A Data-Driven Simulation of Ukrainian Refugee Flows Impact on COVID-19 Dynamics in the UK

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Abstract

In the contemporary global landscape, geopolitical events can profoundly affect public health, particularly concerning infectious diseases. The migration wave resulting from Russia's military aggression in Ukraine presented potential challenges for the epidemiological landscape of recipient countries, notably the UK. This research sought to discern the impact of the Ukrainian refugee influx on the COVID-19 epidemic dynamics in the UK, aiming to understand whether such a significant migration event could alter the disease trajectory. A sophisticated forecasting approach was employed using the Prophet model, tailored for predicting the epidemic process of COVID-19. The model's performance was evaluated using the MAPE over distinct periods before and after the beginning of the Russian full-scale military invasion of Ukraine. The model exhibited commendable accuracy in its predictions, particularly in the retrospective forecasting phase. Despite the high influx of Ukrainian refugees, the UK's epidemic remained stable, with no discernible exacerbation attributable to the migration. The findings underscore the efficacy of the UK's preventive health measures in managing potential outbreaks, even amidst significant geopolitical challenges. The results also highlight the resilience of a well-prepared health system and the value of data-driven forecasting in navigating public health challenges during tumultuous times. The forced migration of Ukrainian citizens due to the military invasion did not emerge as a critical factor influencing the dynamics of COVID-19 incidence in the UK. This study serves as a testament to the importance of proactive public health strategies and the potential of modern forecasting models in guiding policy decisions during global crises.

Keywords 1

COVID-19, epidemic model, machine learning, deep learning, Prophet, war

1. Introduction

The COVID-19 pandemic, caused by the novel coronavirus SARS-CoV-2, has emerged as a paramount global health crisis of the 21st century. Originating in Wuhan, China, in late 2019, the virus swiftly traversed international borders, leading to widespread morbidity and mortality [1]. The pandemic's multifaceted implications extend beyond the immediate health repercussions, influencing socio-economic structures, global trade, education systems, and mental health paradigms [2]. The rapid transmission of the virus underscored the interconnectedness of modern societies and highlighted vulnerabilities in public health infrastructures worldwide [3]. As nations grapple with the direct and

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indirect consequences of the pandemic, the importance of interdisciplinary research, international collaboration, and evidence-based policy-making has been accentuated. The COVID-19 pandemic is a poignant reminder of the intricate balance between human activity, ecological systems, and global health dynamics.

The United Kingdom (UK) has been significantly impacted by the COVID-19 pandemic, with the first confirmed cases reported in late January 2020. The rapid spread of the SARS-CoV-2 virus across the nation necessitated implementing stringent public health measures, including multiple lockdowns, social distancing guidelines, and travel restrictions [4]. The UK's healthcare system, particularly the National Health Service (NHS), faced unprecedented challenges, with surges in hospital admissions and intensive care unit occupancies [5]. Concurrently, the country embarked on an extensive research and vaccination campaign, leading to the swift development, approval, and deployment of multiple vaccines. Despite these efforts, the UK witnessed several waves of infections, exacerbated by the emergence of new viral variants. The pandemic's socio-economic ramifications in the UK have been profound, affecting employment, education, and mental health, necessitating comprehensive policy responses and long-term recovery strategies [6].

On 22 February 2022, Russia initiated a full-scale invasion of Ukraine, marking a significant escalation in the ongoing war of Russia in Ukraine. This military offensive had profound humanitarian implications, particularly for the civilian population [7]. A notable and profoundly concerning aspect of the invasion was the substantial civilian casualties resulting from direct confrontations and collateral damage. Furthermore, critical infrastructure, including hospitals and healthcare facilities, were either directly targeted or inadvertently damaged, severely crippling Ukraine's health system [8]. The destruction of these medical establishments disrupted immediate medical care for the injured and impeded the provision of routine healthcare services to the general population. The compounded effects of civilian casualties and the healthcare infrastructure's debilitation underscored the invasion's profound and lasting impact on Ukraine's societal fabric and public health landscape [9].

