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Research article

Determinants of the epizootic situation in the middle east: the interaction of historical, climatic, and socio-economic factors

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Abstract

Background and Aim. The Middle East is one of the most complex epizootic regions in the world due to the interaction of historical, natural, climatic, and socioeconomic factors that influence the spread of infectious animal diseases. Traditional epidemiological approaches cannot fully explain the persistence of epizootic threats in the region. The aim of this study is to conduct a comprehensive analysis of the epizootic architecture of the Middle East as a complex metasystem operating at the intersection of historical, environmental, and political-economic determinants.

Materials and Methods. The study was conducted as a meta-analysis and retrospective modeling for the period 2020–2024. Data from the international monitoring systems WOAH WAHIS and Handistatus II, FAO and ECDC materials, as well as scientific publications and analytical reports for 2005–2024 were used. A systematization, comparative analysis, and qualitative predictive modeling of epizootological processes were conducted, taking into account spatiotemporal, climatic, and socioeconomic parameters.

Results. It has been established that the epizootic situation in the Middle East is determined by three interrelated groups of factors: historical-institutional, natural-climatic, and socio-economic. The region is a heterogeneous megasystem, encompassing four types of epizootic regimes: high-tech, crisis, transit, and isolationist. Crisis areas form persistent infection hotspots, while transit countries increase the spread of pathogens through migration and animal trade. Climate change contributes to the concentration of livestock and an increased risk of disease outbreaks.

Conclusion. Effective management of epizootological risks requires a shift from universal veterinary measures to differentiated strategies that take into account the historical, environmental, and socio-economic characteristics of individual countries and subregions of the Middle East.

Keywords: Biosecurity; climatic determinants; epizootic regimes; epizootiology; historical gap; Middle East.

Introduction

The Middle East, recognized as the cradle of animal domestication and the locus where early veterinary practices emerged, currently represents one of the world's most complex and multifaceted epizootiological regions [2–4]. Despite substantial investments in biosecurity and disease control programs in the region, the region characterized by the persistence and periodic large-scale outbreaks of socio-economically significant infections such as foot-and-mouth disease (FMD), peste des petits ruminants (PPR), Middle East respiratory syndrome (MERS), and rabies [1, 8, 12, 15, 21].

Traditional epidemiological approaches, which primarily focus on the host-agent-environment triad, prove insufficient to explain the resilience of these threats and the frequent failure of standardized interventions. Paradoxically, intensive control measures in technologically advanced enclaves coexist with a complete institutional collapse in conflict zones, while isolation efforts are undermined by flourishing informal transboundary livestock trade networks. This apparent inconsistency suggests that the region's epizootiological picture is not a random aggregation of national statistics, but rather an emergent property of a deeper, systemic reality [7, 13, 14, 18, 20].

Existing research in the field of veterinary epidemiology in the Middle East is generally limited to the analysis of specific nosologies or the evaluation of technical control aspects within individual countries. At the same time, the fundamental determinants shaping the very architecture of regional epizootiological risks remain poorly understood. These include: historical trajectories that have created a gap between indigenous practices and imported institutions; climatic dynamics acting as an active agent in the spatial reorganization of animal husbandry; and, most crucially, the structural politico-economic heterogeneity that generates fundamentally different regimes of production and management of bio-threat [10, 11, 16, 17, 22]. The lack of an integrative view considering these layers in their synergetic interaction leads to the inadequacy of strategies based on universal "recipes" and direct technology transfer [6, 9, 17].

In this regard, there is an urgent need for a new analytical framework capable of describing the Middle East as an integrated but internally heterogeneous meta-system. This approach involves moving from the study of outbreaks to the analysis of stable "epizootological regimes", from the search for technical solutions to the political and economic diagnosis of systemic causes of vulnerability. Understanding the region as a complex dissipative system where pathogen circulation patterns arise from non-linear relationships between historically established institutions, transformable ecological niches, and contrasting socio-economic orders is key to developing effective and sustainable risk management strategies.

Research Objective: Conducting a comprehensive analysis of the epizootological architecture of the Middle East as a complex metasystem operating at the intersection of historical, environmental and political-economic determinants.

