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THREATS AND RISKS TO HEALTH IN EMERGENCY SITUATIONS: BIOMEDICAL, PREDICTIVE ANALYTICAL, AND MATHEMATICAL ASPECTS

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Introduction. The methodology for assessing health threats and risks is becoming increasingly in demand in the public management of the sanitary and epidemiological welfare of the population. New biomedical, predictive analytical, and mathematical approaches are being developed to assess and analyze health threats and risks in emergencies, including within biological risk monitoring. These issues require a scientifically based comprehensive consideration drawing on various scientific fields, including medicine, biology, management, prediction, sociology, and mathematics (probability theory, set theory, measure theory, etc.). To solve this problem, the authors adopted a convergent approach, paying special attention to the role of effective threat and risk management, which has a significant impact on the quality of life of people exposed to adverse factors in emergency situations.

Objective. To improve the technology for analyzing and predicting threats and risks to human health in emergencies using a convergent multidisciplinary approach.

Materials and methods. The authors searched electronic bibliographic databases in the Russian (eLibrary and CyberLeninka) and English (Web of Science, Scopus, PubMed, Google Scholar, and Cochrane Library) languages. The database “Regulatory Legal Acts on Radiation, Chemical, and Biological Monitoring” created at the Centre for Strategic Planning of the Federal Medical and Biological Agency served as the basis for analyzing regulatory documents. As the information platform in this study, the authors used the information system of the Federal Information and Analytical Center for Monitoring Biological Risks, which aggregates data on the monitoring of biological risks falling within the competence of the Federal Medical and Biological Agency, The predictive and analytical part of the study was scientifically justified using the database “Methods of Scientific Prediction” created at the Centre for Strategic Planning, which contains systematized methodological prognostic information. The theoretical methods used in the study include logical methods (analysis and synthesis of knowledge; analogy method), mathematical methods (modeling, probability theory, measure theory, graph theory, and set theory), and the method of theoretical generalization.

Results. In the study, the existing approaches to assessing health threats and risks arising in emergency situations are summarized and systematized; their main characteristics and key parameters are considered. The phases of the process involving the emergence of threats and risks to health and the specifics of their management are analyzed. The scientific medical and biological point of view on the essence and general characteristics of health threats and risks is presented. The predictive analytical and mathematical aspects of the problem under consideration are outlined. An example algorithm for predictive and analytical calculation of indicators characterizing the resource capability and readiness of the healthcare system to adequately respond to a biological threat is described in detail. The required bed capacity of medical organizations is assessed, as well as the need for artificial lung ventilation devices in case of an epidemic; the final values are calculated. The analysis of the specified issues using a comprehensive convergent approach creates the prerequisites for effective management of health threats and risks in emergency situations.

Conclusions. Predictive and analytical approaches are based on advanced ideas and mechanisms, including risk-based technologies, digital certification of territories and objects, active use of geoinformation developments, assessment procedures drawing on the combination of estimated and field data, situation modeling under changing or specified conditions, consideration of combined impact factors, etc. Characterizing the risk through a health hazard measure that combines the probability of health threats occurring in an emergency and the consequences of adverse effects for life and health, the authors define the value of risk as the mathematical expectation of the product of a function for assessing damage (consequences) to the health of an organism/population and the probability of combined impact of adverse factors in an emergency.

Keywords: health threats and risks; emergency situation; risk management; prediction of threats and risks; threat probability; epidemics; ALV; bed capacity

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УГРОЗЫ И РИСКИ ЗДОРОВЬЮ ПРИ ЧРЕЗВЫЧАЙНЫХ СИТУАЦИЯХ: МЕДИКО-БИОЛОГИЧЕСКИЕ, ПРОГНОЗНО-АНАЛИТИЧЕСКИЕ И МАТЕМАТИЧЕСКИЕ АСПЕКТЫ