Russia's full-scale invasion of Ukraine on 24 February 2022 has had profound implications on the country's management and dynamics of the COVID-19 pandemic [10]. Amidst the backdrop of the war, Ukraine was grappling with the Omicron strain. The war has critically hampered the identification, diagnosis, and registration of COVID-19 cases. Medical facilities in conflict zones have been decimated, and the scarcity of medical personnel has further strained the already beleaguered health system. Diagnostic capacities have dwindled, with only severe cases being identified and registered. Hospital capacities are overwhelmed with COVID-19 patients and war casualties, leading to a drastic reduction in specific care beds and limited access to essential medical supplies, including oxygen. Preventative measures, such as social distancing and mask-wearing, have been overshadowed by the exigencies of war, with people crowding in shelters and evacuation points, creating environments conducive to viral spread. Furthermore, the vaccination campaign has been severely disrupted, with a mere 36.93% of the population receiving two doses before the conflict [11]. The war has thus not only intensified the humanitarian crisis but has also significantly exacerbated the COVID-19 situation in Ukraine.

In the wake of the Russian invasion of Ukraine on 24 February 2022, the United Kingdom witnessed a significant influx of Ukrainian refugees, with the nation becoming the fourth largest recipient in Europe, accommodating approximately 210,800 refugees by August 2023 [12]. This migration was facilitated by the UK Government's rapid response, introducing two new visa routes in March 2022 specifically designed for those affected by the conflict [13]. The Ukraine Family Scheme launched on 4 March 2022, enabled applicants to join family members or extend their stay in the UK. Subsequently, the Ukraine Sponsorship Scheme was introduced on 18 March 2022, permitting Ukrainian nationals and their families to enter the UK, provided they had a named sponsor under the Homes for Ukraine Scheme. An additional provision, the Ukraine Extension Scheme, was established on 3 May 2022, allowing Ukrainian nationals and their immediate family members to extend their stay in the UK under specific conditions [14].

Simulation modeling is a pivotal tool in epidemiology, enabling researchers to gain insights into the intricate dynamics of infectious disease spread and control. By replicating real-world processes in a controlled virtual environment, these models allow for exploring various scenarios, forecasting potential outbreaks, and evaluating the efficacy of intervention strategies [15]. Key tasks addressed by simulation modeling in epidemic process analysis include predicting the trajectory of disease spread

[16], assessing the impact of various intervention measures (such as vaccination campaigns or quarantine protocols) [17], estimating the potential burden on healthcare systems [18], identifying vulnerable populations [19], investigating healthcare data [20], analyzing co-infections [21] and optimizing resource allocation for outbreak containment [22]. Through these capabilities, simulation modeling provides invaluable guidance to policymakers and health professionals in mitigating the adverse effects of epidemics.

The paper aims to develop a deep learning model of COVID-19 dynamics to estimate the impact of the Russian war in Ukraine on COVID-19 spreading in the UK.

2. Materials and Methods

This study introduces a methodological approach to evaluate the impact of Russia's full-scale invasion of Ukraine on the trajectory of the epidemic process. Initially, a machine learning framework is constructed to anticipate the patterns of disease prevalence and associated fatalities in the UK. The validity of this model is then ascertained by gauging its retrospective forecasting accuracy for disease prevalence and fatalities in the UK, spanning from January 25, 2022, to the day before Russia's full-scale invasion of Ukraine on February 23, 2022. Subsequently, projections for disease prevalence and fatalities are made from the onset of the Russian war in Ukraine escalation on February 24, 2022, to March 25, 2022. The subsequent phase involves determining the discrepancy between the actual disease prevalence and fatalities in the UK and the predictions made by the model. The study then delves into analyzing the determinants that shape the epidemic trajectory, considering the specific infectious disease, its propagation characteristics, and the geographical region in focus.

As a basic forecasting model, we have applied the Prophet model [23]. The Prophet model, developed by Facebook's Core Data Science team, serves as a contemporary tool tailored for time series forecasting, adeptly addressing the complexities inherent in datasets like the progression of COVID-19. Its addictive nature characterizes this model, systematically deconstructing a time series into its foundational components: overarching trend, inherent seasonality, and specific holiday effects.

The forecast built by the Prophet model is represented as:

$$y(t) = g(t) + s(t) + h(t) + \varepsilon_t, \quad (1)$$

where y(t) is the forecasted value at time t; g(t) is the trend component, capturing the long-term progression of the series; s(t) is the seasonal component, encapsulating periodic fluctuations; h(t) is the holiday or event-driven component, accounting for irregular events; εt is the error term, capturing any idiosyncratic changes not accounted for by the model.

