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For many years the Department MFRD of IE KarRC RAS, together with scientists of PetrSU, UWF and medical institutions, have been conducting comprehensive research at the intersection of economics, demography, medicine and ecology. Studies were supported by 10 RFBR and RGNF grants. This article examines the impact of the COVID-19 pandemic on mortality in Russian regions. The purpose of the study is to identify the factors that during the pandemic have contributed to a significant mortality increase in Russian regions. The work assessed the impact of socio-economic, demographic, medical and geographical indicators at different stages of the pandemic on the level of morbidity and mortality, taking into account the characteristics of regions. It is shown that in general, the increase in mortality has been facilitated by a higher shares of retirees and urban population, the location of the region in the center of the country and a drop in citizens' incomes in 2020 (compared to 2019). The first (spring) wave of the pandemic in Russia was relatively low, largely due to the imposed strict restrictions. Therefore, only in some months did the lower availability of hospital beds of the population of the region contribute to the increase in mortality. The highest increase in the mortality rate was in the regions of the Central Federal District. During the summer period, the incidence decreased and restrictions were relaxed, but increased mobility of citizens led to an increase in mortality in the Volga Federal District regions, through which the main roads and railways pass. By the end of summer, the availability of doctors and beds in the region became significant factors influencing the increase in mortality, in addition to the three main indicators. In the fall, the second wave began, during this period the increase in mortality depended on the location of the region, the proportion of the urban population and the availability of doctors in the region. In some months, the level of income of the population and its change in 2020 had a significant impact. In December, the situation in the Volga Federal District and the Siberian Federal District stabilized, while mortality in the Southern regions of the country began to grow. The research was carried out by scientists of the IE KarRC RAS and RIH and can be used in the field of regional medical and demographic policy to increase the effectiveness of management decisions and preserve the public health of the nation.

Keywords: demography; mortality; public health; socio-economic factors; modelling; region; pandemic; COVID-19.

Introduction. In 2019 the entire global community faced a serious global challenge, the emergence of a new type of infectious disease COVID-19 (coronavirus infection), which is a potentially severe form of acute respiratory infection caused by coronavirus SARS-CoV-2 [Schelkanov et al., 2020; Glybochko et al., 2020]. The World Health Organization declared an emergency situation in the field of public health and health service, the spread of the virus was recognized as a pandemic [David L. Heymann, 2020; Gideon Meyerowitz-Katz, 2020]. According to preliminary data from Rosstat, mortality in the Russian Federation in 2020 increased by 17.9% compared to 2019. This is excess mortality, which includes mortality from coronavirus infection and exacerbations of other diseases caused by it.

The spread of a new type of dangerous infectious disease that has affected all of humanity has required comprehensive scientific research to address the crisis [Ben Hu, 2020]. The leading role in this case was played by work in the field of biomedical specialties related to virology, the development of vaccines and medicines, as well as the introduction of modern methods of prevention [Kharchenko, 2020; Supotnitsky, 2020; Prevention, 2021]. As of December 2020, various medical institutions and pharmaceutical companies have being developed more than 200 potential vaccines, human trials have begun for 64 drugs. Currently, in some countries a number of vaccines have undergone clinical trials and are allowed for use, among them Gam-KOVID-Vak (Sputnik V, Russia, NITSEM named after N.F. Gamalei), BNT162b2 (Germany, BioNTech; China, Fosun Pharma; USA, Pfizer), mRNA-1273 (USA, Moderna, NIAID), ChAdOx1-S (AZD1222, UK, Sweden AstraZeneca, Oxford University) and a number of other drugs. Nevertheless, the spread of the disease is still ongoing, although its rate has noticeably decreased. The predictions of experts in this matter are quite optimistic, although many of them note that the complexity of the problem lies in the constant mutation of the virus, in connection with which a number of vaccines may not cause an appropriate immune response in humans [Schelkanov et al., 2020; Petter Brodin, 2021; Wei-jie Guan, 2020].

