UDC 614.4: 616-036.22 DOI:10.46847/ujmm.2024.4(5)-057

ASSESSING INFECTIOUS DISEASE SIMULATION IN COMBAT ZONES THROUGH CAPACITY, VULNERABILITY, AND RISK FRAMEWORK

T.O. Chumachenko[1], D.I. Chumachenko[2]

[1]Kharkiv National Medical University, Kharkiv, Ukraine
[2]National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine

Introduction. *Infectious disease modelling is crucial in managing disease spread, particularly in conflict zones where health systems and infrastructure are severely compromised. However, applying these models in unstable environments, such as during the ongoing Russian invasion invasion in Ukraine, presents unique challenges that require adapted approaches.*

Purpose. *This study aims to evaluate the effectiveness of infectious disease simulation models in conflict zones using the Capacity, Vulnerability, and Risk Assessment (CVRA) framework, specifically focusing on the impact of the russian invasion in Ukraine.*

Materials and Methods. *The CVRA framework assessed the capabilities, vulnerabilities, and risks of using infectious disease models in conflict settings. The framework's three components were used to evaluate the resources, susceptibility factors comprehensively, and threats affecting the success of infectious disease simulations in combat-affected areas.*

Results. *The results highlight the strengths and limitations of using disease models during conflict. Ukraine's digital infrastructure and international collaboration provide a basis for disease simulation implementation. However, significant challenges remain due to healthcare disruptions, data quality issues, logistical barriers, and population vulnerabilities resulting from mass displacement and other factors. The CVRA framework provided a structured approach to understanding these factors and optimizing intervention strategies.*

Conclusions. *This study demonstrates the potential for applying infectious disease models in conflict settings but emphasizes the need for substantial adaptation to address the challenges specific to such environments. The CVRA framework is valuable for systematically assessing and enhancing public health interventions in combat zones. The study's findings provide insights that can be transferred to other conflict-affected areas, although limitations in data availability and ethical concerns must be addressed in future work.*

Keywords: *epidemic model, infectious disease modelling, conflict zones, CVRA framework, Ukraine, public health interventions, healthcare disruptions, risk assessment.*

ОЦІНЮВАННЯ СИМУЛЯЦІЇ ІНФЕКЦІЙНИХ ЗАХВОРЮВАНЬ У ЗОНАХ БОЙОВИХ ДІЙ ЧЕРЕЗ КОМПЛЕКС ХАРАКТЕРИСТИК ЗДАТНОСТІ, ВРАЗЛИВОСТІ ТА СТРУКТУРИ РИЗИКУ

Т.О. Чумаченко[1], Д.І. Чумаченко[2]

[1]Харківський національний медичний університет, Харків, Україна
[2]Національний аерокосмічний університет «Харківський авіаційний інститут», Харків, Україна

Вступ. *Моделювання інфекційних хвороб є надзвичайно важливим для контролю їхнього поширення, особливо в зонах конфліктів, де системи охорони здоров'я та інфраструктура сильно порушені. Однак застосування таких моделей в нестабільних умовах, зокрема під час війни росії в Україні, супроводжується унікальними викликами, що потребують адаптованих підходів.*

Мета. *Мета цього дослідження – оцінити ефективність імітаційних моделей інфекційних хвороб у зонах конфлікту, використовуючи фреймворк оцінки потенціалу, вразливості та ризиків (CVRA), з акцентом на вплив війни Росії в Україні.*

Матеріали та методи. *Фреймворк CVRA використовувався для оцінки потенціалу, вразливостей і ризиків застосування моделей інфекційних хвороб в умовах конфлікту. Три компоненти цього фреймворку були використані для комплексної оцінки ресурсів, факторів вразливості та загроз, які впливають на успіх моделювання інфекційних хвороб у зонах війни.*

Результати. *Результати підкреслюють як сильні сторони, так і обмеження використання моделей інфекційних хвороб під час конфліктів. Цифрова інфраструктура України та міжнародна співпраця забезпечують основу для реалізації моделювання захворювань. Однак існують значні виклики, зумовлені порушеннями в системі охорони здоров'я, проблемами якості даних, логістичними бар'єрами та вразливістю населення через масове переселення. Фреймворк CVRA забезпечив структурований підхід до розуміння цих факторів і оптимізації стратегій втручання.*