The trend component, denoted as g(t), elucidates the long-term evolution of the series, encapsulating both linear and logistic trajectories. Such delineation is instrumental in discerning the macroscopic directionality of a dataset, exemplified by the longitudinal rise or decline of COVID-19 incidences. For the logistic trend, the trend component is represented as:

$$g(t) = \frac{c}{1 + e^{-k(l-m)}}, \quad (2)$$

where c is the carrying capacity; k is the growth rate; m is an offset parameter.

The seasonal component, represented as s(t), captures periodic oscillations inherent in the data, which could manifest on daily, weekly, or annual scales. Specific cyclical patterns might emerge in the context of infectious diseases like COVID-19, potentially attributable to systematic testing and reporting mechanisms. The seasonal component is represented as:

$$s(t) = \sum_{n=1}^{N} \left(a_n \cos \frac{2\pi nt}{P} + b_n \sin \frac{2\pi nt}{P} \right), \quad (3)$$

where N is the number of Fourier terms; P is the period; an and bn are coefficients.

The holiday or event-driven component, symbolized by h(t), accounts for sporadic events that, while not part of a regular cycle, can significantly influence data trajectories. This is pivotal in quantifying the repercussions of specific interventions or events on disease reporting or manifestation. The holiday component is represented as:

$$h(t) = \sum_{i=1}^{H} \gamma_i I(t \in D_i), \quad (4)$$

where H is the total number of holidays; Di is the date of the ith holiday; γi is the effect of the ith holiday.

A salient feature of the Prophet model is its capacity to generate uncertainty intervals accompanying its forecasts. Such intervals delineate a probable range for actual values, offering invaluable insights for stakeholders requiring a holistic understanding of potential future scenarios and their variability.

Moreover, the adaptability of the Prophet underscores its efficacy. It permits user-driven modifications through hyperparameter adjustments, the integration of custom seasonalities, or the inclusion of external regressors, thereby ensuring a bespoke forecasting experience.

The Prophet model presents a sophisticated and modular approach to time series forecasting. It establishes itself as an indispensable tool in predicting intricate dynamics, such as those observed in the epidemiology of diseases like COVID-19.

Table 1 shows hyperparameters of the developed model.

Table 1
Model's hyperparameters

Hyperparameter	Cumulative cases	Cumulative death	New cases	New deaths
changepoint_prior_scale	0.101113749	0.4413108	0.001000214441	0.01635017863
changepoint_range	0.895062694	0.9465111	0.822664904257	0.94894466990
daily_seasonality	False	False	True	False
growth	Linear	Linear	Linear	Linear
seasonality_mode	Multiplicative	Additive	Multiplicative	Additive
seasonality_prior_scale	0.0010407514	8.9169199	0.001664327556	0.475209330146335
weekly_seasonality	False	False	False	False
yearly_seasonality	True	True	True	True

In evaluating the performance of the Prophet model, we utilize the Mean Absolute Percentage Error (MAPE) as a critical metric. Mathematically, MAPE is defined as:

$$MAPE = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{A_t - F_t}{A_t} \right| \cdot 100\%, \quad (5)$$

where n is the number of forecasted points; At is the actual value at time t; Ft is the forecasted value at time t.

The appeal of MAPE lies in its capacity to offer a precise, scale-independent measure of forecast accuracy. By quantifying errors as a percentage of the actual values, MAPE delivers an intuitive grasp of the relative size of the forecasting inaccuracies. This feature is especially advantageous when relaying results to audiences unfamiliar with intricate statistical metrics. Moreover, MAPE underscores the significance of errors in terms of their proportional relevance rather than just their sheer magnitude. This is particularly pertinent in scenarios where overpredictions and underpredictions might have uneven consequences. Nonetheless, it is crucial to recognize that MAPE can be sensitive, especially when actual values approach zero, as it can lead to significant percentage errors. However, its general acceptance and ease of interpretation render MAPE an indispensable instrument for assessing the performance of time series forecasting models, such as Prophet.