The pandemic COVID-19 called for a review of the health-care system. A large number of scientific publications have appeared that affect this particular area. In examining this issue, the Global Burden of Disease (GBD) project should be highlighted, which allows comparative analysis of the effectiveness of almost all national health systems by means of visual graphical tools and providing information on the main medico-demographic indicators of public health [Murray, 1996; GBB, 2016; Global, 2013]. Currently, there are several classic health models in the world, including the Bismarck model (Germany), the Beveridge model (UK), the private model (USA) and a number of mixed forms [Donbass et al., 2005;

Prokhorov et al., 2007]. In Russia for a long time there was a Soviet system for organizing medical care (the Semashko-Kaminsky model), which proved its effectiveness and was recognized as one of the best in the world. However, in the transition to a market economy, it was replaced by the insurance principles of the health organization, which were subsequently constantly reorganized. As a result, our country was largely unprepared for such an emergency, it took time to create special hospitals, which entailed heavy human losses.

The emergence of a new global challenge has also affected the socio-economic sphere of life. Many enterprises and organizations faced the threat of closure, significantly reduced incomes, changes in the form of labor organization, increased unemployment, and therefore there was an urgent need to find various forms of support for enterprises and business structures. Currently, it is this area that is given special attention in the study of economic processes in Russia and its regions [Maksimova et al., 2020; Zemtsov et al., 2020]. In addition to the analysis of official statistical information, many scientific organizations conduct special sociological surveys that reveal the extent of the impact of the crisis on the level and quality of life of the population. There is a scientific relationship between socio-economic well-being and medico-demographic indicators, and in case of emergency it manifests itself with even greater force [Velichkovsky, 2005; Gundarov, 2001; Rimashevskaya et al., 2011].

For many years, the Department MFRD of IE KarRC RAS, together with scientists of PetrSU, UWF and medical institutions have been conducting comprehensive research at the intersection of economics, demography, medicine and ecology. Studies were supported by 10 grants from RFBR and RGNF [Burkin et al., 2017; Druzhinin et al., 2020, 2021; Molchanova et al., 2017, 2019; Hyankäinen et al., 2020]. The scientific novelty of this study is an attempt to identify the complex (synergistic) influence of various factors on medical and demographic indicators in the regions of Russia. First of all, in determining the causes of ultra-high mortality in the era of the global pandemic, as well as developing management recommendations to minimize negative consequences. Most of the papers currently published are devoted to the study of only one group of factors (environmental, social or economic). In a number of works [Bobylev, 2020; Kuzmin, 2020] analyzes the consequences of COVID-19 for the ecology of Russia, which are differentiated into three groups: negative, positive and ambiguously interpreted. The authors note that among the conditionally positive consequences of the COVID-19 and the associated economic crisis one can distinguish a short-term reduction in the environmental impact, the need for international coordination in the field of solving environmental problems of modern society. The Research on the economic impact of the pandemic examines the changes in the global economy and energy,

the impact of the COVID-19 and crisis caused by coronavirus on the global economy and energy consumption [Vaganov, 2020; Mastepanov, 2020; Dudin et al., 2020]. Some articles analyze the consequences for the banking and financial system of Russia, foreign trade and international cooperation [Osinin, 2020; Obolensky, 2020]. Researchers suggest focusing on the development of the regional banking sector, the purpose of which is to stimulate regional financial and economic activity, including creating conditions for doing business. A significant part of scientific works is devoted to social issues, including the problems of the modern educational process [Yakovlev et al., 2020; Makarov, 2020]. The authors study the experience of distance education in Russian schools and universities, highlight the advantages and disadvantages of introducing new forms of education, as well as the possible consequences of changing the paradigm of the educational process. It should be noted that in almost all works, scientists agree that coronavirus is a special point of bifurcation of the global socio-historical process and economic security of Russia, which requires the introduction of new forms of management of socio-economic processes [Gureeva, 2020; Gabov, 2020; Kondratiev, 2020].

The purpose of this study is to identify the factors that contributed to a significant increase in mortality in Russian regions during the pandemic. It is necessary to understand to what extent, and at what periods, the increase in mortality was influenced by the state of health and its peculiarities during the reforms, socio-economic, demographic and geographical factors. It is also necessary to assess the impact of decisions taken by the authorities on restrictions, and find out what features of some regions determined the sharp increase in mortality there.