Висновки. *Дане дослідження демонструє потенціал застосування моделей інфекційних хвороб в умовах війни, проте наголошує на необхідності суттєвої адаптації для подолання специфічних викликів цих* *середовищ. Фреймворк CVRA є цінним інструментом для систематичної оцінки та вдосконалення заходів громадського здоров'я в зонах конфлікту. Результати дослідження надають знання, які можуть бути використані в інших регіонах, уражених конфліктом, хоча проблеми доступності даних та етичні питання потребують вирішення в майбутніх дослідженнях.*

Ключові слова: *модель епідемії, моделювання інфекційних хвороб, зони конфлікту, CVRA, Україна, втручання у сферу громадського здоров'я, порушення системи охорони здоров'я, оцінка ризиків.*

Introduction. Infectious disease modelling is a critical tool in understanding and mitigating the spread of diseases, particularly in environments where health systems and infrastructure are compromised. Such models are designed to predict disease dynamics, provide insight into intervention strategies, and guide allocating limited resources [1]. However, applying infectious disease simulation models in conflict zones presents unique challenges, as the conditions in these areas often vary drastically and unpredictably. The ongoing military conflict in Ukraine, following the full-scale invasion by russia in 2022, provides a contemporary example of these challenges and emphasizes the need for an adapted approach to disease simulation during times of war [2].

The russian full-scale invasion of Ukraine has had a profound impact on public health. The widespread damage to healthcare facilities, mass displacement of populations, and overall disruption of essential services have created conditions conducive to the spread of infectious diseases [3]. Destruction of infrastructure has limited access to clean water, sanitation, and healthcare, while population movement has facilitated the spread of diseases across regions, contributing to a complex public health emergency [4]. This situation has led to increased risks of infectious diseases such as respiratory infections, intestinal illnesses, and other, which are exacerbated by factors like overcrowded shelters and poor hygiene conditions. War also affects the environment and increases the risks of zoonotic and vector borne diseases.

In such complex environments, infectious disease simulation models can be vital in understanding potential outbreak scenarios, informing response measures, and enhancing resilience. These models can evaluate different intervention strategies, such as vaccination campaigns, quarantine efforts, or improved healthcare provision, and assess their potential impact on disease control [5]. However, their use in combat zones requires adaptation to account for the unstable context, unreliable data, and unique vulnerabilities affected populations face. This paper employs the Capacity, Vulnerability, and Risk Assessment (CVRA) framework [6] to assess how infectious disease models can be effectively utilized in conflict situations, specifically focusing on the conditions created by the russian invasion of Ukraine. This approach highlights the capabilities, limitations, and risks of using these models in challenging settings, providing insights into how infectious disease control measures can be optimized during military operation.

This paper aims to evaluate the application of infectious disease simulation models in conflict zones using the CVRA framework. It focuses particularly on the impact of the russian full-scale invasion of Ukraine and seeks to identify the strengths, limitations, and risks of using these models to guide public health interventions in complex and unstable environments.

Current research is a part of the comprehensive information system for assessing the impact of emergencies on the spread of infectious diseases described in [7].

Current research analysis. Studying infectious disease dynamics during conflict settings is crucial for understanding the interplay between warfare and public health outcomes. Numerous research efforts have sought to explore this area by using diverse modelling techniques to assess the impact of conflict on disease transmission, healthcare access, and mortality rates. This section provides an overview of key studies contributing to this body of knowledge, particularly those focusing on conflicts in Guinea-Bissau, sub-Saharan Africa, Nagasaki, Bangladesh, Nigeria, Yemen, the Democratic Republic of Congo, Afghanistan, and the recent Ukrainian refugee crisis.

Research on the Guinea-Bissau conflict [8] has shown war's significant impact on public health, using time series analysis to create a reference model for health outcomes during the 1998–1999 civil war. The study finds that conflict disrupts health systems, increasing mortality and morbidity. Time series models help understand trends and provide benchmarks for intervention effectiveness, indicating that disruptions to healthcare services and infrastructure lead to serious health outcomes, which can be analyzed using statistical methods to develop mitigation strategies.