Materials and Methods

The present study is a comprehensive meta-analysis and retrospective modeling conducted between 2020 and 2024 in order to integrate disparate epizootological data on the Middle East into a single socio-ecological model of the meta-system. The work was based on the systematization and critical synthesis of data from multiple sources, which made it possible to move from the analysis of individual outbreaks to the study of the architecture of regional epizootological regimes.

For the retrospective analysis, structured data from open international systems were used: official reports and the database of the World Organization for Animal Health (WOAH) – the WAHIS (World Animal Health Information System) system and the Handistatus II archive (for the period 2005-2024); statistical and reporting materials of the Food and Agriculture Organization of the United Nations (FAO), joint bulletins FAO-WOAH, as well as reports from the European Center for Disease Prevention and Control (ECDC) and relevant regional networks. For political economic and historical analysis, national legislative acts, reports on the development of the agro-industrial complex, historical research, publications in peer-reviewed journals on veterinary epidemiology and social sciences, field research materials and expert interviews were used. All quantitative data (on outbreaks, livestock numbers, vaccinations, livestock movements) have been cross-checked from several sources to minimize errors related to incomplete or contradictory official reporting, especially in areas of instability.

Disparate data was systematized into a single relational database with spatio-temporal reference. Key parameters included: geographic location (country, region), time period (year, season), nosological entity (FMD, PPR, rabies, etc.), animal species, epidemiological indices (number of outbreaks, cases, mortality), and intervention data (vaccination and diagnostic volumes). A comparative systems analysis was conducted by integrating quantitative data and qualitative descriptors (economic basis, animal status, risk configuration, control type). This resulted in the development of a conceptual politico-economic typology identifying four ideal types of the Middle East metasystem: "Purchased Security," "Collapse Zone," "Transit Hub," and "Bio-Fortress." Qualitative predictive modeling was used to assess the sustainability of regimes and the effectiveness of control strategies. Scenarios were constructed taking into account key drivers identified in the meta-analysis: the density of susceptible populations, the permeability of administrative and ecological boundaries, the intensity of economic and trade links, and the adaptability of formal and informal control institutions. The meta-analysis results are presented in a figure and table.

Statistical Analysis and Operationalization of Epizootic Regimes

To transition from a purely conceptual framework to a verifiable quantitative model and establish objective criteria for the proposed country classification, a ROC (Receiver Operating Characteristic) curve analysis was executed. Countries of the Middle East meta-system were divided into two operational cohorts based on epidemiological data: "Favorable" (pathogen prevalence below the calculated regional baseline average) and "Unfavorable" (prevalence strictly exceeding the regional average).

The core evaluation variable utilized to differentiate these regimes was the estimated national livestock vaccination coverage. Through iterative assessment of varying coverage thresholds, diagnostic sensitivity (the probability of accurately identifying epidemiologically unfavorable territories) and specificity (the probability of correctly identifying favorable, high-tech, or isolated enclaves) were calculated. The optimal operational cut-off point was determined using the maximum trade-off balance between sensitivity and specificity, thereby formalizing the boundary conditions separating "Crisis-Driven/ Collapse Zone", " Transit Hub", and "High-Tech/Isolationist (Bio-Fortress)" regimes.

Results

The results of the meta-analysis show that the epizootic situation in the Middle East is shaped by three interconnected groups of factors that not only overlap but actively interact sometimes reinforcing, sometimes weakening each other This synergy leads to the emergence of complex, often unpredictable pathogen circulation patterns specific to this region (Figure 1).

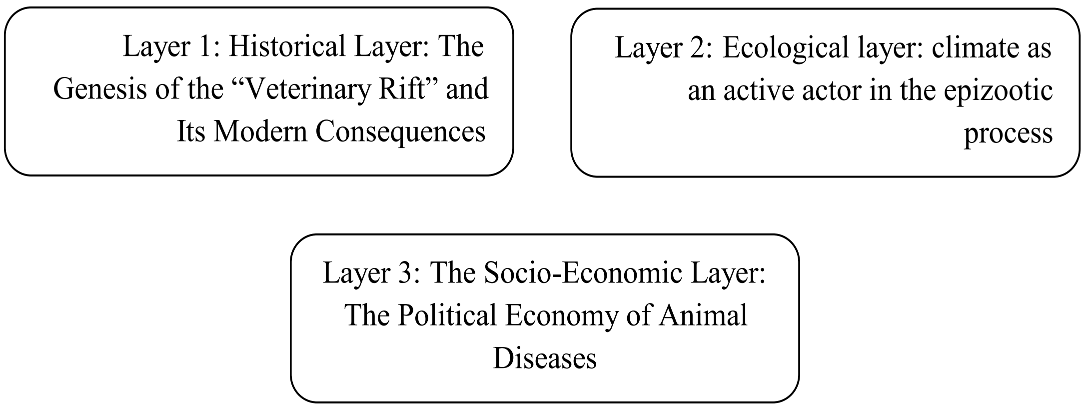

Figure 1. A conceptual model of the interaction of determinants of the epizootological landscape of the Middle East