Materials and methods. For achieving this goal, there is an approach which is based on the study of regional data, the analysis of graphs of indicators to find their relationships, the construction of equations to identify the impact of various indicators on the increase in mortality in the population of regions during the pandemic. As a result, the factors that could have an impact on mortality growth in 2020 were identified.

For all Russian regions, an increase in mortality was determined in 2020 as a whole and by months relative to the corresponding period of 2019. Based on the analysis of literary sources, the indicators, that could potentially have an impact on mortality growth, were identified. Then, to identify possible relationships the graphs for each indicator were drawn and the necessary statistical characteristics were calculated [Aivazyan, 1998]. The factors that had the greatest impact on mortality growth were identified for each month and allotted

periods (spring, summer, autumn). The calculations used econometric tools (multiple regression analysis), the functional dependence of the following type was considered:

$$R(t) = A + B \times Z(t) + D \times X(t) + C \times N(t) + E \times U(t) + M \times S(t) + L \times V(t), \quad (1)$$

where: *R(t)* is the ratio of mortality growth in the region in a certain period of 2020 relative to the corresponding period of 2019 to the population of the region; *Z(t)* - health indicator; *N(t)* - demographic indicator; *X(t)* - socio-economic indicator; *S(t), V(t)* - geographical indicators (north latitude and east longitude); *U(t)* - environmental indicator; *C, D, L, M, E, B, A* are constants.

To assess the impact of medical factors associated with regional health potential, the following indicators were chosen - the number of beds per 10,000 inhabitants, the number of doctors per 10,000 inhabitants and the ratio of these indicators in 2019 to the level of 1990. The following characteristics were used as demographic indicators in this article - the population of the region, the population of the administrative center of the region, the population density, the proportion of urban population and the proportion of pensioners. From socio-economic factors, the indicators, that reflect the level of development of the region, were selected (GRP per capita, the ratio of population income to the subsistence minimum) and characterize the 2020 crisis (change in average per capita income in 2020 relative to 2019). The location of the region can have a noticeable impact on epidemiological processes, so the association of mortality growth with the following geographical indicators was analyzed - the northern latitude of the administrative center of the region, the eastern longitude of the administrative center of the region and the border position. Emissions of pollutants into the atmosphere and discharges of contaminated wastewater were chosen among the environmental characteristics (in the region as a whole and per capita).

The work evaluated the medical and demographic situation in all Russian regions, but calculations were carried out for 77 territorial entities. Regions for which there are no statistics for the 1990s (the Chechen Republic, Crimea and Sevastopol) were excluded, and, due to the peculiarities of the provision of medical care and the organization of the health system, Moscow and Moscow Region, St. Petersburg and Leningrad Region were considered as single regions.

Information for 1990-2020 on the development of Russian regions, the Main source of data - the collections of the FSGS "Regions of Russia" ("Socio-economic indicators" and

"Socio-economic indicators of cities") and the handbook "Natural Population Movement," presented on the FSGS website, as well as Internet resources containing official information about the development of the pandemic COVID-19 in different countries of the world.

Results and discussion. If we rely on official statistics, we can conclude that only mortality from COVID-19 does not fully reflect the medical and demographic processes taking place in Russia today. The pandemic entailed a super-mortality, which is due not only to a new type of virus. The identification of its causes is an urgent task, the solution of which will depend on the effectiveness of the entire socio-demographic policy of our state in the near future.

Analysis of mortality data in the Russian Federation for 2019-2020. showed its noticeable growth from May 2020, although in the first two months mortality decreased, positive trends of the previous year continued (Fig. 1). In 2019, mortality decreased by 1.7% compared to 2018. This indicator increased significantly in May-July 2020, then its rapid growth began to be noted from September and continued until 2021. Apparently, already in February 2020, mortality began to increase due to the penetration of COVID-19, which suspended in April after the adoption of restrictive measures. However, the spread of the disease did not stop, effective treatment regimens were not developed, and after easing the restrictions, the increase in mortality again resumed in the summer, and it was already difficult to stop it in the fall.