In the context of sub-Saharan Africa, another study [9] examines the effect of systematic mass rape during armed conflicts on HIV incidence in seven affected countries. Using a risk equation model parameterized with data from UNAIDS/WHO, the study finds that mass rape significantly increases HIV incidence in specific countries, although the impact on overall prevalence is relatively minor. The authors recommend targeted interventions to reduce HIV spread among survivors, highlighting the importance of focused public health strategies.

A study on the Nagasaki dengue outbreak during World War II [10] investigates factors contributing to the epidemic. The authors, Oki and Yamamoto, utilize a Susceptible-Exposed-Infectious-Recovered (SEIR) model to estimate the vector density required to trigger the outbreak. Their findings suggest that high mosquito density, combined with wartime practices and environmental factors, played a critical role in the 1942 outbreak. This research emphasizes the importance of vector control as a strategy for mitigating future outbreaks.

The impact of the 1970s famine and civil war on measles mortality in rural Bangladesh is explored in another study [11]. Using a time series Susceptible-Infected-Recovered (TSIR) model, the authors estimate the measles case-fatality rate (CFR) during this period. The findings reveal that malnutrition caused by the famine led to an increased CFR during a 1976 measles outbreak, underscoring the significant influence of famine on measles mortality and the critical need for nutritional interventions during conflicts.

In Nigeria, the prevalence of HIV, hepatitis B, and hepatitis C in conflict-affected areas has been assessed through a survey logistic regression model [12]. This study analyzed data from over 186,000 participants across conflict and non-conflict zones, finding that individuals in conflict areas are at significantly higher risk of testing positive for HIV and hepatitis C. These findings emphasize the need for targeted public health interventions in conflict regions to address the heightened vulnerability of affected populations.

The influence of conflict on cholera outbreaks in Yemen has been analyzed using a system dynamics model [13]. The authors employ causal loop diagrams to visualize the impact of infrastructure damage, displacement, and limited access to essential supplies during the Yemeni Civil War. The main findings emphasize the importance of aligning long-term development goals with short-term humanitarian efforts to enhance response efficiency and resilience, demonstrating the need for coordinated approaches in conflict settings.

The conflict in the eastern provinces of the Democratic Republic of Congo (DRC) during the 2018–2020 Ebola outbreak has also been studied [14]. The authors use a deterministic extension of the Susceptible-Infectious-Recovered (SIR) model, incorporating additional classes for contaminated environments and escaped patients. The findings reveal that conflict significantly exacerbated disease spread by disrupting healthcare services, leading to increased transmission and reduced control effectiveness. This underscores the importance of maintaining healthcare services during conflicts to mitigate disease transmission.

A study on COVID-19 in conflict-affected Afghanistan [15] employs an Exponential Smoothing (ES) model, specifically Holt’s linear trend, to forecast COVID-19 cases and deaths from February 2020 to August 2021. The findings indicate a significant increase in predicted COVID-19 cases and mortality over the following 12 months, emphasizing the urgent need for resource allocation to stabilize the overwhelmed healthcare system. The model’s validation, which includes R-squared and mean absolute error (MAE) values, demonstrates reliable predictive performance, making a strong case for timely interventions.

The impact of the Ukrainian refugee crisis caused by the russian full-scale invasion on COVID-19 pandemic dynamics has also been analyzed [16]. This study uses a generalized SIR model to estimate the effect of mass migration caused by the full-scale invasion of Ukraine in 2022. By comparing smoothed daily case numbers across Ukraine, the UK, Poland, Germany, and Moldova, the authors identify an increase in the effective reproduction number in several countries in March 2022, shortly after the mass displacement. The findings suggest that the influx of refugees had a notable short-term effect on pandemic dynamics, underlining the need for enhanced public health measures to manage such movements during health crises.