3. Results

The Prophet model was executed using the Python software environment to validate and fine-tune its capability in forecasting the COVID-19 epidemic trajectory. We assessed the precision of the model over intervals of 3, 7, 14, 21, and 30 days. We sourced data about COVID-19 cases and fatalities in the UK for validation purposes from the World Health Organization's COVID-19 Dashboard [24]. The evaluation dataset encompassed figures on infections and deaths due to COVID-19 in the UK spanning from January 25, 2022, to February 23, 2022, corresponding to the 30 days after the beginning of Russia's full-scale military invasion of Ukraine.

Figure 1 shows results of forecasting of the cumulative cases of COVID-19 in the UK from January, 25, 2022 to February 23, 2022.

Figure 2 shows results of forecasting of the cumulative deaths of COVID-19 in the UK from January, 25, 2022 to February 23, 2022.

Table 2 shows MAPE of cumulative data forecast from January, 25, 2022 to February 23, 2022.

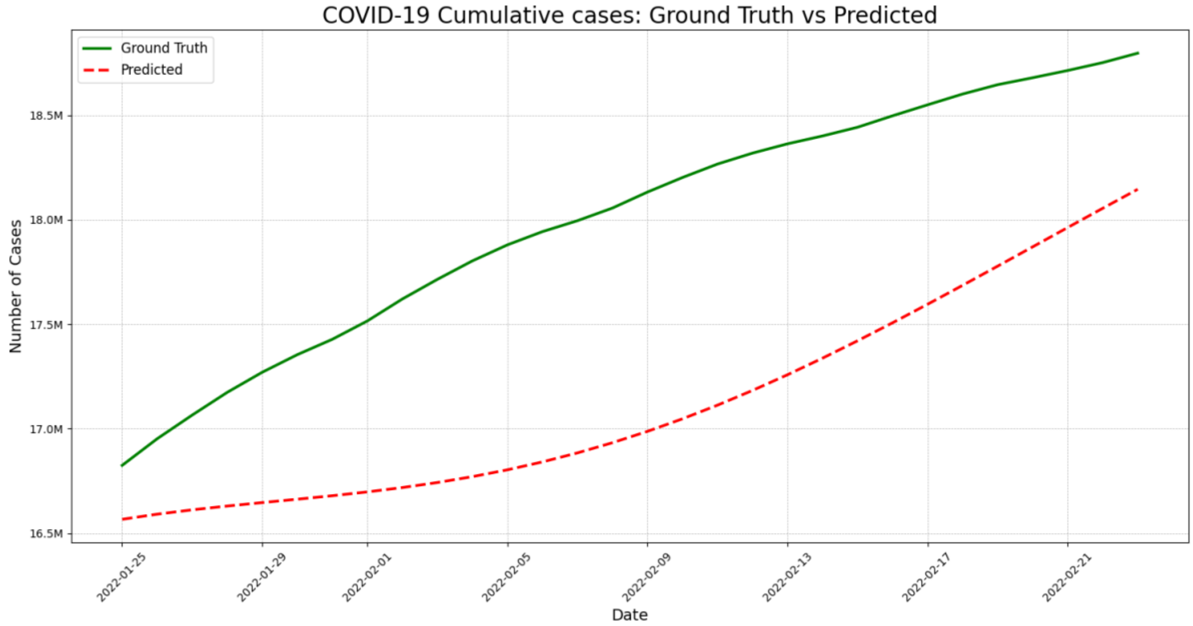

Figure 1: Forecasting of COVID-19 cumulative cases in the UK (25.01.2022 – 23.02.2022)