Regional FSGS data on coronavirus incidence show that the higher the incidence rate, the lower in the region was the increase in mortality (Fig. 2). This dependence is an important indicator of the effectiveness of the regional health system. It should be noted that this trend was observed in previous years, but in a crisis situation it began to take on special importance, as it indicates significant shortcomings in the organization of medical care for the population (problems with testing of patients and, accordingly, the lack of necessary treatment).

The situation in the regions changed differently during the year. In the first two months, mortality did not exceed the level of 2019 and only in a few, mainly border regions, mortality increased (Pskov, Murmansk, Amur regions, Krasnodar Territory). In March, several more regions were added, including the border Karelia, the Trans-Baikal Territory and the Leningrad Region. In mid-March, severe restrictions began to be introduced in the regions, and mortality briefly became less than the level of 2019. The highest increase in mortality was in the Kostroma, Moscow and Novosibirsk regions. Mortality has decreased in most northern and eastern regions. Border closures and tough measures in the PRC have led

to the fact that by the summer the increase in mortality in most Asian border regions has noticeably decreased.

Since May, mortality in the Central Federal District began to grow rapidly, in June, half of the regions out of ten with the largest increase in mortality were in the Central Federal District. In June, the increase in mortality in the Volga Federal District also began, in July, half of the regions with the largest increase in mortality were already in the Volga Federal District. In the future, until December, among the ten regions with the largest increase in mortality, the Volga Federal District was the most. Crimea, actively visited by tourists, became one of the regions with a high increase in mortality only in September, and in the resort Krasnodar Territory, mortality in the summer was relatively low. At the end of the year, mortality in the regions of the Siberian Federal District and the Far Eastern Federal District increased, but in general, among the ten regions with the largest increase in mortality, there were seven regions from the Volga Federal District.

In the border Republic of Karelia located in the west of the country, the change in mortality began in February. In 2019, mortality in the region fell by 4.2%, but already in February 2020 it increased, and reached its maximum value in March. Then, this indicator decreased, but new growth began in the fall and already in November the level of March was exceeded (Fig. 3). Perhaps the increase in mortality in March was affected by the cross-border activity of the population of the republic, and the reduction in April of the closure of the border with Finland, the rigidity of restrictive measures and the discipline of the population. Summer vacation and relocation to summer cottages contributed to a decrease in morbidity, but then its growth resumed, and in December mortality was almost twice the level of the previous year.

Among the possible reasons for the increase in mortality in 2020, first of all, medical ones related to the reform of health care in the Russian Federation, the rejection of the Soviet model of organization of medical care, stood out. Already in the spring there were problems with congestion of medical institutions, for example, in Karelia the number of hospital beds decreased by 2.65 times over 30 years (Fig. 4).

The analysis of the relationship between the increase in mortality in the whole of 2020 from the provision of the population with hospital beds in the regions of the Russian Federation showed that dependence is rather weak, apparently, other factors have a stronger effect. At the same time, the analysis of monthly data by region and correlation coefficients indicates that in some periods, bed security had a noticeable effect on mortality growth, primarily in the spring at the beginning of the pandemic (after the introduction of restrictions,

the impact is noticeably reduced), and from July to September. Therefore, we can say that the introduction of restrictions restrained the development of the disease, reduced the burden on the bed fund and reduced mortality. The provision of doctors also affected mortality in August-September during holidays. The impact of the change compared to 1990 in the level of provision of beds and doctors was not noted, in regions with a larger reduction in the number of beds, higher mortality was not detected.

Demographic factors also have a major impact on epidemic development. Most often, population density, population, the share of urban population and the population of the capital or the largest city in the region are among the significant factors. With an increase in population density, the increase in mortality in the regions increases, but with a high density (above 50 thousand per square km) there is no dependence. The influence of two other factors - the population of the region and the population of the administrative center of the region - is more noticeable. It should be noted that in both cases there is a direct dependence to a certain level, and then, with the growth of the population, the increase in mortality does not increase. Analysis of data by month showed that the population density, like the other two factors (the population of the region and its capital), was most noticeable during the period of severe restrictions in the spring (April, May), in the future their impact was insignificant. Apparently, restrictions on the movement of people affected. The share of the urban population on the contrary turned out to be most significant in the last months of the year and in June.