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Введение. Методология оценки угроз и рисков здоровью становится все более востребованной в решении задач государственного управления санитарно-эпидемиологическим благополучием населения. Развиваются новые медико-биологические, прогнозно-аналитические и математические подходы к оценке и анализу угроз и рисков здоровью при чрезвычайных ситуациях (ЧС), в том числе в рамках мониторинга биологических рисков. Появляется необходимость научно обоснованного рассмотрения указанной проблематики, используя в едином комплексе знания из различных научных областей, включая медицину, биологию, управление, прогнозирование, социологию, математику (теорию вероятностей, теорию множеств, теорию меры и др.). Для решения этой задачи авторы в процессе исследования основывались на принципе конвергентного подхода, уделяя особое внимание роли эффективного управления угрозами и рисками, которое оказывает существенное влияние на качество жизни людей, попадающих под воздействие неблагоприятных факторов при ЧС.

Цель. Совершенствование технологии анализа и прогнозирования угроз и рисков здоровью человека при чрезвычайных ситуациях на основе конвергентного мультидисциплинарного подхода.

Материалы и методы. В качестве основы для анализа нормативно-правовых материалов использовалась созданная в ФГБУ «ЦСП» ФМБА России база данных «Нормативные правовые акты радиационного, химического и биологического мониторинга». Информационной платформой для исследовательской работы послужила информационная система Федерального информационно-аналитического центра мониторинга биологических рисков ФМБА России, агрегирующая данные мониторинга биологических рисков, относящихся к компетенции ФМБА России. Для научного обоснования прогнозно-аналитической части исследования использовалась созданная в ФГБУ «ЦСП» ФМБА России база данных «Методы научного прогнозирования», содержащая систематизированную методологическую прогностическую информацию. К методам теоретического уровня, использованным в исследовании, относятся логические методы (анализ и синтез знаний, метод аналогий), математические методы (моделирования, теории вероятностей, теории меры, графов, множеств) и метод теоретического обобщения.

Результаты. В ходе исследования обобщены и систематизированы существующие подходы к оценке угроз и рисков здоровью, возникающие при чрезвычайных ситуациях, рассмотрены их основные характеристики и ключевые параметры. Проанализированы фазы процесса, связанного с возникновением угроз и рисков здоровью, и особенности управления ими. Изложены прогнозно-аналитические и математические аспекты рассматриваемой проблематики на примере алгоритма прогнозно-аналитического расчета показателей, характеризующих ресурсную возможность и готовность системы здравоохранения к адекватному ответу на угрозу биологического характера. Произведен расчет потребности коечного фонда медицинских организаций и аппаратов искусственной вентиляции легких при эпидемии, вычислены конечные значения. Констатировано, что рассмотрение вышеперечисленных вопросов на основе комплексного конвергентного подхода формирует предпосылки для реализации эффективного управления угрозами и рисками здоровью при чрезвычайных ситуациях.

Выводы. Прогнозно-аналитические подходы базируются на передовых идеях и механизмах, включая риск-ориентированные технологии, цифровую паспортизацию территорий и объектов, активное использование геоинформационных разработок, методики оценки на базе сопряжения расчетных и натурных данных, ситуационное моделирование при изменяющихся или задаваемых условиях, учет факторов сочетанного воздействия и т. д. Характеризуя риск через меру опасности здоровью, сочетающую вероятность реализации угроз здоровью при ЧС и последствия поражающих воздействий для жизни и здоровья, авторы определяют значение риска как математическое ожидание произведения функции оценки ущерба (последствий) здоровью организма/населения и вероятности совокупного воздействия поражающих факторов ЧС.

Ключевые слова: угрозы и риски здоровью; чрезвычайная ситуация; управление рисками; прогнозирование угроз и рисков; вероятность угроз; эпидемии; аппарат ИВЛ; коечный фонд

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INTRODUCTION

The methodology for assessing health threats and risks is currently becoming increasingly in demand in the public management of sanitary and epidemiological welfare of the population [4]. The relevance and significance of this issue can be primarily attributed to the fact that the health of the Russian population is considered to be the main value of the country and one of the most important national security criteria. This makes it important to study the essence of threats and risks to human health.