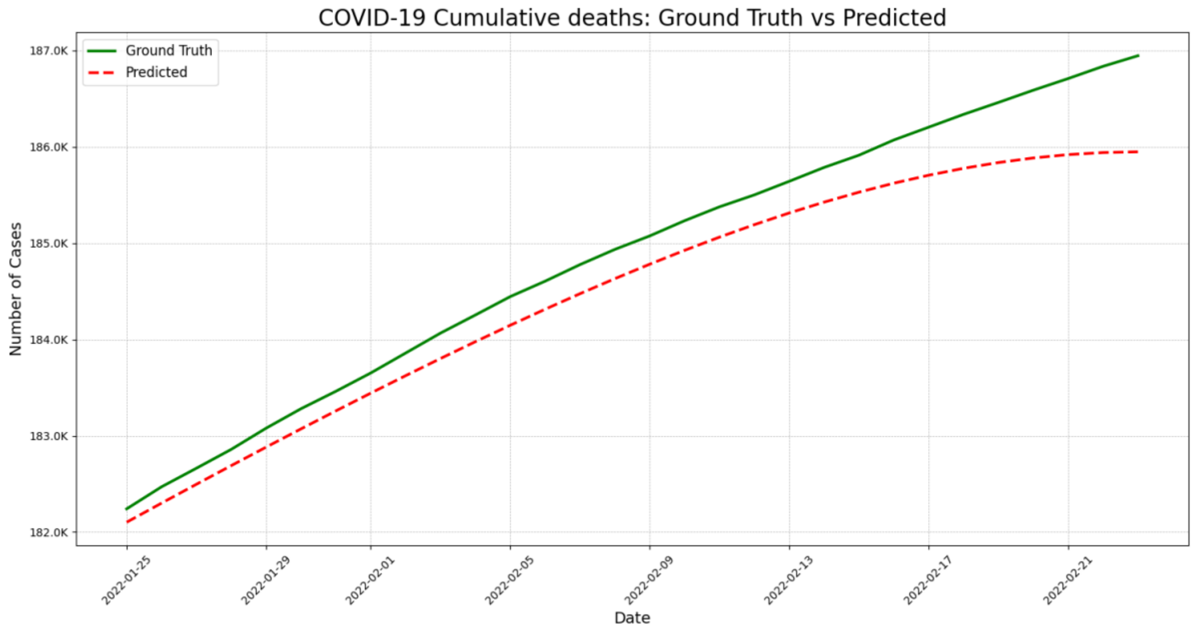

Figure 2: Forecasting of COVID-19 cumulative deaths in the UK (25.01.2022 – 23.02.2022)

Table 2
MAPE of cumulative forecast (25.01.2022 – 23.02.2022)

Period of forecast (days)	Infected	Death
3 days	2.153925519	0.086848042
7 days	3.159034635	0.097957887
14 days	4.563375221	0.121792878
21 days	5.233589249	0.138260882
30 days	5.102090368	0.202638515

Forecasts were calculated concerning the trajectory of the COVID-19 epidemic in the UK, spanning from February 24, 2022, to March 25, 2022, to evaluate the full-scale Russian invasion of Ukraine. This timeframe corresponds to the initial 30 days following Russia's full-scale military invasion of Ukraine.

Figure 3 shows results of forecasting of the cumulative cases of COVID-19 in the UK from February 24, 2022 to March 25, 2022.

Figure 4 shows results of forecasting of the cumulative death of COVID-19 in the UK from February 24, 2022 to March 25, 2022.

Table 3 shows MAPE of cumulative data forecast from February 24, 2022 to March 25, 2022.

