REVIEW ARTICLE

CONTENTS

Assessment of the potential for the implementation of geographic information systems in the public health system of Ukraine

Oksana K. Biloshytska, Oleksandr B. Besarab, Oleksandr Yu. Galkin
NATIONAL TECHNICAL UNIVERSITY OF UKRAINE «IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE», KYIV, UKRAINE

ABSTRACT

Aim: To synthesize current evidence on the use of Geographic Information Systems (GIS) in public health surveillance, with emphasis on digital health integration, spatial epidemiology, and decision support for infectious disease monitoring.

Materials and Methods: A narrative review approach was applied based on the analysis of recent peer-reviewed studies, policy documents, and reports from international health organisations. Sources included research on spatiotemporal disease mapping, digital epidemiology, and GIS-based surveillance systems. The review focused on applications of GIS in infectious disease tracking, health system planning, data integration platforms, and the digital transformation of public health infrastructure. A comparative analysis of methodological approaches and technological frameworks was conducted to identify trends, strengths, and limitations in current practice. The analysis utilized data from the international bibliographic database Scopus, PubMed, international repositories and public health atlases (Global Health Observatory, ECDC Surveillance Atlas of Infectious Diseases), the central eHealth database, as well as relevant regulatory and legal documents. Particular attention was given to publications and reports covering the period 2020-2025.

Conclusions: GIS technologies significantly enhance public health surveillance by enabling real-time visualization, improved spatial analysis, and better-informed decision-making. Integration of GIS with digital health systems and data infrastructures strengthens early warning capabilities and supports evidence-based interventions. However, challenges remain regarding data quality, interoperability, privacy protection, and unequal technological capacity across regions. Further development of standardized frameworks and ethical guidelines is required to ensure the effective and sustainable implementation of geospatial technologies in public health systems.

KEY WORDS: Geographic Information Systems; Public Health

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INTRODUCTION

In the context of the ongoing transformation of Ukraine's public health system, driven both by global challenges (including the rising prevalence of chronic non-communicable diseases, the impact of climate change, and the threat of emerging infectious diseases) and the consequences of the full-scale war, there is an increasing demand for tools capable of providing comprehensive, timely, and evidence-based monitoring of population health status and associated risk factors. Among such tools, Geographic Information Systems (GIS) play a pivotal role. In leading countries worldwide, GIS have long been integrated into epidemiological surveillance, population health analysis, healthcare service planning, and public health risk management [1, 2].

GIS enable the integration of medical, demographic, socio-economic, and environmental data within a spatial framework, thereby facilitating the identification of disease distribution patterns, high-risk population groups, territorial inequalities in access to healthcare services, and the influence of external determinants on population health. Spatial analysis, which underpins GIS methodology, provides significant opportunities for the early detection of health threats, forecasting disease dynamics, and optimizing decision-making processes in prevention and response strategies [3].

International experience demonstrates that GIS constitutes a core component of modern epidemiological surveillance and population health monitoring systems. For instance, in the United States, GIS technologies are integrated into the programs of the Centers for Disease Control and Prevention (CDC); in the European Union, they are applied within the European Centre for Disease Prevention and Control (ECDC); and in Canada, Australia, and South Korea, GIS are embedded in national digital platforms for risk assessment and public health

emergency management [4-6]. Most of these systems combine geospatial data with electronic health records, environmental information, and social determinants of health, significantly enhancing the accuracy and timeliness of public health responses.

For Ukraine, which is actively developing its public health system in accordance with World Health Organization (WHO) and European Union (EU) standards [7, 8], the integration of GIS into national health monitoring is not only a promising direction but also a necessity. The combination of geospatial technologies with existing state health registries, eHealth data, the National Geospatial Data Infrastructure, and information on risk factors creates a foundation for an effective, analytically oriented disease prevention system. This, in turn, can substantially improve the quality of public health decision-making, enhance preventive planning, and ensure evidence-based management of healthcare resources.

AIM

The aim of the study is to provide a comprehensive assessment of the potential for implementing GIS in the national public health system of Ukraine as a critically important tool for transforming the health monitoring framework and transitioning toward a risk-based model of disease prevention.