The economic factors that characterize the level of development of the regions and the level of income of the population turned out to be insignificant, since underdeveloped regions had a low mortality rate. At the same time, the increase in mortality was associated with a change in the average per capita monetary income of the population in 2020 (data for the III quarter relative to the corresponding period of 2019). The stronger the incomes of the region's population, the smaller was the increase in mortality. When analyzing monthly data, it turned out that the level of development of the region (GRP per capita) very poorly affected the increase in mortality in all periods. The impact of the income level of the population only slightly affected at the very end of the year. The change in income of the population had a noticeable impact on the increase in mortality in early spring, in July and in the last two months of the year.

There is no available operational reporting on environmental indicators, and when analyzing environmental indicators of the previous period, their impact on mortality growth in 2020 was not revealed.

When analyzing geographical factors, it was possible to establish that the location of the regions turned out to be significant. The highest increase in mortality in 2020 was among regions located between the 51-57 of the north latitude. As we approach the northern latitude 53, mortality increases. It was also revealed that the highest increase in mortality in 2020 was among the regions located between the 39-83 of east longitude. As the east longitude 50 approaches, mortality increases. For the western regions, growth is fast enough, for the eastern slow. Conventionally, we can say that in the zone with a high increase in mortality, the central regions of the Russian Federation turned out to be and, in accordance with the stretch of the Russian Federation from west to east, this zone is also elongated and narrows east. In some months, the link between the increase in mortality and geographical location disappears, for example, in the spring after the introduction of severe restrictions. For the northern latitude, communication becomes significant in June with the beginning of the vacation period and population movements through the central regions, then it is insignificant, as morbidity and mortality in the south increase, and the connection reappears in the fall after the vacation period, apparently sick citizens, returning to their regions, infected residents of the central regions. For eastern longitude, the association of mortality growth is insignificant in November-December, when the population practically does not leave their places of residence.

The influence of the border was ambiguous, for the eastern and western regions it depended on the time of introduction and severity of restrictions in neighboring countries and the intensity of border crossings in the first months of the year. Regions bordering Kazakhstan were among the regions with a high mortality rate in the fall. In this case, apparently, it was influenced by the fact that the border was not closed for foreign economic activity and relatives' trips.

Table 1 shows the results of calculations for 77 regions. The higher increase in mortality was in regions with higher shares of pensioners and urban population, in the central regions and regions with the largest drop in incomes. The significance of the latter indicator was not high. Calculations were made for the whole year and with the exception of the first two months, when the impact of COVID-19 on the increase in mortality affected only a few regions, and was insignificant. In the calculations for the year, the significance of the parameters obtained turned out to be slightly higher than in ten months (March-December).

The Analysis of data by month showed that the development of the pandemic, changes in the policy of restrictions and behavior of the population led to the fact that the rate of morbidity and mortality in the regions changed, sometimes very dramatically. In some

regions, the mortality rate decreased, in others, on the contrary, it increased. Drastic changes occurred in April after the introduction of restrictions, then in July with an increase in interregional travel during the vacation period, and in September, after the return of vacationers to their native regions.

Conclusions. The closest association of mortality growth in data for the year and for 10 months turned out to be with the geographical location of the regions, which shows the highest correlation coefficient and the highest Student coefficient, reflecting the significance of the parameters of the equations. Moreover, the connection is absent during the period of severe restrictions in the spring, manifested in June and October-November for the northern latitude, and in July-September for the eastern longitude. Summer holidays led to an increase in movements between regions, primarily to the southern and central regions, since travel outside the Russian Federation was limited, as well as entry. Foreigners came to the country by 67.5% less than in 2019 and for the purpose of tourism by 93% less. Citizens of the Russian Federation went outside the country by 70.6% less, with more than half of the trips accounted for the first quarter and less than 5% for the second.