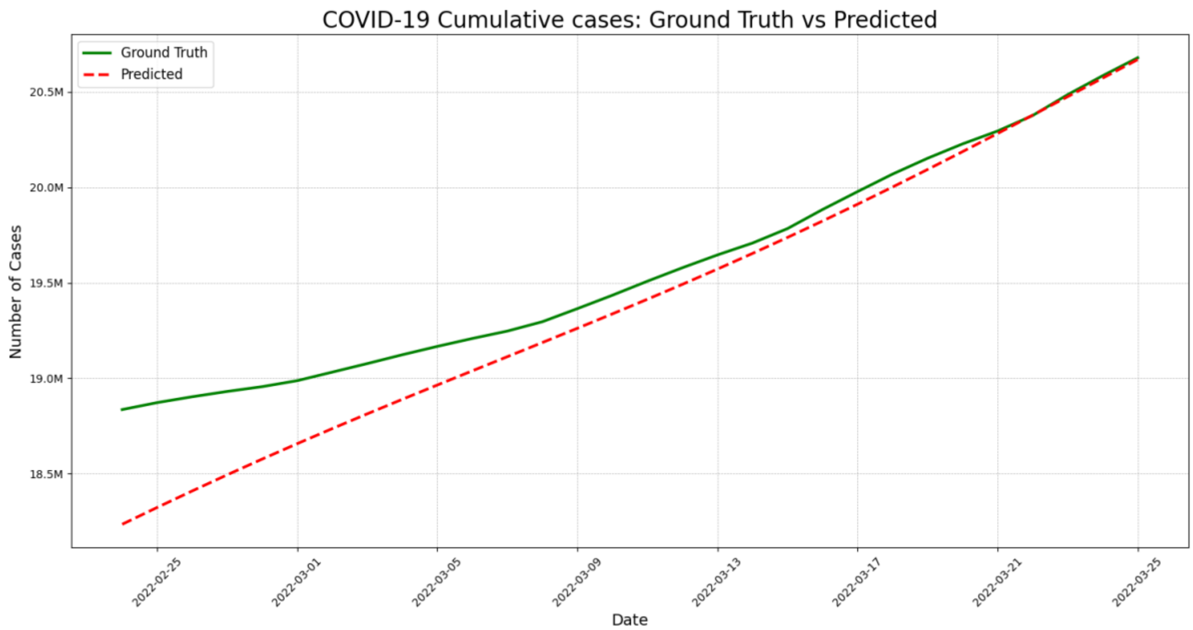

Figure 3: Forecasting of COVID-19 cumulative cases in the UK (24.02.2022 – 25.03.2022)

Table 3
MAPE of cumulative forecast (24.02.2022 – 25.03.2022)

Period of forecast (days)	Infected	Death
3 days	2.98897969	0.684420545
7 days	2.387521129	0.871986795
14 days	1.650379796	1.307621384
21 days	1.225449399	1.874914898
30 days	0.904287248	2.753275576

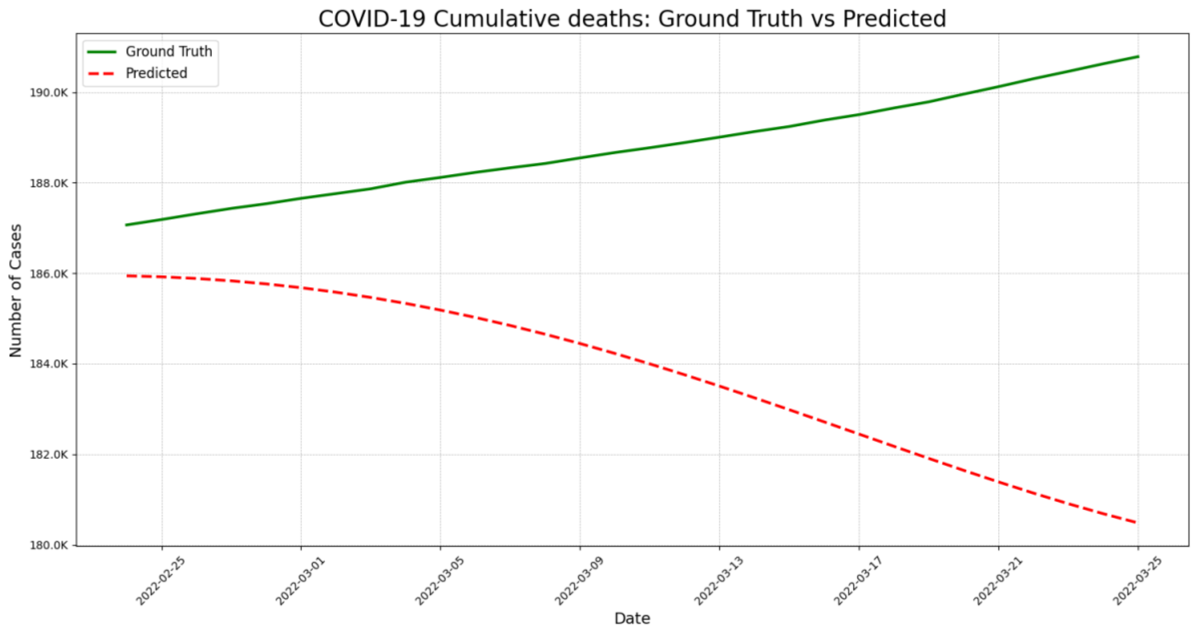

Figure 4: Forecasting of COVID-19 cumulative deaths in the UK (24.02.2022 – 25.03.2022)

4. Discussion

The COVID-19 pandemic in the United Kingdom, caused by the novel SARS-CoV-2 virus, has been a defining public health crisis of the 21st century. The first confirmed cases in the UK were reported in late January 2020 [25]. By March, the virus had spread widely, prompting the UK government to announce a national lockdown on March 23, 2020 [26]. This unprecedented move closed schools, non-essential businesses, and public places.