These studies collectively highlight the complexity of infectious disease dynamics during conflict, and the critical role modelling can play in understanding and mitigating the adverse effects of war on public health. By employing diverse modelling approaches, these studies contribute valuable insights into the impact of warfare on healthcare systems, disease transmission, and mortality, underscoring the need for targeted interventions and strengthening public health infrastructure in conflict-affected settings.

Materials and Methods. The CVRA framework was applied to analyze the use of infectious disease simulation in combat zones. The framework is a comprehensive tool used to evaluate the potential success of public health interventions in challenging environments. The framework consists of three key components: Capacity, Vulnerability, and Risk, which together provide a holistic understanding of the factors affecting the implementation of disease control measures.

Capacity refers to the available resources, infrastructure, and capabilities required to implement infectious disease simulations and interventions. This includes physical infrastructure, such as healthcare facilities and data systems, and human resources, such as trained personnel and technical expertise. Assessing capacity allows us to understand the strengths and opportunities for deploying disease control measures in conflict-affected areas.

Vulnerability considers the factors that make populations and systems more susceptible to infectious disease outbreaks. In conflict zones, vulnerabilities are often exacerbated by population displacement, weakened immunity due to stress, and disrupted healthcare services. Vulnerability assessment helps identify the populations at greatest risk and the structural weaknesses that may hinder effective interventions.

Risk focuses on identifying potential threats that could compromise the success of infectious disease simulations and interventions. This includes risks associated with data availability and quality, continuity of healthcare services, and the potential for misinterpretation or misuse of model outcomes. Understanding these risks is critical for designing robust strategies that minimize negative impacts and ensure effective disease control.

Results. Applying the CVRA Framework to evaluate the use of infectious disease simulation models in combat conditions involves understanding the capabilities, vulnerabilities, and risks that impact the model's effectiveness and the populations it is designed to protect. The table 1 presents an overview of how the CVRA framework was applied in this context, mainly focusing on the ongoing military conflict in Ukraine. Each framework element is broken down into sub-components to illustrate the factors that influence the use of infectious disease models in conflict situations.

Table 1

CVRA analysis

Framework Component	Sub-Component	Description	Key Findings
Capacity	Modelling Resources	Availability of computing power, software tools, and skilled personnel (data scientists, epidemiologists) to develop and interpret infectious disease simulations.	Ukraine has the digital infrastructure and technical capabilities; however, the military conflict has led to a lack of skilled personnel and limited laboratory resources, affecting modelling effectiveness.
	Collaboration	Partnerships with humanitarian organizations and international health agencies to support model calibration and validation.	Collaboration with WHO, Red Cross, and other agencies provides real-time data and resources, enhancing model reliability. However, coordination gaps remain.
	Access to Data	Availability of health data through surveys, surveillance systems, and NGO partnerships for data collection.	Existing surveillance systems facilitate data collection, but conflict hampers data completeness and accuracy, leading to challenges in model calibration.
	Healthcare Workforce	Availability of healthcare workers capable of responding to model-identified outbreaks, including mobilization of volunteers and international aid.	The healthcare workforce is constrained by displacement and infrastructure damage, limiting the ability to respond to outbreaks effectively.
	Intervention Programs	Existing vaccination and emergency preparedness and response programs to implement model-driven interventions.	Vaccination, responses to the TB, HIV/AIDS epidemics and emergency programs exist but are inconsistently applied due to logistical issues caused by ongoing military conflict.
	Communication Networks	Ability to communicate model predictions to stakeholders, healthcare workers, and communities.	Communication channels exist but are disrupted, limiting the effective dissemination of model findings.
	Transport and Logistics	Capacity for rapidly mobilizing medical supplies, vaccines, and healthcare personnel.	Logistics are significantly hindered by damage to infrastructure and limited access to conflict areas, affecting the timely deployment of interventions.
Vulnerability	Population Displacement	Mass displacement results in overcrowded shelters with poor sanitation, increasing susceptibility to outbreaks.	Overcrowded conditions elevate the risk of disease transmission, complicating the assumptions of simulation models and increasing health vulnerabilities.