To achieve this aim, the following objectives were set:

1. To analyse the national needs of Ukraine and identify systemic limitations of the current population health monitoring model that could be addressed through a GIS component.
2. To examine the regulatory and legal framework governing the implementation of spatial technologies in Ukraine and assess its alignment with international standards.
3. To evaluate the existing technological capacity, including an analysis of available medical and environmental data sources suitable for integration into a Health GIS.
4. To conduct a comprehensive assessment of the technical feasibility, financial viability, and organizational readiness of the national healthcare system for GIS implementation.
5. To identify key implementation risks of GIS (in particular, issues of geoprivacy and data fragmentation) and develop evidence-based recommendations for their mitigation.

MATERIALS AND METHODS

The study is based on an analytical review and assessment of the scientific and technical potential for implementing GIS in the public health system. The analysis utilized data from the international bibliographic database Scopus, PubMed, international repositories and public health atlases (Global Health Observatory, ECDC Surveillance Atlas of Infectious Diseases), the central eHealth database, as well as relevant regulatory and legal documents. Particular attention was given to publications and reports covering the period 2020-2025.

ETHICS

This study represents an analytical assessment of the potential implementation of technologies based on a systematic review of publicly available scientific data published in peer-reviewed journals, international strategic guidelines, and official databases. The review is grounded in the analysis of verified sources and the applicable regulatory framework. All sources of information are appropriately cited and properly listed in the references. No patient-identifiable data were used, no new clinical interventions were conducted, and no primary collection of personal data was performed. Therefore, approval from a local ethics committee was not required.

FRAMEWORK

This study was conducted using state budget funding under Contract No. DZ/166-2025 dated 12.02.2025 between the Ministry of Education and Science of Ukraine and the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", within the framework of the research and development project under the state order entitled "Development of a Methodology for Disease Prevention Based on Population Health and Risk Factor Monitoring" (State Registration No. 0125U001020, term: 2025-2026).

REVIEW AND DISCUSSION

The establishment of a modern public health system in Ukraine in accordance with the Law of Ukraine "On the Public Health System" No. 2573-IX dated 06.09.2022 [9] envisages a transition from predominantly descriptive morbidity statistics to analytical, risk-oriented monitoring focused on inequalities and territorial variations. The Law explicitly defines population health monitoring, assessment of risk factors, and early detection of threats as core functions of the public health system. However, it does not provide detailed methodological guidance regarding spatial analysis tools or the integration of geospatial data into routine epidemiological surveillance.

In parallel, the Law of Ukraine "On the National Geospatial Data Infrastructure" No. 554-IX (2020) [10] establishes the legal foundation for the development of a unified national geospatial infrastructure. Nevertheless, the healthcare sector currently utilises these capabilities only fragmentarily. As a result, there remains a significant gap between the needs of the public health system and the actual level of implementation of geoinformation technologies, which highlights the substantial potential for GIS adoption.

The systemic limitations of the current population health monitoring model in Ukraine include the following:

1. Fragmentation of medical and statistical data. Data on morbidity, mortality, risk factors, and socio-demographic characteristics are stored across multiple information systems (eHealth, MoH registries, National Health Service of Ukraine databases, Public Health Centre systems, State Statistics Service, and departmental geoportals). This fragmentation complicates integrated analysis. Spatial referencing (address, coordinates, administrative unit) is often missing or inconsistent, which prevents the construction of comprehensive risk maps.
2. Lack of a systematic spatial component in morbidity analysis. Individual studies in Ukraine have demonstrated the high informativeness of spatial-temporal analysis – for example, research on territorial differences in cause-specific mortality, which revealed significant regional and subregional disparities [11]. However, such approaches are not integrated into routine national surveillance systems.
3. Insufficient spatial resolution of risk assessment. Existing statistical reports are mainly aggregated at the regional level, and less frequently at the community level. This masks local "hotspots" characterized by elevated disease incidence or concentration of risk factors. International evidence emphasizes that without GIS-based approaches, it is not possible to adequately assess the spatial heterogeneity of epidemic processes and health determinants [12, 13].
4. Limited timeliness of outbreak response. Modern surveillance systems in the EU and WHO member states rely on near real-time monitoring with dynamic spatial visualization of infectious diseases (e.g., ECDC Surveillance Atlas of Infectious Diseases; WHO global platforms) [4, 14, 15]. In Ukraine, outbreak information is often disseminated in textual reports without interactive cartographic representation, which delays the localisation and targeted response measures.
5. Insufficient integration of health data with environmental and socio-economic indicators. Although geospatial infrastructure for environmental monitoring is being developed (including air pollution maps and agricultural burden assessments), these datasets are rarely integrated with health indicators within a unified analytical environment [13].
6. New challenges associated with the full-scale war. The WHO emphasizes that in emergency and conflict settings, rapid spatial analysis of risks, population displacement, infrastructure damage, and healthcare accessibility is critical [16]. In Ukraine, such approaches are applied only sporadically (e.g., in projects assessing damaged healthcare facilities), despite the systemic need for comprehensive implementation.