Within the general methodology, new biomedical, predictive analytical, and mathematical approaches are being developed both in the system for biological risk monitoring of the Federal Medical and Biological Agency (FMBA) of Russia and in the state system for socio-hygienic monitoring to assess and analyze health threats and risks in emergencies. These issues require a scientifically based comprehensive consideration drawing on various scientific fields, including medicine, biology, management, prediction, sociology, and mathematics (probability theory, set theory, measure theory, etc.). To solve this problem, the authors used a convergent approach, paying special attention to the role of effective threat and risk management, which has a significant impact on the quality of life of people exposed to adverse factors in emergency situations.

The present work aims to improve the technology for analyzing and predicting threats and risks to human health in emergency situations using a convergent multidisciplinary approach.

MATERIALS AND METHODS

The database “Regulatory Legal Acts on Radiation, Chemical, and Biological Monitoring” created at the Centre for Strategic Planning (FMBA) served as a basis for analyzing regulatory documents [7]. As the information platform in this study, we used the information system of the Federal Information and Analytical Center for Monitoring Biological Risks, which aggregates data on the monitoring of biological risks falling within the FMBA competence. The predictive and analytical part of the study was scientifically justified using the database “Methods of Scientific Prediction” created at the Centre for Strategic Planning (FMBA), which contains systematized prognostic methodological information [8].

The theoretical methods used in the study include logical methods (analysis and synthesis of knowledge; analogy method), mathematical methods (modeling, probability theory, measure theory, graph theory, and set theory), and the method of theoretical generalization.

RESULTS

Primary source and evolution of the health risk concept

The primary source of the risk concept is considered to be the medieval work “The Salerno Code of Health” by the alchemist Arnold de Villa Nova (Arnoldus de Villa Nova, 1235–1311) from the Salerno Medical School near Naples, which is claimed to be the oldest medical school in Europe. In his work, the scientist presented data on various factors leading to diseases, considering, among other things, their combined effect, thus laying the foundation for a systematic approach to diseases [17].

Subsequently, the understanding of the essence and assessment of health risk factors underwent repeated evolutionary changes resulting from the adoption of various foreign (USA and Europe) and Russian approaches (in the late 20th century and at the dawn of the 21st century). Empirical research has long used attributive risk assessment to determine what part of the current disease burden is due to the accumulated effect of all previous exposures [1].

It is currently relevant to address issues related to the probability and severity of biomedical consequences that occur following the emergence of physical, chemical, and biological factors and exposure to them.

The article considers physical, chemical, and biological threats and risks to the health of citizens in natural or man-made emergencies. The concept of an emergency situation is defined in GOST R 22.0.02-2016 as a situation in a territory that has developed as a result of an accident, a dangerous natural phenomenon, a catastrophe, a natural or other disaster that may or have led to human casualties, damage to human health or the environment, significant material losses, and disruption of people’s livelihoods. The risk of an emergency is defined as a measure of danger in an emergency situation, combining the probability of an emergency and its consequences [3].

Definitions of threats and risks: analysis of modern legislation of the Russian Federation

We analyzed the modern legislation of the Russian Federation, including the main normative legal acts and standards defining the concepts of threats and risks. The following documents were identified from the list: the Law of the Russian Federation No. 2446-1 as of 03/05/1992 “On Security”; Federal Law No. 492 as of 12/30/2020 “On Biological Safety in the Russian Federation”; Decree of the President of the Russian Federation No. 97 as of 03/11/2019 “On the Fundamentals of State Policy of the Russian Federation in the Field of Chemical and Biological Safety for the Period up to 2025 and Beyond”; “Guidelines for Assessing the Risk to Public Health when Exposed to Chemicals Polluting the Environment” (R 2.1.10.1920-04); Federal Law No. 184 as of 12/27/2002 “On Technical Regulation”; “Guidelines for Assessing the Risk to Public Health when Exposed to Chemicals Polluting the Environment” (R 2.1.10.3968-23); Federal Law No. 7 as of 01/10/2002 “On Environmental Protection”; GOST R 22.0.02-2016; GOST R 70620-2022; GOST ISO 12100-2013, etc.