	Healthcare Access	Limited access to healthcare facilities due to damage and inaccessibility during military conflict.	The destruction of healthcare infrastructure limits access to medical services, reduces population resilience to disease and impedes the implementation of model-driven responses, especially on the frontline and temporary occupied territories.
	Nutritional Vulnerability	Malnutrition among populations on the frontline territories increases susceptibility to infectious diseases.	Poor nutrition compromises the immune response, increasing the risk of infectious diseases like cholera, measles, and respiratory infections.
	Stress and Mental Health Impact	Psychological stress and trauma among the affected population, increasing susceptibility to physical health issues.	Elevated stress levels and mental health problems weaken immune systems, increasing vulnerability to infectious diseases.
	Contact with Stray and Wild Animals, and vectors	Increased contact with stray and wild animals due to displacement, raising the risk of zoonotic diseases, such as rabies and vector-borne diseases such as Lyme disease.	Displaced populations have heightened exposure to animals and vectors, creating additional health risks, particularly from rabies and other zoonosis and vector-borne diseases.
	Environmental Pollution	Pollution from damaged infrastructure, including sewer damage, heavy metals, and radiation exposure, leading to increased risk of intestinal infections and other health issues.	Environmental hazards exacerbate health vulnerabilities, contributing to increased rates of intestinal infections and other health complications.
	Data Availability and Quality	The quality of data is impacted by the destruction of health infrastructure, restricted access, and incomplete reporting.	Data scarcity and quality issues hinder the reliability of disease simulation models, leading to uncertainty in predictions.
	Assumptions and Uncertainty	Reliance on assumptions that may not hold in conflict settings, such as stable populations or uniform healthcare access.	High uncertainty in model parameters reduces accuracy, making predictions less reliable in dynamic conflict environments.
	Healthcare Disruption	Inoperability or destruction of healthcare facilities, reducing the ability to provide timely interventions.	Disrupted healthcare services prevent timely action based on model outputs, exacerbating health risks in affected populations.
	Fragmented Healthcare Provision	Multiple aid agencies provide fragmented healthcare services, challenging coordinated intervention.	Coordination difficulties between aid agencies lead to inconsistencies in healthcare provision, affecting the effectiveness of intervention measures.
Risk	Model Uncertainty	Limited and inconsistent data leading to incorrect predictions and misguided interventions.	Poor-quality data results in uncertainty, which may cause resource misallocation and under-preparedness for outbreaks.
	Delayed Interventions	Disruption of communication and data collection delaying model predictions and subsequent interventions.	Data collection and dissemination delays lead to postponed interventions, reducing their effectiveness.
	Ineffective Response	Compromised response capability due to poor infrastructure, ongoing combat operation, and resource scarcity.	Even with accurate predictions, response effectiveness is limited by logistical and infrastructure challenges.
	Logistical Challenges	Delays in deploying medical supplies and healthcare personnel due to ongoing combat operation.	Logistical disruptions hinder the timely and effective implementation of model-driven interventions, reducing overall impact.
	Misuse of Data	Potential misuse of health data by conflicting parties risks the privacy and safety of affected populations.	Health data may be exploited, posing privacy risks and reducing trust in health authorities.
	Community Distrust	Distrust in government and international actors undermining intervention implementation.	Lack of trust among the affected population hinders the successful implementation of model-informed interventions, leading to resistance and reduced compliance.

The CVRA framework provides a comprehensive means to evaluate and improve the use of infectious disease models in conflict situations. Capacity assessment identifies the strengths and gaps in infrastructure and human resources. Vulnerability assessment reveals the population and healthcare challenges, particularly regarding disrupted services and data limitations. Risk assessment highlights the uncertainties, logistical challenges, and ethical concerns that must be addressed to ensure the effective use of simulation models in disease control efforts during conflicts such as the ongoing military conflict in Ukraine.

Discussion. The findings of this study underscore the complexities involved in applying infectious disease simulation models in conflict-affected areas, specifically focusing on the warfare in Ukraine. Using the CVRA framework, the study provides a detailed evaluation of the strengths and challenges inherent in deploying these models for effective disease control in martial law conditions.