Key needs that can be addressed by GIS include the following:

1. Real-time monitoring of infectious diseases. International reviews covering 2020–2025 demonstrate that GIS became a fundamental tool of epidemiological surveillance during the COVID-19 pandemic, enabling visualization of disease spread, modelling of spatiotemporal dynamics, and assessment of intervention effectiveness [13, 17]. Spatial analysis is applied both to conventional disease mapping and to more advanced approaches, such as wastewater-based epidemiology, where GIS is integrated with mathematical models for early detection of viral circulation [18].

In study [19], the application of GIS for COVID-19 monitoring in Morocco enabled the identification of high-risk spatial clusters and the delineation of priority zones for public health interventions. Such approaches are directly relevant for Ukraine, where seasonal and emerging infectious disease threats persist (influenza, measles, poliomyelitis, zoonoses, and infection patterns associated with population displacement).

For Ukraine, the GIS potential in this area includes the development of national outbreak maps with real-time updates based on eHealth and laboratory information systems, spatiotemporal analysis, and integration of infectious disease data with population mobility and infrastructure indicators.

2. Spatial analysis of non-communicable diseases (NCDs). A range of studies from 2020–2025 highlights the effectiveness of GIS in examining spatial patterns of non-communicable diseases, particularly cardiovascular, oncological, and respiratory conditions [13]. In Ukraine, a notable example is the analysis of spatial variation in cause-specific mortality, which revealed substantial differences in risk across regions and subregional territories [11].

GIS enables the identification of territorial clusters with elevated NCD incidence or mortality; the analysis

of associations between NCDs and socio-economic determinants (income, employment, urbanization) as well as environmental factors; and the targeting of preventive interventions (screening programs, smoking cessation initiatives, blood pressure control, etc.).

The development of Health Inequality Data Repositories and WHO global platforms further emphasizes the importance of a spatial dimension in health inequality assessment, which is highly relevant for adaptation in Ukraine [14, 15].

3. Mapping environmental risks (air, water, radiation) and their health impacts. Geospatial technologies are widely used to assess the effects of air, water, and soil pollution on population health, including the analysis of strong associations between pollutant concentrations and hospitalization or mortality rates [13, 17]. In Ukraine, regional air quality mapping initiatives already exist; however, these data are rarely integrated with health statistics.

GIS enables the overlay of environmental pollution layers (air quality, water contamination, radiation levels) with disease distribution maps; the assessment of spatial associations between environmental risks and specific nosological entities; and the consideration of consequences of industrial accidents and military activities (destruction of chemical facilities and water supply infrastructure).

4. Healthcare infrastructure planning and service accessibility. The application of GIS in analysing healthcare accessibility (distance- and time-to-care) is a well-established practice in EU countries. For example, study [20] demonstrates how spatial analysis of healthcare facility distribution and transport accessibility can optimize service placement and identify underserved areas.

For Ukraine, this is particularly relevant due to the uneven distribution of the healthcare infrastructure between urban and rural areas; the destruction of healthcare facilities as a result of armed conflict; and the large-scale internal population displacement.

GIS can support the modelling of the optimal placement of primary care units, hospitals, and mobile medical points; the analysis of transport accessibility using isochrone-based travel time mapping; and the assessment of workload distribution across healthcare facilities.

5. Support for biosafety and biosecurity systems. Reviews of geospatial technologies in infectious disease surveillance indicate that GIS is a key tool not only for routine epidemiological monitoring but also for managing biological threats, including emerging and re-emerging infections [12, 13]. Geovisualization of national infectious disease alert systems, as demonstrated in European interactive tools (European Notifiable Diseases Interactive Geovisualization, ENDIG), facilitates system readiness assessment, identification of surveillance gaps, and simulation of response scenarios [21].