The conducted study shows that the conceptual framework related to the categories of “threats and risks” in the Russian legislation can be found in a single information space; exhibits equally structured logical semantic (essential) relationships between these concepts, which represent the risks of consequences depending on the types and nature of threats; exhibits no contradictions; differs logically depending on the application areas.

Here are some definitions. In general, the “safety threat” is defined in the Law of the Russian Federation “On Security” as a set of conditions and factors that pose a danger to the vital interests of the individual, society, and the state [5].

In the Federal Law “On Biological Safety,” a biological threat (danger) is the presence of potentially dangerous biological objects, as well as the presence of internal (located on the territory of the Russian Federation) and external (located outside its territory) dangerous biological factors, that can lead to the emergence and (or) spread of diseases with the development of epidemics, epizootics, epiphytotics, and mass poisoning, exceeding the permissible level of biological risk. Biological risk is defined as the probability of harm (taking into account its severity) to human health, animals, plants, and (or) the environment as a result of exposure to dangerous biological factors [16].

In R 2.1.10.3968-23, danger is a set of properties of environmental factors (or a specific situation) that determine the ability to cause adverse health effects under certain exposure conditions. In this case, risk is considered a characteristic of danger depending on the level of exposure to a chemical factor and the specifics of its actual or potential effects under specific conditions. Risk is the probability of harm to the life and health of citizens, property of individuals and legal entities, state or municipal property, as well as habitat, life, or health of animals and plants, taking into account the severity of this harm. Health risk is the probability of harm to human life and health or a threat to the life or health of future generations, taking into account the severity of this harm, due to the impact of environmental factors [14]. In other words, health risk is defined as a combination (product) of the damage probability and the severity of this damage [9].

R 2.1.10.1920-04 clarifies that the risk, unlike danger, is the result of actual or potential exposure to a chemical compound and depends on exposure and the specifics of particular exposure conditions [13].

World Health Organization (WHO): health hazards and risks

In the WHO practical guidelines for biological safety under laboratory conditions, a dangerous factor is defined as an object or situation that can lead to negative consequences when an organism, system, or group (subgroup) of the population is affected by it. The concept of risk is defined as a combination of the incident probability and the severity of harm (consequences) if this incident occurs. It is emphasized that a dangerous factor does not become a “risk” until the probability and consequences of this dangerous factor causing harm are taken into account [19].

The fourth edition of WHO guidelines presents the results of research on how the likelihood and consequences of danger affect health risk [11]. For example, the likelihood of exposure to cigarette smoke, which is a common hazard, depends on the situation. The impact will be greatest for a smoker, moderate for passive smokers, and smallest for a person using respiratory protection or staying in smoke-free areas. The effects of exposure to cigarette smoke can vary from mild nausea and irritation of the respiratory tract to various heart and lung diseases, cancer, and even a fatal outcome, depending on cigarette toxicity, the frequency and duration of exposure, as well as other factors related to human sensitivity.

Phases of threats and risks to health in emergencies

The study logic required the identification of three main phases of the process involving the emergence of health threats and risks and their management; the relevant data are presented in Figure 1.

The phase involving the emergence of the threat and potential risks (I) includes the following stages:

1) occurrence and development of emergency situations (as a source of threats);

2) occurrence of adverse factors of physical (including radiation), chemical, and biological nature and their manifestations;

3) existence of circumstances and creation of conditions under which the contact of a dangerous chemical, physical, or biological agent with the human body is possible.

The phase of threat realization and occurrence of real risks (II) is characterized by the adverse effects of physical, chemical, and biological factors on the body. The conceptual apparatus of this phase (for example, with chemical exposure) includes “exposure, dose/concentration, effect.”

The phase of managing real risks and eliminating the consequences of an emergency (III) involves the provision of medical and sanitary assistance, which is intended to prevent and eliminate damage to health. For example, when the body is exposed to chemicals, the conceptual apparatus of the phase includes “response, disease, and outcome.”