The main railway and road roads cross the central regions from east to west and from north to south, so movement within the Russian Federation passes to a large extent through these regions. The busiest roads in 2020 included the routes M5 passing through the central regions - Ural, M7 - Volga, M4 - Don, slightly less loading the routes M-10 Russia, M-2 Crimea and M-8 Kholmogory. The maximum passenger traffic at railway stations was also in Moscow, St. Petersburg and the capitals of the central regions. A similar picture is for airports. As a result, there was an increase in morbidity and then mortality in the central regions through which people, including infected tourists, passed from other regions. In the southern regions, in the summer, mortality increased noticeably only in the North Caucasian republics. In the southern coastal regions - Crimea, the Krasnodar Territory and the Rostov Region in the summer, the increase in mortality was small, only at the end of the year there was a noticeable increase.

It should be noted that different demographic indicators were significant at different periods. At the beginning of the pandemic, the population density and the proportion of pensioners were most significant, the population of the region and its capital turned out to be lower. In the summer, the population moved more actively between the regions, some of the townspeople left for the countryside and the importance of demographic indicators decreased. In the fall, city residents returned, and the shares of the urban population and pensioners became significant.

The next most important factor is associated with the standard of living of the population, more precisely with its change, which was manifested in general over the year and in individual months, although its significance in the obtained equations was low. Other socio-economic indicators turned out to be insignificant, the income level of the population and the wealth of the region are not so important, their change is important, a stronger drop in incomes led to an increase in mortality.

Medical indicators turned out to be significant only in certain periods. The low availability of beds contributed to the increase in mortality at the beginning of the pandemic and in July-September. The introduction of severe restrictions in the spring restrained the increase in morbidity, made it possible to buy time, and the lack of a bed fund in the regions did not lead to a rapid increase in mortality. At the end of the year, the health system coped better with the difficult situation, the necessary experience and material support appeared. The shortage of doctors began to affect mortality at the end of summer, and the importance of this factor increased at the end of the year.

Thus, the increase in mortality in different regions depended on the level of development of health care, on the geographical, demographic and socio-economic characteristics of the region, which were manifested differently under different federal and regional policies. In the regions there was different rigidity of restrictions, they were implemented to varying degrees by the population, the factors determining the increase in mortality changed accordingly. The analysis makes it possible to understand the consequences of decisions taken during the epidemic in the regions, depending on their characteristics, and to allocate the necessary resources to reduce the mortality of the population.

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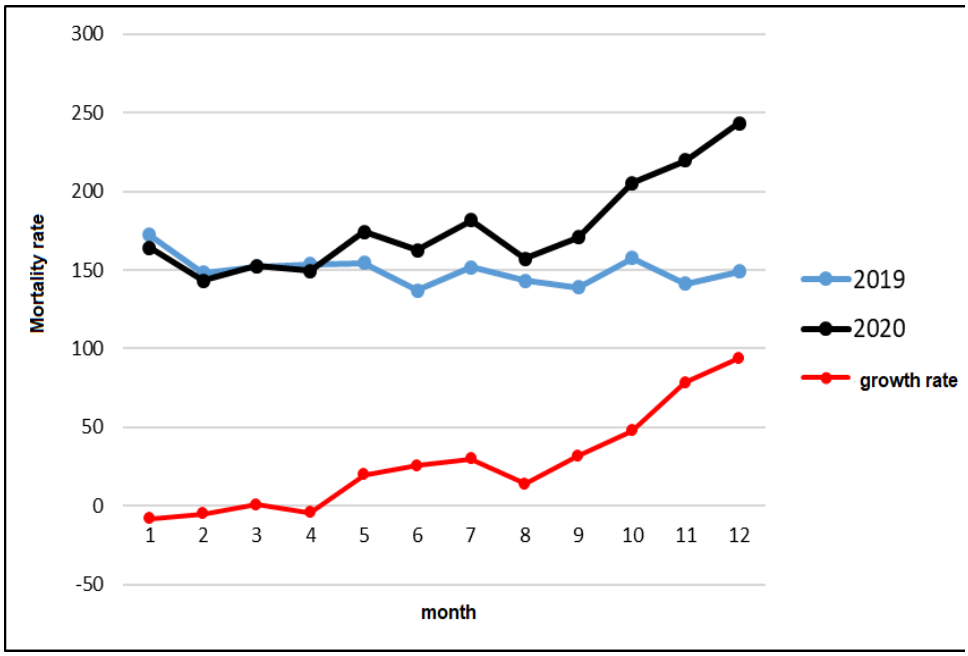