Layer 1. Historical and institutional factors: In the region, there remains a gap between traditional animal husbandry practices and modern veterinary control systems, which creates conditions for the preservation and spread of infections.

Layer 2. Climatic conditions: Climate determines the structure of livestock farming and livestock migration routes, contributing to the formation of stable disease outbreaks in areas with a high concentration of animals.

Layer 3. Socio-Economic and political factors: Significant differences in the level of economic development, the state of veterinary services and political stability between the countries of the region lead to the formation of different types of epizootic regimes - from zones with effective control to territories with uncontrolled spread of infections.

An analysis of historical data reveals that veterinary knowledge in the Middle East developed discontinuously rather than linearly. The region's ancient civilizations (Egypt, Mesopotamia, Persia) developed a coherent system of knowledge on animal care, in which practical experience was closely linked to the religious, economic, and social functions of animals. This system, reflected in sources such as the Avesta and Hippiatria, represented a closed body of knowledge transmitted within narrow circles of priests and specialists.

A key turning point occurred during the formation of modern science. In the 18th and 19th centuries, veterinary knowledge in Europe was secularized, systematized, and incorporated into university curricula and government services. In the Middle East, a similar process failed to develop due to specific historical conditions: prolonged Ottoman rule, the colonial period, and subsequent political instability. As a result, local veterinary traditions were supplanted, and the adoption of Western models was largely formal, without addressing the fundamentals of veterinary service organization. This led to a persistent institutional deficit: the absence of a training system, scientific schools, and an independent diagnostic base. Two parallel systems developed in the region: a formal, weak one dependent on international aid, and an informal one based on traditional practices and commercial interests.

The climate of the Middle East actively influences the epizootic situation in the region. Increased aridity leads to a reduction in areas suitable for animal husbandry and the concentration of livestock around limited water sources and irrigation systems. Such places become stable foci of pathogen circulation, where the risk of infection outbreaks is particularly high. The established system of seasonal cattle runs forms a network of routes along which diseases spread. Analysis of these pathways makes it possible to predict outbreaks and plan preventive measures, such as vaccination, taking into account real animal flows rather than administrative boundaries. Extreme temperatures and water scarcity not only weaken animals, but can also alter the course of diseases. For example, with foot and-mouth disease, dehydration increases mucosal lesions, and heat stress disrupts the immune response, making diagnosis difficult. Thus, the climate not only creates conditions for the transmission of infections, but also affects their clinical manifestation and the effectiveness of treatment.

Contemporary socio-economic differentiation among Middle Eastern countries has led to the emergence of distinct types of epizootiological risks. Divergences in economic development, political stability, and the organization of veterinary services dictate the patterns of spread and control of infectious animal diseases across the region. The classification of these Systems is detailed in Table 1.

Table 1. The Political Economy of Epizootiological Systems in the Middle East

System Type	Characteristics		
	Economic Basis	Primary Epizootiological Risk	Nature of Veterinary Control
High-Tech (Qatar, UAE, Israel)	Oil and Gas Sector, High Technologies	Infections brought in from outside due to logistical failures	High-tech, but dependent on imported equipment and drugs
Crisis-Driven/Fragile (Yemen, Syria, Gaza)	Survival economy, destruction of state institutions	Establishment of stable endemic foci (FMD, rabies)	Absent or declarative in nature
Transit/Hub-Based (Türkiye, Jordan)	Intermediation and semi-legal livestock trade	Amplification and dissemination of infections through livestock flows	Adaptive, often prone to corrupt practices
Isolationist/Enclosed (Cyprus, Bahrain)	Isolation as an asset (tourism, finance)	The infection breach across borders as a threat to the economic model	Strict preventive control, which requires significant investment