For Ukraine, which is developing its national biosafety system in line with European integration priorities and the International Health Regulations, the implementation of GIS-based modules in early warning systems represents a logical step.

6. Analysis of war-related health impacts and territorial inequalities in healthcare access. In the context of prolonged military aggression, the ability to map damaged and destroyed healthcare facilities, assess accessibility of services in frontline and de-occupied areas, and analyse spatial patterns of trauma, psychosocial consequences, and war-related morbidity becomes critically important.

WHO-recommended approaches for surveillance in emergency settings explicitly emphasize the use of geospatial data for risk assessment and intervention planning [15, 17]. When combined with the National Geospatial Data Infrastructure, this provides a foundation for developing specialized GIS modules for monitoring the public health consequences of war.

The analysis of Ukraine's public health needs demonstrates that the implementation and development of a GIS component is not merely a technological innovation but a necessary condition for transitioning towards a risk-oriented, spatially sensitive system of population health and risk factor monitoring. This is consistent with both national regulatory frameworks [9, 10] and contemporary international approaches of WHO, the EU, and leading countries to data-driven, geospatially enabled public health systems.

REGULATORY AND LEGAL FRAMEWORK FOR GIS IMPLEMENTATION IN UKRAINE

The development of Geographic Information Systems (GIS) in the field of public health in Ukraine is based on both national legislation and international strategic frameworks of digital health transformation. The regulatory and legal environment defines the legitimacy of data collection, processing, integration, and spatial visualization of medical and related datasets, while also establishing requirements for personal data protection, interagency interoperability, and data standardization [9, 10, 22-24].

A comparison of Ukrainian legislation with international frameworks indicates substantial potential, but also reveals existing gaps in the formal institutionalization of GIS as a core public health instrument. At the

Table 1. Comparative analysis of international frameworks and the Ukrainian regulatory environment in relation to digital health and GIS

Aspect	WHO: Global Strategy on Digital Health 2020–2025	EU: INSPIRE and related directives	Ukraine: current legal framework
Vision of digital health	Comprehensive strategy integrating digital technologies, including surveillance, data analytics, and decision support; emphasis on governance, ethics, and infrastructure	Creation of a unified spatial data infrastructure ensuring interoperability of geospatial data across sectors, including environment and health	Separate legal acts on public health, geospatial data, and eHealth; partial strategic elements exist, but no dedicated national digital health strategy with a clearly defined GIS component
Regulation of geospatial data	Emphasis on data as a shared resource; recommendations for integration of spatial data into monitoring systems without detailed technical specifications	Clearly defined data sets, metadata standards, and data access services applied across multiple sectors	The Law on the National Geospatial Data Infrastructure establishes general principles; however, sector-specific (health) geospatial standards and integration protocols remain insufficiently developed
Ethical and legal aspects of digital surveillance	Specific guidance on ethical issues in public health surveillance, including GIS use; focus on balancing public benefit and privacy protection	Regulatory focus primarily on technical and organizational standards; ethical aspects addressed in complementary policy documents	Personal data protection is regulated by general legislation; specific ethical frameworks for spatial epidemiological surveillance have not yet been codified
Integration of GIS into public health	Recommended as an effective tool for epidemiological surveillance, outbreak control, risk assessment, and inequality analysis	Widely applied in environmental monitoring, food safety, and One Health risk assessment systems	GIS use in public health remains largely project-based and fragmented; legislation does not formally establish GIS as a mandatory component of health monitoring systems

Source: compiled by the authors of this study

international level, key reference frameworks include the WHO Global Strategy on Digital Health 2020–2025, the INSPIRE Directive 2007/2/EC, and various guidelines on the use of digital technologies in epidemiological surveillance [24-26]. A comparative overview is presented in Table 1.

Thus, the current regulatory and legal framework in Ukraine provides the general enabling conditions for the implementation of GIS in public health; however, further harmonisation with international standards is required. Priority directions for improvement include the formalisation of spatial data requirements within sectoral health standards; the development of protocols for geocoding, anonymisation, and aggregation of health-related geodata for surveillance and analytics; the integration of medical data into the National Geospatial Data Infrastructure using INSPIRE-compliant standards; and the incorporation of GIS as a core component of national digital health strategies in line with WHO, EU, and other leading international recommendations.