Capacity Analysis reveals that despite Ukraine's digital infrastructure and technical capabilities, the martial law has significantly weakened the available resources necessary for effective disease simulation and control. Skilled personnel, including healthcare workers and epidemiologists, have been displaced or diverted to immediate medical emergencies, reducing capacity for disease modelling and response implementation. Logistical disruptions and damage to healthcare infrastructure have hindered the timely deployment of interventions based on simulation outputs. Nevertheless, international collaboration has proven instrumental, as partnerships with organizations such as the WHO and Red Cross provide vital support in data collection and resource allocation.

Vulnerability Assessment highlights that population displacement and healthcare disruptions are critical factors exacerbating the spread of infectious diseases during the martial law. Mass displacement has led to overcrowded shelters, which lack adequate sanitation and healthcare access, creating environments where infectious diseases can thrive. Additionally, data collection challenges due to disrupted health infrastructure have contributed to inconsistencies and gaps in model calibration, affecting the reliability of simulation outcomes. These vulnerabilities reveal the difficulty of accurately modelling disease dynamics in conflict zones, given the lack of stable population data and compromised healthcare services.

Risk Assessment identifies several key risks that impede the implementation of infectious disease simulations. One major risk is data uncertainty, which arises from inconsistent and incomplete reporting in conflict areas. This uncertainty affects the accuracy of model predictions, potentially leading to misguided interventions. Data collection and communication delays further exacerbate these issues, resulting in delayed responses that can significantly reduce the effectiveness of interventions such as vaccination or quarantine. Additionally, ethical concerns regarding the misuse of health data in martial law settings could put vulnerable populations at further risk. Community distrust of government and international actors also risks effective intervention implementation, as it undermines public compliance with model-driven recommendations.

The CVRA framework has proven valuable in systematically assessing the feasibility of using infectious disease models in the unstable context of the russian full-scale invasion of Ukraine. It enables a comprehensive understanding of the strengths, such as existing international support, and weaknesses, such as gaps in healthcare and data availability, that impact the effectiveness of disease control measures. However, the findings emphasize that the effective use of simulation models in combat zones requires substantial adaptation to address the unique challenges conflict settings present.

The findings from this study have broader applicability beyond Ukraine, providing valuable insights into infectious disease control in other conflict settings. The use of the CVRA framework allows for a structured analysis of capacities, vulnerabilities, and risks that can be adapted to different combat-affected regions. Similar conditions, such as disrupted healthcare infrastructure, population displacement, and data scarcity, are common across conflict zones worldwide. Therefore, the lessons learned from this study can inform public health strategies and improve the implementation of disease models in diverse conflict settings, facilitating more effective disease control and prevention.

This study has limitations that must be acknowledged. The ongoing martial law significantly constrained data availability and quality, leading to potential biases and uncertainties in model calibration and validation. The military conflict’s dynamic nature made it difficult to collect consistent and up-to-date information, which impacted the accuracy of simulation outcomes.

Recommendations for improving the application of infectious disease models in conflict areas include strengthening local capacity through training healthcare workers and leveraging alternative data sources, such as satellite imagery and mobile phone tracking, to improve data quality and coverage. Establishing robust communication networks to facilitate real-time information sharing and engaging with community leaders to build trust are also essential for enhancing the success of interventions. Moreover, ethical considerations must be prioritized to protect the privacy and safety of vulnerable populations, particularly in conflict situations where misuse of health data can have severe consequences.

This study highlights the importance of a multifaceted approach to infectious disease control in conflict settings. By addressing capacity gaps, reducing vulnerabilities, and mitigating risks, the application of simulation models can be more effectively aligned with the complex realities of combat-affected regions. The CVRA framework is useful for guiding these efforts, ensuring that infectious disease modeling is both adaptive and responsive to the unique challenges of conflict environments.

Conclusions.

This study provides a comprehensive analysis of the application of infectious disease simulation models in conflict-affected areas using the Capacity, Vulnerability, and Risk Assessment framework, focusing on the martial law in Ukraine.

The findings underscore the strengths and challenges of employing such models in dynamic and unstable environments, highlighting the critical role of capacity building, addressing vulnerabilities, and mitigating risks to enhance public health responses.