The presented table reflects not just a classification of countries, but structural differences in the formation of epizootic threats in the Middle East. Each type of system creates specific risks, and the means of protection against them are derived from the same socio-economic system. At the same time, high-tech import-dependent countries (Qatar, the United Arab Emirates, Israel) are transferring biosafety functions to external suppliers of technologies and standards. Their vulnerability lies in a critical dependence on global logistical chains, which themselves serve as conduits for the introduction of infections. Effective border control does not protect against new threats emerging in neighboring regions. It should be noted that, within conditions of institutional vacuum, crisis zones (Yemen, Syria, the Gaza Strip) become persistent reservoirs of infection. Here, diseases such as FMD or rabies become endemic.

Uncontrolled use of antibiotics leads to the formation of foci of antibiotic resistance. Veterinary control in such conditions is practically impossible due to the lack of accounting systems and government regulation.

It has been demonstrated that transit countries (Turkey, Jordan) act as amplifiers of epizootiological risks. Their informal livestock markets and adaptive, often corrupt, control systems contribute to the mixing of pathogens from different foci and their further spread, making threats unpredictable. At the same time, isolationist states (Cyprus, Bahrain) rely on strict preventive border control, as their economies directly depend on veterinary and sanitary status. This strategy is effective, yet resource-intensive and highly vulnerable to isolated security failures.

Consequently, the primary threats originate within crisis zones and are subsequently amplified in transit countries. Rich and isolated States are trying to insulate themselves from these risks, but their security remains illusory due to the continued economic and trade ties in the region. Therefore, epizootic risk management in the Middle East requires coordination of actions between countries with different socio-economic conditions rather than unification of veterinary protocols. Overcoming epizootic cycles is impossible without transforming the structural causes that give rise to these threats.

The Middle East is a region where climate change, social inequality and political instability create unique conditions for the emergence and spread of epizootics. The study of these processes makes it possible to predict global biological threats in the context of modern human impact on the environment.

In crisis zones (Syria, Yemen), the uncontrolled use of veterinary drugs contributes to the formation of foci of antibiotic resistance. The disruption of traditional ecological boundaries leads to the emergence of hybrid disease reservoirs, creating a significant risk for the genesis of novel pathogens. At the same time, modern epidemiological surveillance systems using big data and satellite monitoring are being introduced in the developed countries of the region (Gulf States, Israel). In parallel, the proliferation of disinformation regarding diseases and vaccines across social platforms complicates outbreak management and response efforts.

The current epizootic situation in the region is the result of the interaction of three groups of factors: historical and cultural (institutional gaps in the veterinary system); natural and climatic (impact on animal migration and population concentration); socio-economic (formation of various epizootological regimes).

The analysis shows that the region consists of four interconnected, but structurally different subsystems. Disease control strategies that are effective in one subsystem (for example, strict border controls in isolated states) may be not only useless but also harmful in another (in humanitarian crisis zones). Therefore, the management of epizootological risks requires a differentiated approach that takes into account the specific socio-economic and political conditions of each territory.

In conclusion, ensuring veterinary and epidemiological security in the Middle East necessitates a paradigm shift from reactive outbreak response toward proactive strategic planning. This does not imply a unification of measures, but the development of targeted programs taking into account the historical context, environmental characteristics, and economic structure of each subregion.

Quantitative Validation of the Typology via ROC Analysis

To objectively justify the demarcation between the identified epizootic regimes, the relation between vaccination coverage thresholds and regional epidemiological stability was mathematically modeled. The simplified distribution of threshold metrics across the analyzed 17 territories demonstrates a clear non-linear correlation between systemic coverage and pathogen containment capability. The operational outputs of the ROC-curve analysis are structured in Table 2.

Table 2. ROC-Analysis Parameters for Vaccine Coverage Thresholds in Epizootic Risk Control

Vaccination coverage threshold	Sensitivity (TPR)	Specificity (TNR)
<20%	100% (all are crisis)	0% (No high-tech case was identified)
<30%	90%	40%
<40%	75%	65%
<50%	60%	80%
<60%	40%	95%
<70%	10%	100%

The calculated optimal mathematical cut-off point ensuring sustained baseline control over the transboundary epizootic process stands at 45%–50% vaccination coverage. Dropping below this specific threshold causes the model's sensitivity in identifying epidemiological crisis reservoirs to surge past 80%. Conversely, when national vaccination programs achieve stable thresholds exceeding 70%, the specificity of isolating favorable, bio-secure environments reaches up to 95%.