Biomedical view of physical, chemical, and biological threats and risks in emergencies

Depending on the type of emergency, the phases have clear or blurred boundaries since the emergent adverse effect may be of a short-term (sometimes instantaneous) or prolonged temporary nature. Short-term effects occur, for example, when lightning strikes a group of people standing under a tree (lightning discharges of natural origin). Adverse factors can manifest themselves in various forms: electromagnetic pulses, light radiation, high-temperature effects, and shock waves. All systems of the body can be affected: musculoskeletal, respiratory, cardiovascular, genitourinary, endocrine, nervous, sensory, visual, etc. Aside from vision loss, seizures, paralysis, stroke, and heart attack, this can sometimes cause chronic headaches and memory problems.

It is generally believed that natural emergencies are hard to predict. However, it is possible to predict the occurrence of adverse factors and take preventive measures against them, thus reducing the likelihood of threats and risks, as well as the level of their impact on health, that is, to manage health threats and risks.

For example, the typical natural emergencies of Yakutia are spring and summer floods. The flood changes the structure and functional connections of natural foci and leads to a wide spread of pathogens of bacterial, viral, and rickettsiosis infections, thus significantly increasing the intensity of contacts between the population and natural foci. During a flood, the risk of infectious diseases (viral hepatitis A, dysentery, and typhoid fever) rises. In flooded areas, water supply is disrupted, and the risk increases of the river being polluted from sewage, cattle burial grounds, and cesspools; from warehouses by pesticides and petroleum products, etc. As a result, the probability of epizootics rises, and the risk of people contracting infectious and parasitic diseases increases (leptospirosis, tularemia, hemorrhagic fever with renal syndrome, yersiniosis, pseudotuberculosis, toxoplasmosis, etc.). The burden on infectious hospitals grows. Due to overcrowding, the airborne transmission of

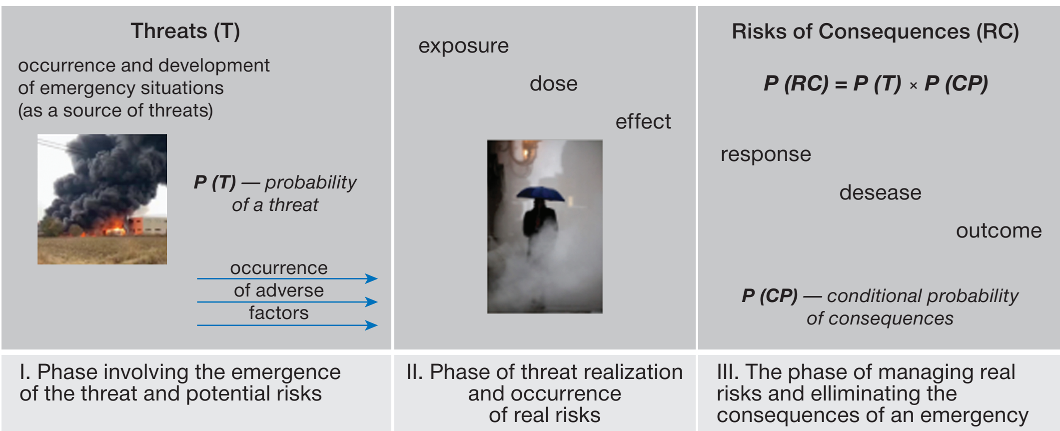

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Fig. 1. Phases of threats and risks in case of emergency

ARVI (acute respiratory virus infection) and other pathogens increases.

Yakut specialists analyzed factors associated with the maximum water levels during the spring flood; the combination of these factors often leads to catastrophic floods. In order to make effective decisions aimed at minimizing risks, a mathematical solution using Bayesian networks was proposed. In particular, the Bayesian network was used to analyze the probability of certain conditions with various combinations of selected factors and investment amounts in the form of preventive measures [15].