THE ASSESSMENT OF THE POTENTIAL FOR GIS IMPLEMENTATION IN THE NATIONAL PUBLIC HEALTH SYSTEM

The assessment of the technical feasibility of implementing GIS in Ukraine's public health system should be based on the analysis of three key components: availability of digital data, the capacity for their integration into a geoinformation environment, and human resource potential.

First, in recent years, Ukraine has developed an extensive digital healthcare infrastructure. The Electronic Health System (eHealth) accumulates billions of electronic medical records, registries of healthcare facilities, physicians, medical services, and contracts with the National Health Service of Ukraine. Its architecture, data standards, and regulatory framework are described in detail in [27]. This indicates that a substantial volume of primary data suitable for spatially oriented analytics already exists in digital form.

Second, the Law of Ukraine "On the National Geospatial Data Infrastructure" No. 554-IX (2020) and the development of the national geoportal provide both legal and technical prerequisites for integrating health-related data into a standardized geospatial data infrastructure [10]. The concept of Spatial Data Infrastructure (SDI) for healthcare, presented in [28], demonstrates that linking electronic health records with SDI frameworks is a logical direction for the evolution of public health systems in many countries.

Third, international literature emphasises that effective use of GIS in public health requires interdisciplinary teams, including epidemiologists, biostatisticians, GIS analysts, and software developers. Reviews of GIS applications in surveillance highlight the institutionalization of the role of spatial epidemiologists within modern public health systems [12]. In Ukraine, human capacity in digital medicine and geoinformatics exists,

as evidenced by publications on spatial health analysis and digital transformation of healthcare [29, 30]; however, this expertise remains fragmented and is not yet concentrated within a unified institutional framework.

Overall, the technical feasibility of GIS implementation in Ukraine's public health system is assessed as high, due to the existing digital and geospatial infrastructure, provided that targeted investments are made in medical data geocoding and workforce development.

The financial feasibility of GIS implementation in public health is considered through the balance between system development and maintenance costs and the potential savings achieved through improved prevention efficiency, reduced outbreak scale, and optimised infrastructure utilization.

Several studies have demonstrated that GIS-based approaches in immunization programme planning and mobile healthcare delivery can be cost-effective. Reviews of digital tools for surveillance and outbreak response in African countries [31] show that well-designed digital surveillance systems, including GIS components, can be scalable and relatively low-cost, particularly when based on open-source software and cloud-based solutions [32]. Furthermore, study [33] emphasizes that GIS provides a structured and cost-efficient framework for managing complex surveillance datasets, thereby improving the overall performance of public health systems.

For Ukraine, where the public health regulatory framework is defined by the Law "On the Public Health System" No. 2573-IX and the digital transformation of healthcare has already been implemented on the basis of the eHealth system, GIS implementation can be viewed as an investment in more efficient resource allocation, including reducing excess hospital-bed capacity, targeting preventive programmes to high-risk areas, and optimising patient referral pathways [9, 27, 29].

Organizational readiness for GIS implementation is determined by the degree of institutional capacity to integrate spatial analytics into routine monitoring and management processes.

At the regulatory level, the Law of Ukraine "On the Public Health System" establishes population health monitoring, risk assessment, and early threat detection as core functions, thereby providing a legitimate framework for the use of analytical tools, including GIS [9]. The Law "On the National Geospatial Data Infrastructure" defines principles of openness, interoperability, and accessibility of geospatial data, which are essential for intersectoral collaboration in the health domain [10].

The WHO Global Strategy on Digital Health 2020–2025 emphasizes that successful implementation of digital technologies requires alignment of financial, organizational, human, and technological resources [25]. Analysis of Ukraine's digital health system shows that coordination mechanisms for eHealth governance have already been established; however, the integration of spatial data has not yet been defined as a distinct policy priority [27, 29].

Accordingly, organizational readiness can be assessed as partial, since:

- basic institutions (the Public Health Centre of the Ministry of Health, the Ministry of Health of Ukraine, and the National Health Service of Ukraine) exist and can act as both users and commissioners of GIS solutions;
- a regulatory framework supporting digitalization and geospatial infrastructure is in place;
- however, there is no dedicated national strategy or roadmap for Health GIS development, and no designated leading institution responsible for coordinating spatial epidemiology and analytics.