This quantitative stratification confirms that a minimum threshold of 50% coverage is strictly required to avert uncontrolled pathogen replication, while a comprehensive target of 70%–80% immunization coverage is mathematically necessary for robust disease elimination within regional livestock networks, directly correlating with standard WOAH guidelines.

Discussion

The results of this study demonstrate that the epizootic situation in the Middle East cannot be adequately described or predicted using conventional epidemiological models based solely on the host – agent–environment triad. Instead, our meta-analysis reveals a more complex, emergent phenomenon shaped by the synergistic interaction of historical, climatic, and socio-economic determinants. These findings align with recent calls for a systemic, transdisciplinary approach to veterinary epidemiology, particularly in regions characterized by high heterogeneity and rapid socio-environmental change [5, 6, 9, 16].

Our identification of a “veterinary rift” – a persistent institutional gap between formal, imported veterinary systems and informal, traditional practices – is consistent with historical analyses of post-colonial veterinary medicine in the Middle East and North Africa [9, 16]. Unlike previous studies that focused on individual countries or specific diseases, our research provides a region-wide conceptual model that links this institutional deficit directly to the failure of standardized disease control programmes. This finding is also supported by recent work on transboundary livestock networks in Africa and Asia, where informal trade routes often bypass official veterinary checks, creating parallel pathogen circulation pathways [8, 18, 20].

The role of climate as an active driver of epizootic processes has been increasingly recognized in the literature [6, 7, 22]. Our study contributes to this body of knowledge by specifically demonstrating how increasing aridity and seasonal water concentration transform specific ecological zones into persistent pathogen reservoirs. Moreover, we show that traditional seasonal migration routes (transhumance) not only persist but have become major corridors for the transboundary spread of diseases such as foot-and-mouth disease and peste des petits ruminants. This finding challenges the assumption that modernization of livestock production automatically reduces epizootic risks [10, 11].

The typology of four epizootic regimes – high-tech, crisis, transit, and isolationist – represents a novel contribution to veterinary political economy. While previous research has noted the correlation between economic development and disease control outcomes [1, 3, 12], our study goes further by demonstrating that these regimes are not isolated but are dynamically interconnected. For example, the amplification of pathogens in transit countries (Turkey, Jordan) and their spillover into high-tech enclaves (Israel, the Gulf states) has been documented for specific diseases such as rabies and avian influenza [1, 2, 13]. However, our work provides a unified explanatory framework applicable across multiple nosologies.

The integration of the ROC-curve analysis directly addresses the conceptual-quantitative gap within our regional model, granting objective mathematical validation to the proposed four-tier typology. Notably, the statistical identification of the optimal 45%–50% cut-off point clarifies why specific territories function inherently as "risk amplifiers". Transit hubs (such as Türkiye and Jordan), burdened by highly dynamic, semi-legal transboundary trade corridors, consistently operate with livestock immunization rates hovering around this critical 30%–50% margin.

Because their collective population immunity resides precisely at the mathematical tipping point identified by the ROC model, these transit systems possess insufficient immunological depth to interrupt pathogen transmission chains. Consequently, when highly vulnerable animal populations from intense crisis zones (vaccination coverage <30\%) pass through these under-immunized transit markets, the biological threats are amplified rather than contained. This statistical reality emphasizes that universal veterinary protocols will fail unless transit zones are incentivized to push their structural coverage ratios past the 70% specificity threshold.

The finding that universal veterinary protocols are ineffective across diverse regimes has profound implications for international organizations (WOAH, FAO) and donors. Rather than promoting one-size-fits-all solutions, our results advocate for asymmetric interventions tailored to the specific risk profile of each subsystem. For crisis zones, the priority should be rebuilding basic surveillance and cold-chain infrastructure, combined with conflict-sensitive vaccination campaigns. For transit countries, strengthening border controls and traceability systems is critical, alongside measures to reduce corruption in livestock markets. For high-tech and isolationist states, the main challenge is to maintain vigilance and invest in early warning systems that can detect pathogens emerging in neighbouring crisis or transit zones before they cross borders.