All emergencies that result in chemical pollution are associated with long-term exposure: for example, industrial waste incineration at a landfill, accompanied by emissions into the atmosphere and the spread of toxic combustion products toward the residential area. Threat prevention can be accomplished through proactive measures: from landfill remediation to the evacuation of population from the predicted spread area. According to experts, despite the extensive regulatory framework developed in the Russian Federation for the permissible content of chemicals in the atmospheric air (1300 maximum permissible concentrations and 450 approximately safe impact levels), most examined sources of pollutants entering the atmosphere are not currently regulated by legally approved hygienic standards [12]. This fact complicates the early and short-term planning and management of health measures to eliminate the consequences; in other words, risk planning and management.

Recent years have seen an increase in the number of diseases associated with new pathogenic viruses, with the exacerbation of diseases caused by them and the involvement of new regions previously untouched by these diseases. Experience shows that infectious diseases caused by new strains of viruses, which had high virulence and the potential for multiple mutations, had a rather severe course in the early stages, with a high mortality rate per the total number of infected people, and were also difficult to treat with the use of chemotherapy drugs [2]. About 20% of patients needed artificial lung ventilation. During this period, planning and risk management were objectively insufficient, which affected the epidemiology of morbidity [10]. According to the authors, the lack of immunization among doctors and nursing staff had a negative impact on the situation since a sharp reduction in the number of available qualified staff increased the risk of a severe course and outcome of diseases in patients. The most popular ways to prevent threats caused by epidemics and pandemics are scientifically based sanitary and anti-epidemic (preventive) measures: preventive vaccination, emergency prevention, disinfection, and restrictive measures.

Scientific and practical assessment of health threats and risks and their main characteristics

Health risk assessment constitutes one of the components of risk analysis, which includes risk assessment, risk management, and risk communication. From the scientific point of view, risk assessment is a consistent systematic consideration of all aspects of the impact that the analyzed factor has on human health, including the justification of acceptable exposure levels. In scientific and practical applications, the rationale for the risk assessment task consists in obtaining and summarizing information about the possible environmental health impacts; in the hygienic justification of the optimal management decision to eliminate and mitigate risk; in optimizing the control of exposure levels and risks [14].

Proceeding from the above, the threat to health in an emergency is defined as a set of phenomena, processes, and factors that contribute (in the context of the occurrence and development of natural or man-made emergencies) to the emergence of adverse effects of harmful physical, chemical, and biological factors on the body. The health risk in an emergency is also characterized as a measure of danger to health, combining both the likelihood of health threats in an emergency and the consequences of adverse effects for human life and health and future generations.

Predictive and analytical aspects

The basis of information and analytical support for the development and implementation of management decisions consists in the monitoring of physical, chemical, and biological risks, as well as social and hygienic monitoring.

The stages and components of analytical and practical monitoring are as follows: data collection, identification of threats and risks, their verification and analysis, situation modeling, prediction of how the situation is going to develop in the present and future periods, and development of appropriate solutions. The analysis and prediction results serve as a reliable basis for developing medical, sanitary-epidemiological, hygienic, socioeconomic, organizational, and technical measures for effective management aimed at eliminating and localizing threats and risks of emergencies.

In the modern theory and practice of prediction, a significant number of different methods are available [8], as well as approaches to their application. These approaches are not limited to using a single method. It is common to use a combination of various prediction methods: for example, information and computer modeling in combination with probabilistic and statistical methods, etc. The combined approach in prediction should be considered the most promising. To increase the reliability and accuracy of predictions, a scheme is used to compare the results of various prediction methods that validate and complement each other or demonstrate any discrepancies in the obtained predictive estimates for their correction.

Predictive and analytical approaches are currently based on advanced ideas and mechanisms, including risk-based technologies, digital certification of territories and objects, active use of geoinformation developments, assessment procedures drawing on the combination of estimated and field data, situation modeling under changing or specified conditions, consideration of combined impact factors, etc. [20].