This study's scientific novelty lies in applying the Capacity, Vulnerability, and Risk Assessment framework to assess the feasibility of using infectious disease simulation models in an active conflict zone. By integrating assessments of capacity, vulnerability, and risk, this study offers a novel approach to understanding the limitations and opportunities for using these models in conflict settings, providing new insights into how public health strategies can be optimized under such conditions.

Practically, this study identifies key areas where public health interventions can be improved, including data collection, capacity building, and community engagement. The insights gained from this study can be directly applied to inform public health policies and strategies in other conflict-affected areas, making it a valuable reference for policymakers, humanitarian organizations, and healthcare professionals working in similar contexts.

Future research should focus on developing more resilient data collection systems that can operate effectively under conflict conditions and improving the integration of alternative data sources such as satellite imagery and mobile tracking technologies. Additionally, efforts should be made to address ethical data privacy concerns and build trust within affected communities. Expanding the application of the Capacity, Vulnerability, and Risk Assessment framework to other conflict settings will also be crucial for validating its broader applicability and enhancing its utility in guiding public health interventions in diverse environments.

Acknowledgements. The study was funded by the National Research Foundation of Ukraine in the framework of the research project 2023.03/0197 on the topic “Multidisciplinary study of the impact of emergency situations on the infectious diseases spreading to support management decision-making in the field of population biosafety”.

References

1. Tang, L., Zhou, Y., Wang, L., Purkayastha, S., Zhang, L., He, J., Wang, F., & Song, P. X. -K. (2020). A Review of Multi-Compartment Infectious Disease Models. *International Statistical Review*, *88*(2), 462–513. https://doi.org/10.1111/insr.12402

2. Armitage, R. C. (2022). War in Ukraine: public health, rehabilitation and assistive technologies. *Disability and Rehabilitation: Assistive Technology*, *17*(8), 989–990. https://doi.org/10.1080/17483107.2022.2110950

3. Awuah, W. A., Mehta, A., Kalmanovich, J., Yarlagadda, R., Nasato, M., Kundu, M., Abdul-Rahman, T., Deborah Fosuah, A., & Sikora, V. (2022). Inside the Ukraine war: health and humanity. *Postgraduate Medical Journal*, *98*(1160), postgradmedj-2022-141801. https://doi.org/10.1136/postgradmedj-2022-141801

4. Essar, M. Y., Matiashova, L., Tsagkaris, C., Vladychuk, V., & Head, M. (2022). Infectious diseases amidst a humanitarian crisis in Ukraine: A rising concern. *Annals of Medicine and Surgery*, *78*, 103950. https://doi.org/10.1016/j.amsu.2022.103950

5. Izonin, I., Tkachenko, R., Yemets, K., & Havryliuk, M. (2024). An interpretable ensemble structure with a non-iterative training algorithm to improve the predictive accuracy of healthcare data analysis. *Scientific Reports*, *14*(1), 12947. https://doi.org/10.1038/s41598-024-61776-y

6. United Nations. (n.d.). Capacities and Vulnerabilities Assessment Framework (CVA). In *United Nations Development Programme*. Retrieved November 1, 2024, from https://www.adaptation-undp.org/sites/default/files/resources/6_capacities_and_vulnerabilities_assessment_framework_cva_framework.pdf

7. Chumachenko, D., Bazilevych, K., Butkevych, M., Meniailov, I., Parfeniuk, Y., Sidenko, I., & Chumachenko, T. (2024). Methodology for assessing the impact of emergencies on the spread of infectious diseases. *Radioelectronic and Computer Systems*, *2024*(3), 6–26. https://doi.org/10.32620/reks.2024.3.01

8. Nielsen, J., Jensen, H., & Andersen, P. K. (2004). Creating a reference to a complex emergency situation using time series methods: war in Guinea-Bissau 1998–1999. *Journal of Applied Statistics*, *32*(1), 75–86. https://doi.org/10.1080/0266476042000305168

9. Supervie, V., Halima, Y., & Blower, S. (2010). Assessing the impact of mass rape on the incidence of HIV in conflict-affected countries. *AIDS*, *24*(18), 2841–2847. https://doi.org/10.1097/qad.0b013e32833fed78