Several significant waves of infections have been observed. The first peak occurred in April 2020, followed by a summer lull. However, a more substantial second wave began in the autumn, partly attributed to the Alpha variant's emergence. This led to the implementing of a tiered restriction system in different parts of the country, culminating in another national lockdown in January 2021 [27].

The UK's vaccination campaign, launched in December 2020, marked a turning point in the nation's pandemic response. The Pfizer-BioNTech vaccine was the first to be administered, followed by the Oxford-AstraZeneca and Moderna vaccines. By mid-2021, a significant proportion of the adult population had received at least one vaccine dose, contributing to a decline in infection rates and hospitalizations [28].

However, the emergence of the Delta variant in the spring of 2021 posed new challenges, leading to increased cases despite high vaccination rates [29]. More transmissible than its predecessors, this variant became the dominant strain in the UK.

The pandemic's impact extended beyond health. The UK economy contracted sharply, with sectors like hospitality, travel, and retail facing significant disruptions. The furlough scheme was introduced to prevent mass unemployment, supporting businesses and workers through periods of inactivity [30].

Educationally, students faced disruptions with school closures, online learning transition, and examination uncertainties. The 2020 A-level and GCSE results became particularly contentious due to the algorithmic grading system, which was later abandoned in favor of teacher-assessed grades [31].

Socially, the pandemic highlighted disparities in health outcomes, with certain communities, particularly ethnic minorities, facing higher infection and mortality rates. Mental health became a significant concern, with many individuals grappling with isolation, anxiety, and the profound changes to daily life.

The COVID-19 pandemic in the UK has been marked by health, economic, educational, and social challenges, with the nation navigating multiple waves of infections, evolving governmental responses, and the rapid development and deployment of vaccines. The long-term implications of the direct and indirect pandemic will likely be subjects of study and reflection for years to come.

The escalation of the Russian war in Ukraine profoundly altered the daily existence of Ukrainians. In regions besieged by missile strikes, artillery fire, and armored assaults, civilians sought refuge in underground shelters, metro stations, residential basements, and other protective structures. These circumstances led to dense congregations of individuals, rendering distancing measures crucial for halting the spread of pathogens unfeasible. The urgency of immediate survival overshadowed preventive health measures, leading many to forgo face masks. Coupled with an inadequate vaccination rate, a significant portion of the sheltered population remained vulnerable to SARS-CoV-2. These conditions fostered an environment conducive to the virus's rampant spread. While infections surged, only those exhibiting severe symptoms typically sought medical attention, and even then, not consistently. The war's impact extended to the healthcare infrastructure, with numerous medical facilities either obliterated or rendered non-operational. The medical workforce dwindled due to casualties, injuries, or necessary evacuations. In several areas, diagnostic laboratories ceased operations due to staff evacuations and disrupted supply chains, curtailing testing capabilities. With physical medical facilities compromised, individuals often resorted to telemedicine, although connectivity remained sporadic in conflict zones.

Consequently, the refugee populace harbored numerous COVID-19 carriers. As they fled perilous regions, they often relied on densely packed transportation, such as trains bound for the country's west, which operated well beyond their capacity. The absence of adequate ventilation and basic sanitation in these transports further exacerbated the spread of COVID-19.

As the UK received many Ukrainian refugees, it was expected to lead to a new outbreak of COVID-19.

When evaluated across two distinct periods, the forecasting model's performance offers insightful revelations about its predictive capabilities under varying circumstances.

For the initial period (25.01.2022 – 23.02.2022), the MAPE for predicting infections remained relatively low, especially for short-term forecasts. Specifically, the 3-day forecast exhibited a MAPE of 2.1539% for infections, which slightly increased as the period extended, reaching 5.1021% for the 30-day forecast. For mortality predictions, the MAPE values were even lower, starting at 0.0868% for the 3-day forecast and culminating at 0.2026% for the 30-day forecast. These results suggest that the model was particularly adept at short-term forecasting, with its accuracy diminishing slightly as the prediction horizon expanded.