Mathematical aspects of assessing and predicting health threats and risks in emergencies

Characterizing the risk through a measure of health hazard that combines the probability of health threats occurring in an emergency and the consequences of adverse effects for life and health, we define the risk value as the mathematical expectation of the product of a function for assessing damage (consequences) to the health of an organism/population and the probability of combined impact of adverse factors in an emergency (Fig. 1).

$$R(x) = \int F(x) \times P(x)\, dx, \qquad (1)$$

Note: *R* — risk;
x — adverse effects;
R(*x*) — integral risk measure;
F(*x*) — function for assessing damage (consequences) to health with exposure to an adverse factor;
P(*x*) — the probability of an adverse effect occurring in an emergency.

If a probabilistic approach and, accordingly, a probabilistic function are used to determine the measure, then the laws of probability theory and mathematical statistics should be applied in the calculation method. In this case, the function *F*(*x*) is probabilistic in character. The resulting integral function *R*(*x*) is also probabilistic, and its values *R*(*x*) are always less than or equal to one.

Let us denote the threat by T; the probability of the threat (more precisely, the occurrence probability of an adverse effect) is P(T). The risk of health consequences is denoted by CR. Then, the probability of a consequence risk — P(CR) — will be expressed through the product formula:

$$P(CR) = P(T) \times P(CP), \qquad (2)$$

where P(CP) — conditional probability of consequences (given the occurrence of a probabilistic event, i.e., the impact of an adverse factor).

It follows from Eq. (2) that the lower the probability of a threat, the lower the risk. In the absence of a threat, the risk is zero. Similarly, the lower the conditional probability of consequences that an adverse effect can have, the lower the risk of these consequences. In the absence of consequences, there is no risk.

The additional probability of a disease associated with the combined effect of climatic and chemical factors is calculated from the modeling of cause-and-effect relationships using multiple regression analysis. The construction of mathematical models uses data on morbidity in the context of classes of diseases or nosologic forms, which are affected by both climatic factors and chemicals, with the latter, in turn, being influenced by climatic factors [9, 18].

Hygienic approaches and calculations distinguish between a priori (predictive) risk based on dose-effective hygienic-normalized effects and a posteriori (real) risk based on a statistical assessment of actual events.

An example algorithm for predictive and analytical calculation of indicators characterizing the resource capacity of the healthcare system to adequately respond to a biological threat

Let us consider a specific example and calculate the final values. Problem statement: in the city of Z with a population of ten thousand people, during the period (T) 1000 people contracted an infectious disease “X” during an epidemic, 200 people were hospitalized, and 20 people were placed on a ventilator due to the severe course of the disease — (E). During the same period, T depends on the diseases characteristic of this city and time of year: 100 patients were reported (N), ten people were admitted to hospital (C), and two patients required a ventilator (F). It is necessary to perform a predictive calculation of the hospital bed capacity and artificial lung ventilation (ALV) units for the city R with a population of twelve thousand people and the impending epidemic of “X” for the same period (T) if it is known that socioeconomic and sanitary characteristics in cities are similar. All events that involve contracting different diseases are incompatible.

To solve this problem, we will construct a predictive graph, a tree of elementary events, using a group of logical and a class of formalized prediction methods [6]. First, we will calculate an a posteriori estimate for the city of Z using a graph in which elementary events are represented by the vertices of chains running from the original vertex Z to the final vertices. The corresponding data are shown in Figure 2.

The probability of the disease spreading through the city of Z during an epidemic is calculated as follows: $P_{ZM} = M/Z = 1000/10{,}000 = 0.1$. By analogy: the probability of contracting a characteristic nosologic disease is $P_{ZN} = 0.01$; the probability of hospitalization during an epidemic is $P_{MA} = 0.2$; the probability of hospitalization with characteristic diseases is $P_{NC} = 0.1$; the probability of a medical organization using ALV during an epidemic is $P_{AE} = 0.1$; the probability of ALV use in patients with characteristic diseases is $P_{CF} = 0.2$.