Fig. 1. Mortality in the Russian Federation in 2019 and 2020 by month and the increase in mortality in 2020 relative to the corresponding month of 2019

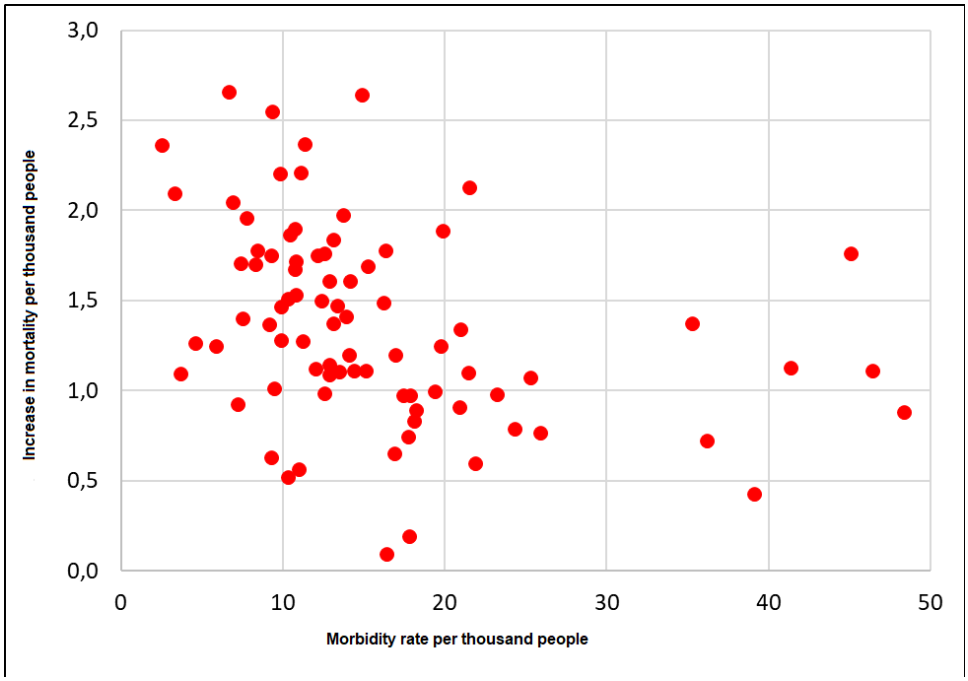

Fig. 2. The relationship between the incidence of COVID-19 and the overall increase in mortality by region in 2020 (data from the official Internet resource for informing the population about the coronavirus (COVID-19) and the FSGS)