10. Oki, M., & Yamamoto, T. (2013). Simulation of the probable vector density that caused the Nagasaki dengue outbreak vectored by*Aedes albopictus*in 1942. *Epidemiology and Infection*, *141*(12), 2612–2622. https://doi.org/10.1017/s0950268813000447

11. Mahmud, A. S., Alam, N., & Metcalf, C. J. E. (2017). Drivers of measles mortality: the historic fatality burden of famine in Bangladesh. *Epidemiology and Infection*, *145*(16), 3361–3369. https://doi.org/10.1017/s0950268817002564

12. Aliyu, G. G., Aliyu, S. H., Ehoche, A., Dongarwar, D., Yusuf, R. A., Aliyu, M. H., & Salihu, H. M. (2021). The Burden of HIV, Hepatitis B and Hepatitis C by Armed Conflict Setting: The Nigeria AIDS Indicator and Impact Survey, 2018. *Annals of Global Health*, *87*(1), 53. https://doi.org/10.5334/aogh.3226

13. Harpring, R., Maghsoudi, A., Fikar, C., Piotrowicz, W. D., & Heaslip, G. (2021). An analysis of compounding factors of epidemics in complex emergencies: a system dynamics approach. *Journal of Humanitarian Logistics and Supply Chain Management*, *11*(2), 198–226. https://doi.org/10.1108/jhlscm-07-2020-0063

14. Chapwanya, M., Lubuma, J., Terefe, Y., & Tsanou, B. (2022). Analysis of War and Conflict Effect on the Transmission Dynamics of the Tenth Ebola Outbreak in the Democratic Republic of Congo. *Bulletin of Mathematical Biology*, *84*(12), 136. https://doi.org/10.1007/s11538-022-01094-4

15. Awan, U. A., Malik, M. W., Khan, M. I., Khattak, A. A., Ahmed, H., Hassan, U., Qureshi, H., & Afzal, M. S. (2021). Predicting COVID-19 incidence in war-torn Afghanistan: A timely response is required! *Journal of Infection*, *84*(1), e6–e8. https://doi.org/10.1016/j.jinf.2021.09.004

16. Nesteruk, I., & Brown, P. (2024). Impact of Ukrainian Refugees on the COVID-19 Pandemic Dynamics after 24 February 2022. *Computation*, *12*(4), 70. https://doi.org/10.3390/computation12040070

Конфлікт інтересів: відсутній.
Conflicts of interest: authors have no conflict of interest to declare.

Відомості про авторів:

Чумаченко Тетяна Олександрівна *A, B, C, D, E, F* – доктор медичних наук, професор, завідувач кафедри епідеміології Харківського національного медичного університету, Україна. E-mail: tatalchum@gmail.com. https://orcid.org/0000-0002-4175-2941

Чумаченко Дмитро Ігорович *A, B, C, D, E, F* – кандидат технічних наук, доцент, доцент кафедри математичного моделювання та штучного інтелекту Національного аерокосмічного університету ім. М.Є. Жуковського «Харківський авіаційний інститут», Україна. E-mail: dichumachenko@gmail.com. https://orcid.org/0000-0003-2623-3294

A – концепція та дизайн дослідження; B – збір даних; C – аналіз та інтерпретація даних;
D – написання статті; E – редагування статті; F –остаточне затвердження статті

Information about authors:

Chumachenko Tetyana *A, B, C, D, E, F* – MD, Doctor of Medical Sciences, Professor, Head of Epidemiology department, Kharkiv National Medical University, Ukraine. E-mail: tatalchum@gmail.com. https://orcid.org/0000-0002-4175-2941

Chumachenko Dmytro *A, B, C, D, E, F* – PhD (Engineering), Associate Professor, Associate Professor of Mathematical Modelling and Artificial Intelligence department, National Aerospace University "Kharkiv Aviation Institute". E-mail: dichumachenko@gmail.com. https://orcid.org/0000-0003-2623-3294

A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation;
D – writing the article; E – critical revision of the article; F – final approval of the article.

Адреса для листування: пр. Науки, 4, м. Харків, 61022, Україна