In contrast, the model's performance exhibited a different trend for the subsequent period (24.02.2022 – 25.03.2022), which coincided with the onset of the Russian invasion. The 3-day forecast for infections had a MAPE of 2.9889%, which progressively decreased to 0.9043% for the 30-day forecast. For mortality, the MAPE started at a higher value of 0.6844% for the 3-day forecast and increased considerably to 2.7533% for the 30-day forecast. This indicates that while the model's predictions for infections improved over more extended forecast periods, its predictions for mortality became less accurate.

Several factors could account for these observed discrepancies in model performance across the two periods. The initial period was characterized by a more stable environment, allowing the model to predict based on established patterns. However, the subsequent period, marked by the onset of the Russian invasion, introduced many unforeseen variables, from socio-political disruptions to mass migrations, which could have influenced the epidemic dynamics in ways not previously accounted for by the model.

Consequently, measures implemented to manage and mitigate COVID-19 – such as visa requirements, social distancing protocols, stringent mask mandates, the UK's extensive vaccination coverage, and entry restrictions – served as practical barriers against the spread of the COVID-19 virus. Even with the potential risk posed by incoming Ukrainian refugees, there was no observed exacerbation of the epidemic situation in the UK. The outcomes derived from the modeling and retrospective analysis of the UK's COVID-19 epidemic trajectory align with the epidemiological assessments, indicating that the mass migration of Ukrainians, prompted by Russia's aggressive military actions, did not play a pivotal role in influencing the UK's COVID-19 case trends.

5. Conclusions

This research embarked on a comprehensive journey spanning various domains to understand the intricate dynamics of the COVID-19 epidemic process in the UK, especially in the context of geopolitical events such as Russia's military aggression in Ukraine. The backdrop of the study was set against the massive migration wave triggered by the war, with the UK emerging as a significant refuge for displaced Ukrainians. This migration posed potential epidemiological challenges, given the ongoing global pandemic.

The study employed the Prophet model, a state-of-the-art forecasting tool tailored to predict the epidemic's trajectory in the UK to navigate this complex scenario. The model's calibration and validation were carried out using morbidity and mortality data from the World Health Organization's COVID-19 Dashboard. The performance of this model was critically assessed across multiple forecast periods, utilizing the MAPE as a benchmark for accuracy.

The results from the model were enlightening. Despite the inherent risks associated with large-scale migration during a pandemic, the UK's stringent COVID-19 preventive measures, encompassing visa protocols, social distancing guidelines, mask mandates, and impressive vaccination coverage, effectively mitigated potential outbreaks. The epidemiological analysis, corroborated by the modeling outcomes, consistently indicated that the influx of Ukrainian refugees did not detrimentally impact the UK's COVID-19 epidemic.

In the broader discussion, this research underscores the resilience of well-prepared public health systems, even in the face of dual challenges - a global pandemic and a significant geopolitical crisis. The findings also highlight the paramount importance of robust modeling techniques, which offer predictive insights and guide evidence-based public health decisions.

From a scientific perspective, this research introduces a nuanced approach to understanding the epidemiological implications of geopolitical events on public health. By integrating the Prophet model, a contemporary forecasting tool, with the backdrop of a significant migration wave due to military aggression, the study pioneers a multidisciplinary methodology. This innovative confluence of epidemiology, data science, and geopolitical analysis offers a fresh lens to scrutinize the dynamics of infectious diseases in a globalized world.

On the practical front, the study's findings have profound implications for public health policy and crisis management. The research underscores the value of preparedness and proactive strategies by demonstrating the efficacy of the UK's preventive measures in mitigating potential outbreaks, even amidst significant migration. It provides tangible evidence that well-orchestrated public health measures and robust modeling techniques can effectively navigate the challenges posed by large-scale population movements during a pandemic. Furthermore, the research serves as a blueprint for other nations, offering insights into crafting evidence-driven policies that balance humanitarian concerns with public health imperatives.

This research contributes significantly to the academic discourse on the interplay between geopolitical events and public health outcomes. It stands as a testament to the importance of preparedness, robust modeling, and evidence-driven policies in navigating the multifaceted challenges of our times.

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