The implementation of GIS in public health is associated with several risks that must be systematically assessed and mitigated:

1. Confidentiality and geoprivacy. Contemporary studies on GIS ethics and digital surveillance highlight increasing risks of privacy breaches when publishing or sharing georeferenced health data. Research [34, 35] and systematic reviews on medical data privacy [36, 37] demonstrate that even anonymized datasets can be re-identified through spatial attributes, and that patients exhibit high sensitivity regarding privacy concerns. Modern geomasking approaches offer technical solutions for protecting geoprivacy while preserving analytical utility [38].
2. Data fragmentation and quality issues. Reviews of GIS applications in epidemiological surveillance indicate that heterogeneity of formats, lack of geocoding standards, and inconsistent data quality represent key barriers to GIS implementation, particularly in health systems undergoing transition [12, 39]. In Ukraine, where health, environmental, and infrastructure data are stored across multiple institutions, the risk of fragmentation is particularly pronounced.
3. Lack of standardization and intersectoral interoperability. Although the National Geospatial Data Infrastructure law formally establishes unified geodata principles, their practical implementation in the health sector remains limited. The absence of standardized data exchange protocols between the Ministry of Health, the Public Health Centre, the National Health Service, the Ministry of Environmental Protection, the State Emergency Service, and other agencies significantly restricts the analytical value of GIS for population health monitoring [10, 28].

4. Organizational inertia and workforce limitations. The introduction of spatial analytics requires transformation of governance processes—from static reporting to interactive dashboards and from episodic analytical reports to continuous spatiotemporal monitoring. Digital health transformation studies emphasize that without investment in user training and changes in organizational culture, digital tools remain underutilized [25, 29, 30].

In summary, the potential for GIS implementation in Ukraine's national public health system can be assessed as high in terms of technical and financial feasibility, and moderate in terms of organisational readiness. The main risks—primarily confidentiality, data fragmentation, and lack of standardisation—are manageable provided that targeted regulatory and institutional support is introduced, in line with WHO recommendations on digital health development and international approaches to Public Health SDI frameworks.

CONCLUSIONS

Based on the results of the conducted study on the potential for implementing Geographic Information Systems (GIS) in the national public health system of Ukraine, the following conclusions were formulated:

1. A critical need for GIS technologies has been identified to address systemic limitations of the current monitoring model, primarily data fragmentation and the lack of systematic spatial analysis. It has been established that the transition to risk-based epidemiological surveillance is not feasible without geovisualisation tools that enable the identification of disease "hotspots" and ensure timely response to public health threats, particularly under conditions of martial law.
2. The analysis of the regulatory and legal framework confirmed the existence of an adequate legal basis (Laws No. 2573-IX and No. 554-IX) for the development of a digital health ecosystem. However, the need for further harmonisation of national standards with international frameworks (WHO, INSPIRE) has been identified, particularly regarding the formalisation of requirements for medical data geocoding.
3. The assessment of technological capacity demonstrated the readiness of the national digital infrastructure for integration. The availability of a substantial dataset within the Electronic Health System (eHealth), together with the gradual development of the National Geospatial Data Infrastructure (NGDI), forms a necessary core for the establishment of an integrated GIS module.
4. The comprehensive feasibility assessment showed that, despite high technical and financial viability, the organisational readiness of the system remains partial. The main barrier is the absence of a unified national roadmap and a designated lead institution responsible for coordinating spatial analytics at the state level.
5. The study identified that the key risks related to geoprivacy and data fragmentation are manageable. The implementation of geomasking techniques, the establishment of interagency data-sharing agreements, and the development of human resources in spatial epidemiology are priority steps for the successful transformation of the public health system.

Thus, the implementation of a GIS component represents not only a technological upgrade but also a strategic prerequisite for establishing a modern, spatially sensitive healthcare system capable of effectively minimising population health risks.

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CONFLICT OF INTEREST
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CORRESPONDING AUTHOR
Oksana K. Biloshytska
Igor Sikorsky Kyiv Polytechnic Institute
16/2 Akademik Yangel St, 03056 Kyiv, Ukraine
e-mail: biloshytska.oksana@lll.kpi.ua

ORCID AND CONTRIBUTIONSHIP
Oksana K. Biloshytska 0000-0002-2901-9667 A D E
Oleksandr B. Besarab 0000-0002-2087-6953 A B D
Oleksandr Yu. Galkin 0000-0002-5309-6099 E F

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