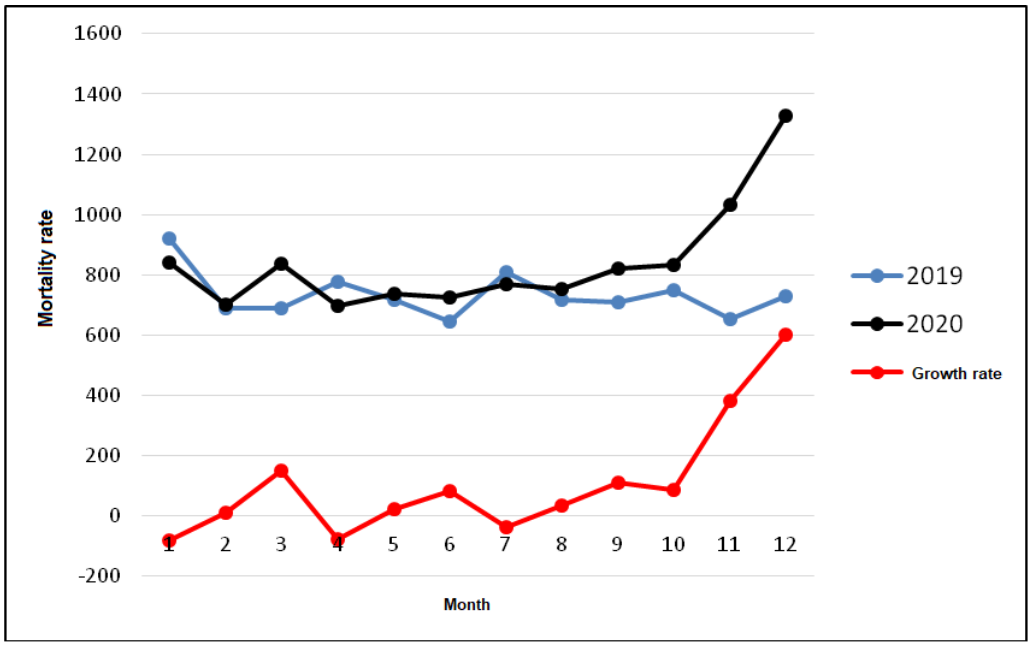

Fig. 3. Mortality in the Republic of Karelia in 2019 and 2020 by month and the increase in mortality in 2020 relative to the corresponding month of 2019

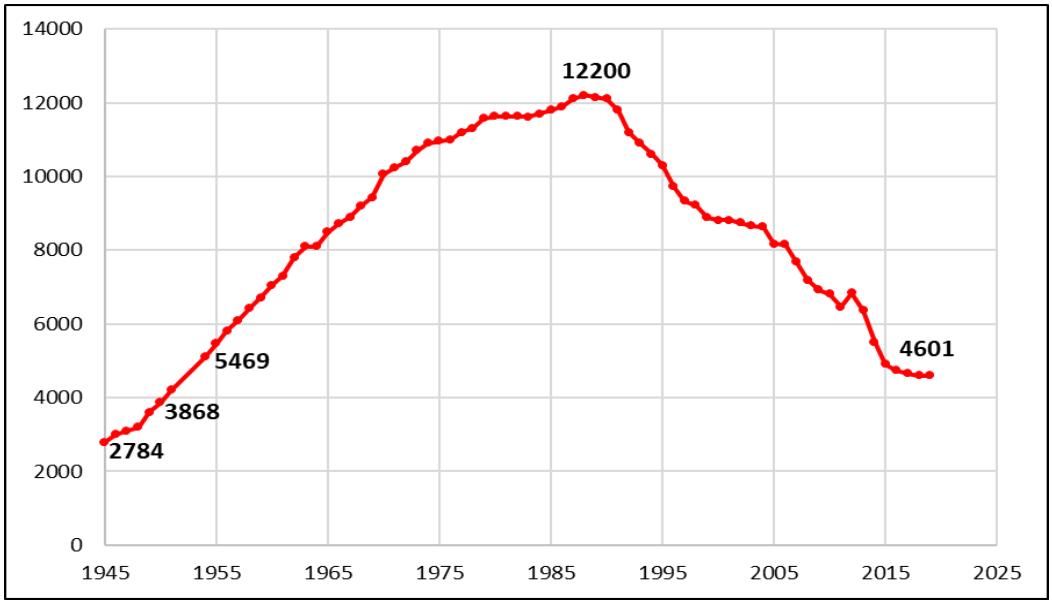

Fig. 4. Dynamics of the number of hospital beds in the Republic of Karelia in 1945-2019

Table 1. Results of calculations of the parameters of the dependence (1) of the increase in mortality (per million people) for different periods of 2020 relative to the corresponding period of 2019

Indicator	The value of statistical characteristics in different periods	
	March-December	January-December
A	4962,8***	3980,5***
Proportion of the urban population	6,43	11,02***
Pensioners per 1000 people of the population	4,26***	2,23
Household income in 2020 relative to 2019	-41,23***	-29,52*
Deviation of the location of the regional capital from 53 s. w.	-62,67***	-60,31***
Deviation of the location of the regional capital from 50 w. d.	-7,01***	-9,03***
R^2	0,53	0,51
p	0,0000	0,0000

*** p<0,01, * p<0,1

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