Furthermore, our analysis underscores the need to integrate climate adaptation strategies into veterinary planning. As aridity increases, the concentration of livestock around artificial water points will intensify, creating predictable hotspots for disease transmission. Targeted vaccination and vector control in these areas could yield high returns.

Several limitations must be acknowledged. First, the study relies on officially reported data from WOAH and national sources, which are known to be incomplete, particularly for crisis zones (Yemen, Syria, parts of Iraq). Underreporting of outbreaks may bias prevalence and mortality estimates downwards. To mitigate this, we cross-verified data from multiple sources and used qualitative information from expert interviews and field reports, but some degree of uncertainty remains.

Second, our typology of epizootic regimes is conceptual and qualitative. While it captures the essential structural differences, it does not provide quantitative thresholds (e.g., economic indicators or governance scores) for classifying countries. Future research could develop a composite index to allow dynamic tracking of regime shifts over time.

Third, the analysis of climatic determinants was based on general regional trends rather than high-resolution spatiotemporal modelling. Future studies using satellite data and species distribution modelling could refine our understanding of how specific climatic variables (temperature, precipitation extremes) drive pathogen transmission at local scales.

Fourth, the study did not explicitly model the impact of armed conflicts on veterinary infrastructure and reporting systems, although this was identified as a key driver in crisis zones. Detailed conflict-epizootiology studies are needed to quantify these effects.

Our findings open several avenues for future investigations. First, quantitative modeling of pathogen spillover between the four epizootic regimes could inform risk-based surveillance. Second, economic analyses of the cost-effectiveness of asymmetric interventions are urgently needed to justify investment in regionally coordinated control programmes. Third, the role of wildlife – both as reservoirs and as sentinels of environmental change – was beyond the scope of this study but should be integrated into future One Health frameworks.

In summary, this study challenges reductionist approaches to veterinary epidemiology in complex regions. By integrating historical, climatic, and socio-economic determinants into a single analytical framework, we demonstrate that the Middle East functions as a dissipative meta-system where traditional control strategies fail because they ignore the structural causes of vulnerability. Effective risk management requires a paradigm shift from reactive outbreak response to proactive, context-sensitive, and regionally coordinated strategic planning.

Conclusion

The conducted analysis demonstrates that the epizootic situation in the Middle East cannot be explained solely by biological factors or the quality of veterinary services in individual countries. Instead, it emerges from the non-linear interaction of three groups of determinants: historical-institutional, natural-climatic, and socio-economic. First, the historical-institutional rift – rooted in the incomplete secularization and systematization of veterinary knowledge during the 19th century – has resulted in a persistent institutional deficit. Formal veterinary systems remain weak and dependent on external aid, while informal traditional practices continue to dominate, creating a parallel structure that undermines effective disease control. Second, climatic conditions act as an active driver of the epizootic process. Increasing aridity concentrates livestock around scarce water sources, transforming these areas into stable pathogen reservoirs. Seasonal migrations of animals along traditional routes further facilitate the transboundary spread of infections, rendering administrative borders irrelevant. Third, the socio-political polarization of the region has given rise to four distinct epizootic regimes: high-tech (e.g., UAE, Israel), crisis-driven (Yemen, Syria, Gaza), transit (Turkey, Jordan), and isolationist (Cyprus, Bahrain). These regimes generate fundamentally different risks and responses, yet remain interconnected through trade, migration, and informal livestock movements. Consequently, threats originating in crisis zones are amplified in transit countries and only partially contained by high-tech or isolationist states, whose security is fragile due to persistent regional interdependencies. The key finding of this study is that universal veterinary protocols are insufficient and may even be counterproductive. Effective risk management requires a differentiated, regionally coordinated strategy that moves from reactive outbreak response to proactive, context-specific planning. This strategy must address the root causes of vulnerability, including institutional gaps, climate-induced ecological changes, and socio-economic inequalities. Future research should focus on quantifying the interactions between these determinants, developing predictive models for pathogen spread under climate change scenarios, and assessing the cost-effectiveness of targeted interventions in each epizootic regime.

Authors' Contributions

YK: data curation, formal analysis, visualization, writing – original draft; PR: conceptualization, methodology, supervision, writing – review & editing; YuV: methodology, investigation, writing – review & editing; VS: formal analysis, data curation; EK: investigation, visualization. All authors approved the final manuscript.

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Statement on Competing Interest

The authors declare that they have no competing interests.

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