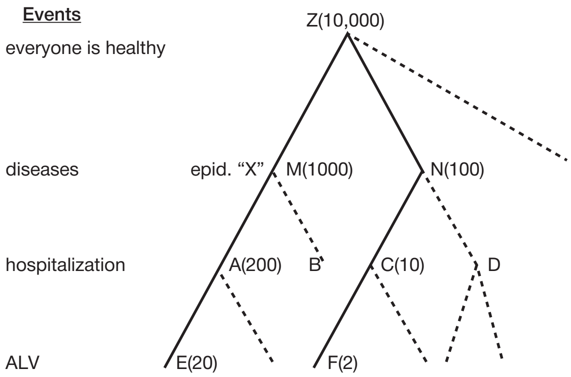
Let us transform the event tree into a probability graph, where the edges of the tree are the probabilities of chain events (Fig. 3).

In order to find the probability of an elementary event, that is, a chain, it is necessary to multiply the conditional probabilities along this chain. So, the probability of hospitalization due to an infectious disease “X” is equal to $P_{ZMA} = P_{ZM} \times P_{MA} = 0.1 \times 0.2 = 0.02$, where P_{ZM} is the probability of disease caused by an epidemic; P_{MA} is the conditional probability of hospitalization due to the disease “X.”

The probability of hospitalization in the city of Z is equal to the total probability of elementary events: $P_{HOSP} = P_{ZMA} + P_{ZNC} = P_{ZM} \times P_{MA} + P_{ZN} \times P_{NC} = 0.021$. By analogy, the probability of ALV use in the city of Z amounts to $R_{ALV} = P_{ZMAE} + P_{ZNCF} = 0.0022$.

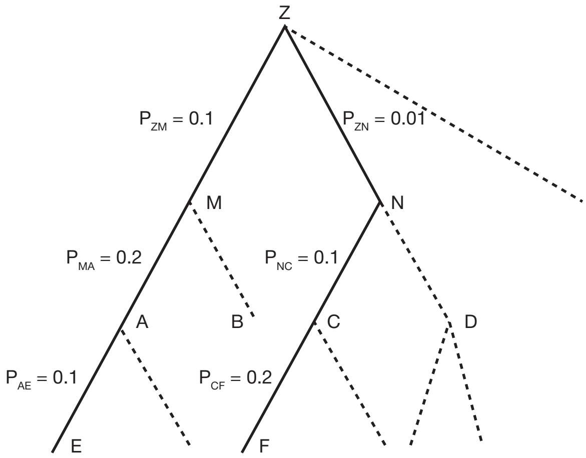
For the city of R with a population of twelve thousand people and the impending epidemic of “X,” the predictive a priori calculation of hospital bed capacity and ventilators for the period of T is performed as follows:

- Hospital bed capacity: $R \times P_{HOSP} = 12000 \times 0.021 = 252$.



The figure was created by the authors

Fig. 2. Graph showing the tree of elementary events
Note: the number in parentheses indicates the number of people involved in elementary events: those who are ill, hospitalized, and placed on ALV; the dashed line represents a transition to alternative and/or insignificant events to be considered.



The figure was created by the authors

Fig. 3. Probability tree graph
Note: the dashed line represents a transition to alternative and/or insignificant events to be considered.

- Reserve of ALV devices: $R \times P_{ALV} = 12000 \times 0.0022 = 26.4$; that is, at least 27 devices.

Another prediction method acceptable for calculations under epidemic conditions is modeling using compartment models (in particular SIR models) that describe the spread of the disease and divide the population into groups called compartments. SIR (Susceptible–Infected–Recovered) models are based on a system of differential equations that express the dynamics between different epidemiological conditions of the population, with recovery providing relatively long-term resistance.

CONCLUSION

The analysis of the specified issues using a comprehensive approach creates favorable prerequisites for effective management of health threats and risks in emergency situations. In the course of the study, we drew on various scientific fields adopting a convergent approach. The implementation of this principle will provide a means to develop measures aimed at reducing and eliminating threats and risks to health in order to ensure the sanitary and epidemiological welfare of the Russian population and its future generations.

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