to protecting the population from RF EMF is used, compared to countries where significantly more stringent "non-thermal" hygienic standards for RF EMF MPL have been adopted. Countries that use the principle of passive regulation of the protection of the population from RF EMF and its socially oriented modifications, on average, are characterized by higher levels of economic development (the level of nominal GDP) and have more economic opportunities to struggle with the pandemic. It is reflected in significantly higher volumes of COVID-19 testing of the population, its implementation of stricter and longer restrictions (quarantines, lockdowns, etc.), as well as in ensuring the highest rates of vaccination of the population.

3. The presence of a correlation between the adopted RF EMF MPLs for the population in different countries (which determine the boundaries of possible electromagnetic pollution of the environment during the implementation of extremely ambitious declarations and scenarios [8, 9] of the development of 4G/5G/6G mobile communications), and the relative lethality of COVID-19, is not the evidence of obligatory existence of an unambiguous causal relationship between these characteristics. The fact is that in countries that use the principle of passive regulation and its socially oriented modifications, this principle is used not only in relation to RF EMF, but also in relation to other environmental factors that determine the overall level of ecology and their impact on collective immunity of the population but not taken into account in this analysis. Therefore, the detected correlation can be interpreted as a correlation between the lethality of COVID-19 and the degree of passivity (the presence of passive regulation) in protecting the population from the effects of factors that worsen the environment.

In this interpretation, the results of this analysis can serve as indirect evidence of the advantages of an alternative second approach to protecting the population from these factors (adopting MPLs that guarantee the absence of harm to health) at an intensity of their impact close to critical. Some confirmation of this assumption may be the Decision No. 20-1025 dt. Aug. 13, 2021, of the United States Court of Appeals (mandatory for the US Federal Communications Commission), on the need to abandon the "thermal" RF EMF standards, similar to [3], and develop more stringent standards that take into account the "non-thermal" effects of RF EMF exposure on public health.

4. The hypothesis [12] about the presence of a noticeable correlation between the potential levels of electromagnetic pollution of the environment and the relative mortality of COVID-19, confirmed by the results of this work, indicates the presence of a potential danger for the population of the declared development of 4G/5G/6G mobile communications. And since this development is global in nature and can both significantly enrich all areas of human existence, and significantly change the characteristics of the environment for the worse, further analysis of the possibility of actual existence of a causal relationship between these important characteristics is rather relevant.

In particular, to confirm or refute the presence of a causal relationship between the factors considered, it is of interest to analyze the actual level of electromagnetic and other pollution of the environment in the considered group of countries, as well as deep and independent studies of the influence of RF EMF created by the basic and user's radio equipment of 4G/5G/6G systems of all allocated frequency bands and modes of operation, on population health and collective immunity.

In general, the results obtained indicate the relevance of a more careful attitude to the habitat at the increasing efforts to provide information services to all aspects of human life within

the framework of 4G/5G/6G evolution, using, whenever possible, alternative technologies and technical solutions where wireless data transmission is not the only possible one.

References

1. Grigoriev O., Goshin M., Prokofyeva A., Alekseeva V. Features of national policy in approaches to electromagnetic field safety of radio frequencies radiation in different countries. *Gigiena i Sanitaria* (Hygiene and Sanitation, Russian journal). 2019; 98(11):1184-1190. DOI: <http://dx.doi.org/10.18821/0016-9900-2019-98-11>. (In Russ.)
2. Grigoriev O.A., Nikitina V.N., Nosov V.N., Pekin A.V., Alekseeva V.A., Dubrovskaya E.N. Electromagnetic radiation safety: Russian national and international regulatory frameworks for radiofrequency electromagnetic fields. *Zdorov'ye Naseleniya i Sreda Obitaniya*. 2020;10(331):28-33. DOI: <https://doi.org/10.35627/2219-5238/2020-331-10-28-33>. (In Russ.)
3. International commission on non-ionizing radiation protection (ICNIRP): Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (100 kHz to 300 GHz). July 6, 2020.
4. Ozdemir A.R., Alkan M., Gulsen M. Time dependence of environmental electric field measurements and analysis of cellular base stations. *IEEE EMC Magazine*. 2014;3:43-48.
5. Gajsek P., Ravazzani P., Wiart J., Grellier J., Samaras T., Thuroczy G. Electromagnetic field exposure assessment in Europe radiofrequency fields (10MHz–6GHz). *J Expo Sci Env. Epidem*. 2015;(25):37–44.
6. Ibrani M., Hamiti E., Ahma L., Halili R., and Dragusha B. Comparative analysis of downlink signal levels emitted by GSM 900, GSM 1800, UMTS, and LTE Base Stations, 16th Annual Mediterranean Ad Hoc Networking Workshop, June 28-30, 2017, Budva, Montenegro.
7. Karpowicz J., Miguel-Bilbao S., Ramos V., Falcone F., Gryz K., Leszko W. and Zradziński P. The evaluation of stationary and mobile components of radiofrequency electromagnetic exposure in the public accessible environment. *Proc. of the Int. Symp. EMC Europe 2017, Angers, France, Sept. 4-8, 2017*.
8. IMT Vision. Framework and overall objectives of the future development of IMT for 2020 and beyond, Rec. ITU-R M.2083.
9. Zhang Z., Xiao Y., Ma Z., Xiao M., Ding Z., Lei X., Karagiannidis G.K. and Fan P. 6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies. *IEEE VT Magazine*. 2019;14(3):28-41.
10. Hardell L., Carlberg M. Health risks from radiofrequency radiation, including 5G, should be assessed by experts with no conflicts of interest. *Oncology Letters* 20:15. 2020;1-11. DOI: 10.3892/ol.2020.11876.
11. Buchner K and Rivasi M: The International Commission on Non-Ionizing Radiation Protection: Conflicts of interest, corporate capture and the push for 5G. 98 p. <https://www.michele-rivasi.eu/wp-content/uploads/2020/06/ICNIRP-rapport-FR-FINAL-JUIN-2020.pdf>.
12. Mordachev V.I. COVID-19 lethality rate may be affected by electromagnetic radio frequency pollution. 4G/5G/6G can be safe for people. *Doklady BGUIR = Doklady BGUIR*. 2020;18(4):96-112.

Information about the author

Mordachev V.I., Cand. of Sci., Associate Professor, Leading Researcher of the Belarusian State University of Informatics and Radioelectronics.

Address for correspondence

220013, Republic of Belarus, Minsk, P. Brovka st., 6,
Belarusian State University of Informatics and Radioelectronics;
tel. +375-17-293-84-38;
e-mail: mordachev@bsuir.by, www.emc.bsuir.by
Mordachev Vladimir Ivanovich